

THE EFFECTS OF VERBAL AND TACTILE CUIING ON SCAPULAR MUSCLE
ACTIVATION DURING COMMON REHABILITATION EXERCISES

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ABSTRACT

Sean Alexander Jones: The Effects of Verbal and Tactile Cuing on Scapular Muscle Activation during Common Rehabilitation Exercises
(Under the direction of Joseph B. Myers; Troy Blackburn)

Objective: Verbal and tactile feedback during rehabilitation exercises for scapular dyskinesis can potentially improve muscle activation. However, it is unclear which method of feedback provides the greatest increase in muscle activation. The purpose of this study is to evaluate the effects of verbal and tactile cuing on scapular stabilizing EMG amplitude in healthy young adults during common shoulder rehabilitation exercises.

Methods: 30 physically active participants volunteered for this study (age=20.23±1.25 years, height=1.71±0.073m, mass=70.11±15.14kg). Electromyography of the scapular stabilizing muscles (serratus anterior, upper/middle/lower trapezii and anterior/posterior deltoid) was recorded.

Results: There was a significant effect for feedback condition for the middle trapezius [$F_{1,2}=4.102$, $p=0.002$] and serratus anterior [$F_{1,2}=3.492$, $p=0.037$] during Y's, the middle trapezius [$F_{1,2}=5.893$, $p=0.005$] during W's, and the upper trapezius [$F_{1,2}=3.854$, $p=0.027$] and middle trapezius [$F_{1,2}=4.268$, $p=0.019$] during T's.

Conclusion: Results indicate that adding tactile feedback to verbal feedback did not increase muscle activation compared to verbal feedback alone.

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Chapter I

Introduction

Approximately 13.7 million people in the United States seek treatment from a physician for shoulder pain each year (Tucker, Campbell, Swartz, & Armstrong, 2008), and up to 54% these individuals report continued discomfort three years following the initial incidence of pain (Chester, Smith, Hooper, & Dixon, 2010). Shoulder pain commonly results from misalignment of the scapula on the thorax (Michener, McClure, & Karduna, 2003). Dysfunction of the shoulder complex is estimated to effect approximately 7-36% of the general population (Witt, Talbott, & Kotowski, 2011), with scapular instability found in as many as 68% of rotator cuff (RC) pathological conditions and 100% of glenohumeral instability pathologies (Voight & Thomson, 2000). Improper scapular position alters the length-tension relationships of the scapular stabilizing muscles leading to dysfunction of the shoulder complex (Kibler & Sciascia, 2010; McClure, Tate, Kareha, Irwin, & Zlupko, 2009). Alteration in length tension relationships typically involves lengthening of the posterior back musculature and shortening of the anterior chest musculature (Kibler & Sciascia, 2010). These altered length-tension relationships manifest as abnormal activation patterns of the scapulothoracic muscles, resulting in scapulothoracic dysfunction (McClure et al., 2009).

Common pathologies resulting from altered scapular position include scapular dyskinesis, shoulder impingement syndrome (SIS), and rotator cuff tendinopathy (Ludewig & Reynolds, 2009). Scapular dyskinesis is the broad term used to describe visible alterations in scapular position and scapulothoracic movement patterns (McClure et al., 2009). Scapular dyskinesis can

be effectively treated with rehabilitative exercises (Cools et al., 2007; De Mey et al., 2013; Witt et al., 2011). Scapular dyskinesis typically will not occur in isolation and commonly contributes to SIS. SIS accounts for 44-65% of shoulder complaints during physician visits (Page, 2011; Umer, Qadir, & Azam, 2012) and is commonly treated by sports medicine clinicians.

Subacromial impingement accounts for 40% of all shoulder pain and is the most common form of SIS (Chester et al., 2010). One long term consequence of SIS is rotator cuff pathology (Joshi, Thigpen, Bunn, Karas, & Padua, 2011; Ludewig & Reynolds, 2009; Maquirriain, Ghisi, & Amato, 2006). The most common location of rotator cuff pathology is the undersurface of the posterior half of the supraspinatus and the superior half of the infraspinatus (Seroyer et al., 2009). These shoulder pathologies can be debilitating as they affect activities ranging from overhead throwing mechanics to activities of daily living (Koester, George, & Kuhn, 2005).

Clinical Anatomy

The shoulder complex consists of three bones, the humerus, the scapula and the clavicle. The head of the humerus is inclined relative to the anatomical neck at an angle of 130° to 150° (Terry & Chopp, 2000). This allows for greater contact of the humeral head within the glenoid fossa, which increases stability of the glenohumeral joint. The scapula acts as the link in the proximal to distal transfer of energy that allows for the most appropriate shoulder position for optimal function (Voight & Thomson, 2000). The scapulothoracic joint is one of the least congruent joints in the body (Terry & Chopp, 2000), as there is no direct articulation between the scapula and the thorax. The stability of this joint is dependent on the actions of the rhomboids, trapezii and serratus anterior muscles (Baskurt, Baskurt, Gelecek, & Ozkan, 2011; Sizer, Phelps, & Giblert, 2003). This allows for the scapula to have greater mobility with motions such as protraction, retraction, elevation, depression and rotation (Voight & Thomson, 2000).

The primary muscles that influence scapular movement are the trapezius, serratus anterior, levator scapulae, rhomboids, pectoralis minor and rotator cuff. The main functions of the trapezius are scapular retraction (upper, middle) and upward and downward rotation (lower) (Reinold, Escamilla, & Wilk, 2009). The serratus anterior is unique in that it contributes to every component of normal three dimensional (3D) scapular motions during arm elevation (Reinold et al., 2009), but its primary function is scapula protraction (Terry & Chopp, 2000). The levator scapulae and rhomboids elevate the superior angle of the scapula resulting in upward and medial rotation of the scapula and scapular retraction (Terry & Chopp, 2000). The rotator cuff provides dynamic stabilization to the glenohumeral joint. The shoulder complex is an extremely intricate body region and the alteration of joint biomechanics or length-tension relationships can lead to abnormal positioning of the scapula and ultimately SIS.

Scapular Kinematics

Scapulothoracic kinematics involve combined sternoclavicular and acromioclavicular joint motions (Ludewig & Reynolds, 2009). During elevation of the arm overhead, the scapula should upwardly rotate and posteriorly tilt on the thorax (Ludewig & Reynolds, 2009). Upward scapular elevation is a product of force coupling between the trapezius and serratus anterior muscles and is essential to prevent the supraspinatus from impinging against the anterolateral acromion (McCabe, Orishimo, McHugh, & Nicholas, 2007). Coordinated timing of muscle recruitment among the scapular stabilizing muscles is a crucial component of dynamic stability of the scapula throughout shoulder elevation (Cools, Witvrouw, Mahieu, & Danneels, 2005). It is important to maintain proper activation patterns of the scapular stabilizers to prevent abnormal scapular kinematics.

Abnormal Scapular Kinematics

Scapular dyskinesis typically presents as alterations in the movement of the scapula, humeral head and clavicle during arm elevation (Roy, Moffet, & McFadyen, 2010). Those with scapular dyskinesis demonstrate greater scapular superior translation, lesser scapular posterior tilt, and lesser upward and internal rotation during shoulder elevation (Tate, McClure, Kareha, Irwin, & Barbe, 2009). A reduction of 5° of posterior tilting of the scapula has been related to a greater disability level (Roy, Moffet, Hebert, St-Vincent, & McFadyen, 2007). Most of the abnormal biomechanics and overuse injuries that occur about the shoulder girdle can be traced to alterations in function of the scapular stabilizing muscles (Voight & Thomson, 2000). In people with scapular dysfunction, significantly less serratus anterior muscle activation and greater upper trapezius activation are observed during scapular elevation (Kibler & Sciascia, 2010; Ludewig & Reynolds, 2009).

Rehabilitation Exercises

Rehabilitative exercises are essential in restoring normal scapular kinematics as well as maintaining proper function of the scapular stabilizers (Hibberd, Oyama, Spang, Prentice, & Myers, 2012; Myers et al., 2005; Sciascia, Kuschinsky, Nitz, Mair, & Uhl, 2012; Thigpen, Padua, Morgan, Kreps, & Karas, 2006; Voight & Thomson, 2000). Exercises should target the middle and lower trapezii and serratus anterior because these are the most commonly inhibited muscles associated with scapular dysfunction either in healthy or pathologic populations (Voight & Thomson, 2000). The goal of shoulder rehabilitative exercises is to increase activation of the serratus anterior, middle and lower trapezii and decrease activation of the upper trapezius resulting in restoration of normal scapular kinematics (Cools et al., 2007). Common rehabilitation exercises for the shoulder include W's, Y's and T's. Scapular retraction with

external rotation (W's) is commonly prescribed for strengthening of the lower trapezius, rhomboids infraspinatus, teres minor and supraspinatus (Hibberd et al., 2012; McCabe et al., 2007). Scapular plane elevation (Y's) is commonly prescribed in scapular rehabilitation for strengthening of the serratus anterior (Reinold et al., 2007; Sciascia et al., 2012; Thigpen et al., 2006). Prone horizontal abduction (T's) is accomplished through activation of the supraspinatus, infraspinatus, deltoid and scapula retractor (i.e. middle and lower trapezii and rhomboids) (De Mey et al., 2013; Sciascia et al., 2012).

Feedback Strategies and Rehabilitation Exercises

Previous studies have examined the effects of feedback on various rehabilitative and functional tasks (Argus, Gill, Keogh, & Hopkins, 2011; De Mey et al., 2013; Herman et al., 2009; Roy, Moffet, & McFadyen, 2010; Roy, Moffet, McFadyen, & Lirette, 2009). Roy et al. (2009) evaluated the short term effects of supervised movement training with verbal and tactile feedback on the motor strategies of persons with SIS. This study found participants with SIS used a more biomechanically efficient pattern of movement during training with feedback; more specifically, during feedback participants displayed less trunk flexion and rotation and less clavicular protraction. Roy et al. (2010) evaluated if unsupervised training with visual feedback could maintain upper limb kinematic patterns obtained immediately after supervised training with verbal, manual, and visual feedback. The researchers concluded that unsupervised movement training with visual feedback should be included in rehabilitation programs as home exercise programs following supervised training. However, the use of unsupervised movement training does not appear to be beneficial and future investigations should analyze the effects of unsupervised movement training.

De May et al. (2013) assessed the effect of conscious correction of scapular orientation on the activation of the upper, middle and lower trapezii during shoulder rehabilitation exercises. Participants received both auditory and kinesthetic cues during the resting scapular assessment and while performing the rehabilitation exercises. The results indicated that conscious correction was effective at increasing absolute muscle activation of all three trapezius muscles in two out of the four exercises performed. Argus et al. (2011) evaluated the effects of verbal feedback on upper-body power in a resistance training session. The study showed that verbal feedback increases movement velocity during resistance training. Furthermore, the study showed that the greatest effect of the verbal feedback was observed during the later sets of the training session as fatigue set in. In summary, previous studies suggest that feedback enhances the effectiveness of common shoulder rehabilitation exercises (Argus et al., 2011; De Mey et al., 2013; Herman et al., 2009; Roy et al., 2009).

Although studies have assessed extrinsic feedback with regards to movement kinematics and muscle activation, it is unclear which method of feedback provides the most efficacious results. This is important to investigate because clinicians commonly prescribe rehabilitative exercises to treat SIS. However, if the exercises are not performed correctly then their therapeutic benefit may be lost. Feedback is a tool used by clinicians to ensure that prescribed exercises are performed correctly. This study will provide evidence that extrinsic feedback during a rehabilitation session can improve the patient's technique.

Therefore, the purpose of this study was to determine if the addition of tactile feedback to verbal feedback (tactile + verbal) increases muscle activation compared to verbal feedback alone during common shoulder rehabilitation exercises. Determining the effectiveness of tactile + verbal and verbal cuing provides clinicians with additional information to optimize

rehabilitation and ensure the desired muscles are activated to their greatest potential. Improving the strength of the scapular stabilizing muscles will ultimately improve the scapulohumeral rhythm and ensure proper shoulder function (Reinold et al., 2009). We hypothesized that verbal and tactile + verbal cuing will improve muscle activation in healthy young adults during common shoulder rehabilitation exercises (Y's, T's and W's). Specifically, we hypothesized that tactile + verbal cuing would be more effective than verbal cuing only at improving muscle activation.

Variables

i. Independent Variables

- a. Condition- verbal cues vs. tactile + verbal cues vs. control

ii. Dependent Variables

- a. Electromyography (upper/middle/lower trapezii, deltoids and serratus anterior).

Research Questions

1. What is the effect of verbal and tactile + verbal cuing on electromyographic activity in healthy young adults performing common shoulder rehabilitation exercises?

- 1a. What is the difference in efficacy of verbal and tactile + verbal cuing on improving mean amplitude in scapular stabilizing muscles (serratus anterior, upper, middle and lower trapezii, and anterior/posterior deltoids) during prone Y's, T's and W's?

Null Hypotheses

H_{0a}: Verbal and tactile + verbal cuing will have the same effect on EMG muscle activation in healthy young adults during common rehabilitation exercises.

H_{0b}: Tactile + verbal and verbal cuing will have the same effect on EMG muscle activation of the upper trapezius.

H_{0c}: Tactile + verbal and verbal cuing will have the same effect on EMG muscle activation of the middle trapezius.

H_{0d}: Tactile + verbal and verbal cuing will have the same effect on EMG muscle activation of the lower trapezius.

H_{0e}: Tactile + verbal and verbal cuing will have the same effect on EMG muscle activation of the serratus anterior.

H_{0f}: Tactile + verbal and verbal cuing will have the same effect on EMG muscle activation of the deltoid.

Hypotheses

H₁: Verbal and tactile + verbal cuing will improve EMG muscle activation in healthy young adults during common shoulder rehabilitation exercises (Y's, T's and W's).

H_{1a}: Tactile + verbal cuing will be more effective than verbal cuing at decreasing EMG activation of the upper trapezius.

H_{1b}: Tactile + verbal cuing will be more effective than verbal cuing at increasing EMG activation of the middle trapezius.

H_{1c}: Tactile + verbal cuing will be more effective than verbal cuing at increasing EMG activation of the lower trapezius.

H_{1d}: Tactile + verbal cuing will be more effective than verbal cuing at increasing EMG activation of the serratus anterior.

H_{1e}: Tactile + verbal cuing will be more effective than verbal cuing at decreasing EMG activation of the deltoids.

Statistical Hypotheses

i. Hypothesis H_1 :

$$H_{01}: \mu_{UTV} = \mu_{UTTV}$$

$$H_{A1}: \mu_{UTV} \leq \mu_{UTTV}$$

$$H_{02}: \mu_{MTV} = \mu_{MTTV}$$

$$H_{A2}: \mu_{MTV} \leq \mu_{MTTV}$$

$$H_{03}: \mu_{LTV} = \mu_{LTTV}$$

$$H_{A3}: \mu_{LTV} \leq \mu_{LTTV}$$

$$H_{04}: \mu_{SAV} = \mu_{SATV}$$

$$H_{A4}: \mu_{SAV} \leq \mu_{SATV}$$

$$H_{05}: \mu_{DELTV} = \mu_{DELTTV}$$

$$H_{A5}: \mu_{DELTV} \leq \mu_{DELTTV}$$

Operational Definitions

- Healthy young adults (18-25): Any individual who performs moderate intensity aerobic physical exercise for a minimum of thirty minutes, five days per week or vigorous activity for a minimum of twenty minutes, three days per week.
- Inhibited muscles: Muscles that do not activate properly due to less nerve input, pain or altered length-tension relationship.
- Weak muscles: Muscles that are unable to resist the force of the lead tester performing MVICs.

Assumptions

- Surface electromyography is a reliable measure to assess muscular electrical activity.
- Individuals who participated in this study are representative of physically active young adults in the population.
- Participants gave full effort during each task.

Delimitations

- Only involved physically active young adults age 18-25
- Only current students at the University of North Carolina at Chapel Hill (UNC) participated in this study.
- Only recorded electromyography data from the upper/middle /lower trapezii, deltoid, and serratus anterior.
- Only investigating the short term effects of the rehabilitation exercises and feedback mechanisms.

Limitations

- Unable to control subject activity outside of the lab.
- Participants were not blinded to group assignment
- Data were collected in one session but the results will be speculated over time
- Inherent limitation exists with the use of surface EMG. Crosstalk may occur with the placement of the EMG surface electrodes on the skin and may not give a true reading of the underlying muscle activity.

Chapter II

Approximately 13.7 million people in the United States seek treatment from a physician for shoulder pain each year (Tucker et al., 2008), up to 54% of these individuals report continued discomfort three years following the initial incidence of pain. (Chester et al., 2010). Furthermore, dysfunction of the shoulder complex is estimated to effect approximately 7-36% of the general population (Witt et al., 2011). Shoulder pain is a common complaint amongst physically active individuals more specifically, those who compete in overhead sports (Agel, Palmieri, Dick, Wojtys, & Marshall, 2007; Dick et al., 2007; Marshall, Hamstra-Wright, Dick, Grove, & Agel, 2007; Yang et al., 2012). Dick et al. (2012) investigated the epidemiology of injuries in collegiate baseball players and found that 29% of reported injuries were shoulder pathologies (impingement, strains, etc.). Agel et al. (2007) reported 17% of injuries reported in female collegiate volleyball players were non-contact shoulder pathology. Yang et al. (2012) investigated the epidemiology of overuse and acute injuries among competitive collegiate athletes. Of the 386 overuse injuries reported, 19 (4.9%) were shoulder impingement.

Shoulder pain commonly results from misalignment of the scapula on the thorax (Michener et al., 2003). Similarly, scapular instability is found in as many as 68% of rotator cuff (RC) problems and 100% of glenohumeral instability problems (Voight & Thomson, 2000). Improper scapular position alters the length-tension relationships of the scapular stabilizing muscles leading to dysfunction of the shoulder complex. Alteration in length tension relationships typically involves lengthening of the posterior back musculature and shortening of the anterior chest musculature (Kibler & Sciascia, 2010). Shortening or lengthening muscle leads

to a decrease in force production because the muscle is no longer at its optimal length resulting in decreased mechanical advantage (McClure et al., 2009). Improper length of muscle either lengthened or shortened, results in a decrease in the number of Actin-Myosin cross bridges which ultimately leads to decreased force production (Lorenz & Holmes, 2010). These altered length-tension relationships manifest as abnormal activation patterns of the scapulothoracic muscles, resulting in scapulothoracic dysfunction (McClure et al., 2009).

Common pathologies resulting from altered scapula position include scapular dyskinesis, shoulder impingement syndrome (SIS) and rotator cuff tendinopathy (Ludewig & Reynolds, 2009). Scapular dyskinesis is the broad term used to describe visible alterations in scapular position and scapulothoracic movement patterns (McClure et al., 2009). Scapular dyskinesis can be effectively treated with rehabilitative exercises (Cools et al., 2007; De Mey et al., 2013; Witt et al., 2011). Shoulder impingement accounts for 44-65% of shoulder complaints during physician visits (Page, 2011; Umer et al., 2012) and is commonly treated by sports medicine clinicians. Subacromial impingement accounts for 40% of all shoulder pain and is the most common form of impingement (Chester et al., 2010). One long term consequence of shoulder impingement is rotator cuff pathology (Heyworth & Williams, 2009) (Neagle & Bennett, 1994). The most common location of rotator cuff pathology is the undersurface of the posterior half of the supraspinatus and the superior half of the infraspinatus (Seroyer et al., 2009). These shoulder pathologies can be a debilitating as they affect activities ranging from overhead throwing mechanics to activities of daily living (Koester et al., 2005).

Clinical Anatomy

Humerus

The shoulder complex consists of three bones, the humerus, the scapula and the clavicle. The humerus is the largest and longest bone of the upper extremity. The head of the humerus is inclined relative to the anatomical neck at an angle of 130° to 150° , allowing for greater contact of the humeral head within the glenoid fossa which increases stability of the glenohumeral joint. The humeral head is retroverted 26° to 31° from the medial and lateral epicondylar plane. The greater tuberosity is the insertion site for the supraspinatus, infraspinatus and teres minor. The lesser tuberosity is the insertion site of the subscapularis (Terry & Chopp, 2000).

Scapula

The scapula is the link in the proximal to distal transfer of energy that allows for the most appropriate shoulder position for optimal functioning (Voight & Thomson, 2000). The scapula lies on the posterolateral aspect of the thorax and overlies ribs 2-7 (Terry & Chopp, 2000). Seventeen muscles originate or insert on the scapula and function to stabilize the scapula and provide motion (Terry & Chopp, 2000).

The spine of the scapula separates the supraspinatus and infraspinatus and forms the base of the acromion. The spine of the scapula is part of the insertion for the trapezius and origin for the deltoid. The acromion forms a portion of the roof of the rotator cuff space and variations in acromial shape can affect contact and wear of the rotator cuff. The coracoid process projects anteriorly and laterally from the upper border of the head of the scapula. The glenoid fossa articulates directly with the head of the humerus. The glenoid fossa is only one third to one fourth the size of the humeral head which allows for greater mobility (Terry & Chopp, 2000).

Clavicle

The clavicle is the only bone that connects the trunk to the shoulder girdle via the scapulothoracic joint medially and the acromioclavicular joint laterally. The clavicle prevents

inferior migration of the shoulder girdle. The outer third serves as an attachment point for muscles and ligaments. The medial third accepts axial loading. The middle one third is the weakest portion mechanically and the most common site of clavicular fractures. (Terry & Chopp, 2000).

Scapulothoracic Joint

The shoulder complex consists of four joints, the scapulothoracic (ST) joint, the acromioclavicular (AC) joint, the sternoclavicular (SC) joint and the glenohumeral (GH) joint (Sizer et al., 2003; Terry & Chopp, 2000). The ST joint is the space where the convex surface of the posterior thoracic cage and the concave surface of the anterior scapula join together. There is no direct articulation between the scapula and the thorax; therefore, the stability of the joint is dependent on the actions of the rhomboids, trapezii and serratus anterior muscles (Baskurt et al., 2011; Sizer et al., 2003). This causes the ST joint to be one of the least congruent joints in the body (Terry & Chopp, 2000), allowing for the scapula to have greater mobility in motions such as protraction, retraction, elevation, depression and rotation (Voight & Thomson, 2000).

Acromioclavicular Joint

The (AC) joint is a diarthrodial joint between the lateral border of the clavicle and the medial edge of the acromion. The average size in an adult is 9 x 19 mm. Stability of the acromioclavicular joint is provided mainly through the static stabilizers composed of the capsule. The inferior capsular ligament is the primary restraint to anterior translation of the clavicle (Sizer et al., 2003). The coracoclavicular ligaments provide additional stability to the joint and are the primary suspensory ligaments of the upper extremity. The trapezoid and the conoid ligaments suspend the shoulder girdle from the clavicle at an average of 13 mm (Terry & Chopp, 2000).

The deltoid and trapezius muscle insertions provide secondary stability to the AC joint (Sizer et al., 2003).

Sternoclavicular Joint

The (SC) joint is the only true articulation between the axial skeleton and the upper extremity. It is a saddle joint formed by the articulation of the medial end of the clavicle and the upper portion of the sternum. The joint surfaces are covered with fibrous cartilage and are completely separated by an intraarticular fibrocartilage disc (Sizer et al., 2003). Stability of the joint is provided by the surrounding ligamentous structures (Sizer et al., 2003). The costoclavicular ligament resists excessive upward rotation (anterior fibers) and excessive downward rotation (posterior fibers) (Sizer et al., 2003; Terry & Chopp, 2000). The interclavicular ligament connects the superomedial aspect of the clavicle with the capsular ligaments and upper sternum. The capsular ligament covers the anterosuperior and posterior aspects of the sternoclavicular joint.

Glenohumeral Joint

A normal GH joint is fully sealed by the capsule and contains less than 1 mL of joint fluid under slightly negative intra-articular pressure. At any specific time, only 25% to 30% of the humeral head is in contact with the glenoid fossa. Decreasing the amount of humeral head contact allows for greater mobility of the shoulder; however, decreasing stability increases the risk of injury (Sizer et al., 2003). The humeral head is inclined approximately 135°-145° and retroverted 20° influencing the available external and internal rotation motion (Sizer et al., 2003). The glenoid fossa is a dense, fibrous structure and is located at the glenoid margin of the scapula (Terry & Chopp, 2000). The concavity of the glenoid fossa creates a suction mechanism allowing for greater stability. The glenoid labrum is a dense fibrous structure which is triangular

in cross section. The glenoid labrum increases the concavity of the glenoid fossa by an average of 9 mm and 5 mm in the superoinferior and anteroposterior planes which helps to increase the stability of the joint. (Terry & Chopp, 2000).

Subacromial Space

The subacromial space is defined by the humeral head inferiorly, the anterior edge and under surface of the anterior third of the acromion, coracoacromial ligament and the acromioclavicular joint superiorly (Michener et al., 2003; Umer et al., 2012). The contents of the subacromial space include the supraspinatus tendon, subacromial bursa, long head of the biceps brachii tendon, and the capsule of the shoulder joint (Michener et al., 2003). The typical distance between the acromion and humeral head ranges from 1.0 to 1.5 centimeters (Umer et al., 2012). The available space can be altered due to structural causes, such as a hooked acromion or functional reasons such as repetitive overhead activity (Jobe, Coen, & Srenar, 2000). Overhead activity decreases the amount of subacromial space which increases the amount stress on the subacromial space contents, specifically the supraspinatus and long head of biceps brachii tendon (Jobe et al., 2000).

Muscles

The integrity of the ST joint is dependent upon dynamic stabilizers. The primary muscles that influence scapular movement are the trapezius, serratus anterior, levator scapulae, rhomboids, pectoralis minor and rotator cuff. The trapezius originates from the occiput, nuchal ligament and spinous processes of C7-C12. It inserts on the lateral clavicle, acromion process, and the spine of the scapula and is innervated by the spinal accessory nerve. The upper trapezius (UT) retracts and elevates the lateral angle of the scapula during arm elevation. The middle

trapezius (MT) retracts the scapula and the lower trapezius (LT) upwardly rotates and depresses the scapula (Reinold et al., 2009).

The serratus anterior originates from ribs 1-9, inserts on the medial boarder of the scapula and is innervated by the long thoracic nerve. The primary function of the SA is scapular protraction (Terry & Chopp, 2000) and it contributes to every component of normal scapular motion during arm elevation (Reinold et al., 2009). The levator scapulae (LS) originate from the transverse processes of C1-C4, insert on the superior angle of the scapula bilaterally and are innervated by the dorsal scapula nerve (Terry & Chopp, 2000). The primary action of the LS is elevation of the superior angle resulting in upward and medial rotation of the scapula (Terry & Chopp, 2000). The rhomboids originate from the spinous processes of C7-T1 (minor) and T2-T5 (major). They insert at the root of the spine of the scapula (minor) and between the root of the spine and inferior angle of the scapula (major). The rhomboids are innervated by the dorsal scapular nerve and primary functions are scapular retraction and elevation. The pectoralis minor originates from ribs 3-5, inserts on the coracoid process of the scapula and is innervated by the medial and lateral pectoral nerves. The primary actions of the pectoralis minor are scapular protraction and depression of the scapula at the SC joint (Terry & Chopp, 2000).

The rotator cuff (RC) muscles provide dynamic stability to the GH joint and proper timing of these muscles is essential to ensure normal scapulohumeral rhythm during elevation. The RC originates from the supraspinous fossa (supraspinatus), infraspinous fossa (infraspinatus), superior lateral boarder of the scapula (teres minor) and subscapular fossa (subscapularis). The supraspinatus, infraspinatus and teres minor insert on the greater tubercle of the humerus while the subscapularis inserts on the lesser tubercle of the humerus (Terry &

Chopp, 2000). The RC is innervated by the suprascapular (supraspinatus, infraspinatus), axillary (teres minor) and upper and lower subscapular nerves (subscapularis) (Terry & Chopp, 2000).

The supraspinatus has an integral role in normal GH joint function during humeral elevation. The supraspinatus stabilizes the humeral head in the lower ranges of abduction (60° to 90°) (Reinold et al., 2009). Without this function, the force produced by the deltoid would cause superior migration of the humeral head decreasing the subacromial space and ultimately leading to impingement (Sizer et al., 2003; Thigpen et al., 2006). The supraspinatus is also an effective abductor in the scapular plane at smaller abduction angles (Reinold et al., 2009). The infraspinatus and teres minor comprise the posterior cuff and together, provide GH external rotation (Reinold et al., 2009). The subscapularis is the most powerful muscle of the RC (Sizer et al., 2003) and provides GH compression, internal rotation and anterior stability of the shoulder (Reinold et al., 2009). One can see the importance of the dynamic stabilizers of the shoulder and how an abnormal scapula position can compromise the integrity of the shoulder complex (Terry & Chopp, 2000).

Normal Scapular Kinematics

Normal scapulohumeral rhythm is the key to optimal shoulder function. Scapulohumeral rhythm is defined as the coordinated movement of the scapula and the humerus to achieve shoulder motion (Kibler & Sciascia, 2010). Upper extremity elevation is a complex movement pattern that is the result of motion occurring at the SC, AC, ST and GH joints (Ludewig et al., 2009; Ludewig & Reynolds, 2009; Sizer et al., 2003). In order for humeral elevation to occur, normal motion has to occur at the ST joint. Abnormal positioning of the scapula on the thorax alters the length of scapula stabilizers and limits the available motion at the ST joint which limits the available motion at the GH joint (Umer et al., 2012). Normal ST motions that occur during

arm elevation include scapular upward rotation, posterior tilting, internal or external rotation and clavicular elevation and retraction (Borsa, Timmons, & Sauers, 2003; Ludewig & Reynolds, 2009; Umer et al., 2012). ST kinematics involves combined SC and AC joint motions (Ludewig & Braman, 2011; Ludewig et al., 2009; Ludewig & Reynolds, 2009). ST elevation is a result of SC elevation and abduction/adduction is a result of SC protraction/retraction (Ludewig & Reynolds, 2009). SC joint retraction and AC joint internal rotation counteract each other allowing scapular internal and external rotation to occur (Kibler & Sciascia, 2010; Ludewig & Braman, 2011). As the humerus moves into elevation, clavicular retraction, elevation and posterior axial rotation occur at the SC joint (Kibler & Sciascia, 2010). Simultaneously, scapular internal rotation, upward rotation and posterior tilting occur at the AC joint (Kibler & Sciascia, 2010).

The accepted ratio of GH elevation to ST upward rotation is 2:1 (Ludewig et al., 2009; Scibek & Carcia, 2012). During the first 60° of elevation, the scapula goes through a setting phase. The setting phase is when scapular motion varies greatly among participants (Borsa et al., 2003; Scibek & Carcia, 2012). Borsa et al (2003) and Scibek et al (2012) observed a period within the first 30° of humeral elevation where the scapula downwardly rotates but did not hypothesize why this phenomenon occurs. Borsa et al (2003), concluded after the initial 30° of elevation, the scapula upwardly rotates to allow GH elevation to occur in the normal 2:1 ratio. Scapular upward rotation is essential to prevent the supraspinatus from impinging against the anterolateral acromion because it helps to maintain optimal area in the subacromial space and occurs as the result of force couple between the trapezius and serratus anterior muscles (McCabe et al., 2007). Coordinated timing of muscle recruitment among the scapular stabilizing muscles is

a crucial component of dynamic stability of the scapula throughout shoulder elevation (Cools et al., 2005).

Proper function of the dynamic stabilizers of the scapula is essential in normal scapular kinematics. The scapula must be dynamically stabilized in a position of relative retraction during arm use to maximize activation of all the muscles that originate on the scapula (Kibler & Sciascia, 2010). The supraspinatus forms a force couple with the middle deltoid to initiate humeral elevation and limit the amount of superior humeral head migration (Thigpen et al., 2006). Proper activation of the SA is essential because it stabilizes the scapula on the thorax during humeral elevation (Merolla, De Santis, Campi, Paladini, & Porcellini, 2010; Tucker et al., 2008). Furthermore, it forms a force couple with the UT and LT to ensure proper scapular upward rotation (Lunden, Braman, Laprade, & Ludewig, 2010; McCabe et al., 2007). The LT also limits the amount of scapula lateral displacement caused by the SA allowing for normal scapula upward rotation to occur (McCabe et al., 2007). It is important to maintain proper activation patterns of the scapular stabilizers to prevent abnormal scapular kinematics.

Abnormal Scapular Kinematics

Improper function of the dynamic scapular stabilizers leads to altered motion at the ST joint and ultimately compromises the function of the shoulder complex (Tate et al., 2009; Tyler, Nicholas, Roy, & Gleim, 2000; Uhl, Kibler, Gecewich, & Tripp, 2009). This altered scapular motion has been referred to as scapular winging and scapular dyskinesia but the most appropriate term is scapular dyskinesis (Kibler & Sciascia, 2010; Tate et al., 2009). Scapular dyskinesis is defined as alterations in scapular position and motion patterns (McClure et al., 2009; Tate et al., 2009; Uhl et al., 2009). Uhl et al. (2009) classified scapular dyskinesis into four types. Type I is prominence of the inferior medial scapular angle and would be associated with excessive anterior

tilting of the scapula. Type II is prominence of the entire medial border and would be associated with excessive scapular internal rotation (scapular winging). Type III is prominence of the superior scapular border and is associated with excessive upward translation of the scapula. Type IV is no asymmetries identified and no prominence of the medial or superior border; this is considered to be normal scapular motion.

Scapular dyskinesis typically presents as alterations in movement of the scapula, humeral head and clavicle during arm elevation (Roy, Moffet, & McFadyen, 2010). Those with scapular dyskinesis demonstrate greater scapular superior translation, lesser scapular posterior tilt, lesser upward rotation and internal rotation during shoulder elevation (Tate et al., 2009). Most of the abnormal biomechanics and overuse injuries that occur about the shoulder girdle can be traced to alterations in function of the scapular stabilizing muscles (Voight & Thomson, 2000). In people with scapular dysfunction, significantly less serratus anterior muscle activation and greater upper trapezius are observed during scapular elevation (Kibler & Sciascia, 2010; Ludewig & Reynolds, 2009). The serratus anterior is the most important dynamic stabilizer as it helps to ensure proper positioning of the scapula on the thorax (Kibler & Sciascia, 2010). Increased upper trapezius activation decreases the amount of posterior tipping during elevation which decreases the subacromial space and results in impingement (Kibler & Sciascia, 2010). A small reduction of only 5° of posterior tilting of the scapula has been related to a higher disability level (Roy et al., 2007). The most common inhibited muscles are the lower stabilizers of the scapula which are the serratus anterior, rhomboids, middle trapezius and lower trapezius (Voight & Thomson, 2000). The inhibited muscles are not strong enough to counteract the upper trapezius which leads to scapular dyskinesis (Voight & Thomson, 2000). Currently, there is not a definitive answer as to why these muscles have greater inhibition. Rehabilitation exercises such as Y's, T's and W's

have been shown to target these muscles and reverse the effects of inhibition leading to proper activation of the lower scapular stabilizers (Hibberd et al., 2012; Oyama, Myers, Wassinger, & Lephart, 2010; Reinold et al., 2007; Sciascia et al., 2012; Thigpen et al., 2006).

Besides muscle inhibition, soft tissue tightness is believed to contribute to scapular dyskinesis. More specifically, posterior capsule tightness is linked to altered arthrokinematics between the humeral head and the glenoid (Tyler et al., 2000). Asymmetrical tightness of the GH joint capsule is thought to cause anterior and superior migration of the humeral head during forward elevation of the GH joint which may contribute to impingement (Page, 2011; Tyler et al., 2000). Posterior capsule tightness can limit internal rotation of the GH joint and result in sustained superior humeral head translation during elevation (Sizer et al., 2003). Tyler et al., 2000 were the first to quantify the relationship between posterior capsule tightness and lesser internal rotation. Their results indicate a significant negative correlation between posterior capsule tightness and lesser internal rotation range of motion (ROM) ($r = -.50$, $p=.006$).

Pathology

Alterations in muscle activation and scapular kinematics are linked to numerous injuries such as shoulder impingement syndrome (SIS), RC pathology and GH instability (Joshi et al., 2011). Greater activation of the upper scapular stabilizers combined with lesser activation of the lower scapular stabilizers leads to SIS (Ludewig & Braman, 2011). The two most common shoulder pathologies are SIS and RC tears (Ludewig & Braman, 2011; Ludewig & Reynolds, 2009; McClure, Bialker, Neff, Williams, & Karduna, 2004; Troskie & Boon, 2005). SIS accounts for 44-65% of shoulder complaints during physician visits (Page, 2011). SIS is reported to be a causative factor for RC pathology (Ludewig & Braman, 2011). RC tears are a common indicator of internal impingement during physical evaluations (Heyworth & Williams, 2009). Typically,

scapular instability is found in as many as 68% of RC problems and 100% of GH instability issues (Voight & Thomson, 2000). Tightness of the anterior GH musculature and weakness of the posterior GH musculature are thought to contribute to the development of instability (Buckler J, 2009).

Shoulder Impingement Syndrome

Shoulder impingement is defined as compression, entrapment or mechanical irritation of the RC structures or long head of the biceps tendon (Ludewig & Reynolds, 2009). Neer, 1972 was the first to classify impingement into two categories: structural and functional (Page, 2011). Structural impingement is the reduction of subacromial space due to bony growth or soft tissue inflammation and functional impingement is superior migration of the humeral head caused by weakness and/or muscle imbalance (Page, 2011). Structural impingement is often treated by surgical intervention while functional impingement is treated conservatively with the use of rehabilitative exercises (Cools et al., 2005; Page, 2011).

Subacromial impingement syndrome (SAIS) is mechanical compression of the rotator cuff, long head of the biceps tendon and subacromial bursa between the humerus and coracoacromial arch (Chester et al., 2010; Page, 2011; Roy et al., 2009). SAIS is the most common cause of shoulder pain, accounting for 40% of shoulder disorders (Baskurt et al., 2011; Chester et al., 2010; Umer et al., 2012). SAIS occurs as a result of dynamic narrowing of the subacromial space due to superior translation of the humeral head leading to RC tendon compression (Page, 2011). Over activation of the upper trapezius and inhibition of the lower trapezius and serratus anterior is also another possible cause of SAIS (Mcclure et al., 2004). The upper trapezius, lower trapezius and serratus anterior provide an important force couple to ensure proper upward rotation (De Mey et al., 2013; McCabe et al., 2007; Page, 2011). People with

SAIS commonly present with lesser posterior tilting, lesser upward rotation and greater internal rotation compared to non-pathologic shoulders (Roy, Moffet, McFadyen, & Macdermid, 2010; Seroyer et al., 2009; Umer et al., 2012). Lastly, increased thoracic spine kyphosis is a causative factor for SAIS (Page, 2011). Thoracic spine kyphosis causes greater scapular anterior tilt at rest limiting upward rotation and scapular posterior tilt during humeral elevation which decreases the amount of available subacromial space (Page, 2011).

Structural impingement is often a result of acromion morphology and is a second type of subacromial impingement (Jobe et al., 2000; Page, 2011; Troskie & Boon, 2005; Umer et al., 2012; Vahakari et al., 2010). Acromion shape is classified into three categories. Type I: flat, Type II: curved, Type III: hooked (Jobe et al., 2000; Vahakari et al., 2010). Type II is the most common and allows for the greatest amount of subacromial space in healthy shoulders (Troskie & Boon, 2005; Vahakari et al., 2010). Vahakari et al. (2010) observed type I acromions to be rare (4.6%) in their sample of 306 acromions. Type III acromions are the most pathologic and are rarely observed in participants who do not have shoulder pain (Tangtrakulwanich & Kapkird, 2012). As a result of the rarity of type III acromions in the young healthy population, researchers hypothesize the type III acromions are age and activity dependent (Tangtrakulwanich & Kapkird, 2012; Vahakari et al., 2010).

Internal impingement is characterized by excessive or repetitive contact of the greater tuberosity of the humeral head with the posterosuperior aspect of the glenoid when the arm is abducted and externally rotated (Heyworth & Williams, 2009). Internal impingement is typically described as a chronic, pathologic condition that is associated with excessive throwing and other overhead activities (Heyworth & Williams, 2009). Internal impingement is classified as either anterior or posterior (Ludewig & Braman, 2011). The cause of internal impingement is still

debated heavily in the literature. Some researchers (Heyworth & Williams, 2009; Jobe et al., 2000) believe that an underlying imbalance of the shoulder muscles (trapezii, rhomboids, serratus anterior) leads to the glenoid impingement. However, other researchers believe internal impingement is the result of abnormal biomechanics which can lead to injury of the superior glenoid labrum and result in the development of GH instability (Jobe et al., 2000). Internal impingement is classified into three stages. Stage I is classified by stiffness, stage II is classified by posterior shoulder pain, and stage III is classified by positive relocation test and posterior shoulder pain (Jobe et al., 2000).

Coracoid impingement (CI) is a relatively new classification of impingement. There is currently not any literature on the prevalence of this condition. CI is due to impingement of the subscapularis tendon between the coracoid process and the lesser tuberosity (Ferrick, 2000; Jobe et al., 2000; Okoro, Reddy, & Pimpelnarkar, 2009). This condition is typically diagnosed through exclusion of all other differential diagnosis. (Okoro et al., 2009). CI presents with a history of dull anterior shoulder pain that is exacerbated by activity requiring the shoulder to be flexed, adducted and internally rotated (Ferrick, 2000; Okoro et al., 2009). There is currently not any literature on the prevalence of this condition.

Rotator Cuff Pathology

Common sequelae to impingement are RC pathology (Joshi et al., 2011; Ludewig & Reynolds, 2009; Maquirriain et al., 2006). A properly functioning RC is essential for activities of daily living (ADL) and strenuous overhead activity (Seroyer et al., 2009). The most common location of RC pathology in overhead throwers is at the undersurface of the posterior half of the supraspinatus and the superior half of the infraspinatus (Seroyer et al., 2009; Thigpen et al., 2006). The supraspinatus is the most likely to contact the acromion when the humerus is

abducted to 90° and internally rotated 45° (Jobe et al., 2000; Page, 2011). Furthermore, GH joint laxity allows anterior humeral head translation and ultimately causes entrapment of the junction of the posterior supraspinatus and anterior infraspinatus tendons between the humeral head and posterior glenoid (Heyworth & Williams, 2009). Partial or full-thickness tendon tears of the supraspinatus are the typical objective findings indicative of shoulder impingement (Heyworth & Williams, 2009; Maquirriain et al., 2006).

Glenohumeral Joint Instability

Functional instability (FI) is typically used interchangeably with functional impingement and occurs during overhead physical activity. Functional instability is defined as general laxity of the GH joint capsule (Crawford & Sauers, 2006). Functional instability occurs mostly in overhead athletes below the age of 35 (Page, 2011). It is caused by excessive shoulder external rotation which leads to increased anterior and inferior translation of the humerus and ultimately results in anterior GH instability (Page, 2011). FI requires the implementation of precise therapeutic exercises with the goal of restoring normal neuromuscular function (Page, 2011).

Rehabilitation Exercises

Proper rehabilitative exercises are essential in restoring normal scapular kinematics in those who have functional impingement. Exercises should target the lower stabilizing muscles of the scapula as these are the most commonly inhibited muscles associated with scapular dyskinesis (Voight & Thomson, 2000). Furthermore, the supraspinatus is also targeted during therapeutic rehabilitation because it is affected with SIS (Dewhurst, 2010; Reinold et al., 2007; Seroyer et al., 2009; Thigpen et al., 2006). Sciascia et al. (2012) analyzed the electromyographic (EMG) activity of shoulder muscles in participants with instability and those who had stable

shoulders during prone ER at 90^0 , scapular plane elevation (Y's), prone horizontal abduction (PHA) (T's) and the push-up plus (PUP).

Another commonly prescribed exercise in scapular rehabilitation is scapular plane elevation (Y's), also known as scaption or the full-can exercise (Reinold et al., 2007; Sciascia et al., 2012; Thigpen et al., 2006). This exercise targets the serratus anterior and the supraspinatus; of which the latter is often identified as the most important muscle of the RC in regards to dynamic stability (Reinold et al., 2007; Sciascia et al., 2012; Thigpen et al., 2006). Reinold et al, (2007) evaluated EMG analysis of the supraspinatus and deltoid during three common rehabilitation exercises. Exercises included the full-can, empty-can and prone full-can. The results indicated that supraspinatus muscle activity was not different between the three exercises ($F_{2, 40} = 0.215$, $p = .807$) and each exercise provided a similar level of supraspinatus activity (62-67% MVIC). The researchers concluded the full-can exercise is the most appropriate of the three because of the minimal activation of the deltoid muscles. Therefore, shoulder abduction is likely attributed to activity of the supraspinatus rather than the deltoid.

Thigpen et al. (2006) evaluated scapular kinematics while performing the full-can and empty-can exercises. There was no significant main effect for type of exercise on scapular upward rotation ($F_{1, 19} = 0.10$, $p = .75$). The results indicate that there is no significant difference in scapular upward rotation at 30^0 , 60^0 and 90^0 of the ascending and descending phases of humeral elevation between the exercises. There was a significant main effect for exercise on scapular internal rotation ($F_{1, 19} = 19.89$, $p = .01$). The results indicate that the scapula was more internally rotated for the empty-can exercise at 30^0 , 60^0 and 90^0 of the ascending and descending phases of humeral elevation in comparison of the full-can exercise. There was also a significant main effect for exercise on scapular posterior tipping ($F_{1, 19} = 8.16$, $p = .01$). The results indicate

that the scapula was more anteriorly tipped for the empty can exercise at 30⁰, 60⁰ and 90⁰ of the ascending and descending phases of humeral elevation in comparison of the full-can exercise.

The researchers concluded the full-can exercise should be preferred over the empty-can exercise in regards to supraspinatus strengthening due to the empty can placing the scapula in a more internally rotated and anterior tipped position which are associated with impingement (Ludewig & Reynolds, 2009; Page, 2011).

Prone horizontal abduction with external rotation (T's) and scapular retraction with external rotation (W's) are two additional exercises used to correct scapular dyskinesis. T's target the lower trapezius, rhomboids, supraspinatus, teres minor and infraspinatus (Hibberd et al., 2012; Oyama et al., 2010). The treatment goals of performing T's are strengthen scapular stabilizers, increase scapular upward rotation, posterior tilt, retraction and external rotation (Hibberd et al., 2012). W's target the lower trapezius, rhomboids, supraspinatus, teres minor and infraspinatus (Hibberd et al., 2012; Oyama et al., 2010). The treatment goals of performing W's are strengthen scapular stabilizers, increase scapular upward rotation, posterior tilt, retraction and external rotation.

Oyama et al. (2010) evaluated scapular stabilizer EMG muscle activity during six retraction exercises in young healthy adults. Amongst those six exercises were Y's, T's and W's. Each subject performed all six exercises and the order was randomized using numbered index cards. All exercises were performed with each subject lying prone on the treatment table. Y's elicited the greatest amount of serratus anterior ($21.2 \pm 12.8\%$ MVIC) as well as lower ($71.9 \pm 27.4\%$ MVIC) and middle (77.4% MVIC) trapezii activity which are three muscles often inhibited in individuals with pathologic conditions (Reinold et al., 2009). However, Y's elicited the greatest amount of upper trapezius activity compared to the other five exercises 72.2 ± 39.2

% MVIC. T's and W's were shown to elicit moderate-high activation 65.8 ± 20.4 and $66.0 \pm 25.1\%$ MVIC respectively of the middle trapezius and only 49.0 ± 28.8 and $45.4 \pm 27.3\%$ MVIC in the upper trapezius. W's elicited greater activation of the serratus anterior compared to T's (16.7 ± 19.5 , 9.7 ± 12.7).

Hibberd et al. (2012) evaluated the effectiveness of a six week strengthening and stretching intervention program on improving glenohumeral and scapular muscle strength in collegiate swimmers. Participants were assigned to either the intervention or control groups. Participants in the intervention group performed the intervention protocol three times per week after practice while the control group did not perform the protocol. Y's T's and W's were included in the protocol and each exercise was performed using resistance tubing. Greater change scores were observed in those in the intervention group compared to the control group. However, the effects of the Y's T's and W's were not evaluated individually.

Feedback Strategies and Rehabilitation Exercises

Previous studies have examined the effects of feedback on various rehabilitative and functional tasks (Argus et al., 2011; De Mey et al., 2013; Herman et al., 2009; Huang, Lin, Guo, Wang, & Chen, 2013; Roy, Moffet, & McFadyen, 2010; Roy et al., 2009). Feedback is a tool used by clinicians to enhance the efficacy of rehabilitation exercises. Extrinsic feedback is given by an external source and provides error information that can be used in addition to the person's own intrinsic error signals (De Mey et al., 2013). Roy et al., (2009) evaluated the short-term effects of supervised movement training with extrinsic feedback on motor strategies of persons with SIS during a reaching task. Tactile feedback was utilized by restricting shoulder girdle movements or guiding scapular movements by the lead tester placing his/her hand on the scapula to influence motion. Verbal feedback was utilized by using comments related to motor

performance. The specific verbal instructions were not discussed in this research article.

Participants with SIS used a more biomechanically efficient pattern of movement during training with feedback; more specifically, less trunk flexion and rotation, as well as, less clavicular protraction. The effects of the training sessions lasted throughout the subsequent trials but the kinematic improvements returned to the baseline levels the following day after training.

Roy et al., (2010) evaluated if unsupervised training with visual feedback could maintain upper limb kinematic patterns obtained immediately after supervised training with verbal, manual, and visual feedback. The supervised movement training with feedback consisted of reaching movements performed in two different planes of elevation under the supervision of a physiotherapist. Tactile feedback was utilized by restricting shoulder girdle movements or guiding scapular movements. Verbal feedback consisted of the physiotherapist making comments related to the subject's shoulder girdle motor performance. Unsupervised movement training was performed the day after performing supervised movement training and consisted of visual feedback using a mirror. The unsupervised movement training allowed the participants to perform the same training session that they performed the day before. The kinematic variables in the SIS group (shoulder elevation and scapular upward rotation) returned to baseline levels 24 hours post supervised movement training. The researchers concluded that unsupervised movement training with visual feedback should be included in rehabilitation programs as home exercise following supervised training. However, the use of unsupervised movement training does not appear to be beneficial and future investigations should analyze the effects of unsupervised movement training.

De Mey et al., (2013) evaluated the influence of conscious correction (external verbal feedback) of scapular orientation on the absolute and relative trapezius muscle activation levels

during the performance of four exercises (prone shoulder extension, side-lying external rotation, side-lying forward flexion and prone horizontal abduction with external rotation) in overhead athletes with scapular dyskinesis. Visual, verbal and tactile cues were provided based on the individual's resting posture in standing and in exercise-specific positions. Visual feedback consisted of the subject using a mirror. Verbal feedback consisted of the lead tester instructing the subject to “gently bring the scapula together,” and tactile feedback consisted of the lead tester placing his/her hand on the medial border and inferior angle of the scapula.

The participants practiced the posture exercise until satisfactory correction, as judged by the investigator, was achieved. Verbal cues were given by the testers any time a subject lost the corrected scapular orientation. Corrected scapular position was defined as the position the lead tester instructed the subject to be in. The primary finding of this study was that conscious correction of scapular orientation significantly increased the absolute muscle activation levels in the three sections of the trapezius muscle only for the prone extension and side-lying external rotation exercises. Conscious correction did not change the activation of the three sections of the trapezius for the side-lying forward flexion and prone horizontal abduction with external rotation exercises.

Huang et al., (2013) investigated the effects of EMG biofeedback training during exercises on muscle balance ratios (upper trapezius/lower trapezius, upper trapezius/middle trapezius, and upper trapezius/serratus anterior) in participants with and without SAIS. All participants performed side-lying external rotation, forward flexion and knee push-up plus. The biofeedback consisted of real time EMG patterns of the muscles of interest displayed on a computer display screen during the exercises. Participants were taught to change their movements to decrease activity of the upper trapezius and facilitate activity of the middle

trapezius, lower trapezius and serratus anterior during the exercises by looking at the computer screen. The results indicated the ratios were lower during exercise with EMG biofeedback than during exercise only in the upper trapezius/serratus anterior and upper trapezius/lower trapezius in patients with SAIS during forward flexion. Upper trapezius/serratus anterior and upper trapezius/middle trapezius ratios were lower during exercise with EMG biofeedback than during exercise only during side-lying external rotation. There was not a significant difference between the upper trapezius/serratus anterior ratio during knee push-up plus. The knee push-up plus exercises elicits greater activation of the serratus anterior regardless if feedback was used.

Other studies have evaluated the effect of adding feedback to resistance training in other populations. Herman et al. (2008) used video feedback during anterior cruciate ligament (ACL) rehabilitation programs. The study used video-assisted feedback to assist the participants in altering lower body kinematics during a stop-jump task. The researchers concluded that visual-assisted feedback along with lower extremity strength training is more effective in improving kinetics and kinematics in females performing a stop-jump task compared to just strength training alone. Argus et al. (2011) evaluated the effects of verbal feedback on upper-body power in a resistance training session. A small increase of 1.8% (90% CI) in mean peak power of all repetitions was observed when feedback was received. The study showed that the greatest effect of the verbal feedback was observed during the later sets of training when fatigue is present. Overall, these studies indicate feedback is effective at improving lower extremity kinematics but it is unclear as to which method of feedback is most effective.

Previous research indicates that extrinsic feedback is effective at increasing EMG muscle activation. However, very little research exists on the efficacy of external feedback during rehabilitation exercises. No previous studies have investigated which form of extrinsic feedback

is most effective. Furthermore, no study has investigated the effectiveness of extrinsic feedback during a traditional rehabilitation session.

Therefore, the purpose of this study was to determine if the addition of tactile feedback to verbal feedback increases muscle activation of the serratus anterior, upper/middle/lower trapezii and anterior/posterior deltoids compared to only verbal feedback during common shoulder rehabilitation exercises. Determining the effectiveness of tactile + verbal versus verbal feedback alone provides clinicians with additional information to optimize rehabilitation and ensure the desired muscles are activated to their greatest potential. Improving the strength of the scapular stabilizing muscles will ultimately improve the scapulohumeral rhythm and ensure proper shoulder function (Reinold et al., 2009). We hypothesized that both verbal feedback and tactile + verbal feedback will improve muscle activation in healthy young adults during common shoulder rehabilitation exercises (Y's, T's and W's), but that tactile + verbal feedback would be more effective than verbal feedback alone at improving muscle activation.

Chapter III

Subject Recruitment

Participants were recruited via flyer, email and in person from undergraduate and graduate classes at the University of North Carolina at Chapel Hill. An equal number of recreationally active males and females (age 18-25) were recruited for this study. Recreationally active was defined as performing moderate intensity aerobic physical exercise a minimum of thirty minutes, five days per week or vigorous activity for a minimum of twenty minutes, three days per week (American College of Sports Medicine). University of North Carolina at Chapel Hill club sport overhead athletes were included in this study.

Exclusion Criteria

Participants were excluded from the study if they had a current or previous injury, within the past six months, to the shoulder, upper back, neck, humerus, scapula or clavicle resulting in three or more consecutive days of missed activity. Additional exclusion criteria included previous surgeries to the upper extremity or upper back. Furthermore, those who were currently or previously a member of a varsity overhead sport at the university level were excluded from this study. These participants were more likely to have performed these exercises previously and receive similar external feedback instructions.

Study Design

The study used a crossover, repeated measures design. The independent variable was condition (control (Con) verbal feedback (VF) and verbal + tactile feedback (VTF)). The dependent variable was the mean EMG amplitude of the upper, middle and lower trapezii,

anterior and posterior deltoids and serratus anterior during Y's, T's and W's. Each subject performed the first set of exercises without feedback and then repeated exercises with feedback (VF or VTF) provided by the primary investigator. Participants completed the remaining condition (VF or VTF, whichever one was not previously received) in a separate data collection session separated by a one-week washout period. The order of feedback was counterbalanced to reduce the chance of an order effect.

Testing Procedures

Prior to data collection, all participants read and signed an informed consent form approved by the Institutional Review Board (IRB) of the University of North Carolina at Chapel Hill, and each subject was able to ask questions to clarify any part of the informed consent form prior to signing it. Age (in years), height (m), mass (kg) and arm dominance were recorded for each subject. Arm dominance was classified as the arm used to throw a ball (Oyama, Myers, Wassinger, Daniel Ricci, & Lephart, 2008). Participants then performed a five minute warm-up on an Airdyne Stationary Bike (Schwinn Bicycle Company, Chicago, IL) at a self-selected pace (Oyama et al., 2008). Following the warm-up, surface EMG electrodes (Bagnoli 8 Desktop EMG System; DelSys Inc, Boston, MA) were placed on the body and three five second maximum voluntary isometric contraction (MVIC) trials were performed. MVICs were performed against manual resistance from the tester for each of the five muscles (serratus anterior, upper trapezius, middle trapezius, lower trapezius, and deltoids). There was a thirty second rest period between each trial and a five minute rest period at the conclusion of the MVIC trials before the start of the intervention. The mean RMS of a five second manual muscle test, for each muscle, was used to normalize muscle activation to a percentage of maximum during rehabilitative exercises ($EMG_{Activity}/EMG_{MVIC} = \%EMG$). The following positions were used for MVIC testing:

- *Serratus Anterior* was tested with the participant seated on a treatment table, the shoulder internally rotated and elevated to 125° in the scapular plane with resistance applied proximal to the participant's elbow (Tucker, Armstrong, Gribble, Timmons, & Yeasting, 2010).
- *Upper Trapezius* was tested with the participant seated, the shoulder elevated to 90° in the frontal plane and the head at neutral with resistance applied downward on the shoulder (Tucker et al., 2010).
- *Middle Trapezius* was tested with the participant lying prone on a treatment table, the shoulder externally rotated and horizontally abducted to 90° with resistance applied distal to the participant's elbow (Tucker et al., 2010).
- *Lower Trapezius* was tested with the subject lying prone on a treatment table, the shoulder externally rotated and the arm elevated to 125° in the frontal plane with resistance applied distal to the elbow (Tucker et al., 2010).
- *Deltoid* was tested with the subject seated, shoulder elevated to 90° in the frontal plane, elbow flexed to 90° and a downward force applied just proximal to the elbow.

Electromyography

Locations for the EMG electrodes were identified utilizing bony landmarks. Bony landmarks were palpated by the primary investigator and marked with an "X". The distance between landmarks was measured using a standard tape measure (MEDCO 60 in/150 cm). The subject's skin was shaved using a standard electric razor, abraded with fine sand paper and prepped using a 70% Isopropyl alcohol prep pad. All electrodes were secured to the skin using double sided adhesive tape and taped over the electrodes to the skin using 3M Transpore tape (3M Company Maplewood, MN). Bipolar surface electrodes (Ag/AgCl) were placed on the serratus anterior, upper trapezius, middle trapezius, lower trapezius and deltoid. The following locations were utilized for electrode placement:

- *Serratus Anterior*: below the axilla, anterior to the latissimus dorsi and placed vertically over the ribs (Pontillo et al., 2007)
- *Upper Trapezius*: one-third of the distance between the spinous process of C7 and the distal clavicle (Pontillo et al., 2007)
- *Middle Trapezius*: half-way between the medial border of the scapula and the spine, at the level of T3 (seniam.org).
- *Lower Trapezius*: at the level of the inferior angle of the scapula, 2 cm from the vertebral column (Pontillo et al., 2007)
- *Deltoids (anterior)*: two to three finger widths below the acromion process, over the muscle belly, in line with the fibers. (*Posterior*): three finger widths behind the angle of the acromion, over the muscle belly, in line with the fibers (Pontillo et al., 2007).

A reference electrode was placed on the olecranon process of the elbow. EMG data was sampled at 1000 Hz and a gain of 1000 (Blackburn & Padua, 2009; Tucker et al., 2010).

Exercises

The three exercises performed were scapular retraction with external rotation (W's), prone scapular plane elevation (Y's), and prone horizontal abduction with external rotation (T's). All exercises were performed on a treatment table (30" H x 30" W x 72" D). All exercises were performed using a handheld dumbbell for resistance. Females used a 2lb dumbbell and males a 3lb dumbbell. These weights were selected in order to elicit greater muscle activation than utilizing gravity alone, but not heavy enough to impair the participants' ability to perform the exercises correctly (Cools et al., 2007).

- *Prone Y's* were performed with the subject's arms elevated to 120° in the scapular plane and externally rotated (Oyama et al., 2010). The subject elevated his/her arms to 90° and returned to the starting position. **Figure 4**
- *Prone T's* were performed with the subject's arms elevated to 90° in the frontal plane, elbows fully extended. The subject elevated his/her shoulders to end range and returned to the starting position (Oyama et al., 2010). **Figure 4**
- *Prone W's* were performed with the subject's shoulders off the edge of the table and elbows flexed to 90°. The subject elevated their shoulders to 90° in the frontal plane and returned to the starting position. (Oyama et al., 2010). **Figure 4**

All participants were shown an instructional video demonstrating proper technique before performing each exercise. The instructional videos were created by the lead investigator who is a certified athletic trainer. The lead investigator also administered the feedback and rehabilitation exercises throughout the duration of this study. Each subject performed all three exercises in a counterbalanced order, determined via Latin square method. All exercises were performed for one set of eight repetitions during each time point. A digital metronome, set at 60 BPM, was used to standardize the speed of each exercise (2 seconds concentric/ 2 seconds eccentric). There was one minute of rest between each set of exercises and 5 minutes of rest between baseline and intervention testing. EMG measurements were recorded during every repetition for each exercise. During the first day of testing, each subject performed Y's, T's and W's without feedback then performed Y's, T's and W's with feedback (VF or VTF). During the second testing session, each subject performed each exercise without feedback then each exercise with feedback that they had yet to receive (VF or VTF). The order of feedback was counterbalanced.

External feedback, tactile and/or verbal, was given to both the TVF and VF groups while performing the experimental condition sets. The verbal feedback group (VF) only received verbal cuing while performing the rehabilitation exercises. Verbal feedback consisted of “imagine that you are pushing the bottom of your shoulder blade towards your back pocket,” “keep your upper body nice and tall throughout the exercise,” and “gently bring your shoulder blade toward your spine.” The verbal + tactile feedback group (VTF) received both the previously described verbal feedback as well as tactile cuing while performing the rehabilitation exercises. Tactile cuing was performed by the primary investigator placing his hand on the subject’s shoulder girdle in hopes to restrict shoulder girdle movements or guiding scapular movements (Roy et al., 2009).

Scapular Kinematics

Before electromagnetic sensor placement, the subject’s skin was prepped using a 70% isopropyl alcohol prep pad. All sensors were secured to the skin using double sided adhesive tape, pre-wrap and athletic tape to minimize movement of the sensor relative to the skin. Four Motion Star electromagnetic sensors were used during each testing session to assess scapular resting position. A sensor was placed over each of the following landmarks: the spinous process of the seventh cervical vertebra, the flat portion of the acromion processes, and the mid-shaft of the posterior humerus. The fourth sensor was attached to the stylus that was used to digitize the anatomical landmarks on the scapula, upper arm and thorax (Oyama et al., 2008). The anatomical landmarks digitized were the eight thoracic vertebra, xiphoid process, jugular notch, SC joint, AC joint, medial scapula border where it intersects with the scapula spine, inferior scapular angle, medial epicondyle, lateral epicondyle and GH joint center. Landmarks on the

scapula and humerus were digitized bilaterally (Oyama et al., 2008). Scapular kinematic data was sampled at 100 Hz (Oyama et al., 2008).

Data Sampling

Scapula and clavicular kinematic data were collected using the Motion Star (Ascension Technology Corp, Burlington, VT) electromagnetic tracking device integrated with MotionMonitor (Innovative Sports Training, Inc., Chicago, Ill) motion capture software (Myers, Jolly, Nagai, & Lephart, 2006; Oyama et al., 2008). The device consists of a transmitter that creates an electromagnetic field and sensors that detect the electromagnetic field emitted by the transmitter. This is a reliable measure for scapulohumeral motion (intraclass correlation = .967 and intersession correlation = .889) (Oyama et al., 2008).

Data Reduction

EMG (Bagnoli 8 Desktop EMG System; Delsys Inc, Boston, MA) was collected for all muscles during all trials. All EMG data were processed using a custom Labview program (National Instruments, Austin, TX). The raw EMG signal was corrected for DC bias, band-pass filtered using a zero-phase lag fourth order Butterworth (20-350 Hz) and notch filtered (59.5-60.5) (Blackburn & Padua, 2009). The data were smoothed using a 50-millisecond root mean square (RMS) (Figure 4) (Blackburn & Padua, 2009). The onset and offset of each EMG burst were identified, and the middle four EMG bursts (3, 4, 5 and 6) were used for analysis in each muscle and exercise performed. EMG onset was defined as the first time point that exceeded two standard deviations of the resting EMG amplitude, and offset was defined as the first point that fell below two standard deviations of the resting EMG amplitude. The onset and offset of EMG bursts 3-6 were used to create a subset. The average EMG amplitude of the subset was used in

the statistical analyses. All mean EMG amplitudes were normalized to the mean RMS of the previously recorded MVICs and expressed as a percentage of maximum.

Statistical Analysis

An a priori power calculation using data from previous studies suggested that 30 participants were required to achieve power of .80 with an effect size of 0.3 to determine if there were statistically significant differences in muscle activation (De Mey et al., 2013; Huang et al., 2013). Power analyses were performed using G*Power version 3.1. All statistical analyses were performed using SPSS (version 20; SPSS Inc, Chicago, IL). Data were inspected for normality using the Shapiro-Wilk test and homogeneity of variance using Levene's test to confirm assumptions of Analysis of Variance (ANOVA). Paired samples t-tests were used to compare the scores of baseline 1 and 2. Baseline 1 was established on day 1 as each participant performed each exercise without external feedback. Baseline 2 was established on day 2 as each participant performed each exercise without external feedback. Change scores were calculated between the pre- and post- intervention normalized RMS values in the VF and VTF groups, and the difference between baseline 1 and 2 was used as a control comparison. One-way repeated measures ANOVA of the change scores (change between baseline 1 and 2, change between baseline and VF, change between baseline and VTF) for each muscle during each exercise was used to determine the difference between feedback conditions using an alpha of 0.05. Bonferonni *post hoc* procedures were used for multiple comparisons when a significant F-statistic was found using an adjusted alpha level of 0.017.

Chapter IV

For Submission to: Journal of Sport Rehabilitation

Overview

Context: Verbal and tactile feedback during rehabilitation exercises for scapular dyskinesis as well as pre-hab can potentially improve muscle activation. However, it is unclear which method of feedback provides the greatest increase in muscle activation.

Objective: To determine if the addition of tactile feedback to verbal feedback increases activation of shoulder muscles during scapular plane elevation (Y's), shoulder abduction with external rotation (T's), and scapular retraction with external rotation (W's).

Design: Crossover repeated measures design

Setting: Biomechanics Laboratory

Participants: 30 physically active participants volunteered for this study (age=20.23±1.25 years, height=1.71±0.073m, mass=70.11±15.14kg).

Interventions: Assessment of muscle activation while verbal and tactile (VT) and verbal feedback (V) were provided in separate sessions during performance of Y's, T's and W's exercises. Participants completed baseline trials without feedback, and received VT & V feedback across 2 counterbalanced sessions.

Main Outcome Measures: Electromyography of the scapular stabilizing muscles (serratus anterior, upper, middle, and lower trapezii and anterior and posterior deltoid) was recorded. Change scores were calculated between pre-and post-feedback intervention, and the difference between baseline 1 and 2 was used as a control. One-way ANOVA of the change scores between

the baseline, VT and V feedback session was used to evaluate the scapular muscle activation during Y's, T's and W's.

Results: There was a significant effect for feedback condition for the middle trapezius [$F_{1,2}=4.102$, $p=0.002$] and serratus anterior [$F_{1,2}=3.492$, $p=0.037$] during Y's, the middle trapezius [$F_{1,2}=5.893$, $p=0.005$] during W's, and the upper trapezius [$F_{1,2}=3.854$, $p=0.027$] and middle trapezius [$F_{1,2}=4.268$, $p=0.019$] during T's. *Post Hoc* testing revealed no significant difference between V and VT feedback during Y's, T's and W's.

Conclusions: Results of this study indicate that adding tactile feedback to verbal feedback did not increase muscle activation compared to verbal feedback alone. This study indicates that feedback, regardless of type, is more beneficial than providing no feedback, for improving muscle activation.

Word Count: 298/300

INTRODUCTION

Approximately 13.7 million people in the United States seek treatment from a physician for shoulder pain each year (Tucker et al., 2008), and up to 54% these individuals report continued discomfort three years following the initial incidence of pain (Chester et al., 2010). Improper scapular position and movement alters the length of scapular stabilizing muscles; commonly, this results in lengthening of the posterior musculature and shortening of the anterior musculature. Altered length tension relationships may result in abnormal muscle activation and scapular dyskinesis. Common pathologies resulting from scapular dyskinesis include shoulder impingement syndrome (SIS), and rotator cuff tendinopathy (Ludewig & Reynolds, 2009). Scapular dyskinesis refers to alterations in static scapular position and dynamic scapular motion (Uhl et al., 2009). Fortunately, scapular dyskinesis and SIS can be effectively treated with rehabilitative exercises (Cools et al., 2007; De Mey et al., 2013; Witt et al., 2011).

Rehabilitative exercises are essential in restoring normal scapular kinematics as well as maintaining proper function of the scapular stabilizers (Hibberd et al., 2012; Myers et al., 2005; Sciascia et al., 2012; Thigpen et al., 2006; Voight & Thomson, 2000). Exercises should target the middle and lower trapezii and serratus anterior as these are the most commonly inhibited muscles associated with scapular dysfunction either in healthy or pathologic populations (Voight & Thomson, 2000). Increased activation of the serratus anterior and middle and lower trapezii helps to restore normal scapular kinematics (Cools et al., 2007). The main functions of the trapezii are scapular retraction (middle) and upward rotation (lower) and depression (lower) (Reinold et al., 2009). The serratus anterior protracts and upwardly rotates the scapula (Terry & Chopp, 2000). Common rehabilitation exercises targeting the trapezii and serratus anterior muscles include Y's, T's and W's. Scapular retraction with external rotation (W's) is commonly prescribed for the

lower trapezius, rhomboids, infraspinatus, teres minor and supraspinatus (Hibberd et al., 2012; McCabe et al., 2007). Scapular plane elevation (Y's) is commonly prescribed for rehabilitation of the serratus anterior and lower trapezius (Reinold et al., 2007; Sciascia et al., 2012; Thigpen et al., 2006). Prone horizontal abduction (T's) focuses on activation of the supraspinatus, infraspinatus, deltoid and scapular retractors (De Mey et al., 2013; Sciascia et al., 2012).

Previous studies have examined the effects of feedback techniques such as verbal and tactile feedback, during rehabilitation and while performing functional tasks on muscle activation and kinematic patterns (Argus et al., 2011; De Mey et al., 2013; Herman et al., 2009; Roy, Moffet, & McFadyen, 2010; Roy et al., 2009). External feedback has been shown to benefit an individual during rehabilitative and functional tasks by increasing activation of the targeted muscles (De Mey et al., 2013; Roy, Moffet, & McFadyen, 2010; Roy et al., 2009). Feedback is a tool used by clinicians to ensure that prescribed exercises are performed correctly and utilize musculature that ensures proper scapula function. The general belief is that more feedback is better and the results of previous studies have indicated this to be true (Herman et al., 2009; Wouters et al., 2012). Although studies have assessed external feedback with regards to movement kinematics and muscle activation, it is unclear which method of feedback provides the most efficacious results. This is important to investigate as clinicians commonly prescribe rehabilitative exercises to treat causes of shoulder dysfunction. However, if the exercises are not performed correctly their therapeutic benefit may be lost.

Therefore, the purpose of this study was to determine if the addition of tactile feedback to verbal feedback increases muscle activation of the serratus anterior, upper, middle and lower trapezii and anterior and posterior deltoids compared to only verbal feedback during common shoulder rehabilitation exercises. Determining the effectiveness of verbal + tactile feedback

compared to verbal feedback alone provides clinicians with additional information to optimize rehabilitation and ensure the desired muscles are activated to their greatest potential. Improving the activation of the scapular stabilizing muscles will manifest itself as increased force output (i.e. strength) and ultimately improve the scapulohumeral rhythm and ensure proper shoulder function (Reinold et al., 2009). We hypothesized that both verbal feedback and tactile + verbal feedback would improve muscle activation in healthy young adults during common shoulder rehabilitation exercises (Y's, T's and W's), but that tactile + verbal feedback would be more effective than verbal feedback alone at improving muscle activation.

METHODS

Participants

Thirty recreationally active participants enrolled at a university setting were recruited for this study (see demographics in Table 1). Participants were included if they were recreationally active males and females, between the ages of 18-25. Participants were excluded if they had sustained an injury six months prior to participation to the shoulder, upper back, neck, humerus, scapula or clavicle resulting in three or more consecutive days of missed physical activity, and were currently or previously a member of a varsity overhead athletic team at the university level. These participants were more likely to have performed these exercises previously and receive similar external feedback instructions.

Design

The study used a crossover, repeated measures design. The independent variable was condition (control (Con) verbal feedback (VF) and verbal + tactile feedback (VTF)). The dependent variables were the mean EMG amplitudes of the upper, middle, and lower trapezii, the anterior and posterior deltoids and serratus anterior during Y's, T's and W's. Each subject

performed the first set of exercises without feedback and then repeated exercises with either verbal feedback or verbal + tactile feedback from the primary investigator. Participants completed the remaining condition (the form of feedback that they did not receive in the initial testing session) in a separate session separated by a one-week washout period. The order of feedback was counterbalanced to eliminate an order effect.

Procedures

Prior to data collection, all participants read and signed an informed consent form approved by a University Institutional Review Board (IRB). Age (in years), height (m), mass (kg) and arm dominance were recorded for each subject. Arm dominance was classified as the arm used to throw a ball (Oyama et al., 2008). Participants then performed a five-minute warm-up on an Airdyne stationary bike (Schwinn Bicycle Company, Chicago, IL) at a self-selected pace (Oyama et al., 2008). Following the warm-up, surface EMG electrodes (Bagnoli 8 Desktop EMG System; DelSys Inc, Boston, MA) were placed over the muscles of interest and three five second maximum voluntary isometric contractions (MVIC) trials were performed. MVICs were performed against manual resistance from the tester for each muscle (serratus anterior, upper trapezius, middle trapezius, lower trapezius, and deltoids). There was a thirty second rest period between each trial and a five minute rest period at the conclusion of the MVIC trials before the start of the kinematic trials. The mean RMS of a five second manual muscle test, for each muscle, was used to normalize muscle activation to a percentage of maximum during rehabilitative exercises ($EMG_{Activity}/EMG_{MVIC} = \%EMG$). The following positions were used for MVIC testing:

- *Serratus Anterior* was tested with the participant seated on a treatment table, the shoulder was internally rotated and elevated to 125° in the scapular plane with resistance applied proximal to participant's elbow (Tucker et al., 2010).
- *Upper Trapezius* was tested with the subject seated, the shoulder elevated to 90° in the frontal plane and the head at neutral with resistance applied downward on the shoulder (Tucker et al., 2010).
- *Middle Trapezius* was tested with the participant lying prone on a treatment table, the shoulder externally rotated and horizontally abducted to 90° with resistance applied distal to the subject's elbow (Tucker et al., 2010).
- *Lower Trapezius* was tested with the participant lying prone on a treatment table, the shoulder externally rotated and the arm elevated to 125° in the frontal plane with resistance applied distal to the elbow (Tucker et al., 2010).
- *Deltoid* was tested with the participant seated, shoulder elevated to 90° in the frontal plane, elbow flexed to 90° and a downward force applied just proximal to the elbow.

Electromyography

Locations for the EMG electrodes were identified utilizing bony landmarks. Bony landmarks were palpated by the primary investigator and marked with an "X". After identification of the electrode sites, the subject's skin was shaved, abraded with fine sand paper and prepped using a 70% isopropyl alcohol prep pad. Bipolar surface electrodes (Ag/AgCl) were placed on the serratus anterior, upper trapezius, middle trapezius, lower trapezius and deltoid. All electrodes were secured to the skin using double sided adhesive tape and taped over the electrodes to the skin using 3M Transpore tape (3M Company Maplewood, MN).. The following locations were utilized for electrode placement:

- *Serratus Anterior*: below the axilla, anterior to the latissimus dorsi and placed vertically over the ribs (Pontillo et al., 2007). **Figure 1**
- *Upper Trapezius*: one-third of the distance between the spinous process of C7 and the distal clavicle (Pontillo et al., 2007). **Figure 1**
- *Middle Trapezius*: half-way between the medial border of the scapula and the spine, at the level of T3 (seniam.org). **Figure 1**
- *Lower Trapezius*: at the level of the inferior angle of the scapula, 2 cm from the vertebral column (Pontillo et al., 2007). **Figure 1**
- *Deltoids (anterior)*: two to three finger widths below the acromion process, over the muscle belly, in line with the fibers. (*Posterior*): three finger widths behind the angle of the acromion, over the muscle belly, in line with the fibers (Pontillo et al., 2007). **Figure 1**

A reference electrode was placed on the olecranon process of the ipsilateral elbow. EMG data was sampled at 1000 Hz. (Blackburn & Padua, 2009; Tucker et al., 2010).

Exercises

The three exercises performed were prone scapular plane elevation (Y's), prone horizontal abduction with external rotation (T's) and scapular retraction with external rotation (W's). All exercises were performed on a treatment table and performed using a handheld dumbbell for resistance (females = 2lb and males = 3lb. These weights were selected because we wanted to elicit greater muscle activation, but not impair the participants' ability to perform the exercises correctly (Cools et al., 2007).

- *Prone Y's* were performed with the participant's arms elevated to 120° in the scapular plane and externally rotated (Oyama et al., 2010). The participant elevated his/her arms to 90° and returned back to the starting position. **Figure 2a**
- *Prone T's* were performed with the participant's arms elevated to 90° in the frontal plane, elbows fully extended. The participant elevated his/her shoulders to end range and returned back to the starting position (Oyama et al., 2010). **Figure 2b**
- *Prone W's* were performed with the participant's shoulders off the edge of the table and elbows flexed to 90°. The participant elevated their shoulders to 90° in the frontal plane and returned back to the starting position. (Oyama et al., 2010). **Figure 2c**

All participants viewed an instructional video demonstrating proper technique before performing each exercise. The primary investigator also administered the feedback and rehabilitation exercises throughout the duration of this study. Each participant performed all three exercises in a counterbalanced order determined via Latin square method. All exercises were performed for one set of eight repetitions. A digital metronome, set at 60 BPM, was used to standardize the speed for each exercise (2 seconds concentric/ 2 seconds eccentric). One minute of rest was provided between each set and 5 minutes of rest between baseline testing and intervention testing. EMG data were sampled during every repetition. During the first day of testing, each subject performed Y's, T's and W's without any feedback then performed Y's, T's and W's with feedback (VF or VTF). During the second testing session, each subject performed each exercise without feedback then each exercise with feedback that they had yet to receive (VF or VTF). The order of feedback was counterbalanced.

External feedback was provided to both the TVF and VF groups while performing the experimental condition sets. The verbal feedback group (VF) received only verbal feedback

while performing the rehabilitation exercises. Verbal feedback consisted of “imagine that you are pushing the bottom of your shoulder blade towards your back pocket,” “keep your upper body nice and tall throughout the exercise,” and “gently bring your shoulder blade toward your spine.” The tactile + verbal feedback group (TVF) received tactile cuing in addition the previously described verbal feedback while performing the rehabilitation exercises. Tactile cuing was performed by the primary investigator placing his hand on the participant’s shoulder girdle in hopes to restrict shoulder girdle movements or guiding scapular movements (Roy et al., 2009).

Signal Processing

EMG (Bagnoli 8 Desktop EMG System; Delsys Inc, Boston, MA) data were collected during all trials for each muscle during each exercise. All EMG data were processed using a custom Labview program (National Instruments, Austin, TX). The raw EMG signal was corrected for DC bias, band-pass filtered using a zero-phase lag fourth order Butterworth (20-350 Hz) and notch filtered (59.5-60.5) (Blackburn & Padua, 2009). The data were smoothed using a 50-millisecond root mean square (RMS) (Figure 4) (Blackburn & Padua, 2009). The onset and offset of each EMG burst were identified, and the middle four EMG bursts (3, 4, 5 and 6) were used for analysis in each muscle and exercise performed. EMG onset was defined as the first time point that exceeded two standard deviations of the resting EMG amplitude, and offset was defined as the first point that fell below two standard deviations of the resting EMG amplitude. The onset and offset of EMG bursts 3-6 were used to create a subset. The average EMG amplitude of the subset was used in the statistical analyses. All mean EMG amplitudes were normalized to the mean RMS of the previously recorded MVICs and expressed as a percentage of maximum activation.

Statistical Analysis

An a priori power calculation using data from previous studies suggested that 30 participants were required to achieve power of .80 with an effect size of 0.3 to determine if there were statistically significant differences in muscle activation (De Mey et al., 2013; Huang et al., 2013). Power analyses were performed using G*Power version 3.1. All additional statistical analyses were performed using SPSS (version 20; SPSS Inc, Chicago, IL). Data were inspected for normality using the Shapiro-Wilk test and homogeneity of variance using Levene's test to confirm assumptions of ANOVA. Paired samples t-tests were used to compare the scores of baseline 1 and 2. Baseline 1 was established on day 1 as each participant performed each exercise without external feedback. Baseline 2 was established on day 2 as each participant performed each exercise without external feedback. Change scores were calculated between the pre- and post- intervention normalized RMS values in the VF and VTF groups, and the difference between baseline 1 and 2 was used as a control comparison. One-way repeated measures analysis of variance (ANOVA) of the change scores (change between baseline 1 and 2, change between baseline and VF, change between baseline and VTF) for each muscle during each exercise was used to determine the difference between feedback conditions using an alpha of 0.05. Bonferonni *post hoc* procedures were used for multiple comparisons when a significant F-statistic was found using an adjusted alpha level of 0.017.

RESULTS

There were no significant differences between the baseline trials except for the middle trapezius during T's (Table 2). There was a significant effect for condition in the upper trapezius ($p=0.033$) and middle trapezius ($p=0.005$) during T's (Table 2). *Post Hoc* testing found that the change in activation was greater during the VF condition compared to baseline in the middle

trapezius ($p=0.001$) and upper trapezius ($p=0.0045$) during T's. The change in activation was greater during the VTF condition compared to baseline in the middle trapezius during T's ($p=0.006$). However, there were no differences in activation in any muscle between the VF and VTF conditions during T's.

There was a significant effect for condition in the middle trapezius ($p=0.022$) and serratus anterior ($p=0.025$) during Y's (Table 2). The change in activation was greater during the VTF condition compared to baseline in the middle trapezius during Y's ($p=0.015$), and serratus anterior during Y's ($p=0.007$). The change inactivation was greater during the VF condition compared to baseline in the serratus anterior during Y's ($p=0.017$). However, there were no differences in activation in any muscle between the VF and VTF conditions during Y's.

There was a significant effect for condition in the middle trapezius ($p=0.001$) during W's (Table 2). The change in activation was greater during the VF condition ($p=0.002$) and VTF condition ($p=0.007$) compared to baseline in the middle trapezius during W's. No differences were found between the VF and VTF conditions in any muscle.

DISCUSSION

The purpose of our study was to determine if the addition of tactile feedback to verbal feedback would improve muscle activation of the serratus anterior, three portions of the trapezii, and anterior and posterior deltoids during common shoulder rehabilitation exercises. The main finding of this study is that the addition of tactile feedback to verbal feedback during Y's, T's and W's was not more effective at increasing muscle activation compared to providing verbal feedback alone. Additionally, both VF and VTF were more effective at eliciting greater muscle activation than no feedback alone. We hypothesized that the addition of tactile feedback would increase the amount of corrective information being provided so that the participant could correct

his/her altered muscle activation patterns resulting in greater activation of the middle and lower trapezii and serratus anterior. We would expect that the external feedback would be more beneficial for those who had shoulder pathology versus those who were otherwise healthy. We decided to evaluate healthy participants because these exercises are also prescribed as pre-hab or maintenance exercises for those who participate in overhead activities (Hibberd et al., 2012; Myers et al., 2005).

Although both feedback methods increased muscle activation compared to no feedback, the magnitude of increase did not differ between feedback conditions. A possible explanation for this is that we used healthy individuals in our study as opposed to those with shoulder pathology (e.g. SIS) which limits the amount of potential errors to correct with rehabilitation exercises. Individuals with shoulder pathology tend to exhibit visible alterations in normal scapular movement such as decreased scapular upward elevation, posterior tilt and external rotation resulting from decreased activation of the lower and middle trapezii, serratus anterior and increased activation of the upper trapezius (Ludewig & Reynolds, 2009; Thigpen et al., 2006). Individuals with shoulder pathology may benefit more from additional feedback than healthy individuals with whom verbal feedback alone is sufficient in improving scapula muscle activation. An additional explanation may be that the addition of tactile feedback to verbal feedback was effective at restoring optimal length-tension relationships therefore optimizing muscle performance and requiring less muscle activation in order to perform the rehabilitation exercises.

Another possible explanation is that the tactile feedback provided may not be the most effective feedback strategy for eliciting greater muscle activation. We used static hand placements located along the middle and lower trapezii. These positions may be more effective

at eliciting greater muscle activation at rest than during a dynamic movement. Hsu et al. 2009 evaluated the effects of Kinesio taping (a form of tactile feedback) on scapular kinematics and muscle performance in baseball players with SIS. The taping tended to increase activation of the serratus anterior and upper trapezius in the entire range of scaption which is the same movement pattern as Y's. It is possible that the increased contact area of the Kinesio tape was able to increase proprioception of more mechanoreceptors than our static hand placements therefore eliciting greater muscle activation.

Feedback had a significant effect on activation of the middle trapezius for all three exercises (Y's, T's and W's). Increased activation of the middle trapezius is desired during scapula stabilizing rehabilitation exercises (Voight & Thomson, 2000). One explanation for why the middle trapezius was statistically significant for each exercise was because the verbal commands given primarily focused on the scapula retractors which is one of the primary actions of the middle trapezius (Voight & Thomson, 2000). The middle trapezius is often inhibited in those with shoulder pathology (Cools et al., 2007; Joshi et al., 2011; Merolla et al., 2010; Voight & Thomson, 2000), it is imperative that the clinician is able to provide external feedback that will elicit greater activation of this muscle.

Feedback only had a significant effect for the upper trapezius during T's. This is not surprising because the upper trapezius is most active with the elbow fully extended and shoulder elevated to 90° in the frontal plane (Tucker et al., 2010); this position is the terminal arm position during T's. Therefore an individual responding to external feedback to increase scapula retraction during T's may recruit the upper trapezius to assist with this task. The serratus anterior only had a statistically significant difference during Y's. This result was not expected because one typically thinks of the serratus anterior as a scapula protractor and Y's require more scapula

retraction and upward elevation (Reinold et al., 2007). We believe that the serratus anterior is more active during this exercise because of its role as a scapula stabilizer (Terry & Chopp, 2000). Greater activation of the serratus anterior along with the middle and lower trapezii helps to counteract the effects of upper trapezius activation (Ludewig & Reynolds, 2009; Page, 2011). As previously stated, the serratus anterior plays an important role in scapula stability (Uhl et al., 2009; Voight & Thomson, 2000). By enhancing scapula stability, scaption can occur with less impedance (Sciascia et al., 2012).

The lower trapezius and both deltoids exhibited no significant difference as a result of feedback for any of the exercises tested. This is not surprising as the deltoids do not play a significant role in scapula stability (Terry & Chopp, 2000) and the feedback provided was not focused on them. It was surprising to us that the lower trapezius did not have any significant differences because of its role as a scapula retractor and along with the middle trapezius, it helps to counteract the activity of the upper trapezius (Joshi et al., 2011; Merolla et al., 2010; Tucker et al., 2010). The lower trapezius forms an important force couple with the serratus anterior that produces scapular upward rotation (Ludewig & Reynolds, 2009; Voight & Thomson, 2000). This force couple helps to ensure the integrity of the subacromial space during humeral elevation which decreases the likelihood of a patient developing shoulder impingement as a result of repetitive overhead activities (Ludewig & Reynolds, 2009; Page, 2011). One reason could have been the difficulty of performing W's correctly. 27% of participants in our study were unable to perform W's correctly. W's require a combination of scapular retraction and shoulder abduction (McCabe et al., 2007). The lower trapezius transitions from a scapular retractor to a stabilizer to allow shoulder abduction to occur (McCabe et al., 2007). Furthermore, the lower trapezius may be a difficult muscle to voluntarily contract. Lastly, W's may not be challenging enough to elicit

lower trapezius activation comparable to the participant's MVIC testing value. We used 2lb and 3lb dumbbells during this study which may not have provided enough resistance to elicit greater muscle activation for a generally strong muscle like the lower trapezius. We did not have an objective way to determine if individuals performed the exercise correctly because we did not analyze the kinematic data collected during this study.

There are limitations to address when interpreting the findings of this study. First, our study lacked a true control condition. We used the difference between baseline scores as a control condition for analysis. Ideally, we would have had a third session where no feedback was given, followed by no feedback again or a randomized controlled trial design. Secondly, we enrolled active, young, healthy participants. Typically, individuals with shoulder pathologies would perform the rehabilitation exercises used in this study. The activation pattern of those with scapula dyskinesis and shoulder impingement is different from healthy individuals (Ludewig & Braman, 2011; Uhl et al., 2009; Voight & Thomson, 2000). Finally, there are limitations when using surface EMG electrodes. Our % MVIC values were high given the tasks that the participants were completing. We assumed that each subject truly gave maximum effort during the MMT's but that could not be the case. There were also large standard deviations within the EMG data for some of the muscles that may account for some of non-significant findings. Additionally, there could be differences in limb position/muscle length between dynamic tasks and MVICs. Future studies should include measures of kinematic changes in addition to EMG changes, which are important when attempting to treat a patient with shoulder pathology (e.g. SIS, dyskinesis etc.). Additionally, future studies should aim to establish muscle specific verbal instructions for the various scapula stabilizing muscles. It may also be beneficial if future studies assessed the effects of feedback while participants are standing or on an unstable surface, such as

a yoga ball, as these methods are commonly prescribed in a clinical setting and may impact the effectiveness of the feedback.

CONCLUSION

This was the first study to compare the efficacy of verbal to tactile + verbal feedback on muscle activation during Y's, T's and W's. The results of our study indicate that verbal and tactile feedback can be used to increase middle trapezius activation during Y's, T's and W's. Furthermore, the addition of tactile to verbal feedback during Y's, T's and W's does not provide additional benefits to muscle activation. Furthermore, our study provides more evidence that Y's, T's and W's are effective at targeting the scapula stabilizing muscles, more specifically the middle trapezius. However, if the clinician's goal is to increase activation of the middle trapezius without increasing the activation of the upper trapezius then T's may not be a proper exercise to select. Our results indicate that it is just as beneficial for clinicians to provide VF only allowing them the ability to work with more than one person at a time in a clinic setting.

TABLES AND FIGURES

Table 1 Participant Demographics

Sex	Age (years)	Height (m)	Mass (kg)	Arm Dominance
Males: 15	20.23 (1.25)	1.71 (.073)	70.11	R 26, L 4
Females: 15			(15.14)	

Table 2 Baseline Comparisons of Mean Difference Change Scores

Comparison	Mean Difference	T	<i>p</i>
W's			
Base1 AD -Base2 AD	-4.722	-0.881	0.386
Base1 LT - Base2 LT	-9.656	-1.412	0.169
Base1 MT- Base2 MT	-2.484	-0.803	0.428
Base1 PD - Base2 PD	-8.544	-1.091	0.284
Base1 SA - Base2 SA	-7.012	-1.143	0.262
Base1 UT - Base2 UT	2.515	0.814	0.422
T's			
Base1 AD -Base2 AD	-2.297	-1.393	0.174
Base1 LT - Base2 LT	-3.483	-0.682	0.501
Base1 MT- Base2 MT	-11.128	-3.350	*0.002
Base1 PD - Base2 PD	4.239	0.836	0.410
Base1 SA - Base2 SA	-3.239	-1.155	0.258
Base1 UT - Base2 UT	-2.533	-1.027	0.313
Y's			
Base1 AD -Base2 AD	-4.722	-0.881	0.386
Base1 LT - Base2 LT	-9.656	-1.412	0.169
Base1 MT- Base2 MT	-2.484	-0.803	0.428
Base1 PD - Base2 PD	-8.544	-1.091	0.284
Base1 SA - Base2 SA	-7.012	-1.143	0.262
Base1 UT - Base2 UT	2.515	0.814	0.422

* Denotes Statistically Significant

Table 3 Activation Comparisons between the Feedback Conditions

Muscle	Verbal Mean Change (SD)	Verbal +Tactile Mean Change (SD)	Baseline Mean Change (SD)	F	<i>p</i>
W's					
SA	-1.09 (17.36)	5.72 (17.53)	-4.03 (12.95)	2.883	0.076
MT	14.48 (18.45)	11.82 (13.86)	1.45 (11.84)	7.828	*0.001
LT	0.18 (27.47)	-4.88 (26.17)	4.22 (28.33)	0.794	0.457
UT	3.28 (16.41)	3.84 (16.41)	3.95 (13.60)	0.016	0.948
AD	-2.50 (16.73)	-0.14 (20.38)	5.11 (19.02)	1.466	0.239
PD	4.45 (18.45)	9.57 (18.91)	2.89 (18.45)	1.271	0.288
T's					
SA	2.32 (14.30)	4.12 (11.84)	2.57 (14.66)	0.150	0.861
MT	18.85 (21.91)	13.93 (16.75)	4.72 (10.76)	5.813	*0.005
LT	8.86 (18.65)	8.48 (26.61)	2.48 (20.92)	0.946	0.394
UT	11.25 (10.23)	8.27 (15.33)	2.53 (13.51)	3.604	*0.033
AD	2.11 (33.27)	6.83 (26.81)	2.29 (9.03)	0.290	0.750
PD	5.03 (22.01)	13.01 (25.88)	-1.24 (26.42)	2.587	0.084
Y's					
SA	10.75 (24.08)	13.13 (20.54)	1.28 (15.26)	3.914	*0.025
MT	5.01 (12.07)	11.34 (14.02)	0.82 (15.64)	4.085	*0.022
LT	10.18 (16.99)	4.49 (23.34)	3.06 (21.28)	0.838	0.438
UT	5.60 (15.10)	3.25 (10.12)	-2.51 (16.91)	2.863	0.065
AD	3.759 (15.49)	9.67 (18.58)	5.78 (21.62)	0.751	0.477
PD	0.46 (19.56)	1.89 (19.94)	-4.12 (20.73)	0.944	0.395

* Denotes Statistically Significant

SA- Serratus Anterior, MT- Middle Trapezius, LT- Lower Trapezius, UT- Upper Trapezius, AD-Anterior Deltoid
PD- Posterior Deltoid

Table 4 Post Hoc Analysis of Significant ANOVA Findings

Exercise (Muscle)	Mean Difference	T	<i>p</i>
W's (MT)			
Con-V	13.02	3.214	*0.001
Con-VT	10.37	4.148	*0.0002
V-VT	-2.65	0.718	0.478
T's (UT)			
Con-V	8.72	3.360	*0.001
Con-VT	5.73	1.622	0.055
V-VT	-2.98	0.813	0.049
T's (MT)			
Con-V	14.12	3.499	*0.001
Con-VT	9.20	2.727	*0.006
V-VT	-4.92	-0.977	0.337
Y's (MT)			
Con-V	4.20	1.019	0.158
Con-VT	10.53	2.588	*0.015
V-VT	6.33	2.274	0.019
Y's (SA)			
Con-V	9.47	2.227	*0.017
Con-VT	11.85	2.659	*0.007
V-VT	-2.38	-0.529	0.301

^t Adjusted P value of 0.017

* Denotes Statistically Significant

SA- Serratus Anterior, MT- Middle Trapezius, LT- Lower Trapezius, UT- Upper Trapezius, AD-Anterior Deltoid
PD- Posterior Deltoid

Figure 1 EMG Electrode Placements

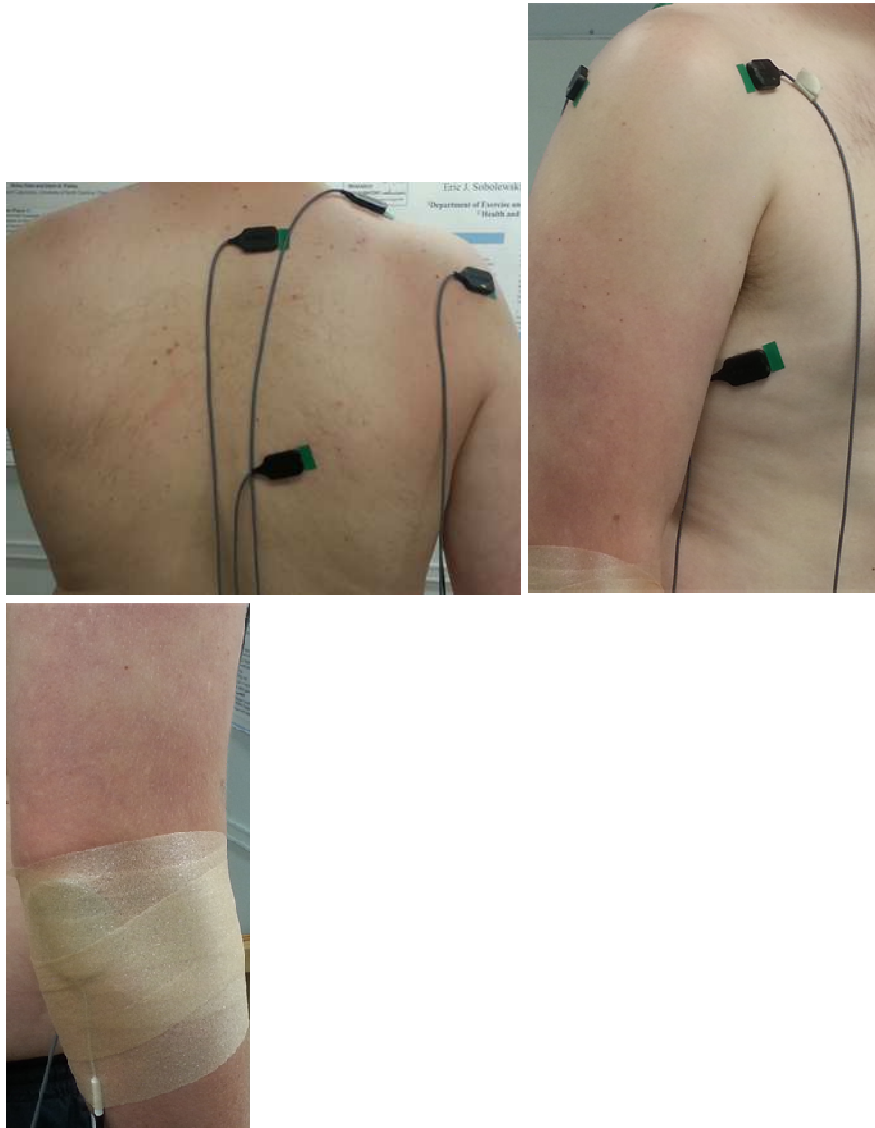


Figure 2 Exercise Positions



Figure 2a (Y's)

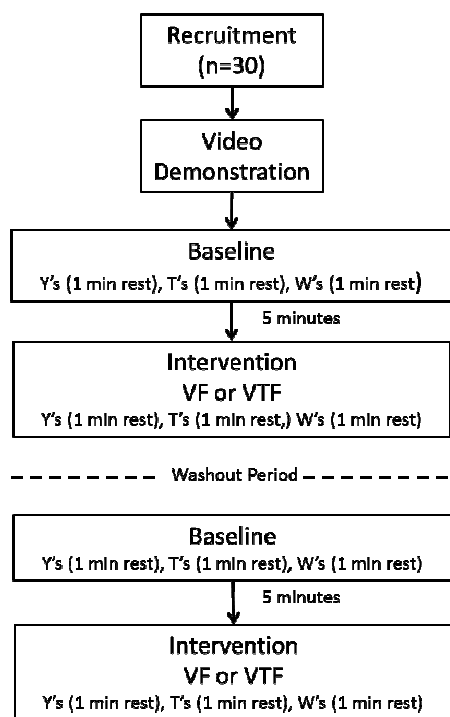


Figure 2b (T's)



Figure 2c (W's)

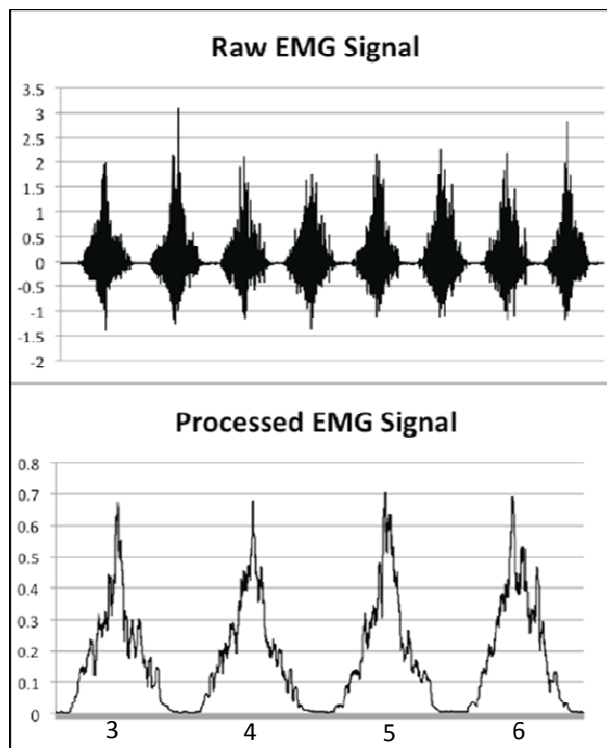
Figure 3 Study Design



- Exercise order and feedback order was counterbalanced
- EMG recorded during all exercises (UT, MT, LT, SA, PD, AD)
- Normalized to % of maximum during a manual muscle test

Figure 4 EMG Signal Processing

(A) Typical Raw EMG for 8 repetitions collected. (B) Processed EMG of the middle 4 repetitions utilized for analysis



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Figures

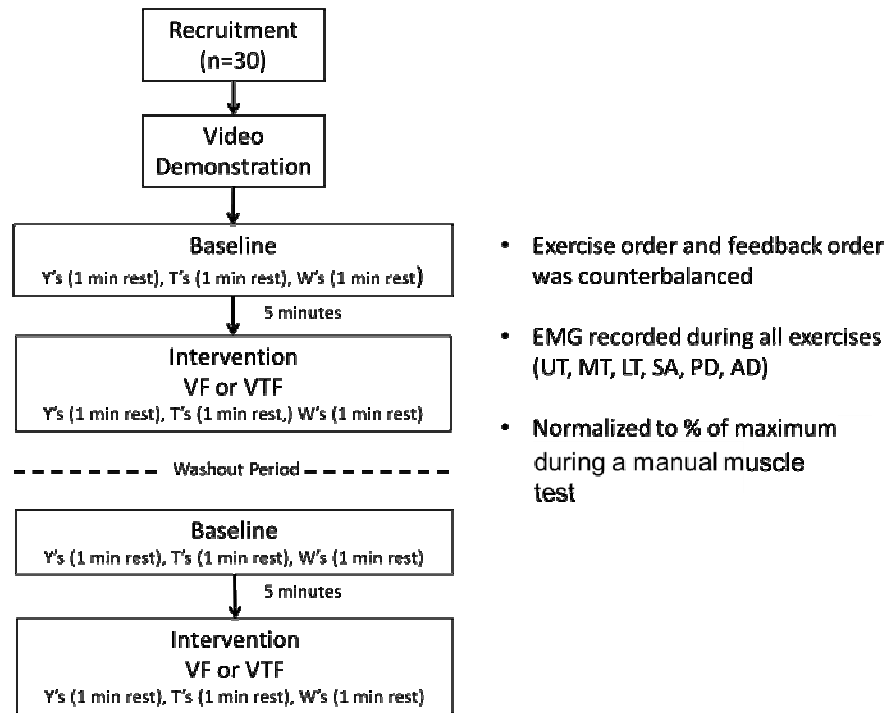


Figure 1 Study Design

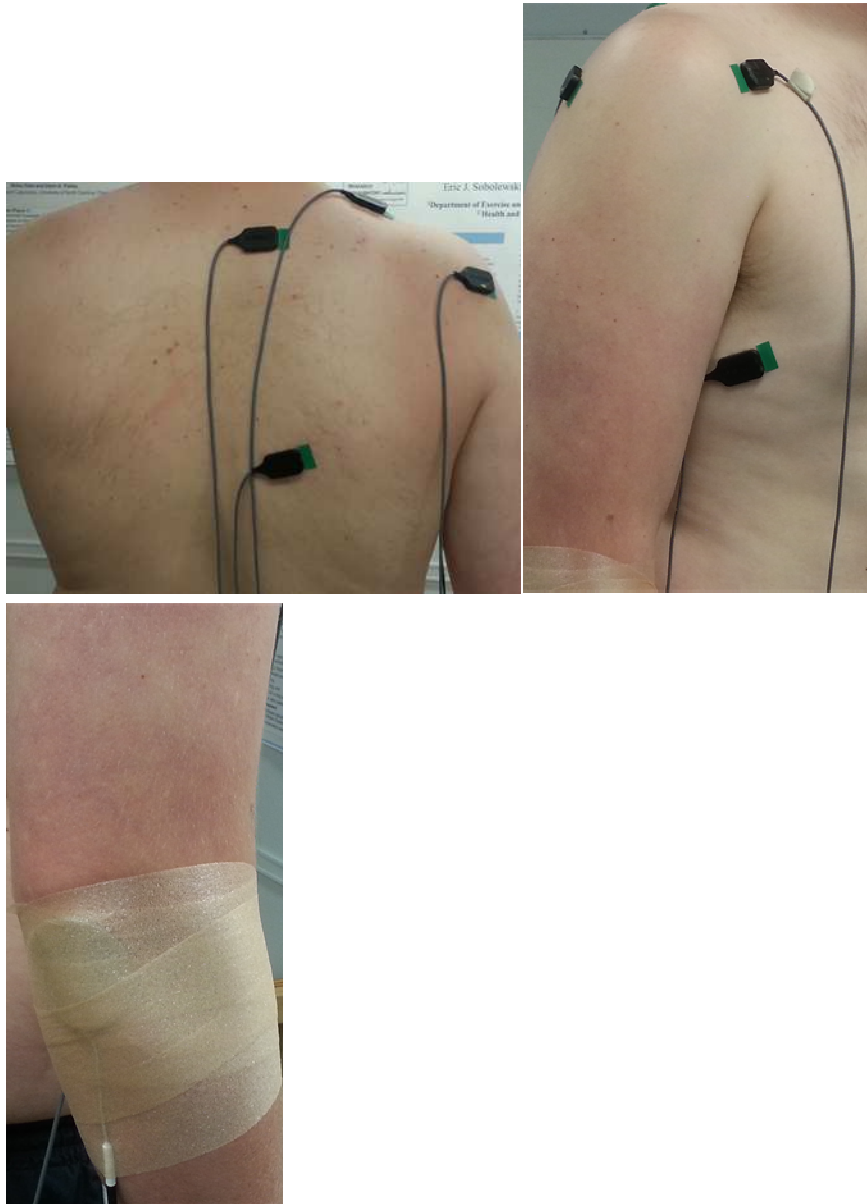


Figure 2 EMG Electrode Placement



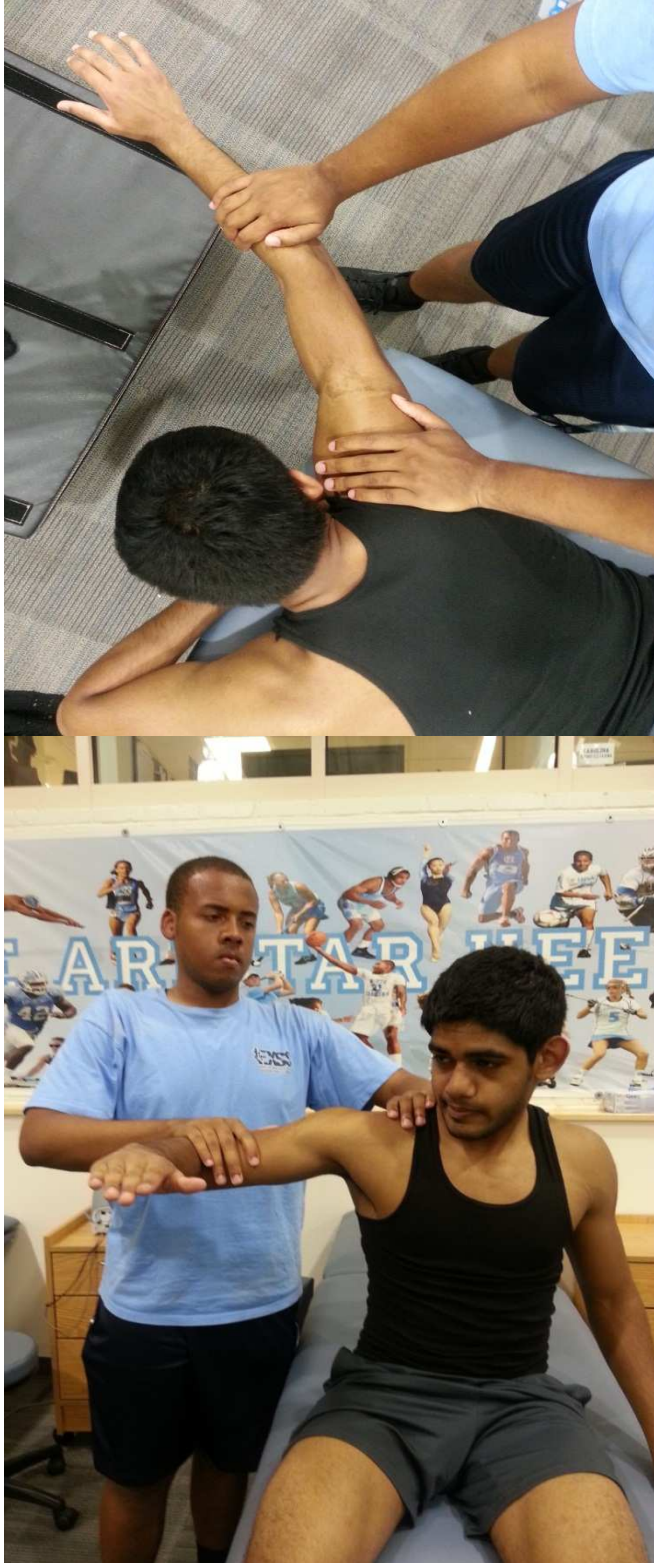


Figure 3 MVIC Positions



Figure 4 Rehabilitation Exercises

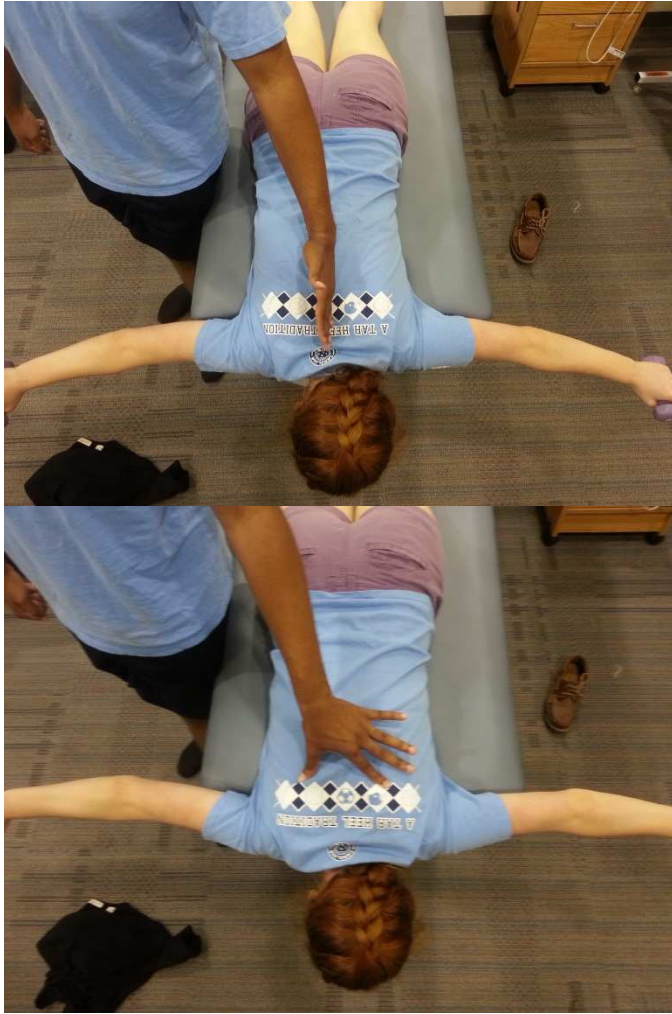


Figure 5 Tactile Feedback Positions

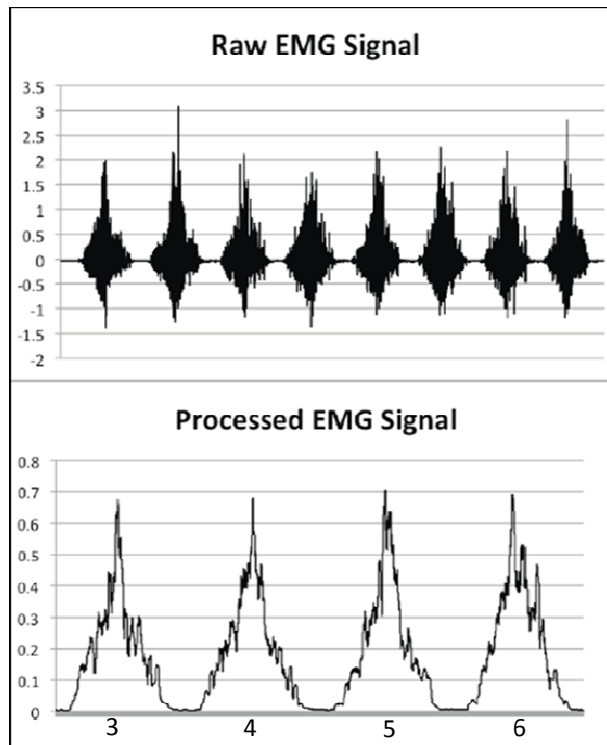


Figure 6 EMG Signal Processing

(A) Typical Raw EMG for 8 repetitions collected. (B) Processed EMG of the middle 4 repetitions utilized for analysis

Tables

Table 1 Statistical Analysis

Question	Description	Data Source	Comparison	Method
1	What is the effect of verbal and tactile & verbal cuing on electromyographic activity in healthy young adults performing common rehabilitation exercises (Y's, T's, W's)	Mean Amplitude (%MVIC) of: - Serratus Anterior - Upper Trapezius - Middle Trapezius - Lower Trapezius - Deltoids (anterior, and posterior)	Mean Amplitude (%MVIC) of those who receive verbal cuing to those who receive tactile and verbal cuing while performing (Y's, T's and W's)	Change scores will be used to calculate the difference between baseline and treatment conditions. A one-way repeated measures ANOVA (with appropriate post hoc testing) will be used to analyze the change scores

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