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The Influence of the Lower Trapezius Muscle on Shoulder Impingement and Scapula Dyskinesis

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THE INFLUENCE OF THE LOWER TRAPEZIUS MUSCLE ON SHOULDER IMPINGEMENT AND SCAPULAR DYSKINESIS

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PREFACE

Chapters 1 and 2 include the dissertation proposal and literature review as submitted previously to the Graduate School. Chapter 3 and 5 correspond with Study 1 and 2, respectively. In accordance with the wishes of the committee, these chapters are formatted as manuscripts to be submitted for peer-review.

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ABSTRACT

This dissertation contains three experiments all conducted in an outpatient physical therapy setting. Shoulder impingement is a common problem seen in overhead athletes and other individuals and associated changes in muscle activity, biomechanics, and movement patterns have been observed in this condition. Differentially diagnosing impingement and specifically addressing the underlying causes is a vital component of any rehabilitation program and can facilitate the individuals return to normal function and daily living. Current rehabilitation attempts to facilitate healing while promoting proper movement patterns through therapeutic exercise and understanding each shoulder muscles contribution is vitally important to treatment of individuals with shoulder impingement. This dissertation consisted of two studies designed to understand how active the lower trapezius muscle will be during common rehabilitation exercises and the effect lower trapezius fatigue will have on scapula dyskinesis. Study one consisted of two phases and examined muscle activity in healthy individuals and individuals diagnosed with shoulder impingement. Muscle activity was recorded using an electromyographic (EMG) machine during 7 commonly used rehabilitation exercises performed in 3 different postures. EMG activity of the lower trapezius was recorded and analyzed to determine which rehabilitation exercise elicited the highest muscle activity and if a change in posture caused a change in EMG activity. The second study took the exercise with the highest EMG activity of the lower trapezius (prone horizontal abduction at 130˚) and attempted to compare a fatiguing resistance protocol and a stretching protocol and see if fatigue would elicit scapula dyskinesis. In this study, individuals who underwent the fatiguing protocol exhibited scapula dyskinesis while the stretching group had no change in scapula motion. Also of note, both groups exhibited a decrease in force production due to the treatment. The scapula

dyskinesis in the fatiguing group implies that lower trapezius function is vitally important to maintain proper scapula movement patterns and fatigue of this muscle can contribute and even cause scapula dyskinesis. This abnormal scapula motions can cause or increase the risk of injury in overhead throwing. This dissertation provides novel insight about EMG activation during specific therapeutic exercises and the importance of lower trap function to proper biomechanics of the scapula.

CHAPTER 1: INTRODUCTION

The complex human anatomy and biomechanics of the shoulder absorbs a large amount of stress while performing activities like throwing a baseball, swimming, overhead material handling, and other repetitive overhead activities. The term “shoulder impingement”, first described by Neer (Neer, 1972), clarified the etiology, pathology, and treatment of a common shoulder disorder. Initially, patients who were diagnosed with shoulder impingement were treated with subacromial decompression, but Tibone (Tibone, et al., 1985) demonstrated that overhead athletes had a success rate of only 43% and only 22% of throwing athletes were able to return to sport. Therefore, surgeons sought alternative causes of the overhead throwers pain. Jobe (Jobe, Kvitne, & Giangarra, 1989) then introduced the concept of instability, which would result in secondary impingement, and hypothesized that overhead throwing athletes develop shoulder instability and this instability in turn led to secondary subacromial impingement. Jobe (Jobe, 1996) also later described the phenomenon of “internal impingement” between the articular side of the posterior rotator cuff and the posterior glenoid labrum while the shoulder is in abduction and external rotation.

From the above stated information, it is obvious that shoulder impingement is a common condition affecting overhead athletes and this condition is further complicated due to the throwing motion being a high velocity, repetitive, and skilled movement (Wilk, et al., 2009; Conte, Requa, & Garrick, 2001). During the throwing motion, an extreme amount of force is placed on the shoulder including an angular velocity of nearly 7250˚/s and distractive or translatory forces less than or equal to a person’s body weight (Wilk, et al., 2009). For this reason, the glenohumeral joint is the most commonly injured joint in professional baseball pitchers (Wilk, et al., 2009) and other overhead athletes (Sorensen & Jorgensen, 2000).

Consequently, an overhead athlete's shoulder complex must maintain a high level of muscular strength, adequate joint mobility, and enough joint stability to prevent shoulder impingement or other shoulder pathologies (Wilk, et al., 2009; Sorensen & Jorgensen, 2000; Heyworth & Williams, 2009; Forthomme, Crielaard, & Croisier, 2008).

Once pathology is present typical manifestations include a decrease in throwing performance, strength deficits, decreased range of motion, joint laxity, and/or pain (Wilk, et al., 2009; Forthomme, Crielaard, & Croisier, 2008). It is important for a clinician to understand the causes of abnormal shoulder dynamics in overhead athletes with impingement in order to implement the most effective and appropriate treatment plan and maintain wellness after pathology. Much of the research in shoulder impingement is focused on the kinematics of the shoulder and scapula, muscle activity during these movements, static posture, and evidence based exercise prescription to correct deficits. Despite the research findings, there is uncertainty as to the link between kinematics and the mechanism of for SIS in overhead athletes. The purpose of this paper is to review the literature on the pathomechanics, EMG activity, and clinical considerations in overhead athletes with impingement.

1.1 SIGNIFICANCE OF DISSERTATION

The goal of this project is to investigate the electromyographic (EMG) activity of the lower trapezius during commonly used therapeutic exercises for individuals with shoulder impingement and to determine the effect the lower trapezius has on scapular dyskinesis. Each therapeutic exercise has a specific EMG profile and knowing this profile is beneficial to help a rehabilitation professional determine which exercise dosage and movement pattern to select muscle rehabilitation. In addition, the data from study one of this dissertation was used to pick the specific exercise which exhibited the highest potential to activate and fatigue the lower

trapezius. From fatiguing the lower trapezius, we are able to determine the effect fatigue plays in inducing scapula dyskinesis and increasing the injury risk of that individual. This is important in preventing devastating shoulder injuries as well as overall shoulder health and wellness and these studies may shed some light on the mechanism responsible for shoulder impingement and injury.

CHAPTER 2: LITERATURE REVIEW

This review will begin by discussing the history, incidence, and epidemiology of shoulder impingement in Section 1.0, which will also discuss the relevant anatomy and pathophysiology of the normal and pathologic shoulder. The next section, 2.0, will cover the specific and general limitations of EMG analysis. The following section, 3.0, will discuss shoulder and scapular movements, muscle activation, and muscle timing in the healthy and impinged shoulder. Finally, section 4.0 will discuss the clinical implications and the effects of rehabilitation on the overhead athlete with shoulder impingement.

2.1 HISTORY, INCIDENCE, AND EPIDEMIOLOGY OF SHOULDER IMPINGEMENT

Shoulder impingement accounts for 44%-65% of all cases of shoulder pain (Neer, 1972; Van der Windt, Koes, de Jong, & Bouter, 1995) and is commonly seen in overhead athletes due to the biomechanics and repetitive nature of overhead motions in sports. Commonly, the most affected types of sports activities include throwing athletes, racket sports, gymnastics, swimming, and volleyball (Kirchhoff & Imhoff, 2010).

Subacromial impingement syndrome (SIS), a diagnosis commonly seen in overhead athletes presenting to rehabilitation, is characterized by shoulder pain that is exacerbated with arm elevation or overhead activities. Typically the rotator cuff, the long head of the biceps tendon, and/or the subacromial bursa are being “impinged” under the acromion in the subacromial space causing pain and dysfunction (Ludewig & Cook, 2000; Lukaseiwicz, McClure, Michener, Pratt, & Sennett, 1999; Michener, Walsworth, & Burnet, 2004; Nyberg, Jonsson, & Sundelin, 2010). Factors proposed to contribute to SIS can be classified as either intrinsic or extrinsic and then further classified, based on the cause of the problem, into primary, secondary, or posterior impingement (Nyberg, Jonsson, & Sundelin, 2010).

2.1.1 Relevant anatomy and pathophysiology of shoulder complex

When discussing the relevant anatomy in shoulder impingement, it is important to have an understanding of the glenohumeral and scapula-thoracic musculature, subacromial space (SAS), and soft tissue which can become “impinged” in the shoulder. The primary muscles of the shoulder complex include the rotator cuff (RTC) (supraspinatus, infraspinatus, teres minor, and subscapularus), scapular stabilizers (rhomboid major and minor, upper trapezius, lower trapezius, middle trapezius, serratus anterior), deltoid, and accessory muscles (latisimmus dorsi, biceps brachii, coracobrachialis, pectoralis major, pectoralis minor). The shoulder also contains numerous bursae, one of which is clinically significant in overhead athletes with impingement called the subacromial bursae. The subacromial bursa is located between the deltoid muscle and the glenohumeral joint capsule and extends between the acromion and supraspinatus muscle. Often, with repetitive overhead activity, the subacromial bursae may become inflamed causing a reduction in the subacromial space (Wilk, Reinold, & Andrews, 2009). The supraspinatus tendon lies underneath the subacromial bursae and inserts on the superior facet of the greater tubercle of the humerus and is the most susceptible to impingement of the RTC muscles. The infraspinatus tendon inserts posterior-inferior to the supraspinatus tendon on the greater tubercle and may become impinged by the anterior acromion during shoulder movement.

The SAS is a 10mm area below the acromial arch in the shoulder (Petersson & Redlund-Johnell, 1984) and contains numerous soft tissue structures including tendons, ligaments, and bursae (Figure 1). These structures can become compressed, or “impinged”, in the SAS causing pain due to excessive humeral head migration, scapular dyskinesis, muscular weakness, and bony abnormalities. Any subtle deviation (1-2 mm) from a normal decrease in the SAS can contribute to impingement and pain (Allmann, et al., 1997; Michener, McClure, & Karduna,

2003). Researchers have compared static radiographs of painful and normal shoulders at numerous positions of glenohumeral range of motion, and the findings include: 1) humeral head excursion greater than 1.5 mm is associated with shoulder pathology (Poppen & Walker, 1976), 2) patient's with impingement demonstrated a 1mm superior humeral head migration (Deutsch, Altchek, Schwartz, Otis, & Warren, 1996), 3) patient's with RTC tears (with and without pain) demonstrated superior migration of the humeral head with increasing elevation between 60°-150° compared to a normal control (Yamaguchi, et al., 2000), and 4) in all studies, it was demonstrated that a decrease in SAS was associated with pathology and pain.

To maintain the SAS, the scapula upwardly rotates which will elevate the lateral acromion and prevent impingement, but the SAS will exhibit a 3mm-3.9mm decrease in non-pathologic subjects at 30-120 degrees of abduction (Ludewig & Cook, 2000; Graichen, et al., 1999). Scapular posterior tilting also prevents impingement of the RTC tendons by elevating the anterior acromion and maintaining the SAS.

Shoulder impingement, believed to contribute to the development of RTC disease (Ludewig & Braman, 2011; Van der Windt, Koes, de Jong, & Bouter, 1995), is the most frequently diagnosed shoulder disorder in primary healthcare and despite its reported prevalence, the diagnostic criteria and etiology of SIS are debatable (Ludewig & Braman, 2011). SIS is an encroachment of soft tissues in the SAS due to narrowing of this space (Figure 1, B), and after impingement occurs the shoulder soft tissue can and may progress through the 3 stages of lesions (typically and overhead athlete progresses through these stages more rapidly)(Wilk, Reinold, Andrews, 2009). Neer described (Neer, 1983) three stages of lesions (Table 1) and the higher the stage the harder to respond to conservative care.

Table 1: Neer classifications of lesions in impingement syndrome		
Stage	Characteristics	Typical Age of Patient
Stage I	edema and hemorrhage of the bursa and cuff, reversible with conservative treatment	< 25 y.o.
Stage II	irreversible changes, such as fibrosis and tendinitis of the rotator cuff	25-40 y.o.
Stage III	by partial or complete tears of the rotator cuff and/ or biceps tendon and acromion and/or AC joint pathology	>40 y.o.

SIS can be separated into two main mechanistic theories and two less classic forms of impingement. The two main theories include Neer's (Neer, 1972) impingement theory which focuses on the extrinsic mechanisms (primary impingement) and the second theory focuses on intrinsic mechanisms (secondary impingement). The less classic forms of shoulder impingement include internal impingement and coracoid impingement.

Primary shoulder impingement results from mechanical abrasion and compression of the RTC tendons, subacromial bursa, or long head of the biceps tendon under the anterior undersurface of the acromion, coracoacromial ligament, or undersurface of the acromioclavicular joint during arm elevation (Neer, 1972). This type of impingement is typically seen in persons older than 40 years old and is typically due to degeneration. Scapular dyskinesis has been observed in this population and causes superior translation of the humeral head, further decreasing the SAS (Lukaseiwicz, McClure, Michener, Pratt, & Sennett, 1999; Ludewig & Cook, 2000; de Witte, et al., 2011).

In some studies, a correlation between acromial shape (Bigliani classification type II or type III) (Figure 1) **(**Bigliani, Morrison, & April, 1986) and SIS has been observed and it is presumed that the hooked acromion is a pre-existing anatomic variation or traction spur caused by repetitive superior translation of the humerus or by tendinopathy (Nordt, Garretson, &

Plotkin, 1999; Hirano, Ide, & Takagi, 2002; Jacobson, et al., 1995; Morrison, 1987). This subjective classification has applied to acromia studies using multiple imaging types and has demonstrated poor to moderate intra-observer reliability and inter-observer repeatability.

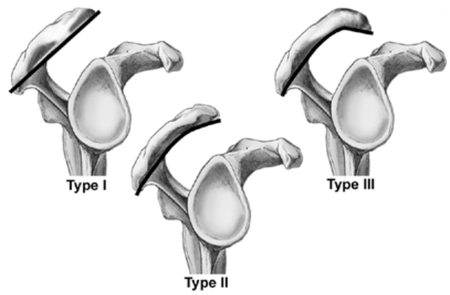

Figure 1: Bigliani classification of acromion shapes based on a supraspinatus outlet view on a radiograph (Bigliani, Morrison, & April, 1986; Wilk, Reinold, & Andrews, 2009).

Other studies conclude that there is no relation between SIS and acromial shape, or discuss the difficulties of using subacromial shape as an assessment tool (Bright, Torpey, Magid, Codd, & McFarland, 1997; Burkhead & Burkhart, 1995). Commonly, partial RTC tears are referred to as a consequence of SIS and it would be expected that these tears would occur on the bursal side of the RTC if it is "impinged" against a hooked acromion. However, the majority of partial RTC tears occur either intra-tendinous or on the articular side of the RTC (Wilk, Reinold, & Andrews, 2009). Despite these discrepancies, the extrinsic mechanism forms the rationale for the acromioplasty surgical procedure, which is one of the most commonly performed surgical procedures in the shoulder (de Witte, et al., 2011).

The second theory of shoulder impingement is based on degenerative intrinsic mechanisms and is known as secondary shoulder impingement. Secondary shoulder impingement results from intrinsic breakdown of the RTC tendons (most commonly the supraspinatus watershed zone) as a result of tension overload and ischemia. It is typically seen in overhead athletes from the age of 15-35 years old and is due to problems with muscular

dynamics and associated shoulder or scapular instability (de Witte, et al., 2011). Typically, this condition is enhanced by overuse, subacromial inflammation, tension overload on degenerative RTC tendons, or inadequate RTC function leading to an imbalance in joint stability and mobility, with consequent altered shoulder kinematics (Yamaguchi, et al., 2000; Mayerhoefer, Breitenseher, Wurnig, & Roposch, 2009; Uhthoff & Sano, 1997). Instability is generally classified as traumatic or atraumatic in origin, as well as by the direction (anterior, posterior, inferior, or multidirectional) and amount (grade I- grade III) of instability (Wilk, Reinold, & Andrews, 2009). Instability in overhead athletes is typically due to repetitive microtrauma, which can contribute to secondary shoulder impingement (Ludewig & Reynolds, 2009).

Recently, internal impingement has been identified and thought to be caused by friction and mechanical abrasion of the undersurface of the supraspinatus and infraspinatus against the anterior or posterior glenoid rim or glenoid labrum.

This has been seen posteriorly in overhead athletes when the arm is abducted to 90 degrees and externally rotated (Pappas, et al., 2006) and is usually accompanied with complaints of posterior shoulder pain during this late cocking phase of throwing when the arm is at the end range of external rotation (Myers, Laudner, Pasquale, Bradley, & Lephart, 2006). Posterior shoulder tightness (PST) and glenohumeral internal rotation deficit (GIRD) have also been linked to internal impingement by Burkhart and colleagues (Burkhart, Morgan, & Kibler, 2003). Correction of the PST through physical therapy has been shown to lead to resolution of the symptoms of internal impingement (Tyler, Nicholas, Lee, Mullaney, & Mchugh, 2012).

Coracoid impingement is typically associated with anterior shoulder pain at the extreme ranges of glenohumeral internal rotation (Jobe, Coen, & Screnar, 2000). This type of impingement is less commonly discussed but consists of the subscapularis tendon being

impinged between the coracoid process and lesser tuberosity of the humerus (Ludewig & Braman, 2011).

Since the RTC muscles are involved in throwing and overhead activities, partial thickness tears, full thickness tears, and rotator cuff disease is seen in overhead athletes. When this becomes a chronic condition, secondary impingement or internal impingement can result in primary tensile cuff disease (PTCD) or primary compressive cuff disease (PCCD). PTCD, hypothesized to be a byproduct of internal impingement, occurs during the deceleration phase of throwing in a stable shoulder and is the result of large repetitive eccentric loads placed on the RTC as it attempts to decelerate the arm resulting in partial undersurface tears in the supraspinatus and infraspinatus tendons (Andrews & Angelo, 1988; Wilk, et al., 2009). In contrast, PCCD occurs on the bursal side of the RTC and results in partial thickness tears of the RTC. It is hypothesized that processes that cause a decrease in the SIS increase the risk of this pathology and this is a byproduct of RTC muscular imbalance and weakness especially during the deceleration phase of throwing (Andrews & Angelo, 1988). During the late cocking and early acceleration phases of throwing, with the arm at maximal external rotation, the rotator cuff has the potential to become impinged between the humeral head and the posterior-superior glenoid, internal or posterior impingement (Wilk, et al., 2009), and may cause articular or undersurface tearing of the RTC in overhead athletes.

In conclusion, tears of the RTC may be caused by primarily 3 mechanisms in overhead athletes including internal impingement, primary tensile cuff disease (PTCD), or primary compressive cuff disease (PCCD) (Wilk, et al., 2009) and the causes of SIS are multifactorial and variable.

2.2 HISTORY, INCIDENCE, AND EPIDEMIOLOGY OF SCAPULA DYSKINESIS

The scapula and its associated movements are a critical component facilitating normal functional movements in the shoulder complex, while maintaining stability of the shoulder and acting as an area of force transfer (Kibler & McMullen, 2003). Assessing scapular movement and position is an important part of the clinical examination (Wright, et. al., 2012) and identifies the presence or absence of optimal motion in order to guide specific treatment options (Ludwig & Reynolds, 2009). The literature lacks the ability to identify if altered scapula positions or motions are specific to shoulder pathology or if these alterations are a normal variation (Wright, et al., 2012). Scapula motion abnormalities consist of premature, excessive, or dysrhythmic motions during active glenohumeral elevation, lowering of the upper extremity or upon bilateral comparison (Ludwig & Reynolds, 2009; Wright, et al., 2012). Research has demonstrated that the scapula upwardly rotates (Ludwig & Reynolds, 2009), posteriorly tilts, and externally rotates to clear the acromion from the humerus in forward elevation. Also, the scapula synchronously externally rotates while posteriorly tilting to maintain the glenoid as a congruent socket for the moving arm and maximize concavity compression of ball and socket kinematics. The scapula is also dynamically stabilized in a position of retraction during arm use to maximize activation and length tension relationships of all muscles that originate on the scapula (Ludwig & Reynolds, 2009). Finally, the scapula is a link in the kinetic chain of integrated segment motions that starts from the ground and ends at the hand (Kibler, Ludewig, McClure, Michener, Bak, Sciascia, 2013). Because of the important but minimal bony stabilization of the scapula by the clavicle through the acromioclavicular joint, dynamic muscle function is the major method by which the scapula is stabilized and purposefully moved to accomplish its roles. Muscle activation is coordinated in task specific force couple patterns to allow stabilization of position and control of

dynamic coupled motion. Also, the scapula will assist with acromial elevation to increase subacromial space for underlying soft tissue clearance (Ludwig & Reynolds, 2009; Wright, et al., 2012) and, for this reason, changes in scapular position are important.

The clavicle exists to help maintain optimal scapular position during arm motion (Ludwig & Reynolds, 2009). In this manner, it acts as a strut for the shoulder as it attaches the arm to the axial skeleton via the acromioclavicular and sternoclavicular joints. Injury to any of the static restraints can cause the scapula to become unstable, which in turn will negatively affect arm function (Kibler & Sciascia, 2010).

Previous research has found that changes to scapular positioning or motion were evident in 68% to 100% of patients with shoulder impairments (Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1992) resulting in compensatory motions at distal segments. The motions begin causing a diminished dynamic control of humeral-head deceleration and lead to shoulder pathologies (Voight, Hardin, Blackburn, Tippett, & Canner, 1996; Wilk, Meister, & Andrews, 2002; McQuade, Dawson, & Smidt, 1998; Kibler & McMullen, 2003; Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1992; Nadler, 2004; Hutchinson & Ireland, 2003). For this reason, the effects of scapular fatigue warrants further research.

Scapular upward rotation provides a stable base during overhead activities and previous research has examined the effect of fatigue on scapula movements and shoulder function (Suzuki, Swanik, Bliven, Kelly, & Swanik, 2006; Birkelo, Padua, Guskiewicz, & Karas, 2003; Su, Johnson, Gravely, & Karduna, 2004; Tsai, McClure, & Karduna, 2003; McQuade, Dawson, & Smidt, 1998; Joshi, Thigpen, Bunn, Karas, & Padua, 2011; Tyler, Cuoco, Schachter, Thomas, & McHugh, 2009; Noguchi, Chopp, Borgs, & Dickerson, 2013; Chopp, Fischer, & Dickerson, 2011; Madsen, Bak, Jensen, & Welter, 2011). Prior studies found no change in scapula upward

rotation due to fatigue in healthy individuals (Suzuki, Swanik, Bliven, Kelly, & Swanik, 2006) and healthy overhead athletes (Birkelo, Padua, Guskiewicz, & Karas, 2003; Su, Johnson, Gravely, & Karduna, 2004). However, the results of these studies should be interpreted with caution and may not be applied to functional movements since one study (Suzuki, Swanik, Bliven, Kelly, & Swanik, 2006) performed seated overhead throwing before and after fatigue with healthy college age men. Since the kinematics and dynamics of overhead throwing cannot be seen in sitting, the author's results can't draw a comparison to overhead athletes or the pathological populations since the participants were healthy. Also, since the scapula is thought to be involved in the kinetic chain of overhead motion (Kibler, Ludewig, McClure, Michener, Bak, & Sciascia, 2013), sitting would limit scapula movements and limit the interpretation of the resulting scapula motion.

Nonetheless, several researchers have identified decreased scapular upward rotation in both healthy subjects and subjects with shoulder pathologies (Su, Johnson, Gravely, & Karduna, 2004; Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1992; Lukaseiwicz, McClure, Michener, Pratt, & Sennett, 1999). In addition, after shoulder complex fatigue, significant changes in scapular position (decreased upward rotation, posterior tilting, and external rotation) have been demonstrated using exercises that induced scapular and glenohumeral muscle fatigue (Tsai, McClure, & Karduna, 2003). However, this previous research has focused on shoulder external rotation fatigue and not on scapular musculature fatigue.

Lack of agreement in the findings are explained by the nature of measurements used, which differ between static and dynamic movements, as well as instrumentation. One explanation for these differences involves the muscles targeted for fatigue. For example, some studies have examined shoulder complex fatigue due to a functional activity (Birkelo, Padua, Guskiewicz, &

Karas, 2003; Su, Johnson, Gravely, & Karduna, 2004; Madsen, Bak, Jensen, & Welter, 2011) while others have compared a more isolated scapular-muscle fatigue protocol (McQuade, Dawson, & Smidt, 1998; Suzuki, Swanik, Bliven, Kelly, & Swanik, 2006; Tyler, Cuoco, Schachter, Thomas, & McHugh, 2009; Chopp, Fischer, & Dickerson, 2011), and others have examined shoulder complex fatigue (Tsai, McClure, & Karduna, 2003; Joshi, Thigpen, Bunn, Karas, & Padua, 2011; Noguchi, Chopp, Borgs, & Dickerson, 2013; Madsen, Bak, Jensen, & Welter, 2011; Chopp, Fischer, & Dickerson, 2011). Therefore to date, no prior research has specifically targeted the lower trapezius muscle using a therapeutic exercise with a maximal activation pattern of the muscle.

2.2.1 Pathophysiology of scapula dyskinesis

Abnormal scapular motion and/or position have been collectively called “scapular winging”, “scapular dyskinesia”, “altered scapula resting position”, and “scapular dyskinesis” (Table 2).

Table 2: Abnormal scapula motion terminology

Term	Definition	Possible Cause	Static/Dynamic
scapular winging	a visual abnormality of prominence of the scapula medial border	long thoracic nerve palsy or overt scapular muscle weakness	both
scapular dyskinesia	loss of voluntary motion has occurred only the scapular translations (elevation/depression and retraction/protraction) can be performed voluntarily, whereas the scapular rotations are accessory in nature	adhesions, restricted range of motion, nerve palsy	dynamic
scapular dyskinesis	refers to movement of the scapula that is dysfunctional	weakness/imbalance, nerve injury and acromioclavicular joint injury, superior labral tears, rotator cuff injury, clavicle fractures, impingement	Dynamic
altered scapular resting position	describing the static appearance of the scapula	fractures, congenital abnormality, SICK scapula	static

The most appropriate term to refer to dysfunctional dynamic movement of the scapula is the term scapular dyskinesis (‘dys’—alteration of, ‘kinesis’—movement). When the arm is raised overhead, the generally accepted pattern of scapulothoracic motion is upward rotation, external rotation, and posterior tilt of the scapula as well as elevation and retraction of the clavicle (Ludewig, et al., 1996; McClure, et al., 2001). Of the 14 muscles that attach to the scapula, the trapezius and serratus anterior play a critical role in the production and control of scapulothoracic motion (Ebaugh, et al., 2005; Inman, et al., 1944; Ludewig, et al., 1996). Furthermore, scapular dyskinesis is reported to be more prominent as the arm is lowered from an overhead position and individuals with shoulder pathology generally report more pain when lowering the arm (Kibler & McMullen, 2003; Sharman, 2002).

Scapular dyskinesis has been identified by a group of experts as: (1) abnormal static scapular position and/or dynamic scapular motion characterized by medial border prominence; or (2) inferior angle prominence and/or early scapular elevation or shrugging on arm elevation; and/or (3) rapid downward rotation during arm lowering (Kibler & Sciascia, 2010). Scapular dyskinesis is a non-specific response to a painful condition in the shoulder rather than a specific response to certain glenohumeral pathology and alters the scapulohumeral rhythm. Scapular dyskinesis occurs when the upper trapezius, middle trapezius, lower trapezius, serratus anterior, and latissimus dorsi (stabilizing muscles) are unable to preserve typical scapular movement (Kibler & Sciascia, 2010). Scapula dyskinesis is potentially harmful when it results in increased anterior tilting, downward rotation, and protraction, which reorients the acromion and decreases the subacromial space width (Tsai, et al., 2003; Borstad, et al., 2009).

Alterations in static stabilizers (bone), muscle activation patterns, or strength in scapula musculature have contributed to scapula dyskinesis. Researchers have shown that injuries to the

stabilizing ligaments of the acromioclavicular joint can cause the scapula to displace in a downward, protracted, and internally rotated position (Kibler & Sciascia, 2010). With displacement of the scapula, significant functional consequences to shoulder biomechanics occur including an uncoupling of the scapulohumeral complex, inability of the scapular stabilizing muscles to maintain appropriate positioning of the glenohumeral and acromiohumeral joints, and a subsequent loss of rotator cuff strength and function (Joshi, Thigpen, Bunn, Karas, & Padua, 2011).

Scapular dyskinesis is associated with impingement by altering arm motion and scapula position upon dynamic elevation, which is characterized by a loss of acromial upward rotation, excessive scapular internal rotation, and excessive scapular anterior tilt (Cools, Struyf, De Mey, Maenhout, Castelein, & Cagnie, 2013; Forthomme, Crielaard, & Croisier, 2008). These associated alterations cause a decrease in the subacromial space and increase the individual's impingement risk.

Prior research has demonstrated altered activation sequencing patterns and strength of the stabilizing muscles of the scapula in individuals diagnosed with impingement risk and scapular dyskinesis (Cools, Struyf, De Mey, Maenhout, Castelein, & Cagnie, 2013; Kibler & Sciascia, 2010). Each scapula muscle makes a specific contribution to scapular function, but the lower trapezius and serratus anterior appear to play the major role in stabilizing the scapula during arm movement. Weakness, fatigue, or injury in either of these muscles may cause a disruption of the dynamic stability, which leads to abnormal kinematics and symptoms of impingement. In a prior study (Madsen, Bak, Jensen, & Welter, 2011), the authors demonstrated increased incidence of scapula dyskinesis in pain-free competitive overhead athletes during increasing training and

fatigue. The prevalence of scapula dyskinesis seemed to increase with increased training to a cumulative presence of 82% in pain-free competitive overhead athletes.

A classification system, which aids in clinical evaluation of scapula dyskinesis, has also been reported in the literature (Kibler, Uhl, Maddux, Brooks, Zeller, & McMullen, 2002) and modified to increase sensitivity (Uhl, Kibler, Gecewich, & Tripp, 2009). This method classifies scapula dyskinesis based on the prominent part of the scapula and includes four types: 1) inferior angle pattern (Type I), 2) medial border pattern (Type II), 3) superior border patters (Type III), and 4) normal pattern (Type IV). The examiner first predicts if the individual has scapula dyskinesis (yes/no method) then classifies the individual pattern type, which has a higher sensitivity (76%) and positive predictive value (74%) than any other clinical dyskinesis measure (Uhl, Kibler, Gecewich, & Tripp, 2009).

Increased upper trapezius activity, imbalance of upper trapezius/lower trapezius activation, and decreased serratus anterior activity have been reported in patients with impingement (Cools, Struyf, De Mey, Maenhout, Castelein, & Cagnie, 2013; Lawrence, Braman, Laprade, & Ludewig, 2014). Authors have hypothesized that impingement due to lack of acromial elevation is caused by increased upper trapezius activity (shrug maneuver) resulting in a type III (upper medial border prominence) dyskinesis pattern (Kibler & Sciascia, 2010). Frequently, lower trapezius activation is inhibited or is delayed (Cools, Struyf, De Mey, Maenhout, Castelein, & Cagnie, 2013), which results in a type III/type II (entire medial border prominence) dyskinesis pattern and impingement due to loss of acromial elevation and posterior tilt (Kibler & Sciascia, 2010).

Scapular position and kinematics influence rotator cuff strength (Kibler, Ludewig, McClure, Michener, Bak, & Sciascia, 2013) and prior research (Kebaetse, McClure, & Pratt, 1999) has

demonstrated a 23% maximum rotator cuff strength decrease due to excessive scapular protraction, a posture seen frequently in individuals with scapular dyskinesis. Another study (Smith, Dietrich, Kotajarvi, & Kaufman, 2006) indicates that maximal rotator cuff strength is achieved with a position of 'neutral scapular protraction/retraction' and the positions of excessive protraction or retraction demonstrates decreased rotator cuff abduction strength. Lastly, research has demonstrated (Kibler, Sciascia, & Dome, 2006) an increase of 24% supraspinatus strength in a position of scapular retraction in individuals with shoulder pain and 11% increase in individuals without shoulder pain. The clinically observable finding in scapular dyskinesis, prominence of the medial scapular border, is associated with the biomechanical position of scapular internal rotation and protraction, which is a less than optimal base for muscle strength (Kibler, & Sciascia, 2010).

Table 3: Causes of scapula dyskinesis

Cause	Associated pathology
Bony	thoracic kyphosis, clavicle fracture nonunion, clavicle shortened mal-union, scapular fractures
Neurological	cervical radiculopathy; long thoracic, dorsal scapular nerve, or spinal accessory nerve palsy
Joint	high grade AC instability, AC arthrosis, GH joint internal derangement (labral injury), glenohumeral instability, biceps tendinitis
Soft Tissue	inflexibility (tightness) or intrinsic muscle problems. Inflexibility and stiffness of the pectoralis minor and biceps short head can create anterior tilt and protraction due to their pull on the coracoid soft tissue posterior shoulder inflexibility can lead to glenohumeral internal rotation deficit (GIRD), shoulder rotation tightness (GIRD and Total Range of Motion Deficit) and pectoralis minor inflexibility
Muscular	periscapular muscle activation serratus anterior activation and strength is decreased the upper trapezius/lower trapezius force couple may be altered delayed onset of activation in the lower trapezius lower trapezius and serratus anterior weakness, upper trapezius hyperactivity or scapular muscle detachment and kinetic chain factors include hip/leg weakness and core weakness

Causes of scapula dyskinesis remain multifactorial (Table 3), but altered scapular motion or position decrease linear measures of the subacromial space (Giphart, van der Meijden, & Millett, 2012), increase impingement symptoms (Kibler, Ludewig, McClure, Michener, Bak, & Sciascia, 2013), decrease rotator cuff strength (Kebaetse, McClure, & Pratt, 1999; Smith, Dietrich, Kotajarvi, & Kaufman, 2006; Kibler, Sciascia, & Dome, 2006) and increase the risk of internal impingement (Kibler & Sciascia, 2010).

However, no conclusive study indicating the occurrence of scapular dyskinesis occurring as a direct result of solely lower trapezius muscle fatigue, even though scapular orientation changes in an impinging direction (downward rotation, anterior tilt, and protraction), have been reported with fatigue (Birkelo, Padua, Guskiewicz, & Karas, 2003; Su, Johnson, Gravely, & Karduna, 2004; Madsen, Bak, Jensen, & Welter, 2011; McQuade, Dawson, & Smidt, 1998; Suzuki, Swanik, Bliven, Kelly, & Swanik, 2006; Tyler, Cuoco, Schachter, Thomas, & McHugh, 2009; Chopp, Fischer, & Dickerson, 2011; Tsai, McClure, & Karduna, 2003; Joshi, Thigpen, Bunn, Karas, & Padua, 2011; Noguchi, Chopp, Borgs, & Dickerson, 2013; Madsen, Bak, Jensen, & Welter, 2011; Chopp, Fischer, & Dickerson, 2011). Determining the effects of upper extremity muscular fatigue and the associated mechanisms of subacromial space reduction is important from a prevention and rehabilitation perspective. However, changes in scapular orientation following targeted fatigue of scapular stabilizing lower trapezius muscles is currently unverified, but one study (Borstad, Szucs, & Navalgund, 2009) used a ‘‘modified push-up plus’’ as a fatiguing protocol, which elicited fatigue from the serratus anterior, upper and lower trapezius, and the infraspinatus. The resulting kinematics from fatigue includes a decrease in posterior tilt (-3.8˚), increase in internal rotation (protraction) (+3.2˚), and no change in upward rotation. The prone rowing exercises, in which a patient lies prone on a bench and flexes the elbow from 0˚ to

90˚ while the shoulder flexion angle moves from 90˚ to 0˚ using a resistive weight, are clinically recommended to strengthen the scapular stabilizers while minimally activating the rotator cuff (Escamilla, et al., 2009; Reinold, et al., 2004). Research (Noguchi, Chopp, Borgs, & Dickerson, 2013) investigates the ability of this prone rowing task to solely target the scapular stabilizers in order to help clarify whether scapular dyskinesis is a possible mechanism of fatigue-induced subacromial impingement risk. However the authors (Noguchi, Chopp, Borgs, & Dickerson, 2013) showed no significant changes in 3-Dimensional scapula orientation. These results may be due to the fact that the prone rowing exercise has a moderate to minimal EMG activation profile of the lower trapezius (45±17%MVIC; Ekstrom, Donatelli, & Soderberg, 2003) and (67±50%MVIC; Moseley, Jobe, Pink, Perry, & Tibone, 1992). Prone rowing has a maximal activation of the upper trapezius (112±84%MVIC; Moseley, Jobe, Pink, Perry, & Tibone, 1992 and 63±17%MVIC; Ekstrom, Donatelli, & Soderberg, 2003), middle trapezius (59±51%MVIC; Moseley, Jobe, Pink, Perry, & Tibone, 1992 and 79±23%MVIC; Ekstrom, Donatelli, & Soderberg, 2003), and levator scapulae (117±69%MVIC; Moseley, Jobe, Pink, Perry, & Tibone, 1992). Therefore, it is difficult to demonstrate significant changes in scapular motion when the primary scapular stabilizer (lower trapezius) isn't specifically targeted in a fatiguing exercise. Therefore, prone rowing or similar exertions intended to highly activate the scapular stabilizing muscles, while minimally activating the rotator cuff, failed to do so, suggesting that the correct muscle which contributes to maintain healthy glenohumeral and scapulothoracic kinematics was not targeted.

2.3 LIMITATIONS OF STUDYING EMG ON SHOULDER MUSCLES

Abnormal muscle activity patterns have been observed in overhead athletes with impingement (Lukaseiwicz, McClure, Michener, Pratt, & Sennett, 1999; Ekstrom, Donatelli, &

Soderberg, 2003; Ludewig, & Cook, 2000) and electromyography (EMG) analysis is used to assess muscle activity in the shoulder (Kelly, Backus, Warren, & Williams, 2002). Fine wire (fw) EMG and surface (s) EMG have been used to demonstrate changes in muscle activity (Jaggi, et al., 2009) and the study of muscle function through EMG helps quantify muscle activity by recording the electrical activity of the muscle (Solomonow, et al., 1994). In general, the electrical activity of an individual muscle's motor unit is measured and therefore the more active the motor units the greater the electrical activity. The choice of electrode type is typically determined by the size and site of the muscle being investigated with fwEMG used for deep muscles and sEMG used for superficial muscles (Jaggi, et al., 2009). It is also important to note that it can be difficult to test in the exact same area for fwEMG and sEMG, since they are both attached to the skin and the skin can move above the muscle.

Jaggi (Jaggi, et al., 2009) examined the level of agreement in sEMG and fwEMG in the infraspinatus, pectoralis major, latissimus dorsi, and anterior deltoid of 18 subjects with a diagnosis of shoulder instability. While this study didn't have a control, the sEMG and fwEMG demonstrated a poor level of agreement but the sensitivity and specificity for the infraspinatus was good (Jaggi, et al., 2009). However, this article demonstrated poor power, a lack of a control group, and a possible investigator bias. In this article, two different investigators performed the five identical uniplanar movements, but at different times the individual investigator bias may have affected levels of agreement in this study. Also, the diagnosis of shoulder instability is a multifactorial diagnosis which may or may not include pain and which may also contain a secondary pathology like a RTC tear, labral tear, shoulder impingement, and numerous types of instability (including anterior, inferior, posterior, and superior instability).

In a study by Meskers and colleagues (Meskers, de Groot, Arwert, Rozendaal, & Rozing, 2004), 12 subjects without shoulder pathology underwent sEMG and fwEMG testing of 12 shoulder muscles while performing various movements of the upper extremity. Also, some subjects were retested again at days 7 and 14 and this method demonstrated sufficient accuracy for intra-individual measurements on different days. Therefore, this article gives some support to the use of EMG testing of shoulder musculature before and after interventions.

In general, sEMG may be more representative of the overall activity of a given muscle, but a disadvantage to this is that some of the measured electrical activity may originate from other muscles not being studied, a phenomenon called crosstalk (Solomonow, et al., 1994). Generally, sEMG may pick up 5-15% electrical activity from surrounding muscles not being studied and subcutaneous fat may also influence crosstalk in sEMG amplitudes (Solomonow, et al., 1994; Jaggi, et al., 2009). Inconsistencies in sEMG interpretations arise from differences in subcutaneous fat layers, familiarity with test exercise, actual individual strain level during movement, or other physiological factors.

Methodological inconsistencies of EMG testing include accuracy of skin preparation, distance between electrodes, electrode localization, electrode type and orientation, and normalization methods. The standard for EMG normalization is the calculation of relative amplitudes, which is referred to as maximum voluntary contraction level (MVC) (Anders, Bretschneider, Bernsdorf, & Schneider, 2005). However, some studies have shown non-linear amplitudes due to recruitment strategies and the speed of contraction (Anders, Bretschneider, Bernsdorf, & Schneider, 2005).

Maximum voluntary isometric contraction (MVIC) has also been used in normalization of EMG data. Knutson et al. (Knutson, Soderberg, Ballantyne, & Clarke, 2005) found that

MVIC method of normalization demonstrates lower variability and higher inter-individual reliability compared to MVC of dynamic contractions. The overall conclusion was that MVIC was the standard for normalization in the normal and orthopedically impaired population. When comparing EMG between subjects, EMG is normalized to MVIC (Ekstrom, Soderberg, & Donatelli, 2005).

When testing EMG on healthy and orthopedically impaired overhead athletes, muscle length, bone position, and muscle contraction can all add variance to final observed measures. Intra-individual errors between movements and between groups (healthy vs pathologic) and intra-observer variance can also add variance to the results. Pain in the pathologic population may not allow the individual to perform certain movements, which is a limitation specific to this population. Also, MVIC testing is a static test, which may be used for dynamic testing but allows for between subject comparisons. Kelly and colleagues (Kelly, Backus, Warren, & Williams, 2002) have described 3 progressive levels of EMG activity in shoulder patients. The authors suggested that a minimal reading was between 0-39% MVIC, a moderate reading was between 40-74% MVIC, and a maximal reading was between 75-100% MVIC.

When dealing with recording EMG while performing therapeutic exercise, changing muscle length and the speed of contraction is an issue that should be addressed since it may influence the magnitude of the EMG signal (Ekstrom, Donatelli, & Soderberg, 2003). This can be addressed by controlling the speed by which the movement is performed since it has been demonstrated that a near linear relationship exists between force production and EMG recording in concentric and eccentric contractions with a constant velocity (Ekstrom, Donatelli, & Soderberg, 2003). The use of a metronome has been used in prior studies to address the velocity of movements and keep a constant rate of speed.

2.4 SHOULDER AND SCAPULA DYNAMICS

Shoulder dynamics result from the interplay of complex muscular, osseous, and supporting structures, which provide a range of motion that exceeds that of any other joint in the body and maintain proper control and stability of all involved joints. The glenohumeral joint resting position and its supporting structures static alignment are influenced by static thoracic spine alignment, humeral bone components, scapular bone components, clavicular bony components, and the muscular attachments from the thoracic and cervical spine (Wilk, Reinold, & Andrews, 2009).

Alterations in shoulder range of motion (ROM) have been associated with shoulder impingement along with scapular dyskinesis, (Lukaseiwicz, McClure, Michener, Pratt, Sennett, 1999; Ludewig & Cook, 2000; Endo, Ikata, Katoh, & Takeda, 2001) clavicular movement, and increased humeral head translations (Ludewig & Cook, 2002; Laudner, Myers, Pasquale, Bradley, & Lephart, 2006; McClure, Michener, & Karduna, 2006; Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1992; Deutsch, Altchek, Schwartz, Otis, & Warren, 1996; Lin, et al., 2005). All of these deviations are believed to reduce the subacromial space or approximate the tendon undersurface to the glenoid labrum, creating decreased clearance of the RTC tendons and other structures under the acromion (Graichen, et al., 1999). These altered shoulder kinematics cause alterations in shoulder and scapular muscle activation patterns or altered resting length of shoulder muscles.

2.4.1 Shoulder/scapular movements

Normal shoulder biomechanics have been studied with EMG during ROM (Ludewig & Cook, 2000; Kibler & McMullen, 2003; Bagg & Forrest, 1986), cadaver studies (Johnson, Bogduk, Nowitzke, & House, 1994), patients with nerve injuries (Brunnstrom, 1941; Wiater &

Bigliani, 1999), and in predictive biomechanical modeling of the arm and muscular function (Johnson, Bogduk, Nowitzke, & House, 1994; Poppen & Walker, 1978). These approaches have refined our knowledge about the function and movements of the shoulder and scapula musculature. Understanding muscle adaptation to pathology in the shoulder is important for developing guidelines for interventions to improve shoulder function. These studies have defined a general consensus on what muscles will be active and when during normal shoulder range of motion.

In 1944 Inman (Inman, Saunders, & Abbott, 1944) discussed the "scapulohumeral rhythm", which is a ratio of "2:1" glenohumeral joint to scapulothoracic joint range of motion during active range of motion. Therefore, if the glenohumeral joint moves 180 degrees of abduction then the scapula rotates 90 degrees. However, this ratio doesn't account for the different planes of motion, speed of motion, or loaded movements and therefore this 2:1 ratio has been debated in the literature with numerous recent authors reporting various scapulohumeral ratios (Table 4) from 2.2:1 to 1.7:1 with some reporting even larger ratios of 3:2 (Freedman & Munro, 1966) and 5:4 (Poppen & Walker, 1976). Many of these discrepancies may be due to different measuring techniques and different methodologies in the studies. McQuade and

Table 4: Scapulohumeral ratio during shoulder elevation

Study Year	Scapulohumeral ratio
Fung et al. 2001	2.1/1
Ludewig et al. 2009	2.2/1
McClure et al. 2001	1.7/1
Inman et al. 1944	2:1
Freedman & Monro 1966	3:2
Poppen & Walker 1976	1.24:1 or 5:4
McQuade & Smidt 1998	7.9:1 to 2.1:1 (PROM) 1.9:1 to 4.5:1 (loaded)

colleagues (McQuade & Smidt, 1998) also reported that that the 2:1 ratio doesn't adequately explain normal shoulder kinematics. However, McQuade and colleagues didn't look at submaximal loaded conditions, a pathological population, EMG activity during the test, but rather looked at only the concentric phase which will all limit the clinical application of the research results.

There is also disagreement as to when this 2:1 scapulohumeral ratio occurs even though it is generally considered to occur in 60 to 120 degrees with 1 degree of scapular movement occurring for every 2 degrees of elevation movement until 120 degrees and thereafter 1 degree of scapular movement for every 1 degrees of elevation movement (Reinold, Escamilla, & Wilk, 2009). Contrary to general considerations some authors have noted the greatest scapular movement at 30 to 60 degrees while others have found the greatest movement at 80 to 140 degrees, but generally these discrepancies are due to different measuring techniques (Bagg & Forrest, 1986).

Normal scapular movement during glenohumeral elevation helps maintain correct length tension relationships of the shoulder musculature and prevent the subacromial structures from being impinged and generally includes upward rotation, external rotation, and posterior tilting on the thorax with upward rotation being the dominant motion (McClure, et al., 2001; Ludewig & Reynolds, 2009). Overhead athletes generally exhibit increased scapular upward rotation, internal rotation, and retraction during elevation and this is hypothesized to be an adaptation to allow for clearance of subacromial structures during throwing (Wilk, Reinold, & Andrews, 2009). Generally accepted normal ranges have been observed for scapular upward rotation (45-55 degrees), posterior tilting (20-40 degrees), and external rotation (15-35 degrees) during elevation and the scapular muscles are vitally important in maintaining the scapulohumeral

kinematic balance since they cause scapular movements (Wilk, Reinold, & Andrews, 2009; Ludewig & Reynolds, 2009).

However, the amount of scapular internal rotation during elevation has shown a great deal of variability across investigations, elevation planes, subjects, and points in the glenohumeral range of motion. Authors suggest that a slight increase in scapular internal rotation may be normal early in glenohumeral elevation (McClure, Michener, Sennett, & Karduna, 2001) and it is also generally accepted (but has limited evidence to support) that end range elevation involves scapular external rotation (Ludewig & Reynolds, 2009).

Scapulothoracic "translations" (Figure 2) also occur during arm elevation and include elevation/depression and adduction/abduction (retraction/protraction), which are derived from clavicular movements. Also scapulothoracic kinematics involve combined acromioclavicular (AC) and sternoclavicular (SC) joint motions, therefore, authors have performed studies of the 3-dimensional motion analysis of the AC and SC joints in healthy subjects and have linked scapulothoracic elevation to SC elevation and scapulothoracic abduction/adduction to SC protraction/retraction (Ludewig & Reynolds, 2009).

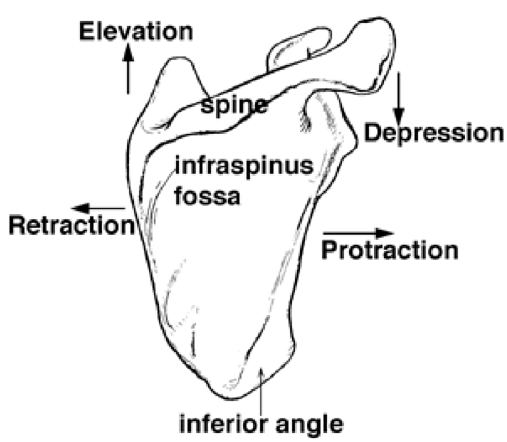

Figure 2: Scapulothoracic translations during arm elevation

Despite these numerous scapular movements, there remain gaps in the literature and unanswered questions including: 1) which muscles are responsible for internal/external rotation or anterior/posterior tilting of the scapula, 2) what are normal values for protraction/retraction 3) what are normal values for scapulothoracic elevation/depression, 4) how do we measure scapulothoracic “translations”?

2.4.2 Loaded vs unloaded

The effect of an external load in the hand during elevation remains unclear on scapular mechanics, scapulohumeral ratio, and EMG activity of the scapular musculature. Adding a .5kg load in the hand while performing shoulder movements has been shown to increase the EMG activity of the shoulder musculature. In a study of 16 subjects by Antony and Keir (Antony & Keir, 2010), subjects performed scaption with a .5kg load added to the hand and shoulder maximum voluntary excitation (MVE) increased by 4% across all postures and velocities. Also, when the subjects use a firmer grip on the load a decrease of 2% was demonstrated in the anterior and middle deltoid, and increase of 2% was seen in the posterior deltoid infraspinatus and trapezius, and lastly the biceps increased by 6% MVE. While this study gives some evidence for the use of a loaded exercise with a firmer grip on dumbbells while performing rehabilitation, the study had limited participants and was only performed on a young and healthy population which limits clinical application of the results.

Some researchers have shown no change in scapulothoracic ratio with the addition of resistance (Freedman & Munro, 1966), while others reported different ratios with addition of resistance (McQuade & Smidt, 1998). However, several limitations are noted in the McQuade & Smidt study including: 1) submaximal loads were not investigated; 2) pathological population not assessed; 3) EMG analysis was not performed; and 4) only concentric movements were

investigated. All of these shortcomings limit the study's results to a pathological population and more research is needed on the effect of loads on the scapulohumeral ratio.

Witt and colleagues (Witt, Talbott, & Kotowski, 2011) examined upper, middle, and lower trapezius, and serratus anterior EMG activity with a 3 pound dumbbell weight and elastic resistance during diagonal patterns of movement in 21 healthy participants. They concluded that the type of resistance didn't significantly change muscle activity in the diagonal patterns tested. However, this study did demonstrate limitations which will alter interpretation including: 1) the study population's exercise/fitness level was not determined; 2) the resistance selection procedure didn't use any form of repetition maximum percentage; and 3) there may have been crosstalk with the sEMG selection.

2.4.3 Scapular plane vs. other planes

The scapular plane is located 30 to 40 degrees anterior to the coronal plane, which offers biomechanical and anatomical features. In the scapular plane elevation the joint surfaces have greater conformity, the inferior shoulder capsule ligaments and RTC tendons remain untwisted, and the supraspinatus and deltoid are advantageously aligned for elevation than flexion and/or abduction (Dvir & Berme, 1978). Besides these advantages, the scapular plane is where most functional activities are performed and is also the optimal plane for shoulder strengthening exercises. While performing strengthening exercises in the scapular plane, shoulder rehabilitation is enhanced since unwanted passive tension on the RTC tendons and the glenohumeral joint capsule are at its lowest point and much lower than in flexion and/or abduction (Wilk, Reinold, & Andrews, 2009). Scapular upward rotation is also greater in the scapular plane, which will decrease during elevation, but will allow for more "clearance in the subacromial space" and decrease the risk of impingement.

2.4.4 Scapulothoracic EMG activity

Previous studies have also examined scapulothoracic EMG activity and kinematics simultaneously to relate the functional status of muscle with scapular mechanics. In general during normal shoulder elevation, the scapula will upwardly rotate and posteriorly tilt on the thorax. Scapula internal rotation has also been studied but shows variability across investigations (Ludwig & Reynolds, 2009).

A general consensus has been established regarding the role of the scapular muscles during arm movements even with various approaches (different positioning of electrodes on muscles during EMG analysis [Ludwig & Cook, 2000; Lin, et al. 2005; Ekstrom, Bifulco, Lopau, Andersen, & Gough, 2004)], different normalization techniques (McLean, Chislett, Keith, Murphy, & Walton, 2003; Ekstrom, Soderberg, & Donatelli, 2005), varying velocity of contraction, various types of contraction, and various muscle length during contraction. Though EMG activity doesn't specify if a muscle is stabilizing, translating or rotating a joint, it does demonstrate how active a muscle is during a movement. Even with these various approaches and confounding factors, it is generally understood that the trapezius and serratus anterior (middle and lower) can stabilize and rotate the scapula (Bagg & Forrest, 1986; Johnson, Bogduk, Nowitzke, & House, 1994; Brunnstrom, 1941; Ekstrom, Bifulco, Lopau, Andersen, Gough, 2004; Inman, Saunders, & Abbott, 1944). Also during arm elevation the scapulothoracic muscles produce upward rotation and resist downward rotation acting on the scapula (Dvir & Berme, 1978). Three muscles including the trapezius (upper, middle, and lower), the pectoralis minor, and the serratus anterior (middle, lower, and superior) have been observed using EMG analysis.

In prior studies, the trapezius has been responsible for stabilizing the scapula since the middle and lower fibers are perfectly aligned to produce scapula external rotation facilitating scapular stabilization (Johnson, Bogduk, Nowitzke, & House, 1994). Also, the trapezius is more active during abduction versus flexion (Inman, Saunders, & Abbott, 1944; Wiedenbauer & Mortensen, 1952) due to decreased internal rotation of the scapula in scapular plane abduction. The upper trapezius is most active with scapular elevation and is produced through clavicular elevation. The lower trapezius is the only part of the trapezius that can upwardly rotate the scapula while the middle and lower trapezius are ideally suited for scapular stabilization and external rotation of the scapula.

Another important muscle is the serratus anterior which can be broken into upper, middle, and lower groups. The middle and lower serratus anterior fibers are oriented in such a way that they are at a substantial mechanical advantage for scapular upward rotation (Dvir & Berme, 1978) in combination with the ability to posterior tilt and externally rotate the scapula. Therefore, the middle and lower serratus anterior are the primary movers for scapular rotation during arm elevation and they are the only muscles that can posteriorly tilt the scapula on the thorax. Lastly, the upper serratus has been minimally investigated (Ekstrom, Bifulco, Lopau, Andersen, Gough, 2004).

The pectoralis minor can produce scapular downward rotation, internal rotation, and anterior tilting (Borstad & Ludewig, 2005) opposing upward rotation and posterior tilting during arm elevation (McClure, Michener, Sennett, & Karduna, 2001). Prior studies (Borstad & Ludewig, 2005) have demonstrated that decreased length of the pectoralis minor decreases the posterior tilt and increases the internal rotation during arm elevation which increases impingement risk.

2.4.5 Glenohumeral EMG activity

Besides the scapulothoracic musculature, the glenohumeral musculature including the deltoid and rotator cuff (supraspinatus, infraspinatus, subscapularis, and teres minor) are contributors to proper shoulder function. The deltoid is the primary mover in elevation and it is assisted by the supraspinatus initially (Sharkey, Marder, & Hanson, 1994). The rotator cuff stabilizes the glenohumeral joint against excessive humeral head translations through a medially directed compression of the humeral head into the glenoid (Sharkey & Marder, 1995). The subscapularis, infraspinatus, and teres minor have an inferiorly directed line of action offsetting the superior translation component of the deltoid muscle (Sharkey, Marder, & Hanson, 1994). Therefore, proper balance between increasing and decreasing forces results in (1-2mm) superior translation of humeral head during elevation. Finally, the infraspinatus and teres minor produce humeral head external rotation during arm elevation.

2.4.6 Shoulder EMG activity with impingement

Besides experiencing pain and other deficits, decreased EMG activation of numerous muscles has been observed in patients with shoulder impingement. In patients with shoulder impingement, a decrease in overall serratus anterior activity from 70 to 100 degrees and a decrease activation of lower serratus anterior from 31 to 120 degrees in scapular plane arm elevation (Ludwig & Cook, 2000). The upper trapezius has also shown decreased activity between 40 to 100 degrees and increased activity of the upper and lower trapezius from 61-120 degrees while performing scaption loaded (Ludwig & Cook, 2000; Peat & Grahame, 1977). Increased upper trap activation is consistent (Ludwig & Cook, 2000; Peat & Grahame, 1977) and associated with increased clavicular elevation or scapular elevation found in studies (McClure, Michener, & Karduna, 2006; Kibler & McMullen, 2003). This increased clavicular elevation at

the SC joint may be produced by increased upper trapezius activity (Johnson, Bogduk, Nowitzke, & House, 1994) and results in scapular anterior tilting causing a potential mechanism to cause or aggravate impingement symptoms. In conclusion, middle and lower serratus weakness or decreased activity contributes to impingement syndrome. Increasing function of this muscle may alleviate pain and dysfunction in shoulder impingement patients.

Alterations in rotator cuff muscle activation have been seen in patients with impingement. Decreased activity of the deltoid and rotator cuff is not pronounced in early areas of motion (Reddy, Mohr, Pink, & Jobe, 2000). However, the infraspinatus, supraspinatus, and middle deltoid demonstrate decreased activity from 30-60 degrees, decreased infraspinatus activity from 60-90 degrees, and no significant difference was seen from 90-120 degrees. This decreased activity is theorized to be related to inadequate humeral head depression (Reddy, Mohr, Pink, & Jobe, 2000). Another study demonstrated that impingement decreased activity of the subscapularus, supraspinatus, and infraspinatus; increased middle deltoid activation from 0-30 degrees; decreased coactivation of the supraspinatus and infraspinatus from 30-60 degrees; and increased activation of the infraspinatus, subscapularis, and supraspinatus from 90-120 degrees (Myers, Hwang, Pasquale, Blackburn & Lephart, 2008). Overall, impingement caused decreased RTC coactivation and increased deltoid activity at the initiation of elevation (Reddy, Mohr, Pink, & Jobe, 2000; Myers, Hwang, Pasquale, Blackburn, & Lephart, 2008).

2.4.7 Normal shoulder EMG activity

Normal Shoulder EMG activity will allow for proper shoulder function and maintain adequate clearance of the subacromial structures during shoulder function and elevation (Table 5). The scapulohumeral muscles are vitally important to provide motion, provide dynamic stabilization, and provide proper coordination and sequencing in the glenohumeral complex of

overhead athletes due to the complexity and motion needed in overhead sports. Since the glenohumeral and scapulothoracic joints are attached by musculature, the muscular activity of the shoulder complex musculature can be correlated to the maintenance of the scapulothoracic rhythm and maintenance of the shoulder force couples including: 1) Deltoid-rotator cuff; 2) Upper trapezius and serratus anterior; and 3) anterior posterior rotator cuff.

Table 5: Mean glenohumeral EMG normalized by MVIC during scaption with neutral rotation (Adapted from Alpert, Pink, Jobe, McMahon, & Mathiyakom, 2000).

Interval	Anterior Deltoid EMG (%MVIC)	Middle Deltoid EMG (%MVIC)	Posterior Deltoid EMG (%MVIC)	Supraspinatus EMG (%MVIC)	Infraspinatus EMG (%MVIC)	Teres Minor EMG (%MVIC)	Subscapularis EMG (%MVIC)
0-30˚	22±10	30±18	2±2	36±21	16±7	9±9	6±7
30-60˚	53±22	60±27	2±3	49±25	34±14	11±10	14±13
60-90˚	68±24	69±29	2±3	47±19	37±15	15±14	18±15
90-120˚	78±27	74±33	2±3	42±14	39±20	19±17	21±19
120-150˚	90±31	77±35	4±4	40±20	39±29	25±25	23±19

During initial arm elevation the more powerful deltoid exerts an upward and outward force on the humerus. If this force would occur unopposed then superior migration of the humerus would occur and result in impingement and a 60% pressure increase of the structures between the greater tuberosity and the acromion when the rotator cuff is not working properly (Ludewig & Cook, 2002). While the direction of the RTC force vector is debated to be parallel to the axillary border (Inman, et al., 1944) or perpendicular to the glenoid (Poppen & Walker, 1978), the overall effect is a force vector which counteracts the deltoid.

In normal healthy shoulders, Matsuki and colleagues (Matsuki, et al., 2012) demonstrated 2.1mm of average humeral head superior migration from 0-105˚ of elevation and a .9mm average inferior translation from 105-180˚ in elevation during fluoroscopic images of the shoulder of 12 male subjects. The deltoid-rotator cuff force couple exists when the deltoids superior directed force is counteracted by an inferior and medially directed force from the infraspinatus, subscapularis, and teres minor. The supraspinatus also exerts a compressive force on the humerus onto the glenoid, therefore serving an approximating role in the force couple (Inman, Saunders, & Abbott, 1944). This RTC helps neutralize the upward shear force, reduces workload on the deltoid through improving mechanical advantage (Sharkey, Marder, & Hanson, 1994), and assists in stabilization. Previous authors have also demonstrated that RTC fatigue or tears will increase superior migration of the humeral head (Yamaguchi, et al., 2000) demonstrating the importance of a correctly functioning force couple.

A second force couple, a synergistic relation between the upper trapezius and serratus anterior, exists to produce upward rotation of the scapula during shoulder elevation and servers 4 functions: 1) allows for rotation of the scapula, maintaining the glenoid surface for optimal positioning; 2) maintains efficient length tension relationship for the deltoid; 3) prevents impingement of the rotator cuff from the subacromial structures; and 4) provides a stable scapular base enabling appropriate recruitment of the scapulothoracic muscles. The instantaneous center of rotation starts near the medial border of the scapular spine at lower levels of elevation and therefore the lower trapezius has a small lever arm due to its distal attachment being near the center of rotation. However during continued elevation the instantaneous center of rotation moves laterally along the spine toward the acromioclavicular joint and therefore at higher levels of abduction (≥90˚) the lower trapezius will have a larger lever arm and a greater

influence on upward rotation and scapular stabilization, along with the serratus anterior (Bagg & Forrest, 1988).

Overall, the position of the scapula is important to center the humeral head on the glenoid creating a stable foundation for shoulder movements in overhead athletes (Ludwig & Reynolds, 2009). In healthy shoulders, the force couple between the serratus anterior and the trapezius rotates the scapula whereby maintaining the glenoid surface in an optimal position, positions the deltoid muscle in an optimal length tension relationship, and provides a stable foundation (Wilk, Reinold, & Andrews, 2009). A correctly functioning force couple will prevent impingement of the subacromial structures on the coracoacromial arch and enable the deltoid and scapulothoracic muscles to generate more power, stability, and force (Wilk, Reinold, & Andrews, 2009). A muscle imbalance from weakness or shortening can result in an alteration of this force couple, whereby contributing to impaired shoulder stabilization and possibly leading to impingement.

The anterior-posterior RTC force couple creates inferior dynamic stability (depressing the humeral head) and a concavity-compression mechanism (compress humeral head in glenoid) due to the relationship between the anterior-based subscapularis and the posterior-based teres minor and infraspinatus. Imbalances have been demonstrated in overhead athletes due to overdeveloped internal rotators and underdeveloped external rotators in the shoulder.

2.4.8 Abnormal scapulothoracic EMG activity

While no significant change has been noted in resting scapular position of the impingement population (Ludewig & Cook, 2000; Lukaseiwicz, McClure, Michener, Pratt, & Sennett, 1999) alterations of scapular upward rotation, posterior tilting, clavicular elevation/retraction, scapular internal rotation, scapular symmetry, and scapulohumeral rhythm have been observed (Ludewig & Reynolds, 2009; Lukasiewicz, McClure, Michener, Pratt, &

Sennett, 1999; Ludewig & Cook, 2000; McClure, Michener, & Karduna, 2006; Endo, Ikata, Katoh, & Takeda, 2001). Overhead athletes have also demonstrated a relationship between scapulothoracic muscle imbalance and altered scapular muscle activity has been associated with SIS (Reinold, Escamilla, & Wilk, 2009).

SAS has been linked with altered kinematics of the scapula while elevating the arm called scapular dyskinesis, which is defined as observable alterations in the position of the scapula and the patterns of scapular motion in relation to the thoracic cage. JP Warner coined the term scapular dyskinesis and Ben Kibler described a classification system which outlined 3 primary scapular dysfunctions which names the condition based on the portion of the scapula most pronounced or most presently visible when viewed during clinical examination.

Burkhart and colleagues (Burkhart, Morgan, & Kibler, 2003) also coined the term SICK (Scapular malposition, Inferior medial border prominence, Coracoid pain and malposition, and dyskinesis of scapular movement) scapula to describe an asymmetrical malposition of the scapula in throwing athletes.

In normal healthy arm elevation, the scapula will upwardly rotate, posteriorly tilt, and externally rotate and numerous authors have studied the alterations in scapular movements with SAS (Table 6). The current literature is conflicting in regard to the specific deviations of scapular motion in the SAS population. Researchers have reported a decrease in posterior tilt in the SAS population (Lukasiewicz, McClure, Michener, Pratt, & Sennett, 1999; Ludewig & Cook, 2000, 2002; Endo, Ikata, Katoh, & Takeda, 2001; Lin, Hanten, Olson, Roddey, Soto-quijano, Lim, et al., 2005) while others have demonstrated an increase (McClure, Michener, & Karduna, 2006; McClure, Michener, Sennett, & Karduna, 2001; Laudner, Myers, Pasquale, Bradley, & Lephart, 2006) or no difference (Hebert, Moffet, McFadyen, & Dionne, 2002).

Table 6: Scapular movement differences during shoulder elevation in healthy controls and the impingement population

Study	Method	Sample	Upward rotation	Posterior tilt	External rotation	internal rotation	Interval (˚)/ plane	Comments
Lukasiewicz et al. (1999)	Electromechanical digitizer	20 controls 17 SIS	No difference	↓ at 90° and max elevation	No difference	?	0-max / scapular	25-66 y.o. male and female
Ludewig & Cook (2000)	sEMG	26 controls 26 SIS	↓ at 60° elevation	↓ at 120° elevation	↓ when loaded	?	0-120 / scapular	20-71 y.o. males only, overhead workers
McClure et al. (2006)	sEMG	45 controls 45 SIS	↑ at 90° and 120° in sagittal plane	↑ at 120° in scapular plane	No difference	?	0-max / scapular and sagittal	24-74 y.o. male and female
Endo et al. (2001)	Static radiographs	27 SIS bilateral comparison	↓ at 90° elevation	↓ at 45° and 90° elevation	No difference	?	0-90 / frontal	41-73 y.o. male and female
Graichen et al. (2001)	Static MRI	14 controls 20 SIS	No significant difference	?	?	?	0-120 / frontal	22-62 y.o. male female
Hebert et al. (2002)	calculated with optical surface sensors	10 controls 41 SIS	No significant differences	No significant differences	?	↑ on side with SIS	0-110 / frontal and coronal	30-60 y.o. both genders, used bilateral shoulders
Lin et al. (2005)	sEMG	25 controls, 21 shoulder dysfunction	↓ in SD group	↓ in SD group	?	No significant differences	Approximate 0-120 / scapular plane	Males only, 27-82 y.o.
Laudner et al. (2006)	sEMG	11 controls 11 internal impingement	No significant difference	↑ in impingement	?	No significant differences	0-120 / scapular plane	Males only, throwers, 18-30 y.o.

Similarly, Researchers have reported a decrease in upward rotation in the SAS population (Ludewig & Cook, 2000, 2002; Endo, Ikata, Katoh, & Takeda, 2001; Lin, Hanten, Olson, Roddey, Soto-quijano, Lim, et al., 2005) while others have demonstrated an increase (McClure, Michener, & Karduna, 2006) or no difference (Lukasiewicz, McClure, Michener, Pratt, & Sennett, 1999; Hebert, Moffet, McFadyen, & Dionne, 2002; Laudner, Myers, Pasquale, Bradley, & Lephart, 2006; Graichen, Stammberger, Bone, Wiedemann, Englmeier, Reiser, & Eckstein, 2001). Lastly, researchers have also reported a decrease in external rotation during weighted elevation (Ludewig & Cook, 2000) while other have shown no difference during unweighted elevation (Lukasiewicz, McClure, Michener, Pratt, & Sennett, 1999; Endo, Ikata, Katoh, & Takeda, 2001; McClure, Michener, Sennett, & Karduna, 2001). One study has reported an increase internal rotation (Hebert, Moffet, McFadyen, & Dionne, 2002) while others have shown no differences (Lin, Hanten, Olson, Roddey, Soto-quijano, Lim, et al., 2005; Laudner, Myers, Pasquale, Bradley, & Lephart, 2006) or reported a decrease (Ludewig & Cook, 2000). However with all these deviations and differences, researches seem to agree that athletes with SIS have decreased upward rotation during elevation (Ludewig & Cook, 2000, 2002; Endo, Ikata, Katoh, & Takeda, 2001; Lin, Hanten, Olson, Roddey, Soto-quijano, Lim, et al., 2005) with exception of one study (McClure, Michener, & Karduna, 2006).

These conflicting results in the scapular motion literature are likely due to the smaller measurements of scapular tilt and internal/external rotation (25˚-30˚) when compared to scapular upward rotation (50˚), the altered scapular kinematics related to a specific type of impingement, the specific muscular contributions to anterior/posterior tilting and internal/external rotation are unclear, and/or the lack of valid scapular motion measurement techniques in anterior/posterior tilting and internal/external rotation compared to upward rotation.

The scapular muscles have also exhibited altered muscle activation patterns during elevation in the impingement population including increased activation of the upper trapezius and decreased activation of the middle/lower trapezius and serratus anterior (Cools et al., 2007; Cools, Witvrouw, Declercq, Danneels, & Cambier, 2003; Wadsworth & Bullock-Saxton, 1997). In contrast Ludewig & Cook (Ludewig & Cook, 2000), demonstrated increased activation in both the upper and lower trapezius in SIS when compared to a control, and Lin and colleagues (Lin, et al., 2005) demonstrated no change in lower trapezius activity. These different results make the final EMG assessment unclear in the impingement population, however there are some possible explanation for the differences in results including: 1) Ludewig & Cook performed there experiment weighted in male and female construction workers, 2) Lin and colleagues performed their experiment with numerous shoulder pathologies and in males only, 3) Cools and colleagues used maximal isokinetic testing in abduction in overhead athletes, and 4) all of these studies demonstrated large age ranges in their populations.

However, there is a lack of reliable studies in the literature pertaining to the EMG activity changes in overhead throwers with SIS after injury/pre-rehabilitation and after injury post-rehabilitation. The inability to detect significant differences between groups by investigators is primarily due to limited sample sizes, limited statistical power for some comparisons, the large variation in the healthy population, sEMG signals in studies is altered by skin motion, and limited static imaging in supine.

2.4.9 Abnormal glenohumeral/rotator cuff EMG activity

Abnormal muscle patterns in the deltoid-rotator cuff and/or anterior posterior rotator cuff force couple can contribute to SIS and have been demonstrated in the impingement population (Myers, Hwang, Pasquale, Blackburn, & Lephart, 2008; Reddy, Mohr, Pink, & Jobe, 2000). In

general, researchers have found decreased deltoid activity (Reddy, Mohr, Pink, & Jobe, 2000), deltoid atrophy (Leivseth & Reikeras, 1994), and decreased rotator cuff activity (Reddy, Mohr, Pink, & Jobe, 2000) which can lead to decreased stabilization, unopposed deltoid activity, and induce compression of subacromial structures causing a 1.7mm-2.1mm humeral head anteriosuperior migration during 60˚-90˚ of abduction (Sharkey, Marder, & Hanson, 1994). The impingement population has demonstrated decreased infraspinatus and subscapularis EMG activity from 30˚-90˚ elevation when compared to a control (Reddy, Mohr, Pink, & Jobe, 2000).

Myers and colleagues (Myers, Hwang, Pasquale, Blackburn, & Lephart, 2009) have demonstrated with fwEMG analysis, decreased rotator cuff coactivation (subscapularis-infraspinatus and supraspinatus-infraspinatus) and abnormal deltoid activation (increased middle deltoid activation from 0-30˚) during humeral elevation in 10 subjects with subacromial impingent when compared to 10 healthy controls and the authors hypothesized this was contributing to their symptoms.

Isokinetic testing has also demonstrated lower protraction/retraction ratios in 30 overhead athletes with chronic shoulder impingement when compared to controls (Cools, Witvrouw, Mahieu, & Danneels, 2005). Decreased isokinetic force output has also been demonstrated in the protractor muscles of overhead athletes with impingement (-13.7% at 60degrees/s; -15.5% at 180degrees/s) (Cools, Witvrouw, Mahieu, & Danneels, 2005).

2.5 REHABILITATION CONSIDERATIONS

Current treatment of impingement generally starts with conservative methods, including arm rest, physical therapy, nonsteroidal anti-inflammatory drugs (NSAIDs), and subacromial corticosteroids injections (de Witte, et al., 2011). While it is beyond the scope of this paper, interventions should be based on a thorough and accurate clinical examination including

observations, posture evaluation, manual muscle testing, individual joint evaluation, functional testing, and special testing of the shoulder complex. Based on this clinical examination and stage of healing, treatments and interventions are prescribed and, while each form of treatment is important, this section of the paper will primarily focus on the role of prescribing specific therapeutic exercise in rehabilitation. Also of importance but beyond the scope of this paper, is applying the appropriate exercise progression based on pathology, clinical examination, and healing stage.

Current treatments in rehabilitation aim to addresses the type of shoulder pathology involved and present dysfunctions including compensatory patterns of movement, poor motor control, shoulder mobility/stability, thoracic mobility, and finally decrease pain in order to return the individual to their prior level of function. As our knowledge of specific muscular activity and biomechanics have increased, a gradual progression towards more scientifically based rehabilitation exercises, which facilitate recovery while placing minimal strain on healing tissues, have been reported in the literature (Reinold, Escamilla, & Wilk, 2009). When treating overhead athletes with impingement, the stage of the soft tissue lesion will have an important impact on the prognosis for conservative treatment and overall recovery. Understanding the previously discussed biomechanical factors of normal shoulder function, pathological shoulder function, and the performed exercise is necessary to safely and effectively design and prescribe appropriate therapeutic exercise programs.

2.5.1 Rehabilitation protocols in impingement

Typical treatments of impingement in the clinical setting of physical therapy include specific supervised exercise, manual therapy, posture education, flexibility exercises, taping, and modality treatments and are administered based on the phase of treatment (acute, intermediate,

advanced strengthening, or return to sport). For the purpose of this paper, the focus will be on specific supervised exercise which refers to addressing individual muscles with therapeutic exercise geared to address the strength or endurance deficits in that particular muscle. The muscles which are the foci in rehabilitation include the rotator cuff (RTC) (supraspinatus, infraspinatus, teres minor, and subscapularus), scapular stabilizers (rhomboid major and minor, upper trapezius, lower trapezius, middle trapezius, serratus anterior), deltoid, and accessory muscles (latisimmus dorsi, biceps brachii, coracobrachialis, pectoralis major, pectoralis minor).

Recent research has demonstrated strengthening exercises focusing on certain muscles (serratus anterior, trapezius, infraspinatus, supraspinatus, and teres minor) may be more beneficial for athletes with impingement and exercise prescription should be based on the EMG activity profile of the exercise (Reinold, Escamilla, & Wilk, 2009). In order to prescribe the appropriate exercise based on scientific rationale, the muscle EMG activity profile of the exercise must be known and various authors have found different results with the same exercise (See APPENDIX). Another important component is focusing on muscles which are known to be dysfunctional in the shoulder impingement population, specifically the lower and middle trapezius, serratus anterior, supraspinatus, and infraspinatus.

Numerous researchers have demonstrated the 3 parts of trapezius generally acting as a scapular upward rotator and elevator (upper trapezius), a scapular retractor (middle trapezius), and a downward rotator and depressor (lower trapezius)(Reinold, Escamilla, & Wilk, 2009). The lower trapezius has also contributed to scapular posterior tilting and external rotation during elevation, which is hypothesized to decrease impingement risk (Ludewig & Cook, 2000) and make the lower trapezius vitally important in rehabilitation. Upper trapezius EMG activity has demonstrated a progressive increase from 0-60˚, remain constant from 60-120˚, and increased

from 120-180˚ during elevation (Bagg & Forrest, 1986). In contrast, the lower trapezius EMG activity tends to be low during elevation, flexion, and abduction below 90˚ and then progressively increases from 90˚-180˚ (Bagg & Forrest, 1986; Ekstrom, Donatelli, & Soderberg, 2003; Hardwick, Beebe, McDonnell, & Lang, 2006; Moseley, Jobe, Pink, Perry, & Tibone, 1992; Smith, et al., 2006).

Several exercises have been recommended in order to maximally activate the lower trapezius and the following exercises have demonstrated a high moderate to maximal (65-100%) contraction including: 1) prone horizontal abduction at 135˚ with ER (97±16%MVIC; Ekstrom, Donatelli, & Soderberg, 2003); 2) standing ER at 90˚ abduction (88±51%MVIC; Myers, Pasquale, Laudner, Sell, Bradley, & Lephart, 2005); 3) prone ER at 90˚ abduction (79±21%MVIC; Ekstrom, Donatelli, & Soderberg, 2003); 4) prone horizontal abduction at 90˚ abduction with ER (74±21%MVIC; Ekstrom, Donatelli, & Soderberg, 2003)(63±41%MVIC; Moseley, Jobe, Pink, Perry, & Tibone, 1992); 5) abduction above 120˚ with ER (68±53%MVIC; Moseley, Jobe, Pink, Perry, & Tibone, 1992); and 6) prone rowing (67±50%MVIC; Moseley, Jobe, Pink, Perry, & Tibone, 1992).

Significantly greater EMG activity has been reported in prone ER at 90˚ when compared to the empty can exercise (Ballantyne, et al., 1993) and authors have reported significant EMG amplitude during prone ER at 90˚, prone full can, and prone horizontal abduction at 90˚ with ER (Ekstrom, Donatelli, & Soderberg, 2003). Based on these results, it appears that obtaining maximal EMG activity of the lower trapezius in prone exercises, requires performing exercises prone approximately 120-130˚ of abduction may be most beneficial and will fluctuate depending on body type. It is also important to note that these exercises have been performed in prone instead of standing. Typically symptoms of SIS are increased during standing abduction greater

than 90˚, therefore this exercise is performed in the scapular plane with shoulder external rotation in order to clear the subacromial structures from impinging on the acromion and should not be performed during the acute phase of healing in SIS.

It is often clinically beneficial to enhance the ratio of lower trapezius to upper trapezius in rehabilitation. Poor posture and muscle imbalance is often seen in shoulder impingement along with alterations in the force couple between the upper trapezius and serratus anterior. McCabe and colleagues (McCabe, Orishimo, McHugh, & Nicholas, 2007) demonstrated that "the press up" (56%MVIC) and "scapular retraction" (40%MVIC) exercises exhibited significantly greater lower trapezius sEMG activity than the "bilateral shoulder external rotation" and "scapular depression" exercise. The authors also demonstrated that the "bilateral shoulder external rotation" and "the press up" demonstrated the highest UT:LT ratios at 2.35 and 2.07 (McCabe, Orishimo, McHugh, & Nicholas, 2007). Even with the authors proposed interpretation to apply to patient population; it is difficult to apply the results to a patient since the experiment was performed on a healthy population.

The middle trapezius has demonstrated high EMG activity during elevation at 90˚ and >120˚ (Bagg & Forrest, 1986; Decker, Hintermeister, Faber, & Hawkins, 1999; Ekstrom, Donatelli, & Soderberg, 2003), while other authors have shown low EMG activity in the same exercise (Moseley, Jobe, Pink, Perry, & Tibone, 1992).

However, several exercises have been recommended in order to maximally activate the middle trapezius and the following exercises have demonstrated a high moderate to maximal (65-100%) contraction including: 1) prone horizontal abduction at 90˚ abduction with IR (108±63%MVIC; Moseley, Jobe, Pink, Perry, & Tibone, 1992); 2) prone horizontal abduction at 135˚ abduction with ER (101±32%MVIC; Ekstrom, Donatelli, & Soderberg, 2003); 3) prone

horizontal abduction at 90˚ abduction with ER (87±20%MVIC; Ekstrom, Donatelli, & Soderberg, 2003)(96±73%MVIC; Moseley, Jobe, Pink, Perry, & Tibone, 1992); 4) prone rowing (79±23%MVIC; Ekstrom, Donatelli, & Soderberg, 2003); and 5) prone extension at 90˚ flexion (77±49%MVIC; Moseley, Jobe, Pink, Perry, & Tibone, 1992). In the" prone horizontal abduction at 90˚ abduction with ER" exercise, the authors demonstrated some agreement in amplitude of EMG activity. One author demonstrated 87±20%MVIC (Ekstrom, Donatelli, & Soderberg, 2003) while a second demonstrated 96±73%MVIC (Moseley, Jobe, Pink, Perry, & Tibone, 1992), while these amplitudes are not exact they are both considered maximal EMG activity.

The supraspinatus is also a very important muscle to focus on in rehabilitation of SIS due to the numerous force couples it is involved in and the potential for injury during SIS. Initially Jobe (Jobe & Moynes, 1982) recommended scapular plane elevation with glenohumeral IR (empty can) exercises to strengthen the supraspinatus muscle, but other authors (Poppen & Walker, 1978; Reinold, et al., 2004) have suggested scapular plane elevation with glenohumeral ER (full can) exercises. Recently, evidence based therapeutic exercise prescriptions have avoided the use of the empty can exercise due to the increased deltoid activity potentially increasing the amount of superior humeral head migration and the inability of a weak RTC to counteract the force in the impingement population (Reinold, Escamilla, & Wilk, 2009).

Several exercises have been recommended in order to maximally activate the supraspinatus and the following exercises have demonstrated a high moderate to maximal (65-100%) contraction including: 1) push-up plus (99±36%MVIC; Decker, Tokish, Ellis, Torry, & Hawkins, 2003), 2) prone horizontal abduction at 100˚ abduction with ER (82±37%MVIC; Reinold et al., 2004); 3) prone ER at 90˚ abduction (68±33%MVIC; Reinold et al., 2004); 4)

military press (80±48%MVIC; Townsend, Jobe, Pink, & Perry, 1991); 5) scaption above 120˚ with IR (74±33%MVIC; Townsend, Jobe, Pink, & Perry, 1991); and 6) flexion above 120˚ with ER (67±14%MVIC; Townsend, Jobe, Pink, & Perry, 1991)(42±21%MVIC; Myers, Pasquale, Laudner, Sell, Bradley, & Lephart, 2005). Interestingly, some of the same exercises showed different results in the EMG amplitude in different studies. For example, "flexion above 120˚ with ER" demonstrated 67±14%MVIC (Townsend, Jobe, Pink, & Perry, 1991) in one study and 42±21%MVIC (Myers, Pasquale, Laudner, Sell, Bradley, & Lephart, 2005) in another study. As you can see this is a large disparity but potential mechanisms for the difference may be due to the fact that one study used dumbbell's and the other used resistance tubing. Also the participants weren't given a weight based on a ten repetition maximum.

3-D biomechanical model data implies that the infraspinatus is a more effective shoulder ER at lower angles of abduction (Reinold, Escamilla, & Wilk, 2009) and numerous studies have tested this model with conflicting results in exercise selection (Decker, Tokish, Ellis, Torry, & Hawkins, 2003; Myers, Pasquale, Laudner, Sell, Bradley, & Lephart, 2005; Townsend, Jobe, Pink, & Perry, 1991; Reinold, et al., 2004). In general infraspinatus and teres minor activity progressively decrease as the shoulder moves into the abducted position while the supraspinatus and deltoid increase activity.

Several exercises have been recommended in order to maximally activate the infraspinatus, the following exercises have demonstrated a high moderate to maximal (65-100%) contraction including: 1) push-up plus (104±54%MVIC; Decker, Tokish, Ellis, Torry, & Hawkins, 2003); 2) SL ER at 0˚ abduction (62±13%MVIC; Reinold et al., 2004) (85±26%MVIC, Townsend, Jobe, Pink, & Perry, 1991); 3) prone horizontal abduction at 90˚ abduction with ER (88±25%MVIC; Townsend, Jobe, Pink, & Perry, 1991); 4) prone horizontal

abduction at 90˚ abduction with IR (74±32%MVIC; Townsend, Jobe, Pink, & Perry, 1991); 5) abduction above 120˚ with ER (74±23%MVIC; Townsend, Jobe, Pink, & Perry, 1991); and 6) flexion above 120˚ with ER (66±16%MVIC; Townsend, Jobe, Pink, & Perry, 1991) (47±34%MVIC; Myers, Pasquale, Laudner, Sell, Bradley, & Lephart, 2005).

Reinold and colleagues (Reinold, et al., 2004) also examined several exercises, commonly used in rehabilitation, used to strengthen the posterior RTC and specifically the infraspinatus and teres minor. The authors determined that 3 exercise's demonstrated the best combined EMG activity and in order include: 1) side lying ER (infraspinatus, 62%MVIC; teres minor, 67%MVIC); 2) standing ER in scapular plane at 45˚ abduction (infraspinatus, 53%MVIC; teres minor, 55%MVIC); and 3) prone ER in the 90˚ abducted position (infraspinatus, 50%MVIC; teres minor, 48%MVIC). The 90˚ abducted position is commonly used in overhead athletes to simulate the throwing position in overhead athletes. The side lying ER exercise is also clinically significant since it exerts less capsular strain, specifically on the anterior band of the glenohumeral ligament (Reinold, et al., 2004), than the more functionally advantageous standing ER at 90˚. It has also been demonstrated that the application of a towel roll while performing ER at 0˚ increases EMG activity by approximately 20% when compared to no towel roll (Reinold, et al., 2004).

The serratus anterior contributes to scapular posterior tilting, upward rotation, and external rotation of the scapula (Ludewig & Cook, 2000; McClure, Michener, & Karduna, 2006) and has demonstrated decreased EMG activity in the impingement population (Cools et al., 2007; Cools, Witvrouw, Declercq, Danneels, & Cambier, 2003; Wadsworth & Bullock-Saxton, 1997). Serratus anterior activity tends to increase as arm elevation increases; however, increased elevation may also increase impingement symptoms and risk (Reinold, Escamilla, & Wilk,

2009). Interestingly, performing 90˚ shoulder abduction with IR or ER has generated high serratus anterior activity, while initially Jobe (Jobe & Moynes, 1982) recommended IR or ER for rotator cuff strengthening. Serratus anterior activity also increases as the gravitational challenge increased when comparing the wall push up plus, push-up plus on knees, and push up plus with feet elevated (Reinold, Escamilla, & Wilk, 2009).

Prior authors have recommended the push-up plus, dynamic hug, and punch exercise to specifically recruit the serratus anterior (Decker, Hintermeister, Faber, & Hawkins, 1999) while other authors' (Ekstrom, Donatelli, & Soderberg, 2003) data indicated that performing movements which create scapular upward rotation/protraction (punch at 120˚ abduction) and diagonal exercises incorporating flexion, horizontal abduction, and ER.

Hardwick and colleges (Hardwick, Beebe, McDonnell, & Lang, 2006) contrary to previous authors (Ekstrom, Donatelli, & Soderberg, 2003) demonstrated no statistical difference in serratus anterior EMG activity during the wall slide, push-up plus (only at 90˚), and scapular plane shoulder elevation in 20 healthy individuals measured at 90˚, 120˚, and 140˚. The study also demonstrated that the wall slide and scapular plane shoulder elevation EMG activity was highest at 140˚ (approximately 76%MVIC and 82%MVIC). However, these results should be interpreted with caution since the methodological issues of limited healthy sample and only the plus phase of the push up plus exercise was examined in the study.

The serratus anterior is important for the acceleration phase of overhead throwing and several exercises have been recommended to maximally activate this muscle. The following exercises have demonstrated a high moderate to maximal (65-100%) contraction including: 1) D1 diagonal pattern flexion, horizontal adduction, and ER (100±24%MVIC; Ekstrom, Donatelli, & Soderberg, 2003); 2) scaption above 120˚ with ER (96±24%MVIC; Ekstrom, Donatelli, &

Soderberg, 2003)(91±52%MVIC Middle Serratus, 84±20%MVIC Lower Serratus; Moseley, Jobe, Pink, Perry, & Tibone, 1992); 3) supine upward punch (62±19%MVIC; Ekstrom, Donatelli, & Soderberg, 2003); 4) flexion above 120˚ with ER(96±45%MVIC Middle Serratus, 72±46%MVIC Lower Serratus; Moseley, Jobe, Pink, Perry, & Tibone, 1992) (67±37%MVIC; Myers, Pasquale, Laudner, Sell, Bradley, & Lephart, 2005); 5) abduction above 120˚ with ER (96±53%MVIC Middle Serratus, 74±65%MVIC Lower Serratus; Moseley, Jobe, Pink, Perry, & Tibone, 1992); 7) military press (82±36%MVIC Middle Serratus, 60±42%MVIC Lower Serratus; Moseley, Jobe, Pink, Perry, & Tibone, 1992); 7) push-up plus (80±38%MVIC Middle Serratus, 73±3%MVIC Lower Serratus; Moseley, Jobe, Pink, Perry, & Tibone, 1992); 8) push-up with hands separated (57±36%MVIC Middle Serratus, 69±31%MVIC Lower Serratus; Moseley, Jobe, Pink, Perry, & Tibone, 1992); 9) standing ER at 90˚ abduction (66±39%MVIC; Myers, Pasquale, Laudner, Sell, Bradley, & Lephart, 2005); and 10) standing forward scapular punch (67±45%MVIC; Myers, Pasquale, Laudner, Sell, Bradley, & Lephart, 2005).

Even though the research has demonstrated exercises which may be more beneficial than others, the lack of statistical analysis, lack of data, and absence of the significant muscle activity (including the deltoid) were methodological limitations of these studies. Also, while performing exercises with a high EMG activity are the most effective to maximally exercise specific muscles, the stage of rehabilitation may contraindicate the specific exercise recommended. For example, it is generally accepted that performing standing exercises below 90˚ elevation is necessary to avoid exacerbations of impingement symptoms. In conclusion, the previously described therapeutic exercises have demonstrated clinical benefit and high EMG activity in the prior discussed muscles (Table 5).

2.5.2 Rehabilitation of scapula dyskinesis

Scapular rehabilitation should be based on an accurate and thorough clinical evaluation performed by an individual licensed to evaluate and treat dysfunction to permit appropriate goal setting and rehabilitation for the patient. A comprehensive initial patient interview is necessary to ascertain the individual's functional requirements and problematic activities followed by the physical examination. The health care professional should address all possible deficiencies found on different levels of the kinetic chain and appropriate treatment goals should be set leading to proper rehabilitation strategies. Therefore, although considered to be key points in functional shoulder and neck rehabilitation, more proximal links in the kinetic chain, such as thoracic spine mobility and strength, core stability and lower limb function, will not be addressed in this manuscript.

Treatment of scapular dyskinesis is only successful if the anatomical base is optimal and the individual does not exhibit problems which require surgery such as nerve injury, scapular muscle detachment, severe bony derangement (acromioclavicular separation, fractured clavicle) or soft tissue derangement (labral injury, rotator cuff disease, glenohumeral instability) (Kibler & Sciascia, 2010; Wright, Wassinger, Frank, Michener, & Hegedus, 2012). The large majorities of cases of dyskinesis, however, are caused by muscle weakness, inhibition or inflexibility, and can be managed with rehabilitation.

Optimal rehabilitation of scapular dyskinesis requires addressing all of the causative factors that can create the dyskinesis and then restoring the balance of muscle forces that allow scapular position and motion. The emphasis of scapular dyskinesis rehabilitation should start proximally and end distally with an initial goal of achieving the position of optimal scapular function (posterior tilt, external rotation and upward elevation). The serratus anterior is an

important external rotator of the scapula, and the lower trapezius is a stabilizer of the acquired scapular position. Scapular stabilization protocols should focus on re-educating these muscles to act as dynamic scapula stabilizers, first by the implementation of short lever, kinetic chain assisted exercises then progress to long lever movements. Maximal rotator cuff strength is achieved off a stabilized, retracted scapula and rotator cuff emphasis should be after scapular control is achieved (Kibler & Sciascia, 2010). An increase in impingement pain when doing open chain rotator cuff exercises indicates an incorrect protocol emphasis and stage of rehabilitation. A logical progression of exercises (isometric to dynamic) focused on strengthening the lower trapezius and serratus anterior while minimizing upper trapezius activation has been described in the literature (Kibler & Sciascia, 2010; Kibler, Ludewig, McClure, Michener, Bak, & Sciascia, 2013), and on an algorithm guideline (Figure 3) has been proposed that is based on restoration of soft tissue inflexibilities and maximizing muscle performance (Cools, Struyf, De Mey, Maenhout, Castelein, & Cagnie, 2013).

Several principles guide the progression through the algorithm with the first requirement being acquisition of flexibility in muscles and joints because tight muscles and joint capsules can inhibit strength activation. Also, later protocols in rehabilitation should train functional movements in sport or activity specific patterns since research has demonstrated maximal scapular muscle activation when muscles are activated in functional patterns (vs isolated)(i.e. when the muscles are activated in specific diagonal patterns using kinetic chain sequencing) (Kibler & Sciascia, 2010). Using these principles, many rehabilitation interventions can be considered, but a reasonable program could start with standing low-load/low-activation (activate the scapular retractors >20% MVIC) exercises with the arm below shoulder level and progress to prone and side-lying exercises that increase the load, but still emphasize lower trapezius and

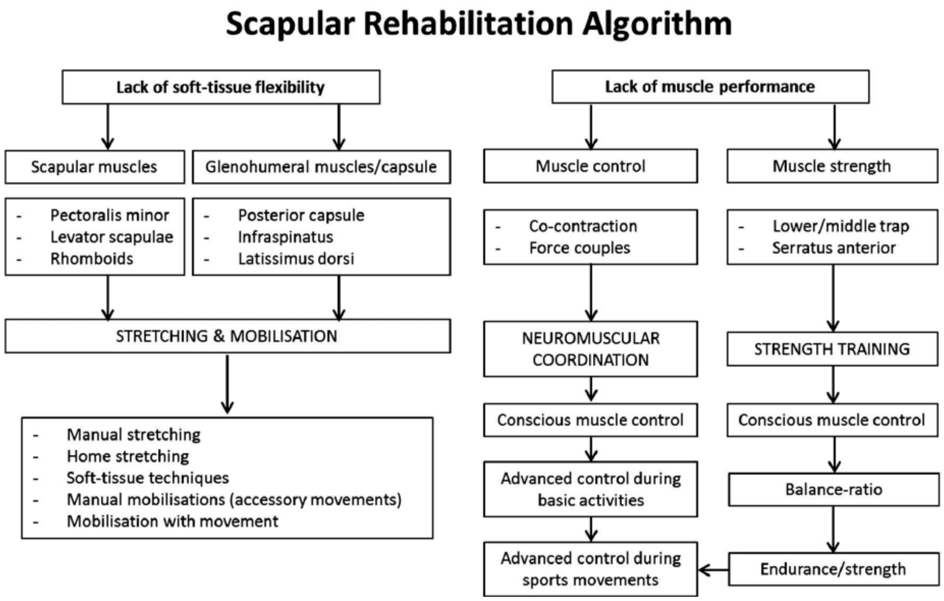

Figure 3: A scapular rehabilitation algorithm guideline (Adapted from Cools, Struyf, De Mey, Maenhout, Castelein, & Cagnie, 2013).

serratus anterior activation over upper trapezius activation. Additional loads and activations can be stimulated by integrating ipsilateral and contralateral kinetic chain activation and adding distal resistance. Final optimization of activation can occur through weight training emphasizing proper retraction and stabilization. Progression can be made by increasing holding time, repetitions, resistance, and speed parameters of exercise relevant to the patient’s functional needs.

The lower trapezius is frequently inhibited in activation, and specific effort may be required to ‘jump start’ it. Tightness, spasm and hyperactivity in the upper trapezius, pectoralis minor and latissimus dorsi are frequently associated with lower trapezius inhibition, and specific therapy should address these muscles.

Multiple studies have identified methods to activate scapular muscles that control scapular motion and have identified effective body and scapular positions that allow optimal activation in order to improve scapular muscle performance and decrease clinical symptoms.

Only two randomized clinical trials have examined the effects of a scapular focused program by comparing it to a general shoulder rehabilitation, and the findings indicate the use of scapular exercises results in higher patient-rated outcomes (Başkurt, Başkurt, Gelecek, & Özkan, 2011; Struyf, Nijs, Mollekens, Jeurissen, Truijen, Mottram, & Meeusen, 2013).

Multiple clinical trials have incorporated scapular exercises within their rehabilitation programs and have found positive patient-rated outcomes in patients with impingement syndrome (Kromer, Tautenhahn, de Bie, Staal, & Bastiaenen, 2009). It appears that it is not only the scapular exercises but also the inclusion of the scapular exercises as part of a rehabilitation program that may include the use of the kinetic chain is what achieves positive outcomes. When the scapular exercises are prescribed, multiple components must be emphasized, including activation sequencing, force couple activation, concentric/eccentric emphasis, strength, endurance and avoidance of unwanted patterns (Cools, Struyf, De Mey, Maenhout, Castelein, & Cagnie, 2013).

2.5.3 Effects of rehabilitation

Conservative therapy is successful in 42% (Bigliani type III) to 91% (Bigliani type I) (de Witte, et al., 2011) and most shoulder injuries in the overhead thrower can be successfully treated non-operatively (Wilk, Obma, Simpson, Cain, Dugas, & Andrews, 2009). Evidence supports the use of thoracic mobilizations (Theisen, et al., 2010), glenohumeral mobilizations (Tyler, Nicholas, Lee, Mullaney, & Mchugh, 2012; Sauers, 2005), supervised shoulder and scapular muscle strengthening (Fleming, Seitz, & Edaugh, 2010; Osteras, Torstensen, & Osteras, 2010; McClure, Bialker, Neff, Williams, & Karduna, 2004; Sauers, 2005; Bang & Deyle, 2000; Senbursa, Baltaci, & Atay, 2007), supervised shoulder and scapular muscle strengthening with manual therapy (Bang & Deyle, 2000; Senbursa, Baltaci, & Atay, 2007), taping (Lin, Hung, & Yang, 2011; Williams, Whatman, Hume, & Sheerin, 2012; Selkowitz, Chaney, Stuckey, & Vlad,

2007; Smith, Sparkes, Busse, & Enright, 2009), and laser therapy (Sauers, 2005) in decreasing pain, increasing mobility, improving function, and improving altering muscle activity of shoulder muscles.

In systematic reviews of randomized controlled trials, there is a lack of high quality intervention studies, but some studies suggest that therapeutic exercise is as effective as surgery in SIS (Nyberg, Jonsson, & Sundelin, 2010; Trampas & Kitsios, 2006), the combination of manual therapy and exercise is better than exercise alone in SIS (Michener, Walsworth, & Burnet, 2004), and high dosage exercise is better than low dosage exercise in SIS (Nyberg, Jonsson, & Sundelin, 2010) in reducing pain and improving function. In evidence-based clinical practice guidelines, therapeutic exercise is effective in treatment of SIS (Trampas & Kitsios, 2006; Kelly, Wrightson, & Meads, 2010) and is recommended to be combined with joint mobilization of the shoulder complex (Tyler, Nicholas, Lee, Mullaney, & Mchugh, 2012; Sauers, 2005). Joint mobilization techniques have demonstrated increased improvements in symptoms when applied by experienced physical therapists rather than applied by novice clinicians (Tyler, Nicholas, Lee, Mullaney, & Mchugh, 2012). A course of therapeutic exercise in the SIS population has also been shown to be more beneficial than no treatment or a placebo treatment, and should be attempted to reduce symptoms and restore function before surgical intervention is considered (Michener, Walsworth, & Burnet, 2004).

In a study by McClure and colleagues (McClure, Bialker, Neff, Williams, & Karduna, 2004), the authors demonstrated, after a 6 week therapeutic exercise program combined with education, significant improvements in pain, shoulder function, increased passive range of motion, increased ER and IR force, and no changes in scapular kinematics in a SIS population.

However, these results should be interpreted with caution since the rate of attrition was 33%, there was no control group, and numerous clinicians performed the interventions.

In a randomized clinical trial by Conroy & Hayes (Conroy & Hayes, 1998), 14 patients with SIS underwent either a supervised exercise program or a supervised exercise program with joint mobilization for 9 sessions over 3 weeks. At 3 weeks, the supervised exercise program with joint mobilization had less pain compared to the supervised exercise program group. In a larger randomized clinical trial by Bang & Deyle (Bang & Deyle, 2000), patients' with SIS underwent either an exercise program or an exercise program with manual therapy for 6 sessions over 3-4 weeks. At the end of treatment and at 1 month follow up, the exercise program with manual therapy group had superior gains in strength, function, and pain compared to the exercise program group.

Recently, numerous studies have observed the EMG activity in the shoulder complex musculature during numerous rehabilitation exercises. In exploring evidence-based exercises while treating SIS the population, the following has been shown to be effective to improve outcome measures for this population: 1) serratus anterior strengthening, 2) scapular control with external rotation exercises, 3) external rotation exercises with tubing, 4) resisted flexion exercises, 5) resisted extension exercises, 6) resisted abduction exercise, 7) resisted internal rotation exercise (Dewhurst, 2010).

Table 7: Therapeutic exercises for the shoulder musculature, which is involved in rehabilitation, that has demonstrated a moderate to maximal EMG profile for that particular muscle along with its clinical significance (DB=dumbbell, T=Tubing)		
Muscle	**Exercise**	**Clinical Significance**
lower trapezius	1. Prone horizontal abduction at 135˚ with ER (DB) 2. Standing ER at 90˚ (T) 3. Prone ER at 90˚ abd (DB) 4. Prone horizontal abduction at 90˚ with ER (DB) 5. Abd > 120˚ with ER (DB) 6. Prone rowing (DB)	1. In line with lower trapezius fibers, High EMG activity of trapezius, effective/good supraspinatus/serratus anterior 2. High EMG activity lower trap, rhomboids, serratus anterior; moderate-maximal EMG activity of RTC 3. Below 90˚ abduction; High EMG of lower trapezius 4. Below 90˚ abduction, good UT:LT ratio, moderate to maximal EMG of upper, middle and lower trapezius 5. Used later in rehabilitation since >90˚ abduction can ↑ symptoms, high serratus anterior EMG, moderate upper and lower trapezius EMG 6. Below 90˚ abduction, High EMG of upper, middle, and lower trapezius
middle trapezius	1. Prone horizontal abduction at 90˚ with IR (DB) 2. Prone horizontal abduction at 135˚ with ER (DB) 3. Prone horizontal abduction at 90˚ with ER (DB) 4. Prone rowing (DB) 5. Prone extension at 90˚ flexion (DB)	1. IR ↑ tension on subacromial structures, ↑ deltoid activity not for patient with SIS, high EMG for all parts of trapezius 2. High EMG activity of all parts of trapezius, effective and good for supraspinatus and serratus anterior also 3. Below 90˚ abduction, good UT:LT ratio, moderate to maximal EMG of upper, middle and lower trapezius 4. Below 90˚ abduction, High EMG of upper, middle, and lower trapezius 5. Below 90˚ abduction, High middle trapezius activity
serratus anterior	1. D1 diagonal pattern flexion, horizontal adduction, and ER (T) 2. Scaption above 120˚ with ER (DB) 3. Supine upward punch (DB) 4. Flexion above 120˚ with ER (DB) 5. Abduction above 120˚ with ER (DB) 6. Military press (DB) 7. Push-up Plus 8. Push-up with hands separated 9. Standing ER at 90˚ abduction (T) 10. Standing forward scapular punch (T)	1. Effective to begin functional movements patterns later in rehabilitation, high EMG activity 2. Above 90˚ to be performed after resolution of symptoms 3. Effective and below 90˚ 4. Above 90˚ to be performed after resolution of symptoms 5. Used later in rehabilitation since >90˚ abduction can ↑ symptoms, high serratus anterior EMG, moderate upper and lower trapezius EMG 6. Perform in advanced strengthening phase since can cause impingement 7. Closed chain exercise below 90˚, high serratus anterior, supraspinatus, and infraspinatus activity 8. Closed chain exercise 9. High teres minor, lower trapezius and rhomboid EMG activity 10. Below 90˚ abduction, high subscapularis and teres minor EMG activity
supraspinatus	1. Push-up plus 2. Prone horizontal abduction at 100˚ with ER (DB) 3. Prone ER at 90˚ abd (DB) 4. Military press (DB) 5. Scaption above 120˚ with IR (DB) 6. Flexion above 120˚ with ER (DB)	1. Closed chain exercise below 90˚, high serratus anterior, supraspinatus, and infraspinatus activity 2. High supraspinatus, middle/posterior deltoid EMG activity 3. Below 90˚ abduction; High EMG of lower trapezius also 4. Perform in advanced strengthening phase since can cause impingement 5. IR ↑ tension on subacromial structures, ↑ anterior/middle deltoid activity not for patient with SIS moderate infraspinatus EMG activity 6. High anterior/middle deltoid activity not for patient with SIS, moderate infraspinatus and subscapularis EMG activity

Table 7: Therapeutic exercises for the shoulder musculature, which is involved in rehabilitation, that has demonstrated a moderate to maximal EMG profile for that particular muscle along with its clinical significance (DB=dumbbell, T=Tubing)(Continued)		
Muscle	**Exercise**	**Clinical Significance**
Infraspinatus	1. Push-up plus 2. SL ER at 0˚ abduction (DB) 3. Prone horizontal abduction at 90˚ with ER (DB) 4. Prone horizontal abduction at 90˚ with IR (DB) 5. Abduction > 120˚ with ER (DB) 6. Flexion above 120˚ with ER (DB)	1. Closed chain exercise below 90˚, high serratus anterior, supraspinatus, and infraspinatus activity 2. Stable shoulder position; Most effective exercise to recruit infraspinatus 3. Below 90˚ abduction, good UT:LT ratio, moderate to maximal EMG of upper, middle and lower trapezius 4. IR increases tension on subacromial structures, increased deltoid activity not for patient with SIS, high EMG for all parts of trapezius 5. Used later in rehabilitation since >90˚ abduction can increase symptoms, high serratus anterior EMG, moderate upper and lower trapezius EMG 6. High anterior/middle deltoid activity not for patient with SIS, moderate infraspinatus and subscapularis EMG activity
Infraspinatus & Teres minor	1. SL ER at 0˚ abduction (DB) 2. Standing ER in scapular plane at 45˚ abduction (DB) 3. Prone ER in 90˚ abduction (DB)	1. Stable shoulder position; Most effective exercise to recruit infraspinatus 2. High EMG of teres and infraspinatus 3. Below 90˚ abduction; High EMG of lower trapezius

However, no studies have explored whether or not specific rehabilitation exercises targeting muscles, based on EMG profile, could correct prior EMG deficits and speed recovery in patients with shoulder impingement. In conclusion, there is a need for further well-defined clinical trials on specific exercise interventions for the treatment of SIS. This literature reveals the need for improved sample sizes, improved diagnostic criteria and similar diagnostic criteria applied between studies, longer follow ups, studies measuring function and pain, and (specifically in overhead athletes) sooner return to play.

2.6 SUMMARY

Overhead athletes with SIS or shoulder impingement will exhibit muscle imbalances and tightness in the GH and scapular musculature. These dysfunctions can lead to altered shoulder complex kinematics, altered EMG activity, and functional limitations, which will cause impingement. The exact mechanism of impingement is debated in the literature as well its relation to scapular kinematic variation. Therapeutic exercise has shown to be beneficial in alleviating dysfunctions and pain in SIS, and supervised exercise with manual techniques by an experienced clinician is an effective treatment. It is unknown whether prescribing specific therapeutic exercise based on EMG profile will speed the recovery time, increase force production, resolve scapular dyskinesis, or change SAS height in SIS. Few research articles have examined these variables and its association with prescribing specific therapeutic exercise and there is a general need for further well-defined clinical trials on specific exercise interventions for the treatment of SIS.

CHAPTER 3: THE EFFECT OF VARIOUS POSTURES ON THE SURFACE ELECTROMYOGRAPHIC ANALYSIS OF THE LOWER TRAPEZIUS DURING SPECIFIC THERAPEUTIC EXERCISE

3.1 INTRODUCTION

Individuals diagnosed with shoulder impingement exhibit muscle imbalances in the shoulder complex and specifically in the force couple (lower trapezius, upper trapezius, and serratus anterior), which controls scapular movements. The deltoid plays an important role in the muscle force couple since it is the prime mover of the glenohumeral joint. Dysfunctions in these muscles lead to altered shoulder complex kinematics and functional limitations, which will cause an increase in impingement symptoms. Therapeutic exercises are beneficial in alleviating dysfunctions and pain in individuals diagnosed with shoulder impingement. However, no studies demonstrate the effect various postures will have on electromyographic (EMG) activity in healthy adults or in adults with impingement during specific therapeutic exercise. The purpose of the study was to identify the therapeutic exercise and posture which elicits the highest EMG activity in the lower trapezius shoulder muscle tested. This study also tested the exercises and postures in the healthy population and the shoulder impingement population since very few studies have correlated specific therapeutic exercises in the shoulder impingement population.

Individuals with shoulder impingement exhibit muscle imbalances in the shoulder complex and specifically in the lower trapezius, upper trapezius, and serratus anterior, all of which control scapular movements, with the deltoid acting as the prime mover of the shoulder.

Dysfunctions in these muscles lead to altered kinematics and functional limitations, which cause an increase in impingement symptoms. Therapeutic exercise has shown to be beneficial in alleviating dysfunctions and pain in impingement and the following exercises have been shown to be effective treatment to improve outcome measures for this diagnosis: 1) serratus

anterior strengthening, 2) scapular control with external rotation exercises, 3) external rotation exercises, 4) prone extension, 5) press up exercises, 6) bilateral shoulder external rotation exercise, and 7) prone horizontal abduction exercises at 135˚ and 90˚ of abduction (Dewhurst, 2010; Trampas & Kitsios, 2006; Kelly, Wrightson, & Meads, 2010; Fleming, Seitz, & Edaugh, 2010; Osteras, Torstensen, & Osteras, 2010; McClure, Bialker, Neff, Williams, & Karduna, 2004; Sauers, 2005;; Senbursa, Baltaci, & Atay, 2007; Bang & Deyle, 2000; Senbursa, Baltaci, & Atay, 2007). The therapeutic exercises in this study were derived from specific therapeutic exercises shown to improve outcomes in the impingement population and of particular importance are the amount of EMG activity in the lower trapezius since this muscle is directly responsible for stabilizing the scapula.

Evidence based treatment of impingement requires a high dosage of therapeutic exercises over a low dosage (Nyberg, Jonsson, & Sundelin, 2010) and applying the exercise EMG profile to exercise prescription facilitates a speedy recovery. However, no studies have correlated the effect various postures will have on the EMG activity of the lower trapezius in healthy adults or in adults with impingement. The purpose of this study was to identify the therapeutic exercise and posture which elicits the highest EMG activity in the lower trapezius muscle. The postures included in the study include a normal posture with towel roll under the arm (if applicable), a posture with the feet staggered/scapula retracted and a towel roll under the arm (if applicable), and a normal posture/scapula retracted with a towel roll under the arm (if applicable) with a physical therapist observing and cueing to maintain the scapula retraction. Recent research has demonstrated that the application of a towel roll increases the EMG activity of the shoulder muscles by 20% in certain exercises (Reinold, Wilk, Fleisig, Zheng, Barrentine, Chmielewski, Cody, Jameson, & Andrews, 2004) thereby increasing the effectiveness of therapeutic exercise.

However, no studies have examined the effect of the towel roll in conjunction with different postures or the effect of a physical therapist observing the movement and issuing verbal and tactile cues.

This study addressed two current issues. First, it sought to demonstrate if it is more beneficial to change posture in order to facilitate increased activity of the lower trapezius in healthy individuals or individuals diagnosed with shoulder impingement. Second, it attempts to l provide more clarity over which therapeutic exercise exhibits the highest percentage of EMG activity in a healthy and pathologic population. Since physical therapists use therapeutic exercise to target specific weak muscles, this study will better help determine which of the selected exercises help maximally activate the target muscle, and allow for better exercise selection and, although it is unknown in research, a hypothesized faster recovery time for an individual with shoulder impingement.

3.2 METHODS

One investigator conducted the assessment for the inclusion and exclusion criteria through the use of a verbal questionnaire. The inclusion criteria for all subjects are: 1) 18-50 years old, and 2) able to communicate in English. The exclusion criteria of the healthy adult group (phase 1) include: 1) recent history (less than 1 year) of a musculoskeletal injury, condition, or surgery involving the upper extremity or the cervical spine, and 2) a prior history of a neuromuscular condition, pathology, or numbness or tingling in either upper extremity. The inclusion criteria for the adult impingement group (phase 2) included: 1) recent diagnosis of shoulder impingement by physician, 2) diagnosis confirmed by physical therapist (based on having at least 4 of the following 7 criteria): 1) a Neer impingement sign, 2) a Hawkins sign, 3) a positive empty or full can test, 4) pain with active shoulder elevation, 5) pain with palpation of

the rotator cuff tendons, 6) pain with isometric resisted abduction, and 7) pain in the C5 or C6 dermatome region (Table 8).

Table 8: Description of the inclusion criteria for the adult impingement group (phase 2)

Criteria	Description
Neer impingement sign	This is a reproduction of pain when the examiner passively flexes the humerus, or shoulder, to the end range of motion and applies overpressure
Hawkins sign	This is reproduction of pain when the shoulder is passively placed in 90˚ of forward flexion and internally rotated to the end range of motion
positive empty or full can test	pain with resisted forward flexion at 90˚ either with the thumb pointing up (full can) or the thumb pointing down (empty can)
pain with active shoulder elevation	pain during active shoulder elevation or shoulder abduction from 0-180 degrees
pain with palpation of the rotator cuff tendons	pain with palpation of the shoulder muscles including the supraspinatus, infraspinatus, teres minor, and subscapularus
pain with isometric resisted abduction	pain with a manual muscle test where a downward force is placed on the shoulder at the wrist while the shoulder is in 90 degrees of abduction and the elbow is extended
pain in the C5 or C6 dermatome region	pain the C5 and C6 dermatome is located from the front and back of the shoulder down to the wrist and hand, dermatomes correlate to the nerve root level with the location of pain, so since the rotator cuff is involved then then dermatome which will present with pain includes the C5, C6 dermatomes since the rotator cuff is innervated by that nerve root

The exclusion criteria of the adult impingement group included: 1) diagnosis and/or MRI confirmation of a complete rotator cuff tear, 2) signs of acute inflammation including severe resting pain or severe pain with resisted isometric abduction, 3) subjects who had previous spine related symptoms or are judged to have spine related symptoms, 4) glenohumeral instability (as determined by a positive apprehension test, anterior drawer, and sulcus sign; (Table 9), and 5) a previous shoulder surgery. Subjects were also excluded if they exhibited any contraindications to exercise (Table 10).

The study was explained to all subjects and they signed the informed consent agreement approved by the Louisiana State University institutional review board. Subjects were screened

Table 9: Glenohumeral instability tests used in exclusion criteria of the adult impingement group	
Test	Procedure
apprehension test	reproduction of pain when an anteriorly directed force is applied to the proximal humerus in the position of 90˚ of abduction an 90˚ of external rotation
anterior drawer	subject supine and examiner stands facing the affected shoulder and holds it at 80-120° of abduction, 0-20° of forward flexion and 0-30° of external rotation. The examiner holds the patients scapula spine forward with his index and middle fingers; the thumb exerts counter pressure on the coracoid. The examiner uses his right hand to grasp the patient's relaxed upper arm and draws it anteriorly with a force. The relative movement between the fixed scapula and the moveable humerus is appreciated and graded. An audible click on forward movement of the humeral head due to labral pathology is a positive sign
sulcus sign	with the subject sitting, the elbow is grasped and an inferior traction is applied, the area adjacent to the acromion is observed and if dimpling of the skin is present then a positive sulcus sign is present

Table 10: Contraindications to exercise
1. a recent change in resting ECG suggesting significant ischemia
2. a recent myocardial infarction (within 7 days),
3. an acute cardiac event
4. unstable angina
5. uncontrolled cardiac dysrhythmias
6. symptomatic severe aortic stenosis
7. uncontrolled symptomatic heart failure
8. acute pulmonary embolus or pulmonary infarction
9. acute myocarditis or pericarditis
10. suspected or known dissecting aneurysm
11. acute systemic infection accompanied by fever, body aches, or swollen lymph glands.

for latex allergies or current pregnancy. Pregnant individuals were excluded from the study and individuals with latex allergy used the latex free version of the resistance band.

Phase 1 participants were recruited from university students, pre-physical therapy students, and healthy individuals willing to volunteer. Phase 2 participants were recruited from current physical therapy patients willing to volunteer who are diagnosed by a physician with shoulder impingement and referred to physical therapy for treatment. Participants filled out an informed consent, PAR-Q, HIPAA authorization agreement, and screened for the inclusion and

exclusion criteria through the use of a verbal questionnaire. Each phase participants was randomized into one of three posture groups, blinded from the expected/hypothesized outcomes of the study, and all exercises were counterbalanced.

Surface electrodes were applied and recorded EMG activity of the lower trapezius during exercises and various postures in 30 healthy adults and 16 adults with impingement. The healthy subjects (phase 1) were randomized into one of three groups and performed ten repetitions on each of seven exercises. The subjects with impingement (Phase 2) and were randomized into one of three groups and perform ten repetitions on each of the same exercises.

The therapeutic exercises selected are common in rehabilitation of individuals diagnosed with shoulder impingement and each subject performed ten repetitions of each exercise (Table 11) with the repetition speed regulated by a metronome set to sixty beats per minute (bpm). The subject performed each concentric or eccentric phase of the exercise during 2 beats of the metronome. The mass determination was based on a standardizing formula based on anthropometrics and calculated the desired weight from height, arm length, and weight measurements.

On the day of testing, the subjects were informed of their rights, procedures of participating in this study, read and signed the informed consent, read and signed the HIPPA authorization, discussed inclusion and exclusion criteria with examiner, received a brief screening examination, and were oriented to the testing protocol. The protocol was sequenced as follows: randomization, 10-repetition maximum determination, electrode placement, practice and familiarization, MVIC testing, five minute rest, and exercise testing. In total, the study took one hour of the individual's time. Phase 1 participants (healthy adult subjects) were randomized into 1 of three groups (Table 11). Group 1 consisted of specific therapeutic exercises performed with

Table 11: Specific Therapeutic Exercises Descriptions and EMG activation	
Group 1(control Group, not altered posture): 1.Prone horizontal abduction at 90˚ abduction 2.Prone horizontal abduction at 130˚ abduction 3.Sidelying external rotation 4.Prone extension 5.Bilateral shoulder external rotation 6.Prone ER at 90˚ abduction 7.Prone rowing	1. The subject is positioned prone with the shoulder resting at 90˚ forward flexion. From this position, the subject horizontally abducts the arm while maintaining the shoulder at 90˚ abduction with the shoulder in external rotation (thumb up) until the arm reached the frontal plane. (without conscious correction,) 2. The subject is positioned prone with the shoulder resting at 90˚ forward flexion. From this position, the subject horizontally abducts the arm while maintaining the shoulder at 130˚ abduction with the shoulder in external rotation (thumb up) until the arm reached the frontal plane. (without conscious correction,) 3. The subject is side lying with the arm at the side with a towel between the elbow and rib cage. The subject then externally rotates the shoulder to 50 degrees above the horizontal then returns back to resting position. 4. The subject is positioned prone with the arm resting at 90˚ forward flexion. The subject then extends the shoulder while keeping the hand in supination (thumb pointing outward) until the arm reaches 5 degrees past the frontal plane then returns back to resting position. 5. The subject is standing with a taut elastic band in the subjects hand with the palms facing each other. The subject then bilaterally externally rotates the shoulder while maintaining the shoulder and elbow position past 50 degrees from the sagittal plane and then returns to the resting position. 6. The subject is lying prone with the shoulder in 90˚ abduction and the elbow in 90˚ flexion the slight hand supination (thumb up). The subject then lifts the arm off the mat in its entirety clearing the ulna and humerus from the mat then returns to the resting position. (without conscious correction,) 7. The subject is lying prone with the arm resting at 90˚ forward flexion and hand in supination (thumb facing laterally). The subject then extends the shoulder and flexes the elbow simultaneously until the hand is parallel to the body. The subject then returns to resting position.
Group 2 exercises include (feet staggered Group): 1.Standing horizontal abduction at 90˚ abduction 2.Standing horizontal abduction at 130˚ abduction 3.Standing external rotation 4.Standing extension 5.Bilateral shoulder external rotation 6.Standing ER at 90˚ abduction 7.Standing rowing	1. The subject is positioned standing with the shoulder resting at 90˚ forward flexion and holds an elastic band. From this position, the subject horizontally abducts the arm while maintaining the shoulder at 90˚ abduction with the shoulder in external rotation (thumb up) until the arm reached the frontal plane. While performing this exercise, a therapist will initially verbally and tactilely cueing the subject to stand in a feet staggered posture with the ipsilateral (relative to the test shoulder) foot placed 1 foot length posterior to the midline and maintain a constant scapular squeeze while performing the exercise (staggered posture, 2. The subject is positioned standing with the shoulder resting at 90˚ forward flexion. From this position, the subject horizontally abducts the arm while maintaining the shoulder at 130˚ abduction with the shoulder in external rotation (thumb up) until the arm reached the frontal plane. While performing this exercise, a therapist will initially verbally and tactilely cueing the subject to stand in a feet staggered posture with the ipsilateral (relative to the test shoulder) foot placed 1 foot length posterior to the midline and maintain a constant scapular squeeze while performing the exercise (staggered posture,). 3. The subject is standing with the arm at the side with a towel between the elbow and rib cage. The subject then externally rotates the shoulder to 50 degrees above the horizontal then returns back to resting position. While performing this exercise, a therapist will initially verbally and tactilely cueing the subject to stand in a feet staggered posture with the ipsilateral (relative to the test shoulder) foot placed 1 foot length posterior to the midline and maintain a constant scapular squeeze while performing the exercise (staggered posture).

Table 11: Specific Therapeutic Exercises Descriptions and EMG activation (continued 1)	
	4. The subject is positioned standing with the arm resting at 90˚ forward flexion. The subject then extends the shoulder while keeping the hand in supination (thumb pointing outward) until the arm reaches 5 degrees past the frontal plane then returns back to resting position. While performing this exercise, a therapist will initially verbally and tactilely cueing the subject to stand in a feet staggered posture with the ipsilateral (relative to the test shoulder) foot placed 1 foot length posterior to the midline and maintain a constant scapular squeeze while performing the exercise (staggered posture,). 5. The subject is standing with a taut elastic band in the subjects hand with the palms facing each other. The subject then bilaterally externally rotates the shoulder while maintaining the shoulder and elbow position past 50 degrees from the sagittal plane and then returns to the resting position. While performing this exercise, a therapist will initially verbally and tactilely cueing the subject to stand in a feet staggered posture with the ipsilateral (relative to the test shoulder) foot placed 1 foot length posterior to the midline and maintain a constant scapular squeeze while performing the exercise (staggered posture,). 6. The subject is standing with the shoulder in 90˚ abduction and the elbow in 90˚ flexion the slight hand supination (thumb up). The subject then extends the arm clearing the frontal plane then returns to the resting position. While performing this exercise, a therapist will initially verbally and tactilely cueing the subject to stand in a feet staggered posture with the ipsilateral (relative to the test shoulder) foot placed 1 foot length posterior to the midline and maintain a constant scapular squeeze while performing the exercise (staggered posture). 7. The subject is standing with the arm resting at 90˚ forward flexion and hand in supination (thumb facing laterally). The subject then extends the shoulder and flexes the elbow simultaneously until the hand is parallel to the body. The subject then returns to resting position. While performing this exercise, a therapist will initially verbally and tactilely cueing the subject to stand in a feet staggered posture with the ipsilateral (relative to the test shoulder) foot placed 1 foot length posterior to the midline and maintain a constant scapular squeeze while performing the exercise (staggered posture,).
Group 3 exercises include (conscious correction Group): 1.Prone horizontal abduction at 90˚ abduction 2.Prone horizontal abduction at 130˚ abduction 3.Sidelying external rotation 4.Prone extension 5.Bilateral shoulder external rotation 6.Prone ER at 90˚ abduction 7.Prone rowing	1. The subject is positioned prone with the shoulder resting at 90˚ forward flexion. From this position, the subject horizontally abducts the arm while maintaining the shoulder at 90˚ abduction with the shoulder in external rotation (thumb up) until the arm reached the frontal plane. While performing this exercise, a therapist will be verbally and tactilely cueing the subject to contract the lower trapezius (conscious correction). 2. The subject is positioned prone with the shoulder resting at 90˚ forward flexion. From this position, the subject horizontally abducts the arm while maintaining the shoulder at 130˚ abduction with the shoulder in external rotation (thumb up) until the arm reached the frontal plane. While performing this exercise, a therapist will be verbally and tactilely cueing the subject to contract the lower trapezius (conscious correction). 3. The subject is side lying with the arm at the side with a towel between the elbow and rib cage. The subject then externally rotates the shoulder to 50 degrees above the horizontal then returns back to resting position. While performing this exercise, a therapist will be verbally and tactilely cueing the subject to contract the lower trapezius (conscious correction). 4. The subject is positioned prone with the arm resting at 90˚ forward flexion. The subject then extends the shoulder while keeping the hand in supination (thumb pointing outward) until the arm reaches 5 degrees past the frontal plane then returns back to resting position. While performing this exercise, a therapist will be verbally and tactilely cueing the subject to contract the lower trapezius (conscious correction,).

Table 11: Specific Therapeutic Exercises Descriptions and EMG activation (continued 2)	
	5. The subject is standing with a taut elastic band in the subjects hand with the palms facing each other. The subject then bilaterally externally rotates the shoulder while maintaining the shoulder and elbow position past 50 degrees from the sagittal plane and then returns to the resting position. While performing this exercise, a therapist will be verbally and tactilely cueing the subject to contract the lower trapezius (conscious correction,). 6. The subject is lying prone with the shoulder in 90˚ abduction and the elbow in 90˚ flexion the slight hand supination (thumb up). The subject then lifts the arm off the mat in its entirety clearing the ulna and humerus from the mat then returns to the resting position. While performing this exercise, a therapist will be verbally and tactilely cueing the subject to contract the lower trapezius (conscious correction). 7. The subject is lying prone with the arm resting at 90˚ forward flexion and hand in supination (thumb facing laterally). The subject then extends the shoulder and flexes the elbow simultaneously until the hand is parallel to the body. The subject then returns to resting position. While performing this exercise, a therapist will be verbally and tactilely cueing the subject to contract the lower trapezius (conscious correction,).

a normal posture without conscious correction or a staggered foot posture. Group 2 performed specific therapeutic exercises with a staggered foot posture where the foot ipsilateral to the arm performing the exercise is placed behind the frontal plane. Group 3 was comprised of specific therapeutic exercises performed with a conscious posture correction by a physical therapist. Phase 2 of the study involved individuals who had been diagnosed with shoulder impingement and met the inclusion and exclusion criteria. Then each subject in phase 2 was randomized into one of the three groups described above and shown in Table 11.

Group 1 exercises included (control Group, not altered posture): 1) prone horizontal abduction at 90˚ abduction, 2) prone horizontal abduction at 130˚ abduction, 3) side lying external rotation, 4) prone extension, 5) bilateral shoulder external rotation, 6) prone external rotation at 90˚ abduction, and 7) prone rowing. Exercises for Group 2 included (feet staggered Group): 1) standing horizontal abduction at 90˚ abduction, 2) standing horizontal abduction at 130˚ abduction, 3) standing external rotation, 4) standing extension, 5) bilateral shoulder external rotation, 6) standing external rotation at 90˚ abduction, and 7) standing rowing. The exercises Group 3 performed were (conscious correction Group): 1) prone horizontal abduction at 90˚ abduction, 2) prone horizontal abduction at 130˚ abduction, 3) side lying external rotation, 4) prone extension, 5) bilateral shoulder external rotation, 6) prone external rotation at 90˚ abduction, 7) prone rowing (Table 11).

The phase 1 participants included 30 healthy adults (12 males and 18 females) with an average height of 59.6 inches (range 52 to 72 inches), average weight of 149.37 pounds (range 115 to 220 pounds), and average of 22.57 years (range 18-49 years). In phase 2, participants included 16 adults diagnosed with impingement and having an average height of 65.3 inches (range 58 to 70 inches), average weight of 182.31 pounds (range 129 to 290 pounds), average

age of 47.44 years (range 19-65 years), and an average duration of symptoms of 12.81 months (range 20 days to 10 years).

Muscle activity was measured in the dominant shoulder's lower trapezius muscle using surface electromyography (sEMG). Noraxon Ag–AgCl bipolar surface electrodes (Noraxon, Arizona, USA) were placed over the belly of the lower trapezius using published placements (Basmajian & DeLuca, 1995). The electrode position of the lower trapezius was placed obliquely upward and laterally along a line between the intersection of the spine of the scapula with the vertebral border of the scapula and the seventh thoracic spinous process (Figure 4). Prior to electrode placement, the placement area was shaved and cleaned with alcohol to minimize impedance with a ground electrode placed over the clavicle. EMG signals were collected using a Noraxon MyoSystem 1200 system (Noraxon, Arizona, USA) 4 channel EMG to collect data on a processing and analyzing computer program. The lower trapezius EMG activity was collected during therapeutic exercises and the skin was prepared prior to electrode placement by shaving hair (if necessary), abrading the skin with fine sandpaper, and cleaning the skin with isopropyl alcohol to reduce skin impedance.

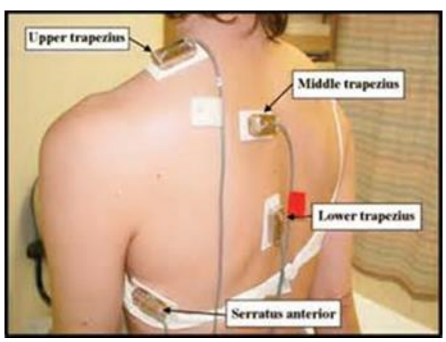

Figure 4: Surface electrode placement for lower trapezius muscle.

Data collection for each subject began by first recording the resting level of EMG electrical activity. Post exercise EMG data was rectified and smoothed within a root mean square

in 150ms window and MVIC was normalized over a 500ms window. ECG reduction was also used if ECG rhythm was present in the data.

During the protocol, EMG data was recorded over a series of three isometric contractions selected to obtain the maximum voluntary isometric contraction (MVIC) of the lower trapezius muscle tested and sustained for three seconds in positions specific to the muscle of interest (Kendall, 2005)(Figure 5). The MVIC test consisted of manual resistance provided by the investigator, a physical therapist, and a metronome used to control the duration of contraction.

Figure 5: The MVIC position for the lower trapezius was prone, shoulder in 125˚ of abduction and the MVIC action will be resisted arm elevation.

All analyses were performed using SPSS statistics software (SPSS Science Inc, Chicago, Illinois) with significance established at the $p \leq 0.05$ level. A 3x7 repeated measures analysis of variance (ANOVA) was used to test hypothesis. Mauchly's tests of sphericity were significant in phase one and phase two, therefore the Huynh-Feldt correction for both phases. Tukey post-hoc tests were used in phase one and phase two and least significant difference adjustment for multiple comparisons were used in comparison of means.

3.3 RESULTS

Our data revealed no significant difference in EMG activation of the lower trapezius with varying postures in phase one participants. Pairwise comparisons between Group 1 and Group 2 ($p = .371$) p Group 2 and Group 3 ($p = .635$, and Group 1 and Group 3 ($p = .176$ (Table 12).

However, statistical differences did exist between exercises. All exercises were

Table 12: Pairwise comparisons of the 3 Groups in phase 1	
Comparison	Significance
Group 1 v Group 2	.371
Group 3	.176
Group 2 v Group 3	.635

statistically significant from the others with the exceptions of exercise 1 and 6 for lower trapezius activation (p=.323), exercise 3 and 5 (p=.783), and exercise 4 and 7 (p=.398). Also, some exercises exhibited the highest EMG activity of the lower trapezius including exercises 2, 6, and 1. Exercise 2 exhibited 73.9% (Group 1), 88.9% (Group 2), and 73.6% (Group 3) %MVIC EMG activation of the lower trapezius. Exercise 6 exhibited 58.5% (Group 1), 79.2% (Group 2), and 47.9% (Group 3) %MVIC EMG activation of the lower trapezius. Lastly, exercise 1 exhibited 59.7% (Group 1), 59.5% (Group 2), and 57.4% (Group 3) %MVIC EMG activation of the lower trapezius. Overall exercise 2 exhibited the greatest EMG activation of the lower trapezius.

Our data suggests no significant difference in EMG activation of the lower trapezius with varying postures when comparing Group 1 to Group 2 (p =.161) and when comparing Group 3 to Group 1 (p=.304) in phase two participants (Table 13). However a significant difference was obtained when comparing Group 2 to Group 3 (p=.021). In general, Group 3 exhibited higher

Table 13: Pairwise comparisons of the 3 Groups in phase 2	
Comparison	Significance
Group 1 v Group 2	.161
Group 3	.304
Group 2 v Group 3	.021

EMG activity of the lower trapezius in every exercise when compared to Group 2. Also, statistical differences existed between exercises. All exercises were statistically significant from the others for lower trapezius activation with the exceptions of exercise 2 and 6 (p=.481), exercise 3 and 4 (p=.270), exercise 3 and 5 (p=.408), and exercise 3 and 7 (p=.531). Also, some

exercises exhibited the highest %MVIC EMG activity of the lower trapezius including exercises 2, 6, and 1. Exercise 2 exhibited an average of 76.4% (Group 1), 55.3% (Group 2), and 80.1% (Group 3) %MVIC EMG activation of the lower trapezius. Exercise 6 exhibited 80.3% (Group 1), 43.9% (Group 2), and 73% (Group 3) %MVIC EMG activation of the lower trapezius. Lastly, exercise 1 exhibited 48.9% (Group 1), 39.3% (Group 2), and 60.8% (Group 3) %MVIC EMG activation of the lower trapezius. Overall exercise 2 exhibited the greatest EMG activation of the lower trapezius and Group 3 exhibited the highest percentage 80.1% (Table 14).

Table 14: Percentage of MVIC exhibited by exercise 2 in all Groups	
Group 1	76.4%
Group 2	55.27%
Group 3	80.1%

3.4 DISCUSSION

Our data showed no differences between EMG activation in different postures in phase one and phase two except for Groups 2 and 3 in phase two, which contradicted what other authors have demonstrated (Reinold, et al., 2004; De Mey, et. al., 2013). In phase 2 however, Group 2 (feet staggered Group) performed standing resistance band exercises and Group 3 (conscious correction Group) performed the exercises lying on a plinth while a physical therapist cued the participant to contract the lower trapezius during repetitions. This gave some evidence to the need for individuals, who have shoulder impingement, to have a supervised rehabilitation program. While there was no statistical difference between Groups one and three in phase 2, every exercise in Group 3 exhibited higher EMG activation of the lower trapezius than Groups 1 and 2 except for exercise 6 in Group 1 (Group 1=80%, Group 3=73%). While the data was not statistically significant, it was important to note that this project looked at numerous exercises which did made it more difficult to show a significant difference between Groups. This may

warrant further research looking at individual exercises with changed posture and the effect on EMG activation.

When looking at the exercises which exhibited the highest EMG activation, phase one exercise 2 exhibited the highest EMG activation in the participants 73.9% (Group 1), 88.9% (Group 2), and 73.6% (Group 3) and there was no statistical difference between Groups. Phase 2 participants also exhibited a high EMG activation in the lower trapezius in exercise two 76.4% (Group 1), 55.3% (Group 2), and 80.1% (Group 3). Overall this exercise showed to exhibited the highest EMG activity of the lower trapezius which demonstrates its importance to activating the lower trap during therapeutic exercises in rehabilitation patients. Prior research has demonstrated the prone horizontal abduction at 135˚ with external rotation (97±16%MVIC; Ekstrom, Donatelli, & Soderberg, 2003) to exhibit high EMG activity of the lower trapezius. Therefore, in both phases the prone horizontal abduction at 130˚ with external rotation exercise is the optimal exercise to activate the lower trapezius.

Exercise 6 also exhibited a high EMG activity of the lower trapezius in both phases. In phase one, exercise 6 exhibited 58.5% (Group 1), 79.2% (Group 2), and .47.9% (Group 3) %MVIC EMG activation of the lower trapezius and in phase two exercise 6 exhibited 80.3% (Group 1), 43.9% (Group 2), and 73% (Group 3) %MVIC EMG activation of the lower trapezius. Prior research has demonstrated standing external rotation at 90˚ abduction (88±51%MVIC; Myers, Pasquale, Laudner, Sell, Bradle, & Lephart, 2005) to have a high EMG activation of the lower trapezius, which was comparable to the Group 2 postures in phase one (79.2%) and two (43.9%). Both Groups seemed consistent in the findings of prior research on activation of the lower trapezius.

Prior research has also demonstrated the prone external rotation at 90˚ abduction (79±21%MVIC; Ekstrom, Donatelli, & Soderberg, 2003) exhibited high EMG activation of the lower trapezius. This was comparable to exercise 6 in Group 1 (58.5%) and Group 3 (.47.9%) in phase one and Group 1 (80.3%) and Group 3 in phase 2 (73%). Our results seemed comparable to prior research on the EMG activation of this exercise. Exercise 1 also exhibited high-moderate lower trapezius activation, which was comparable to prior research. In phase one, exercise 1 exhibited 59.7% (Group 1), 59.5% (Group 2), and 57.4% (Group 3) and in phase two exercise 1 exhibited 48.9% (Group 1), 39.3% (Group 2), and 60.8% (Group 3) EMG activation of the lower trapezius. Prior research has demonstrated prone horizontal abduction at 90˚ abduction with external rotation (74±21%MVIC; Ekstrom, Donatelli, & Soderberg, 2003)(63±41%MVIC; Moseley, Jobe, Pink, Perry, & Tibone, 1992) exhibited moderate to high EMG activation, which was comparable to phase one Group 1(59.7%), phase one Group 3(57.4%), phase two Group 1 (48.9%), and phase two Group 3(60.8%). Our results seemed comparable to prior research.

Inherent limitations existed using surface EMG (sEMG) since the point of attachment was a mobile skin, and the skins mobility made it difficult to test over the same area in different exercises. Another limitation was the possibility that some electrical activity originated from other muscles not being studied, called crosstalk (Solomonow, et al., 1994). In this study, subjects also had varying amounts of subcutaneous fat, which may have may have influenced crosstalk in the sEMG amplitudes (Solomonow, et al., 1994; Jaggi, et al., 2009). Another limitation included the fact that the phase two participants were currently in physical therapy and possibly had performed some of the exercises in a rehabilitation program, which would have increased their familiarity with the exercise as compared to phase one participants.

In weight selection determination, a standardization formula was used, which calculated the weight for the individual, based on their anthropometrics. This limits the amount of interpretation because individuals were not all performing at the same level of their % rep maximum, which may decrease or increase the individuals strain level and alter EMG interpretation. One reason for the lack of statistically significant differences may be due to the participants were not performing a repetition maximum test and determining the weight to use from a percentage of the one repetition max. This may have yielded higher EMG activation in certain Groups or individuals. Also, fatiguing exertion may have caused perspiration or changes in skin temperature which may have decreased the adhesiveness of electrodes and or skin markers, where by altering EMG signals.

Intra-individual errors between movements and between Groups (healthy vs pathologic) and intra-observer variance can also add variance to the results. Even though individuals in phase 2 were screened for pain during the project, pain in the pathologic population may not allow the individual to perform certain movements, which is a limitation specific to this population.

3.5 CONCLUSION

In conclusion, the prone 130° of abduction with external rotation exercise demonstrated a maximal %MVIC activation profile for the lower trapezius. Unfortunately, no differences were displayed in the Groups to correlate a change in posture with an increase in EMG activation of the lower trapezius; however, this may warrant further research which examines each exercise individually.

3.6 ACKNOWLEDGEMENTS

I would like to acknowledge Dennis Landin for his help guidance in this project, Phil Page for providing me with the tools to perform EMG analysis, and Peak Performance Physical Therapy for providing the facilities for this project.

CHAPTER 4: THE EFFECT OF LOWER TRAPEZIUS FATIGUE ON SCAPULAR DYSKINESIS IN INDIVIDUALS WITH A HEALTHY PAIN FREE SHOULDER COMPLEX

4.1 INTRODUCTION

Subacromial impingement is used to describe a decrease in the distance between the inferior border of the acromion and superior border of the humeral head and proposed precursors include altered scapula kinematics or scapula dyskinesis. The proposed study examined the effect of lower trapezius fatigue on scapular dyskinesis in a healthy male adult population with a pain-free (dominant arm) shoulder complex. During the study, the subjects were under the supervision and guidance of a licensed physical therapist while each individual performed a fatiguing protocol on the lower trapezius, a passive stretching protocol on the lower trapezius, and the individual was evaluated for scapular dyskinesis and muscle weakness before and after the protocols.

Subacromial impingement is defined by a decrease in the distance between the inferior border of the acromion and superior border of the humeral head (Neer, 1972). This has been shown to cause compression and potential damage of the soft tissues including: the supraspinatus tendon, subacromial bursa, long head of the biceps tendon, and the shoulder capsule (Bey, et al., 2007; Flatow, et al., 1994; McFarland, et al., 1999; Michener, et al., 2003). This impingement, often a precursor to rotator cuff tears, have been shown to result from either (1) superior humeral head translation (2) altered scapular kinematics (Grieve & Dickerson, 2008), or a combination of the two. The first mechanism, superior humeral translation, has been linked to rotator cuff fatigue, (Chen, et al., 1999; Chopp, et al., 2010; Cote, et al., 2009; Teyhen, et al., 2008) and confirmation has been attained radiographically following a generalized rotator cuff fatigue protocol (Chopp, et al., 2010). The second previously proposed mechanism for impingement has

been altered scapular kinematics during movement. Individuals diagnosed with shoulder impingement have exhibited muscle imbalances in the shoulder complex and specifically in the force couple responsible for controlled scapular movements. The lower trapezius, upper trapezius, and serratus anterior have been included as the target muscles in this force couple (Figure 6).

Figure 6: Trapezius Muscles

During arm elevation in an asymptomatic shoulder, upward rotation, posterior tilt, and retraction of the scapula have been demonstrated (Michener, et al., 2003). However, for individuals diagnosed with subacromial impingement or shoulder dysfunction, these movements have been impaired (Endo, et al., 2001; Lin, et al., 2005; Ludewig & Cook, 2000). Endo et al. (2001) examined scapular orientation through radiographic assessment in patients with shoulder impingement and healthy controls, taking radiographs at three angles of abduction: 0°, 45°, and 90°. Patients with unilateral impingement syndrome had significant decreases in upward rotation and posterior tilt of the scapula compared to the contralateral arm, and these decreases were more pronounced when the arm was abducted from neutral (0°). These decreases were absent in both shoulders of healthy controls; thus changes seem related to impingement.

Prior research has demonstrated that shoulder external rotator muscle fatigue contributed to altered scapular muscle activation and kinematics (Joshi, et al., 2011), but to this authors knowledge, no prior articles have examined the effect of fatiguing the lower trapezius. The lower trapezius and serratus anterior have been generally accepted as the scapular stabilizing muscles, which have produced scapular upward rotation, posterior tilting, and retraction during arm elevation. It has been anticipated that by functionally debilitating these muscles by means of fatigue, changes in scapular orientation similar to impingement should occur. In prior shoulder external rotator fatiguing protocols from pre-fatigue to post-fatigue, lower trapezius activation decreased by 4% and scapular upward rotation motion increased in the ascending phase by 3° while serratus activation remained unchanged from pre-fatigue to post-fatigue (Joshi, et al., 2011). The authors concluded that alterations in the lower trapezius due to shoulder external rotator muscle fatigue might predispose the shoulder to injury and has contributed to alterations in scapula movements.

Scapular dysfunction or scapular dyskinesis has been defined as abnormal motion or position of the scapula during motion (McClure, et al., 2009). These altered kinematics have been caused by a shoulder injury such as impingement or by alterations in muscle force couples (Forthomme, Crielaard & Croisier, 2008; Kolber & Corrao, 2011; Cools, et al., 2007). Kibler et al. (2002) published a classification system for scapular dyskinesis for use during clinically practical visual observation. This classification system has included three abnormal patterns and one normal pattern of scapular motion. Type I pattern, characterized by inferior angle prominence, has been present when increased prominence or protrusion of the inferior angle (increased anterior tilting) of the scapula was noted along a horizontal axis parallel to the scapular spine. Type II pattern, characterized by medial border prominence, has been present

when the entire medial border of the scapula was more prominent or protrudes (increased internal rotation of the scapula) representing excessive motion along the vertical axis parallel to the spine. Type III pattern, characterized by superior scapular prominence, has been present when excessive upward motion (elevation) of the scapula was present along an axis in the sagittal plane. Type IV pattern was considered to be normal scapulohumeral motion with no excess prominence of any portion of the scapula and motion symmetric to the contralateral extremity (Kibler, et al., 2002).

According to Burkhart et al., scapular dysfunction has been demonstrated in asymptomatic overhead athletes (Burkhart, Morgan, & Kibler, 2003). Therefore, dyskinesis can also be the causative factor of a wide array of shoulder injuries not only a result. Of particular importance, the lower trapezius has formed and contributed to a force couple with other shoulder muscles and the general consensus from current research has stated that lower trapezius weakness has been a predisposing factor to shoulder injury although little data has demonstrated this theory (Joshi, et al., 2011; Cools, et. al., 2007) However, one study has demonstrated that scapula dyskinesis can occur in asymptomatic shoulders of competitive swimmers during a training session (Madsen, Bak, Jensen, & Welter, 2011). Previous authors (Madsen, et al., 2011) have demonstrated that training fatigue can induce scapula dyskinesis in healthy adults without shoulder problems and current research has stated that the lower trapezius can predispose and individual to injury and scapula dyskinesis. However, limited data has reinforced this last claim, and current research has lacked information as to what qualifies as weakness or strength. Therefore, the purpose of this study was to look at asymptomatic shoulders for lower trapezius weakness using hand held dynamometry and scapula dyskinesis due to a fatiguing and stretching protocol.

Our aim therefore was to determine if strength, endurance, or stretching of the lower trapezius will have an effect on inducing scapula dyskinesis. The purpose of the study is to identify if fatigue or stretching can cause scapula dyskinesis in healthy adults and predispose individuals to shoulder impingement. We based a fatiguing protocol on prior research which has shown to produce known scapula orientation changes (Chopp, et al., 2010; Tsai, et al., 2003) and on prior research and studies which have shown exercises with a high EMG activity profile of the lower trapezius (Coulon & Landin, 2014). Previous studies have consistently demonstrated that an acute bout of stretching reduces force generating capacity (Behm, et al., 2001; Fowles, et al., 2000; Kokkonen, et al., 1998; Nelson, et al., 2001), which led us in the present investigation to hypothesize that such reductions would translate to an increase in muscle fatigue.

This study has helped address two currently open questions. First, we have demonstrated if lower trapezius fatigue can induce scapula dyskinesis in healthy individuals as classified by Kibler's classification system. Second, we have provided more clarity over which mechanism (superior humeral translation or altered scapular kinematics) dominates changes in the subacromial space following fatigue. Lastly, we have determined if there is a difference in fatigue levels after a stretching protocol or resistance training protocol and if either causes scapula dyskinesis.

4.2 METHODS

The proposed study examined the effect of lower trapezius fatigue on scapular dyskinesis in 15 healthy males with a pain-free (dominant arm) shoulder complex. During the study, the subjects were under the supervision and guidance of a licensed physical therapist with each individual performing a fatiguing protocol on the lower trapezius, a passive stretching protocol on the lower trapezius, and an individual evaluation for scapular dyskinesis and muscle weakness before and after the protocols. The exercise consisted of an exercise (prone horizontal abduction

at 130˚ of abduction) specifically selected since it exhibited high EMG activity in the lower trapezius from prior work (Coulon & Landin, 2012) and research (Ekstrom, Donatelli, & Soderberg, 2003)(Figure 7).

STUDY	EMG activation (%MVIC)
Coulon & Landin, 2012	80.1%
Ekstrom, Donatelli, & Soderberg, 2003	97%

Figure 7: EMG activation of the lower trapezius during the prone horizontal abduction at 130˚ of abduction

The stretching protocol consisted of a passive stretch which attempted to increase the distance from the origin (spinous process T7-T12 vertebrae) to the insertion (spine of the scapula) as previously described (Moore & Dalley, 2006). There were a minimum of ten days between protocols if the fatiguing protocol was performed first and three days between protocols if the stretching protocol was performed first. The extended amount of time was given for the fatiguing protocol since delayed onset muscle soreness has been demonstrated to cause a detrimental effect of the shoulder complex movements and force production and prior research has shown these effects have resolved by ten days (Braun & Dutto, 2003; Szymanski, 2001; Pettitt, et al., 2010).

Upon obtaining consent, subjects were familiarized with the perceived exertion scale (PES) and rated their pretest level of fatigue. Subjects were instructed to warm up for 5 minutes at resistance level one on the upper body ergometer (UBE). After the subject completed the warm up, the lower trapezius isometric strength was assessed using a hand held dynamometer (microFET2, Hoggan Scientific LLC, Salt Lake City, UT). The isometric hold was assessed 3 times and the average of the 3 trials was used as the pre-fatigue strength score. The isometric hold position used for the lower trapezius has been described in prior research (Kendall, et al.,

2005)(Figure 8) and the handheld dynamometer was attached to a platform device, which the subject pushed into at a specific point of contact.

Figure 8: The MMT position for the lower trapezius will be prone, shoulder in 125-130˚ of abduction and the action will be resisted arm elevation against device (not shown).

A lever arm measurement of 22 inches was taken from the acromion to the wrist for each individual and was the point of contact for isometric testing. Following dynamometry testing, a visual observation classification system was used to classify the subject's pattern of scapular dyskinesis (Kibler, et al., 2002). Subjects were then given instructions on how to perform the prone horizontal abduction at 130˚ exercise. In this exercise, the subject was positioned prone with the shoulder resting at 90˚ forward flexion. From this position, the subject horizontally abducted the arm while maintaining the shoulder at 130˚ abduction (as measured by a licensed physical therapist with a goniometric device) with the shoulder in external rotation (thumb up) until the arm reached the frontal plane (Figure 9).

Figure 9: Prone horizontal abduction at 130˚ abduction (goniometric device not pictured)

This exercise was designed to isolate the lower trapezius muscle and was therefore used to facilitate fatigue of the lower trapezius. The percent of MVIC and EMG profile of this

exercise is 97% for lower trapezius, 101% middle trapezius, 78% upper trapezius, and 43% serratus anterior (Ekstrom, Donatelli, & Soderberg, 2003). Data collection for each subject began with a series of three isometric contractions of which the average was determined and a scapula classification system and lateral scapular glide test allowed for scapula assessment and was performed before and after each fatiguing protocol.

Once the subjects were comfortable with the lower trapezius exercise, they were then instructed to complete this exercise for two minutes at a rate of 30 repetitions per minute (metronome assisted) using a dumbbell weight and maintaining a scapular squeeze. Each subject performed repetitions of each exercise with the speed of the repetition regulated by the use of a metronome set to 60 beats per minute. The subject performed each concentric and eccentric phase of the exercise during two beats. The repetition rate was set by a metronome and all subjects used a weighted resistance 15%-20% of their average maximal isometric hold assessment. Subjects were asked to rate their level of fatigue using the PES after the 2 minutes (Figure 10) and were given max encouragement during the exercise.

Figure 10: Perceived Exertion Scale (PES) (Adapted from Borg, 1998)

The subjects were then given a one minute rest period before performing the exercise for another two minutes. This process was repeated until they could no longer perform the exercise and reported a 20 on the PES. This fatiguing activity is unilateral and once fatigue was reached, the subject's lower trapezius isometric strength was again assessed using a hand held dynamometer. The isometric hold was assessed three times and the average of the three trials was used as the post-fatigue strength. Then the scapula classification system and lateral scapula slide test were assessed again.

The participants of this study had to meet the inclusion/exclusion criteria. The inclusion criteria for all subjects were: 1) 18-65 years old, and 2) able to communicate in English. The exclusion criteria of the healthy adult Group included: 1) recent history (less than 1 year) of a musculoskeletal injury, condition, or surgery involving the upper extremity or the cervical spine, and 2) a prior history of a neuromuscular condition, pathology, or numbness or tingling in either upper extremity. Subjects were also excluded if they exhibited any contraindications to exercise (Table 15).

Table 15: Contraindications to exercise
1. a recent change in resting ECG suggesting significant ischemia 2. a recent myocardial infarction (within 7 days), 3. an acute cardiac event 4. unstable angina 5. uncontrolled cardiac dysrhythmias 6. symptomatic severe aortic stenosis 7. uncontrolled symptomatic heart failure 8. acute pulmonary embolus or pulmonary infarction 9. acute myocarditis or pericarditis 10. suspected or known dissecting aneurysm 11. acute systemic infection accompanied by fever, body aches, or swollen lymph glands.

Participants were recruited from Louisiana State University students, pre-physical therapy students, and healthy individuals willing to volunteer. Participants filled out an informed consent, PAR-Q, HIPAA authorization agreement, and met the inclusion and exclusion criteria

through the use of a verbal questionnaire. Each participant was blinded from the expected outcomes and hypothesized outcome of the study. Data was processed and the study will look at differences in muscle force production, scapula slide test, and scapula dyskinesis classification.

Fifteen males participated in this study and data was collected from their dominant upper extremity (13 right and 2 left upper extremities). Sample size was determined by a power analysis using the results from previous studies (Chopp, et al., 2011; Noguchi, et al., 2013); fifteen participants were required for adequate power. The mean height, weight, and age were 69.27 inches (range 66 to 75), weight 175.8 pounds (range 150 to 215), and age 24.67 years (range 20 to 57 years), respectively. Participants were excluded from the study if they reported any upper extremity pain or injury within the past year, or any bony structural damage (humeral head, clavicle or acromion fracture, or joint dislocation). The study was approved by the Louisiana State University Institutional Review Board, and each participant provided informed consent.

The investigators conducted the assessment for the inclusion and exclusion criteria through the use of a verbal questionnaire and PAR-Q. The study was explained to all subjects and they read and signed the informed consent agreement approved by the university institutional review board. On the first day of testing, the subjects were informed of their rights and procedures of participating in this study, discussed and signed the informed consent, read and signed the HIPPA authorization, discussed inclusion and exclusion criteria, received a brief screening examination, and were oriented to the testing protocol.

The fatiguing protocol was sequenced as follows: pre-fatigue testing, practice and familiarization, two minute fatigue protocol and one minute rest (repeated), post-fatigue testing. The stretching protocol was sequenced as follows: pre-stretch testing, practice and

familiarization, manually stretch protocol (three stretches for 65 seconds each), one min rest (after each stretch), and post-stretch testing. In total the individual was tested over two test periods, with a minimum of ten days between protocols if the fatiguing protocol was performed first and three days between protocols if the stretching protocol was performed first. The extended amount of time was given for the fatiguing protocol since delayed onset muscle soreness may cause a detrimental effect of the shoulder complex movements and force production and prior research has shown these effects have resolved by ten days (Braun & Dutto, 2003; Szymanski, 2001).

The fatiguing protocol consisted of five parts: (1) pre-fatigue scapula kinematic evaluation, (2) muscle-specific maximum voluntary contractions, used to determine repetition max and weight selection, (3) scaling of a weight used during the fatiguing protocol, (4) a prone horizontal abduction at 130˚ fatiguing task, and (5) post-fatigue scapula kinematic evaluation. The stretching protocol consisted of four parts: (1) pre-stretch scapula kinematic evaluation, (2) muscle-specific maximum voluntary contractions, (3) a manual lower trapezius stretch performed by a physical therapist performed in prone, and (5) post-stretch scapula kinematic evaluation.

Participants performed three repetitions of lower trapezius muscle-specific maximal voluntary contractions (MVCs) against a stationary device using a hand held dynamometer (microFET2, Hoggan Scientific LLC, Salt Lake City, UT). Two minute rest periods were provided between each exertion to reduce the likelihood of fatigue (Knutson, et al., 1994; Chopp, et al., 2010) and the MVC were preformed prior to and after the stretching and fatigue protocols. During the fatiguing protocol, participants held a weight in their hand (determined to be between 15%-20% of MVC) with their thumb facing up and a tight grip on the dumbbell.

Pre-fatigue trials consisted of obtaining MVC test levels during isometric holds and scapular evaluation/orientation measurements at varying humeral elevation angles and during active elevation. Data was later compared to post-fatigue trials. To avoid residual fatigue from MVCs, participants were given approximately five minutes of rest prior to the pre-fatigue measurements.

The fatiguing protocol consisted of a repeated voluntary movement of prone horizontal abduction at 130˚ repeated until exhaustion. The task consisted of repetitively lifting a dumbbell with thumb up and a firm grip on dumbbell weight from 90˚ shoulder flexion with 0˚ elbow flexion to 180˚ shoulder flexion with 0˚ elbow flexion at a controlled speed of 60 bpm (controlled by metronome) until fatigued. The subject performed each task for two minutes and the subjects were given a one minute rest period before performing the task for another two minutes. The subject repeated the process until the task could no longer be performed and the subject reported a 20 on the PES. The subject performed the fatiguing activity unilateral and once fatigue was reached, the subject's lower trapezius isometric strength was assessed using a hand held dynamometer. The isometric hold was assessed three times and the average of the three trials was used as the post-fatigue strength. The subject was also classified with the scapular dyskinesis classification system and data was analyzed. All arm angles during task were positioned by the experimenter using a manual goniometer.

During the protocol, verbal coaching and max encouragement were continuously provided by the researcher to promote scapular retraction and subsequent scapular stabilizer fatigue. Fatigue was monitored using a Borg Perceived Exertion Scale (PES)(Borg, 1982). The participants verbally expressed the PES prior to and after every two minute fatiguing trial during the fatiguing protocol. Participants continued the protocol until "failure" as determined by prior

scapular retractor fatigue research (Tyler, et al., 2009; Noguchi, et al., 2013). The subject was considered in failure when the subject verbally indicated exhaustion (PES of 20), the subject demonstrated and inability to maintain repetitions at 60 bpm, the subject demonstrated an inability to retract the scapula completely before exercise on three consecutive repetitions, and the subject demonstrated the inability to break the frontal plane at the cranial region with the elbow on three consecutive repetitions.

Fifteen healthy male adults without shoulder pathology on their dominant shoulder performed the stretching protocol. Upon obtaining consent, subjects were familiarized with the perceived exertion scale (PES) and asked to rate their pretest level of fatigue. Subjects were instructed to warm up for five minutes at resistance level one on the upper body ergometer (UBE). After the warm up was completed, the examiner assessed the lower trapezius isometric strength using a hand held dynamometer (microFET2, Hoggan Scientific LLC, Salt Lake City, UT). The isometric hold was assessed three times and the average of the three trials indicated the pre-fatigue strength score. The isometric hold position used for the lower trapezius is described in prior research (Kendall et al, 2005); the handheld dynamometer was attached to a platform and the subject then pushed into the device. Prior to dynamometry testing, a visual observation classification system classified the subject's pattern of scapular dyskinesis (Kibler, et al., 2002). Subjects were then manually stretched which attempted to increase the distance from the origin (spinous process of T7-T12 thoracic vertebrae) to the insertion (spine of the scapula) as previously described (Moore & Dalley, 2006). The examiner performed three passive stretches and held each for 65 seconds since only long duration stretches (>60 s) performed in a pre-exercise routine have been shown to compromise maximal muscle performance and are hypothesized to induce scapula dyskinesis. The examiner performed the stretching activity

unilaterally and once performed the subject's lower trapezius isometric strength was assessed using a hand held dynamometer. The isometric hold was assessed 3 times and the average of the 3 trials was then used as the post-stretch strength. Lastly, the subject was classified into the scapular dyskinesis classification system and all data will be analyzed.

Post-fatigue trials were collected using an identical protocol to that described in pre-fatigue trials. In order to prevent fatigue recovery confounding the data, the examiner administered post-fatigue trials immediately after completion of the fatiguing or stretching protocol.

When evaluating the scapula, the examiner observed both the resting and dynamic position and motion patterns of the scapula to determine if aberrant position or motion was present (Magee, 2008; Ludewig & Reynolds, 2009; Wright, et al., 2012). This classification system (discussed earlier in this paper) consisted of three abnormal patterns and one normal pattern of scapular motion. (Kibler, et al., 2002). The examiner used two observational methods. First determining if the individual demonstrated scapula dyskinesis with the YES/NO method and secondary determining what type the individual demonstrated (type I-type IV). The sensitivity (76%), inter-rater agreement (79%), and positive predictive value (74%) have all been documented (Kibler, et al., 2002). The second method used was the lateral scapula slide test, a semi-dynamic test used to evaluate scapular position and scapular stabilizer strength. The test is performed in three positions (arms at side, hands-on-hips, 90˚ glenohumeral abduction with full internal rotation) measured (cm) from the inferior angle of the scapula to the spinous process in direct horizontal line. A positive test consisted of greater than 1.5cm difference between sides and indicated a deficit in dynamic stabilization or postural adaptations. The ICC (.84) and inter-tester reliability (.88) have been determined for this test (Kibler, 1998).

A paired-sample t-test was used to determine differences in lower trapezius muscle testing and stretching between pre-fatigue and post-fatigue conditions. All analyses were performed using Statistical Package for Social Science Version 12.0 software (SPSS, Inc, Chicago, IL). An alpha level of .05 probability was set a priori to be considered statistically significant.

4.3 RESULTS

Data suggested a statistically significant difference between the fatigue and stretching Group ($p=.002$). The stretching Group exhibited no scapula dyskinesis pre-stretching protocol and post-stretching protocol in the scapula classification system or the 3 phases of the scapula slide test (arms at side, hands on hips, 90˚ glenohumeral abduction with full humeral internal rotation). However, a statistically significant difference ($p<.001$) was observed in the pre-stretch MVC test (25.1556 pounds) and post-stretch MVC test (24.5556 pounds). This is a 2.385% decrease in force production after stretching.

In the pre-testing of the pre-fatigue Group, all participants exhibited no scapula dyskinesis in the Yes/No classification system and all exhibited type IV scapula movement pattern prior to fatigue protocol. All participants were negative for the three phases of the scapula slide test (arms at side, hands on hips, 90˚ glenohumeral abduction with full humeral internal rotation) with the exception of one participant who had a positive result on the 90˚ glenohumeral abduction with full humeral internal rotation part of the test. During testing, this participant did report he had participated in a fitness program prior to coming to his assessment.

Our data suggests a statistically significant difference ($p<.001$) in pre-fatigue MVC (25.2444 pounds) and post-fatigue MVC (16.5333 pounds). This is a 34.5% decrease in force production, and all participants exhibited a decrease in average MVC with a mean of 16.533 pounds. There was also a statistically significant difference in mean force production pre- and

post- fatiguing exercise (p=<.001) demonstrating the individuals exhibited true fatigue. In the post-fatigue trial all but four of the participants were classified as yes (73.3%) for scapula dyskinesis and the post fatigue dyskinesis types were type I (6; 40%), type II (5; 33.33%), type III (0), and type IV (4; 26.67%). All participants were negative for the arms at side phase of the scapula slide test except for participants 4,6,10,11,12, and 14 (6; 40%). All participants were negative for the hands on hips phase of the scapula slide test except participants 4, 6, 9, and 10 (4; 26.67%). All participants were negative for the 90˚ glenohumeral abduction with full humeral internal rotation phase of the scapula slide test with the exception of participants 1, 2, 3, 4, 7, 8, 9, 10, 12, 13, and 14 (10; 66.67%).

The average number of fatiguing trials each participant completed was 8.466 with the lowest being four trials and the longest being sixteen trials. The average weight used based on MVC was 4.6 pounds with the lowest being four pounds and the highest being seven pounds.

4.4 DISCUSSION

In this study, the participants exhibited scapula dyskinesis with an exercise specifically selected to fatigue the lower trapezius. The results agreed with prior research, which has shown significant differences in scapula upward rotation and posterior tilt for 0 to 45 degrees and 45 to 90 degrees of elevation (Chopp, Fischer, & Dickerson, 2010). The presence of scapula dyskinesis gives some evidence that fatigue of the lower trapezius had a detrimental effect on shoulder function and possibly leads to shoulder pathology. Also, these results demonstrated that proper function and training of the lower trapezius is vitally important for overhead athletes and shoulder health.

With use of the classification system, an investigator bias was possible since the same participants and tester participated in both sessions. Also, the scapula physical examination test have demonstrated a moderate level of sensitivity and specificity (Table G in Appendix) with

prior research finding sensitivity measurements from 28-96 depending on position and specificity measurements ranging from 4-58.

The results of our study have also demonstrated relevance for shoulder rehabilitation and injury-prevention programs. Fatigue induced through repeated overhead glenohumeral movements while in external rotation resulted in altered strength and endurance in the lower trapezius muscle and in scapular dyskinesis, and has been linked to many injuries, including subacromial impingement, rotator cuff tears, and glenohumeral instability. Addressing imbalances in the lower trapezius through appropriate exercises is imperative for establishing normal shoulder function and health.

4.5 CONCLUSION

In conclusion, lower trapezius fatigue appeared to contribute or even caused scapula dyskinesis after a fatiguing task, which could have identified a precursor to injury in repetitive overhead activities. This demonstrated the importance of addressing lower trapezius endurance, especially in overhead athletes, and the possibility that lower trapezius is the key muscle in rehabilitation of scapula dyskinesis.

CHAPTER 5: SUMMARY AND CONCLUSIONS

In summary, shoulder impingement has been identified as a common problem in the orthopedically impaired population and scapula dyskinesis is involved in this pathology. The literature has been uncertain as to the causative factor of scapula dyskinesis in shoulder impingement and no links have been demonstrated as to the specific muscle contributing to the biomechanical abnormality. These studies attempted to demonstrate therapeutic exercises which specifically activate the lower trapezius and use the appropriate exercise to fatigue the lower trapezius and induce scapula dyskinesis.

The first study demonstrated that healthy individuals and individuals diagnosed with shoulder impingement can maximally activate the lower trapezius with a specific prone shoulder exercise (prone horizontal abduction at 130˚ with external rotation). This knowledge demonstrated an important finding in the application of rehabilitation exercise prescription in shoulder pathology and scapula pathology. The results from the second study demonstrated the importance of the lower trapezius in normal scapula dynamic movements and the important muscles contribution to scapula dyskinesis. Interestingly, lower trapezius fatigue was a causative factor in initiating scapula dyskinesis and possibly increased the risk of injury. Applying this knowledge to clinical practice, a clinician might have assumed that lower trapezius endurance may be a vital component in preventing injuries in overhead athletes. This might lead future injury prevention studies to examine the effect of a lower trapezius endurance program on shoulder injury prevention.

Also, the results of this research have allowed further research to specifically target rehabilitation protocols in scapula dyskinesis which determine if addressing the lower trapezius may abolish scapula dyskinesis and prevent future shoulder pathology. This would be a groundbreaking discovery since no other studies have demonstrated appropriate rehabilitation

protocols for scapula dyskinesis and no research articles have demonstrated a cause effect relationship to correct the abnormal movement pattern.

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APPENDIX A: TABLES A-G

Table A: Mean tubing force and EMG activity, normalized by MVIC, during shoulder exercises with intensity normalized by a ten repetition maximum (Adapted from Decker, Tokish, Ellis, Torry, & Hawkins, 2003).

Exercise	Upper subscapularis EMG (%MVIC)	Lower subscapularis EMG (%MVIC)	Supraspinatus EMG (%MVIC)	Infraspinatus EMG (%MVIC)	Pectoralis Major EMG (%MVIC)	Teres Major EMG (%MVIC)	Latissimus dorsi EMG (%MVIC)
Standing Forward Scapular Punch	33±28[a]	<20[a,b,c,d]	46±24[a,*]	28±12[a]	25±12[a,b,c,d]	<20[a]	<20[a,d]
Standing IR at 90˚ Abduction	58±38[a,*]	<20[a,b,c,d]	40±23[a,*]	<20[a]	<20[a,b,c,d]	<20[a]	<20[a,d]
Standing IR at 45˚ abduction	53±40[a,*]	26±19	33±25[a,b]	<20[a]	39±22[a,d]	<20[a]	<20[a,d]
Standing IR at 0˚ abduction	50±23[a,*]	40±27[*]	<20[a,b,d,e]	<20[a]	51±24[a,d,*]	<20[a]	<20[a,d]
Standing scapular dynamic hug	58±32[a,*]	38±20	62±31[a,*]	<20[a]	46±24[a,d,*]	<20[a]	<20[a,d]
D2 diagonal pattern extension, horizontal adduction, IR	60±34[a,*]	39±26	54±35[a,*]	<20[a]	76±32[*]	<20[a]	21±12[a]
Push-up plus	122±22[*]	46±29[*]	99±36[*]	104±54[*]	94±27[*]	47±26[*]	49±25[*]

*=>40% MVIC or moderate level of activity
a=significantly less EMG amplitude compared to push-up plus (p<.002)
b= significantly less EMG amplitude compared with standing scapular dynamic hug (p<.002)
c= significantly less EMG amplitude compared to standing IR at 0˚ abd (p<.002)
d= significantly less EMG amplitude compared to D2 diagonal pattern extension (p<.002)
e= significantly less EMG amplitude compared to standing forward scapular punch (p<.002)
IR=internal rotation

Table B: Mean RTC and deltoid EMG, normalized by MVIC, during shoulder dumbbell exercises with intensity normalized to ten-repetition maximum (Adapted from Reinold et al., 2004)

Exercise	Infraspinatus EMG (%MVIC)	Teres Minor EMG (%MVIC)	Supraspinatus EMG (%MVIC)	Middle Deltoid EMG (%MVIC)	Posterior Deltoid EMG (%MVIC)
SL ER at 0˚ abduction	62±13[*]	67±34[*]	51±47[e,*]	36±23[e]	52±42[e,*]
Standing ER in scapular plane	53±25[*]	55±30[*]	32±24[c,e]	38±19	43±30[e,*]
Prone ER at 90˚ abduction	50±23[*]	48±27[*]	68±33[*]	49±15[e,*]	79±31[*]
Standing ER at 90˚ abduction	50±25[*]	39±13[a]	57±32[*]	55±23[e,*]	59±33[e,*]
Standing ER at 15˚abduction (towel roll)	50±14[*]	46±41[*]	41±37[c,e,*]	11±6[c,d,e]	31±27[a,c,d,e]
Standing ER at 0˚ abduction (no towel roll)	40±14[a,*]	34±13[a]	41±38[c,e,*]	11±7[c,d,e]	27±27[a,c,d,e]
Prone horizontal abduction at 100˚ abduction with ER	39±17[a]	44±25[*]	82±37[*]	82±32[*]	88±33[*]

*=>40% MVIC or moderate level of activity
a=significantly less EMG amplitude compared to SL ER at 0˚ abduction ($p<.05$)
b= significantly less EMG amplitude compared to standing ER in scapular plane ($p<.05$)
c= significantly less EMG amplitude compared to prone ER at 90˚ abduction ($p<.05$)
d= significantly less EMG amplitude compared to standing ER at 90˚ abduction ($p<.05$)
e= significantly less EMG amplitude compared to prone horizontal abduction at 100˚ abduction with ER ($p<.05$)
ER=external rotation SL=side-lying

Table C: Mean trapezius and serratus anterior EMG activity, normalized by MVIC, during dumbbell shoulder exercises with and intensity normalized by a five repetition max (Adapted from Ekstrom, Donatelli, & Soderberg, 2003). 45±17

Exercise	Upper Trapezius EMG (%MVIC)	Middle Trapezius EMG (%MVIC)	Lower trapezius EMG (%MVIC)	Serratus Anterior EMG (%MVIC)
Shoulder shrug	119±23[*]	53±25[b,c,d,*]	21±10[b,c,d,f,g,h]	27±17[c,e,f,g,h,i,j]
Prone rowing	63±17[a,*]	79±23[*]	45±17[c,d,h,*]	14±6[c,e,f,g,h,i,j]
Prone horizontal abduction at 135˚ abduction with ER	79±18[a,*]	101±32[*]	97±16[*]	43±17[e,f,*]
Prone horizontal abduction at 90˚ abduction with ER	66±18[a,*]	87±20[*]	74±21[c,*]	9±3[c,e,f,g,h,i,j]
Prone ER at 90˚ abduction	20±18[a,b,c,d,e,f,g]	45±36[b,c,d,*]	79±21[*]	57±22[e,f,*]
D1 diagonal pattern flexion, horizontal adduction, and ER	66±10[a,*]	21±9[a,b,c,d,f,g,h]	39±15[b,c,d,f,g,h]	100±24[*]
Scaption above 120˚ with ER	79±19[a,*]	49±16[b,c,d,*]	61±19[c,*]	96±24[*]
Scaption below 80˚ with ER	72±19[a,*]	47±16[b,c,d,*]	50±21[c,h,*]	62±18[e,f,*]
Supine scapular protraction with shoulders horizontally flexed 45˚ and elbows flexed 45˚	7±5[a,b,c,d,e,f,g,h]	7±3[a,b,c,d,f,g,h]	5±2[b,c,d,f,g,h]	53±28[e,f,*]
Supine upward punch	7±3[a,b,c,d,e,f,g,h]	12±10[b,c,d]	11±5[b,c,d,f,g,h]	62±19[e,f,*]

*=>40% MVIC or moderate level of activity
a= significantly less EMG amplitude compared to shoulder shrug (p<.05)
b= significantly less EMG amplitude compared to prone rowing (p<.05)
c= significantly less EMG amplitude compared to Prone horizontal abduction at 135˚ abduction with ER (p<.05)
d= significantly less EMG amplitude compared to Prone horizontal abduction at 90˚ abduction with ER (p<.05)
e= significantly less EMG amplitude compared to D1 diagonal pattern flexion, horizontal adduction, and ER (p<.05)
f= significantly less EMG amplitude compared to Scaption above 120˚ with ER (p<.05)
g= significantly less EMG amplitude compared to Scaption below 80˚ with ER (p<.05)
h= significantly less EMG amplitude compared to Prone ER at 90˚ abduction (p<.05)
i= significantly less EMG amplitude compared to Supine scapular protraction with shoulders horizontally flexed 45˚ and elbows flexed 45˚ (p<.05)
j= significantly less EMG amplitude compared to Supine upward punch (p<.05)
ER=external rotation

Table D: Peak EMG activity, normalized by MVIC, over 30˚ arc of movement during dumbbell shoulder exercises (Adapted from Townsend, Jobe, Pink, & Perry, 1991).

Exercise	Anterior Deltoid EMG (%MVIC)	Middle Deltoid EMG (%MVIC)	Posterior Deltoid EMG (%MVIC)	Supraspinatus EMG (%MVIC)	Subscapularis EMG (%MVIC)	Infraspinatus EMG (%MVIC)	Teres Minor EMG (%MVIC)	Pectoralis Major EMG (%MVIC)	Latissimus dorsi EMG (%MVIC)
Flexion above 120˚ with ER	**69±24**	**73±16**	≤50	**67±14**	**52±42**	**66±16**	≤50	≤50	≤50
Abduction above 120˚ with ER	**62±28**	**64±13**	≤50	≤50	**50±44**	**74±23**	≤50	≤50	≤50
Scaption above 120˚ with IR	**72±23**	**83±13**	≤50	**74±33**	**62±33**	≤50	≤50	≤50	≤50
Scaption above 120˚ with ER	**71±39**	**72±13**	≤50	**64±28**	≤50	**60±21**	≤50	≤50	≤50
Military press	**62±26**	**72±24**	≤50	**80±48**	**56±46**	≤50	≤50	≤50	≤50
Prone horizontal abduction at 90˚ abduction with IR	≤50	**80±23**	**93±45**	≤50	≤50	**74±32**	**68±28**	≤50	≤50
Prone horizontal abduction at 90˚ abduction with ER	≤50	**79±20**	**92±49**	≤50	≤50	**88±25**	**74±28**	≤50	≤50
Press-up	≤50	≤50	≤50	≤50	≤50	≤50	≤50	**84±42**	**55±27**
Prone Rowing	≤50	**92±20**	**88±40**	≤50	≤50	≤50	≤50	≤50	≤50
SL ER at 0˚ abduction	≤50	≤50	**64±62**	≤50	≤50	**85±26**	**80±14**	≤50	≤50
SL eccentric control of 0-135˚ horizontal adduction (throwing deceleration)	≤50	**58±20**	**63±28**	≤50	≤50	**57±17**	≤50	≤50	≤50
ER=external rotation; IR=internal rotation; BOLD=>50%MVIC									

Table E: Peak scapular muscle EMG, normalized to MVIC, over a 30˚ arc of movement during shoulder dumbbell exercises with intensity normalized by a ten-repetition maximum (Moseley, Jobe, Pink, Perry, & Tibone, 1992).

Exercise	Upper Trapezius EMG (%MVIC)	Middle Trapezius EMG (%MVIC)	Lower Trapezius EMG (%MVIC)	Levator Scapulae EMG (%MVIC)	Rhomboids EMG (%MVIC)	Middle Serratus EMG (%MVIC)	Lower Serratus EMG (%MVIC)	Pectoralis Major EMG (%MVIC)
Flexion above 120˚ with ER	≤50	≤50	**60±18**	≤50	≤50	**96±45**	**72±46**	≤50
Abduction above 120˚ with ER	**52±30**	≤50	**68±53**	≤50	**64±53**	**96±53**	**74±65**	≤50
Scaption above 120˚ with ER	**54±16**	≤50	**60±22**	**69±49**	**65±79**	**91±52**	**84±20**	≤50
Military press	**64±26**	≤50	≤50	≤50	≤50	**82±36**	**60±42**	≤50
Prone horizontal abduction at 90˚ abduction with IR	**62±53**	**108±63**	**56±24**	**96±57**	**66±38**	≤50	≤50	≤50
Prone horizontal abduction at 90˚ abduction with ER	**75±27**	**96±73**	**63±41**	**87±66**	≤50	≤50	≤50	≤50
Press-up	≤50	≤50	≤50	≤50	≤50	≤50	≤50	**89±62**
Prone Rowing	**112±84**	**59±51**	**67±50**	**117±69**	**56±46**	≤50	≤50	≤50
Prone extension at 90˚ flexion	≤50	**77±49**	≤50	**81±76**	≤50	≤50	≤50	≤50
Push-up Plus	≤50	≤50	≤50	≤50	≤50	**80±38**	**73±3**	**58±45**
Push-up with hands separated	≤50	≤50	≤50	≤50	≤50	**57±36**	**69±31**	**55±34**
ER=external rotation; IR=internal rotation; BOLD=>50%MVIC								

Table F: Mean shoulder muscle EMG, normalized to MVIC, during shoulder tubing exercises (Myers, Pasquale, Laudner, Sell, Bradley, & Lephart, 2005).

Exercise	Anterior Deltoid EMG (%MVIC)	Middle Deltoid EMG (%MVIC)	Subscapularis EMG (%MVIC)	Supraspinatus EMG (%MVIC)	Teres Minor EMG (%MVIC)	Infraspinatus EMG (%MVIC)	Pectoralis Major EMG (%MVIC)	Latissimus dorsi EMG (%MVIC)	Biceps Brachii EMG (%MVIC)	Triceps brachii EMG (%MVIC)	Lower Trapezius EMG (%MVIC)	Rhomboids EMG (%MVIC)	Serratus Anterior EMG (%MVIC)
D2 diagonal pattern extension, horizontal adduction, IR	27±20	22±12	**94±54**	36±32	**89±57**	33±22	36±30	26±37	6±4	32±15	**54±46**	**82±82**	**56±36**
Eccentric arm control portion of D2 diagonal pattern flexion, abduction, ER	30±17	44±16	**69±48**	**64±33**	**90±50**	**45±21**	22±28	35±48	11±7	22±16	**63±42**	**86±49**	**48±32**
Standing ER at 0˚ abduction	6±6	8±7	**72±55**	20±13	**84±39**	**46±20**	10±9	33±29	7±4	22±17	**48±25**	**66±49**	18±19
Standing ER at 90˚ abduction	22±12	**50±22**	**57±50**	**50±21**	**89±47**	**51±30**	34±65	19±16	10±8	15±11	**88±51**	**77±53**	**66±39**
Standing IR at 0˚ abduction	6±6	4±3	**74±47**	10±6	**93±41**	32±51	36±31	34±34	11±7	21±19	44±31	41±34	21±14
Standing IR at 90˚ abduction	28±16	41±21	**71±43**	41±30	**63±38**	24±21	18±23	22±48	9±6	13±12	**54±39**	**65±59**	**54±32**
Standing extension from 90-0˚	19±15	27±16	**97±55**	30±21	**96±50**	**50±57**	22±37	**64±53**	10±27	**67±45**	**53±40**	**66±48**	30±21
Flexion above 120˚ with ER	**61±41**	32±14	**99±38**	42±22	**112±62**	**47±34**	19±13	33±34	22±15	22±12	**49±35**	**52±54**	**67±37**
Standing high scapular rows at 135˚ flexion	31±25	34±17	**74±53**	42±28	**101±47**	31±15	29±56	36±36	7±4	19±8	**51±34**	**59±40**	38±26
Standing mid scapular rows at 90˚ flexion	18±10	26±16	**81±65**	40±26	**98±74**	27±17	18±34	40±42	17±32	21±22	39±27	**59±44**	24±20
Standing low scapular rows at 45˚ flexion	19±13	34±23	**69±50**	**46±38**	**109±58**	29±16	17±32	35±26	21±50	21±13	44±32	**57±38**	22±14
Standing forward scapular punch	**45±36**	36±24	**69±47**	**46±31**	**69±40**	35±17	19±33	32±35	12±9	27±28	39±32	**52±43**	**67±45**
ER=external rotation; IR=Internal rotation; **BOLD**=MVIC>45%													

Table G: Scapula physical examination tests

List of scapula physical examination tests (Wright, et. al., 2013)						
Test Name	**Pathology**	**Lead Author**	**Specificity**	**Sensitivity**	**+LR**	**-LR**
Lateral Scapula Slide test (1.5cm threshold) 0˚ abduction	Shoulder Dysfunction	Odom, et al., 2001	53	28	.6	1.36
Lateral Scapula Slide test (1.5cm threshold) 45˚ abduction	Shoulder Dysfunction	Odom, et al., 2001	58	50	1.19	.86
Lateral Scapula Slide test (1.5cm threshold) 90˚ abduction	Shoulder Dysfunction	Odom, et al., 2001	52	34	.71	1.27
Lateral Scapula Slide test (1.5cm threshold) 0˚ abduction	Shoulder Pathology	Shadmehr, et al., 2010	12-26	90-96	1.02-1.3	.15-.83
Lateral Scapula Slide test (1.5cm threshold) 45˚ abduction	Shoulder Pathology	Shadmehr, et al., 2010	15-26	83-93	.98-1.26	.27-1.13
Lateral Scapula Slide test (1.5cm threshold) 90˚ abduction	Shoulder Pathology	Shadmehr, et al., 2010	4-19	80-90	.83-1.11	.52-5.0
Scapula Dyskinesis Test	Shoulder Pain >3/10	Tate, et al., 2009	71	24	.83	1.07
Scapula Dyskinesis Test	Shoulder Pain >6/10	Tate, et al., 2009	72	21	.75	1.10
Scapula Dyskinesis Test	Acromioclavicular dislocation	Gumina, et al., 2009	NT	71	-	-
SICK scapula	Acromioclavicular dislocation	Gumina, et al., 2009	NT	41	-	-

APPENDIX B: IRB INFORMATION STUDY ONE AND TWO

HIPAA authorization agreement

This NOTICE DESCRIBES HOW MEDICAL INFORMATION ABOUT YOU MAY BE USED, DISCLOSED, AND HOW YOU CAN GET ACCESS INFROMATION. PLEASE REVIEW IT CAREFULLY. NOTICE OF PRIVACY PRACTICE PURSUANT TO 45 C.F.R.164.520

OUR DUTIES: We are required by law to maintain the privacy of your protected health information ("Protected Health information ") we must also provide you with notice of our legal duties and privacy practices with respect to protected Health information. We are required to abide by the terms of our Notice of privacy Practices currently in effect. However we reserve the right to change our privacy practices in regard to protected health Information and make new privacy policies effective form all protected Health information that we maintain. We will provide you with a copy of any current privacy policy upon your written request, addressed or our privacy officer. At our correct address. You're Complaints: You may complain to us and to the secretary of the department of health and human services if you believe that your privacy rights have been violated. You may file a complaint with us by sending a certified letter addressed to privacy officer at our current address, stating what Protected Health Information you belie e has been used or disclosed improperly. You will not be retaliated against for making a complaint. For further information you may contact our privacy officer at telephone number (337) 303-8150.

Description and Examples of uses and Disclosures of Protected Health Information: Here are some examples of how we may use or disclose your Protect Health Information. In connection with research we will for example allow a health care provider associated with us to use your medical history, symptoms, injuries or diseases to determine if you are eligible for the study. We will treat your protected Health Information as confidential.

Uses and Disclosures Not Requiring Your Written Authorization: The privacy regulation give us the right to use and disclose your Protected Health Information if ( ) you are an inmate in a correctional institution, we have a direct or indirect treatment relationship with you, we are so required or authorized by law. The purposed for which we might use your Protected Health information would be to carry out procedures related to research and health care operations similar to those described in Paragraph 1.

Uses of Protected Health Information to Contact You: We may use your Protected Health Information to contact you regarding scheduled appointment reminders or to contact you with information about the research you are involved in.

Disclosures for Directory and notification purposes: If you are incapacitated or not present at the time we may disclose your protected health information (a) for use in a facility directory, (b) to notify family of other appropriate persons of your location or condition and to inform family friend or caregivers of information relevant to their involvement in your care or involved research. If you are present and not incapacitated, we will make the above disclosures, as well as disclose any other information to anyone you have identified, only upon your signed consent, your verbal agreement, or the reasonable belief that you would not object to disclosures.

Individual Rights: You may request us to restrict the uses and disclosures of our Protected Health Information, but we do not have to agree to your request. You have the right to request that we but we communicate with you regarding your Protected Health Information in a confidential manner or pursuant to an alternative means, such as by a sealed envelope rather than a postcard, or by communicating to an alternative means, such as by a sealed to a specific phone number, or by sending mail to a specific address. We are required to accommodate all reasonable request in this regard. You have the right to request that you be allowed to inspect and copy your Protected Health Information as long as it is kept as a designated record set. Certain records are exempt from inspection and cannot be

inspected and copied. Certain records are exempt from inspection and cannot be inspected and copied, so each request will be reviewed in accordance with the stands published in 45 C.F.R 164.524 You have the right to amend your protected Health Information for as long as the Protected Health Information is maintained in the designated record set. We may deny your request for an amendment if the protected Health Information was not created by us , or is not part of the designated record set, or would not be available for inspection as described under 45 C.F.R 164.524 , or if the Protected Health Information is already accurate and complete without regard to the amendment. You also have a right to receive a copy of this Notice upon request. By signing this agreement you are authorizing us to perform research, collect data, and possibly publish research on the results of the study. Your individual health information will be kept confidential.
Effective Date
The effective date of this Notice is ____.
I hereby acknowledge that I have received a copy of this notice.

Signature____

Date____

Physical Activity Readiness Questionnaire (PAR-Q)

For most people, physical activity should not pose any problem or hazard. This questionnaire has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the suitable type of activity.

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

2. Do you frequently suffer from chest pains? Yes No

3. Do you often feel faint or have spells of severe dizziness? Yes No

4. Has a doctor ever said your blood pressure was too high Yes No

5. Has a doctor ever told you that you have a bone or joint problem such asarthritis that has been aggravated by, or might be made worse with exercise

   Yes No

6. Is there any other good physical reason why you should not follow an activity program even if you want to?
   Yes No

7. Are you 65 and not accustomed to vigorous exercise Yes No

If you answer "yes" to any question, vigorous exercise or exercise testing should be postponed. Medical clearance may be necessary.

I have read this questionnaire, I understand it does not provide a medical assessment in lieu of a physical examination by a physician.

Participant's signature _____________________ Date ----------

Investigator'signature _____________________ Date___________

Adapted from PAR-Q Validation Report, British Columbia Department of Health, June, 19

75. Reference:

Hafen, B. Q. & Hoeger, W. W. K. (1994). Wellness: Guidelines for a Healthy Lifestyle.
Morton Publishing Co: Englewood, CO.

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Robert Mathews, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
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TO: Dennis Landin
Kinesiology

FROM: Robert C. Mathews
Chair, Institutional Review Board

DATE: December 18, 2013
RE: **IRB#** 3438

TITLE: The Effect of Various Postures on the Surface Electromyographic Analysis of the Trapezius, Serratus Anterior, and Deltoid during Specific Therapeutic Exercise

New Protocol/Modification/Continuation: New Protocol

Review type: Full X Expedited ___ **Review date:** 12/13/2013

Risk Factor: Minimal X Uncertain _______ Greater Than Minimal_______

Approved* X **Disapproved** _________

Approval Date: 12/13/2013 **Approval Expiration Date:** 12/12/2014

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 60

Protocol Matches Scope of Work in Grant proposal: (if applicable) ________

***Approval Note: Your study is not to begin until your Certificate of Confidentiality is approved and on file with the LSU-BR Institutional Review Board**

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*

Application for Approval of Projects Which Use Human Subjects

This application is used for projects/studies that cannot be reviewed through the exemption process.

LSU
Institutional Review Board
Dr. Robert Mathews, Chair
130 David Boyd Hall
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- Applicant, Please fill out the application in its entirety and include two copies of the competed application as well as parts A-E, listed below. Once the application is completed, please submit to the IRB Office for review and please allow ample time for the application to be reviewed. Expedited reviews usually takes 2 weeks. Carefully completed applications should be submitted 3 weeks before a meeting to ensure a prompt decision.

- A Complete Application Includes All of the Following:
  (A) Two copies of this completed form and two copies of part B thru F.
  (B) A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts 1&2)
  (C) Copies of all instruments to be used.
  *If this proposal is part of a grant proposal, include a copy of the proposal and all recruitment material.
  (D) The consent form that you will use in the study (see part 3 for more information.)
  (E) Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project, including students who are involved with testing or handling data, unless already on file with the IRB. Training link: (http://phrp.nihtraining.com/users/login.php)
  (F) IRB Security of Data Agreement: (https://sites01.lsu.edu/wp/ored/files/2013/07/Security-of-Data-Agreement.pdf)

1) Principal Investigator*: Dennis Landin, EdD   Rank: Professor
*PI must be an LSU Faculty Member

Dept: Kinesiology   Ph: 225-578-2916   E-mail: dlandin@lsu.edu

2) Co Investigator(s): please include department, rank, phone and e-mail for each
Christian Coulon, PT, PhD(c), OCS, CSCS
PhD student, Kinesiology Department, 337-303-8150, c_coulon58@yahoo.com

IRB# 3438 LSU Proposal # ______
Full   Expedited
Complete Application
Human Subjects Training
IRB Security of Data Agreement

3) Project Title: The Effect of Various Postures on the Surface Electromyographic Analysis of the Trapezius, Serratus Anterior, and Deltoid during Specific Therapeutic Exercise

4) Proposal Start Date: 11/28/2013   5) Proposed Duration Months: 3

6) Number of Subjects Requested: 60   7) LSU Proposal #:

8) Funding Sought From: no funding sought

STUDY APPROVED BY:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
130 David Boyd Hall
225-578-8692 / www.lsu.edu/irb
Approval Expires: 12/12/2014

ASSURANCE OF PRINCIPAL INVESTIGATOR named above
I accept personal responsibility for the conduct of this study (including ensuring compliance of co-investigators/co-workers) in accordance with the documents submitted herewith and the following guidelines for human subject protection: The Belmont Report, LSU's Assurance (FWA00003892) with OHRP and 45 CFR 46 (available from http://www.lsu.edu/irb). I also understand that copies of all consent forms **must be maintained at LSU for three years after the completion of the project.** If I leave LSU before that time, the consent forms should be preserved in the Departmental Office.

Signature of PI D Landin   Date 11·15·13

ASSURANCE OF STUDENT/PROJECT COORDINATOR named above. If multiple Co-Investigators, please create a "signature page" for all Co-Investigators to sign. Attach the "signature page" to the application.

I agree to adhere to the terms of this document and am familiar with the documents referenced above.

Signature of Co-PI (s) Christian L Coulon   Date 11/14/13

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

TO: Dennis Landin
Kinesiology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: November 6, 2014
RE: **IRB#** 3540

TITLE: The Effect of Lower Trapezius Fatigue on Scapular Dyskinesis in Individuals with a Healthy Pain Free Shoulder Complex

New Protocol/Modification/Continuation: New Protocol

Review type: Full _X_ Expedited ____ **Review date:** 10/31/2014

Risk Factor: Minimal __X__ Uncertain ________ Greater Than Minimal______

Approved __X__ **Disapproved** _________

Approval Date: 10/31/2014 **Approval Expiration Date:** 10/30/2015

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 15

LSU Proposal Number (if applicable): _________

Protocol Matches Scope of Work in Grant proposal: (if applicable)______

By: Dennis Landin, Chairman DLandin

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.lsu.edu/irb*

Consent Form-Clinical Study

1. Study Title: The Effect of Various Postures on the Surface Electromyographic Analysis of the Trapezius, Serratus Anterior, and Deltoid during Specific Therapeutic Exercise

2. Performance Site: Peak Performance Physical Therapy, 11320 Industriplex Blvd., Baton Rouge, LA 70809

3. Investigators:
Christian Coulon, PT, PhD(c), OCS, CSCS
Dennis Landin, EdD
M-F, 8:00 a.m. - 5:00 p.m.
(337)303-8150

4. Purpose of the Study: The purpose of the study is to identify the exercises and postures which cause the highest muscle activity in the shoulder muscles of healthy adults and adults with shoulder impingement.

5. Subject Inclusion: All subjects will be between 18-50 years old, complete a PAR-Q, and able to communicate in English. To be included in the adult impingement group (or Phase 2) you must have a recent diagnosis of shoulder impingement by physician and the diagnosis confirmed by a physical therapist (based on having at least 4 of 7 criteria). The criteria include: 1) A Neer impingement sign: which is a reproduction of pain when the examiner passively flexes the shoulder to the end range of motion and applies pressure, 2) A Hawkins sign: which is reproduction of pain when the shoulder was passively placed forward and rotated inward to the end range of motion, 3) A positive Empty or Full can test: which is pain with downward resistance with the arm pointed forward either with the thumb pointing up (full can) or the thumb pointing down (empty can), 4) Pain with active shoulder elevation: which is pain while lifting your arm either at your side or midway between your side and forward, 5) Pain with palpation of the rotator cuff tendons: which is pain with touching your shoulder with moderate pressure over the rotator cuff or shoulder muscles, 6) Pain with isometric resisted abduction: which is pain when a downward force is placed on the shoulder at the wrist while the shoulder is straight out to your side and your elbow is straight, 7) Pain in the C5 or C6 dermatome region: which is pain located from the front and back of the shoulder down to the wrist and hand. **Subject Exclusion:** All subjects in phase 1 will be excluded from the study if they have 1 of the following: 1) recent history (less than 1 year) of a muscle or bone injury, condition, or surgery involving the upper extremity or the upper spine or 2) a prior history of a nerve or muscle condition, disease, or numbness or tingling in either arm or shoulder. Phase 2 subjects will be excluded if 1 of the following is present: 1) diagnosis and/or MRI confirmation of a complete rotator cuff tear, 2) signs of acute inflammation including severe resting pain or severe pain with resisted isometric abduction, 3) previous spine related symptoms or have spine related symptoms, 4) shoulder instability (as determined by a testing from a physical therapist), or 5) a previous shoulder surgery. A subject will also be excluded if they exhibit any contraindications to exercise including: 1) heart problems, 2) lung problems, 3) difficulty breathing, 4) vein or artery problems, or 5) a body infection.

6. Number of Subjects: 60

7. Study Procedures: This study is a 2 phase study which examines the electrical activity in the shoulder muscles (see figures of muscles in appendix) during exercises in various postures. Surface electromyography is an electronic medical device used to evaluate and record the electrical activity (or muscle activity) produced by shoulder muscles. This will be used under the direction and supervision of a licensed physical therapist. The exercises used in the study are also used frequently in a physical therapy setting and will also be supervised by a licensed physical therapist. Phase 1 and phase 2 participants have to pass the inclusion and exclusion criteria and fill out a physical activity readiness questionnaire (PAR-Q). The physical activity readiness questionnaire is used to determine if you need medical clearance prior to participating in this study. A phase 2 participant consists of an adult with impingement and will have been evaluated

and diagnosed with impingement and prescribed physical therapy by a licensed and board certified physician. This study should take 1 hour of your time to complete. See electrode placement in appendix.

8. Benefits: Individuals participating in the study will receive a shoulder musculoskeletal assessment at no cost to them by a licensed physical therapist. There are no direct benefits to the subjects. However, information gained from the study may provide information that will lead to better techniques in rehabilitation and improve the clinical treatment of individuals diagnosed with shoulder impingement.

9. Risks/Discomforts: There are inherent risks associated with exercise, but it is important to remember that exercise only provokes a cardiac event in individuals with preexisting heart disease. Exercise doesn't provoke cardiac events in individuals with normal cardiovascular systems. A slight discomfort during exercise may occur due to muscle fatigue. There is also a slight risk of delayed onset muscle soreness (DOMS) due to exercise induced damage to an untrained muscle. There is a slight risk of an allergic reaction if you have a latex allergy. If you have latex allergy please notify the supervising physical therapist.

10. Injury/Illness: In the unlikely event of injury or medical illness resulting from the exercise protocol, contact Christian Coulon, Physical Therapist, (337)303-8150. You will be referred for medical treatment, but the expense of medical treatment will be your responsibility. No compensation is available in case of study-related illness or injury.

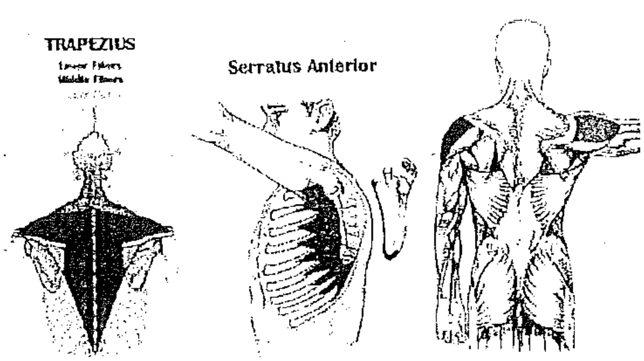
11. Right to Refuse: Subjects may choose not to participate or to withdraw from the study at any time with no jeopardy to their treatment by their respective doctors or other penalty at the present time or in the future.

12. Privacy: The LSU Institutional Review Board (which oversees university research with human subjects) may inspect and/or copy the study's records. The Health Insurance Portability and Accountability Act (HIPAA) privacy rule will be followed to protect individually identifiable health information and your respected rights. Other than as set forth above, subject identity will remain confidential unless disclosure is legally compelled. Results of the study may be published, but no names or identifying information will be included in the publication.

13. Financial Information: There is no cost to the subjects, nor is there any compensation for participating in the study.

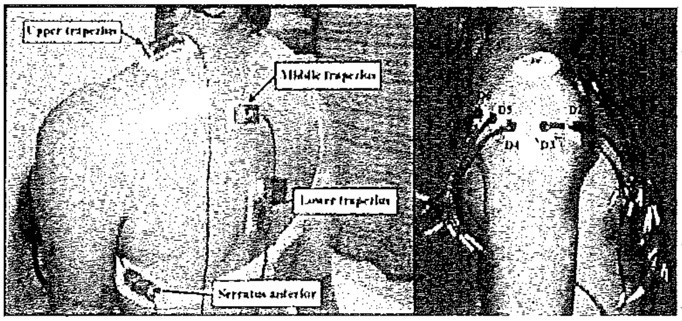
14. Signatures: The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about subjects' rights or other concerns, I can contact Robert C. Mathews, Institutional Review Board, (225) 578-8692, irb@lsu.edu, www.lsu.edu/irb. I agree to participate in the study described above and acknowledge the investigator's obligation to provide me with a signed copy of the consent form.

15. Appendix: The figures below depict the muscles being studied.



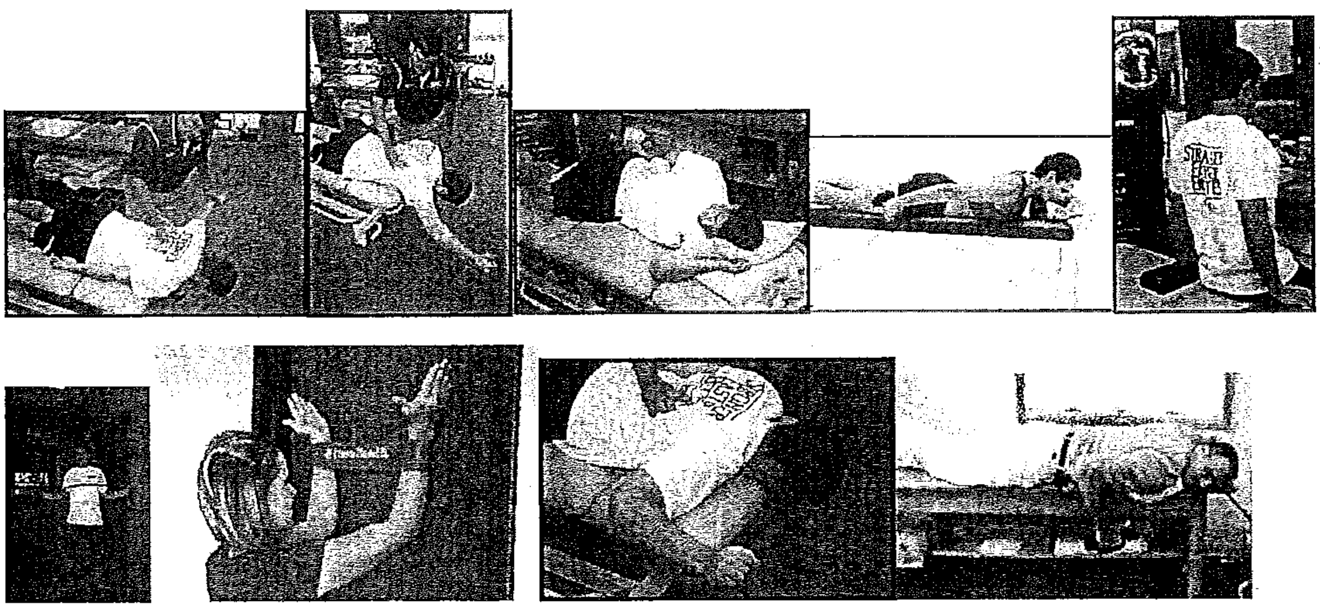
Consent Form-Clinical Study

The figures below depict the electrode placement for the studied muscles. All electrodes on the left picture will or may be used and D3 on second picture (right) will be used.

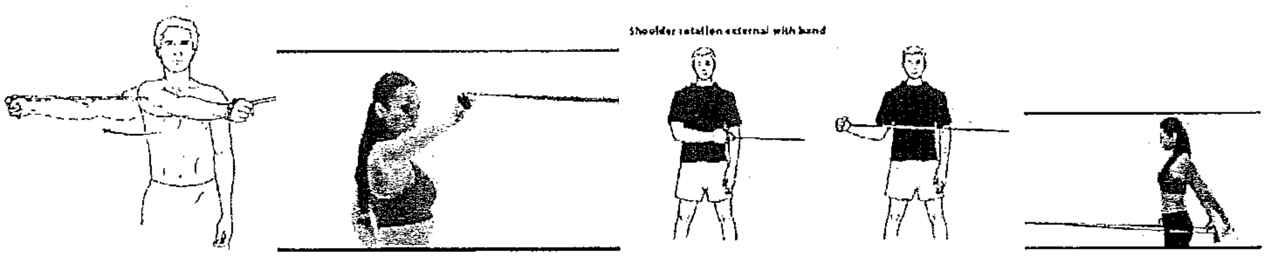


You will be performing all of the exercises in one of the following groups:

Group 1:

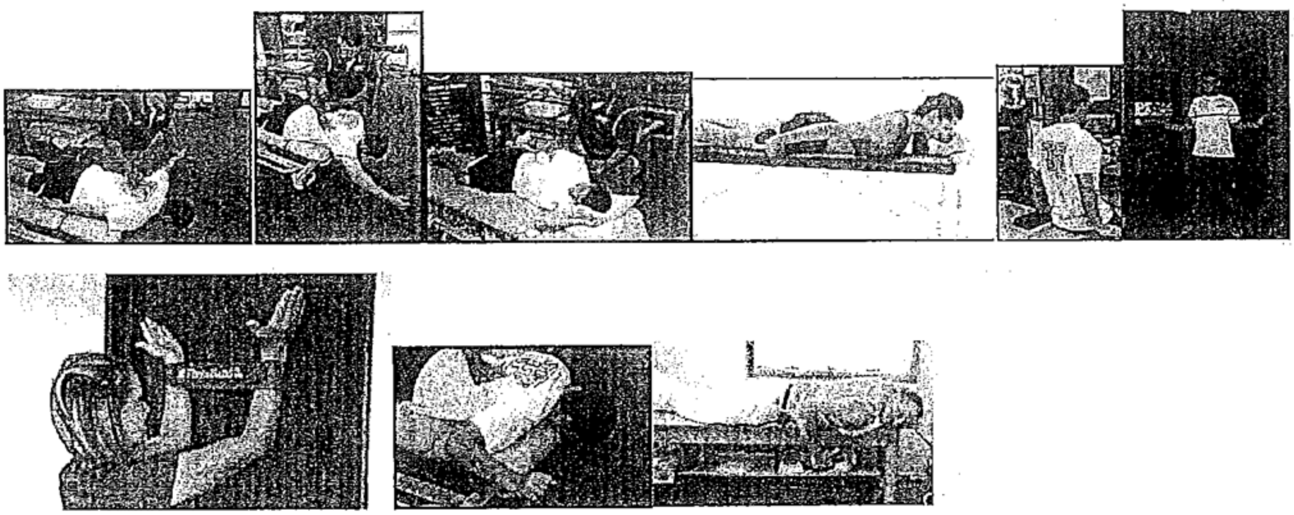


Group 2:



Consent Form-Clinical Study

Group 3:



Subject Signature:____ Date:_______________

The study subject has indicated to me that he/she is unable to read. I certify that I have read this consent form to the subject and explained that by completing the signature line above, the subject has agreed to participate.

Signature of Reader: ____ Date:_______________

This study has been approved by the LSU Institutional Review Board.
Institutional Review Board
Dr. Robert Mathews, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
F: 225.578.5983
irb@lsu.edu | lsu.edu/irb

STUDY APPROVED BY:
Dr. Robert C. Mathews, Chairman
Institutional Review Board
Louisiana State University
130 David Boyd Hall
225-578-8692 / www.lsu.edu/irb
Approval Expires: 12/12/2014

VITA

Christian Coulon is a native of Louisiana and a practicing physical therapist. He specializes in shoulder pathology and rehabilitation of orthopedic injuries. He began his pursuit of this degree in order to better his education and understanding of shoulder pathology. In completion of this degree he has become a published author, performed clinical research, and advanced his knowledge and understanding of the shoulder.