EXAMINING THE EFFECTIVENESS OF ELECTROMYOGRAPHY BIOFEEDBACK AT IMPROVING THE UPPER TRAPEZIUS TO SERRATUS ANTERIOR MUSCLE ACTIVATION RATIO

A Thesis

presented to

the Faculty of California Polytechnic State University,

San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Kinesiology

by

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August 2019

COMMITTEE MEMBERSHIP

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ABSTRACT

Examining the Effectiveness of Electromyography Biofeedback at Improving the Upper Trapezius to Serratus Anterior Muscle Activation Ratio

Julia Evelyn Holton

Purpose: The upper trapezius to serratus anterior muscle activation ratio is essential for optimal shoulder function. An alteration of this ratio, specifically a decrease in upper trapezius and increase in serratus anterior activation, is a main area of focus in shoulder rehabilitation (Kibler, 1998; Paine & Voight, 1993). Electromyography (EMG) biofeedback has been shown to be an effective rehabilitation technique to address many musculoskeletal disorders but there is limited research on the retention of improvements seen with EMG biofeedback (Ma et al., 2011; Lim et al., 2014; Weon, et al., 2011). The purpose of this study was to determine if EMG biofeedback can be used to improve scapular control by decreasing the upper trapezius to serratus anterior activation ratio. A secondary purpose was to determine if these predicted improvements in the ratio can be retained beyond the timeframe in which the treatment is provided. Methods: Twenty college aged (age=21.75 $\pm$ 1.77) subjects (10 males, 10 females) volunteered to participate in this study. Subjects were randomized to the exercise only group or EMG biofeedback group. The exercise only group performed three exercises twice a week for four weeks with supervision. The EMG biofeedback group performed the same exercises twice a week for four weeks with the addition of watching EMG biofeedback on a computer monitor with the instructions to decrease the upper trapezius activation and increase the serratus anterior activation by adjusting the corresponding lines on the monitor. The percent maximal voluntary contraction (MVC) for each muscle during each exercise was measured on visit one, visit nine (after the four weeks of practice) and visit ten (after a two-week retention period). The ratio and the individual muscle changes were analyzed using multi-factor ANOVAs against group, exercise, and group by exercise interaction. Results: There was no significant effect of any of the variables on the ratios visit one to visit nine, nor when comparing visit nine to visit ten. The was a significant effect of group on the upper trapezius when comparing visit one to visit nine (p=0.007) with no effect seen comparing visit nine to visit ten. There was also a significant effect of group on the serratus anterior activation for both visit one to visit nine (p=0.000) and visit nine to visit ten (p=0.001). Conclusion: EMG biofeedback did not decrease the upper trapezius to serratus anterior activation ratio, but the individual muscle activation changes indicate that EMG biofeedback is effective at altering muscle activation rates in individual muscles and that those changes can be retained beyond the timeframe of the intervention. Additional research is needed with more subjects and in populations with shoulder pathologies to further investigate the effectiveness of this concept.

Keywords: Electromyography, biofeedback, EMG biofeedback, upper trapezius, serratus anterior, muscle activation ratio, retention

ACKNOWLEDGMENTS

I would first like to thank Dr. Clark for the expertise and guidance offered throughout this process. The support and trust that he provided to me to develop and execute my ideas in this research has been invaluable in my academic development. I also would like to thank Dr. Greever for always being available for any advice or guidance I needed on this project, as well as being a support throughout my whole time in graduate school. To Professor Smith for the help on the methods and especially the statistics on this project, I truly could not have done it without you.

Thank you to the faculty and staff in the Department of Kinesiology and Public Health. There has been so much moral and financial support with this project, and I am so grateful to be a part of a wonderful department who has allowed me the freedom to explore ideas and has challenged me to become better.

I would also like to thank subjects who agreed to participate in this study and who devoted six weeks of their time for the completion of my research.

To the graduate students who were always around to be my sounding board in all stages of this process, I would like to thank you. The words of encouragement, open ears, and willingness to spend countless hours working on projects have kept me grounded throughout my years at Cal Poly.

Finally, I want to thank my parents, sisters, brother-in-law's and nieces for their continued support during my time at graduate school. I can't express the gratitude I feel for having such a supportive group around me. Thank you for being available in person, over the phone and video calls to talk or not talk about this process and keeping me sane through the highs and lows of the last couple of years.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Introduction

1.1 Background of the Study

Shoulder pain has been found to be a common musculoskeletal disorder complaint with up to 70% of the general population reporting shoulder pain in their lifetime (Singh et al., 2015). Only half of the patients who report shoulder pain completely recover from the pain within six months of onset which can create lasting disability (Struyf, Geraets, Noten, Meeus, & Nijs, 2016). Because of the high prevalence of shoulder pain and length of symptoms, there is a great deal of interest in improving the prognosis of common shoulder injuries to reduce the incidence of disability and length of discomfort (Antunes, Carnide, & Matias, 2016).

This increased interest in shoulder injuries has led to developments in rehabilitation techniques aimed at decreasing shoulder pain and improving treatment for shoulder injuries. One such technique is electromyography (EMG) which allows for the examination and quantification of muscular activation timing and amplitude which can then be presented as biofeedback (Giggins, Persson, & Caulfield, 2013). EMG biofeedback is the technique that converts the muscle activation amplitudes and timing into real-time visual feedback presented on a computer monitor (Giggins et al., 2013).

EMG biofeedback has been utilized as a rehabilitation technique to address many different disorders including whiplash, hemiplegia post-stroke, and patella-femoral pain syndrome to name a few (Giggins et al., 2013). For example, Lim, Kim, Song, Cynn, and Yi (2014) examined the effectiveness of EMG biofeedback at immediately decreasing the activation of the posterior deltoid and increasing infraspinatus muscle activation. The subjects in their study were able to selectively activate the infraspinatus while

subsequently inhibiting the activation of the posterior deltoid. The results of their study indicate that EMG biofeedback can be a useful technique in improving the selective activation and the activation ratio of shoulder musculature (Lim et al., 2014).

There is evidence to suggest that a useful EMG measure may be the activation ratio of the upper trapezius to the serratus anterior which has been identified as a significant predictor of potential shoulder problems (Kibler, 1998; Schory, Bidinger, Wolf, & Murray, 2016; Paine & Voight, 1993). In a healthy shoulder, the upper trapezius and serratus anterior work together through force coupling (pairing of muscles to produce movements) to facilitate correct movement to provide essential scapular stabilization (Kibler & Sciascia, 2015; Mottram, 1997). In some cases, the force coupling of these muscles can be negatively altered to the extent that the stabilization properties on the scapula are jeopardized. For instance, the scapula relies on dynamic control through concurrent muscle activation to provide the stable base necessary to execute normal upper extremity function. However, when this function is altered there is often abnormal scapular motion, function and position known as scapular dyskinesis (Kibler, Ludewig, Michener, Bak, & Sciascia, 2013). Scapular dyskinesis is harmful because it can lead to disordered shoulder girdle mechanics creating abnormal stresses on the glenohumeral joint leading to shoulder pain and subsequent injury.

Rehabilitation of shoulder injuries typically focuses on prescribing exercises which aim to create non-conscious alteration in the activation of shoulder musculature through the central nervous system to enable normal scapular function (Nowotny, Kopow, Mauch, & Kasten, 2016). These usually consist of exercises explicitly aiming to increase the activation of the serratus anterior without over-activating the upper trapezius.

Though classic rehabilitation techniques can be effective at improving these activation ratios, recent research has been focused on how to effectively and efficiently improve the muscle activation in the most time-efficient, lasting manner. For example, Ma et al. (2011) determined that EMG biofeedback is more effective than both active exercise and passive treatment at improving muscle activation patterns and decreasing neck and shoulder pain with results lasting six months (Ma et al., 2011).

These previous works suggest that there is a possibility for improved neuromuscular control in specific muscles through the utilization of EMG biofeedback (Holterman, Mork, Andersen, Olsen, & Søgaard, 2010; Holterman, et al., 2009). Therefore, this technique could be utilized as an effective method for improving the upper trapezius to serratus anterior activation ratio (Huang, Lin, Guo, Wang, & Chen, 2013). An improvement in the upper trapezius to serratus anterior activation ratio may allow for more normal and effective scapular movements decreasing the possibilities of the injuries generally associated with this abnormal movement. However, evidence is lacking regarding the retention of these possible improvements from EMG biofeedback as many research studies did not include long-term retention tests (Lim et al., 2014; Weon, et al., 2011). This thesis aims to address if EMG biofeedback can provide lasting benefits to this upper trapezius to serratus anterior activation ratio and the associated improvements in scapular control.

1.2 Statement of Purpose and Hypotheses

The purpose of this study was to determine if EMG biofeedback can be used to improve scapular control by decreasing the upper trapezius to serratus anterior activation ratio. A secondary purpose of this study was to determine if these predicted

improvements in the ratio can be retained beyond the timeframe in which the treatment is provided. Therefore, it was hypothesized that the utilization of EMG biofeedback for four weeks will significantly decrease the upper trapezius to serratus anterior muscle activation ratio during common scapular rehabilitation exercises. It was also hypothesized that the decrease in the ratio will be present at the end of the treatment period of four weeks as well as after a two-week retention period.

Chapter 2: Literature Review

2.1 Shoulder Anatomy

The shoulder is often regarded as the most complicated joint in the body allowing for more range of motion of the upper extremity than any other joint (Culham & Peat, 1993; Watkins, 1999). This large amount of movement is the result of combined motion at three separate joints: the scapulothoracic, acromioclavicular and the shoulder joint itself, the glenohumeral joint, forming the shoulder complex (Kibler, Ludewig, Michener, Bak, & Sciascia, 2013; Watkins, 1999).

There is a coordination between the humerus and the scapula which is a result of the interaction of various muscles that attach to the humerus, the scapula, the ribs and vertebral bodies. The scapula also has the ability to glide and rotate relative to the posterior aspect of the rib cage; this is termed the scapulothoracic gliding mechanism (Watkins, 1999). The complexity of possible movements of the shoulder complex can be attributed to the number of joint articulations possible as well as the shape of the articulating surfaces. This extensive range of motion at the glenohumeral joint and the shape of the surfaces means that the joint is inherently unstable; when examining freely movable joints, mobility and stability are inversely related. In addition, the shoulder joint is often classified as a ball and socket joint however, the shallowness of the "socket" and the incongruent size of the articular surface or the "ball" of this ball and socket joint results in a joint that can move in all three planes of motion as well as rotate and glide within the glenoid fossa (Culham & Peat, 1993; Saladin, 2011). The congruence of a joint describes the area in which the joint reaction force is transmitted; having more congruence indicates a greater area in the joint for forces to be distributed (Watkins,

1999). Congruence in a joint is crucial as it minimizes the compressive stress on the articular surfaces of a joint, maintains normal movement, and improves shock absorption (Watkins, 1999). The shoulder joint does not have reciprocally shaped articular surfaces, which decreases the congruence, increases the stresses on and reduces the stability of the glenohumeral joint. Various ligaments (e.g., the superior, middle and inferior glenohumeral ligaments, along with the coracohumeral ligaments) act to increase the stability of this joint as well, but the muscles of the rotator cuff including subscapularis, supraspinatus, teres minor and infraspinatus, are the main contributors to the stability of the glenohumeral joint (Watkins, 1999).

In addition to the ligamentous and muscular stabilizers, additional components contribute to the functionality of the shoulder complex. For example, to compensate for the possible mechanical instability of the shoulder complex and allow for normal upper extremity function there exists a well-organized coordination of the movement of the humerus, clavicle and scapula (Culham & Peat, 1993). The scapula in particular plays an essential role in establishing and maintaining the normal kinematics of upper extremity movement due to the stable base the scapula creates against the chest wall (Mottram, 1997; Winter, 2005). This normal function is maintained through the force coupling of four stabilizer muscles attached to the scapula; serratus anterior, rhomboids, trapezius and levator scapulae (Kibler, 1998; Mottram, 1997; Paine & Voight, 1993; Saladin, 2011) . Force coupling describes the synergistic coordination of two or more muscles to produce movements around a joint (Mottram, 1997). The force coupling of shoulder musculature is complex and involves a variety of shoulder muscles, but the focus of this study is on

the upper trapezius and serratus anterior force-coupling to produce normal shoulder function, specifically essential scapular stabilization (Kibler, 1998; Mottram, 1997).

2.2 Shoulder Musculature

The trapezius and serratus anterior are the most critical stabilizing muscles when analyzing the scapulothoracic joint (Mottram, 1997). The trapezius is separated into three sections: Upper trapezius, middle trapezius, and the lower trapezius. (Kibler & Sciascia, 2015). The trapezius originates from the occiput, nuchal ligament, and spinous processes of C7 through T12 vertebrae and the upper aspect inserts across the distal third of the clavicle and the acromion. The middle aspect inserts across the scapular spine and the lower portion of the base of the spine (Kibler & Sciascia, 2015). The trapezius muscle assists in scapular retraction, elevation, and posterior tilting.

The serratus anterior is a complex muscle and has been found to assist in the three-dimensional movement of the scapula through depression and elevation, though especially elevation. The serratus anterior is made up of three parts and originates from the first eight ribs and inserts at the medial aspect of the scapula (Paine & Voight, 1993; Kibler & Sciascia, 2015). This muscle acts as a primary stabilizer of the scapula during elevation, as the major protractor of the shoulder and maintains the scapula in upward rotation (Paine & Voight, 1993; Mottram, 1997).

As previously mentioned, the trapezius is often force coupled with the serratus anterior to provide essential scapular stabilization (Kibler & Sciascia, 2015). This force-coupling is essential to normal shoulder function but can be disrupted and lead to abnormal motion and altered muscle activation (Kibler & Sciascia, 2015).

Researchers have determined that a majority of the abnormality in shoulder biomechanics can be traced back to abnormal (aka, disordered), muscular function in those muscles that control the scapula (Kibler, 1998; Schory, Bidinger, Wolf, & Murray, 2016; Paine & Voight, 1993). Abnormalities in muscle function can be triggered from muscle injuries either from direct trauma to the muscles or repeated micro-trauma both of which create muscle weakness from strain (Kibler, 1998; Poppen & Walker, 1976). The muscles can also be inhibited due to abnormal muscle coordination or by painful conditions around the shoulder hindering motion (Kibler, 1998; Poppen & Walker, 1976). Kibler (1998) described muscle inhibition as the decreased ability to exert torque as well as disordered firing patterns of the muscles around the shoulder.

When looking at the disordered muscle function in the shoulder, the serratus anterior and lower trapezius are commonly examined. These muscles are most commonly altered due to inhibition rather than actual trauma to the tissues (Kibler, 1998). There is often inhibition of the serratus anterior coupled with over-activation of the upper trapezius which can lead to shoulder abnormalities in various forms as described earlier (Kibler, 1998).

2.3 Scapular Dyskinesis

As previously mentioned, the scapula relies on the force-coupling of stabilizer muscles to maintain the dynamic control and functional stability of the scapula producing normal upper extremity function (Mottram, 1997). Disruption in the force-coupling capabilities of the scapular muscles can result in abnormal scapular motion and position termed scapular dyskinesis (Kibler et al., 2013). This loss of normal control of scapular motion is not inherently an injury but can be related to changes in: glenohumeral

angulation (the angle of rest and movement in the glenohumeral joint), strain on the acromioclavicular joint, muscle activation abnormalities, and humeral position and motion (Kibler et al., 2013).

Scapular dyskinesis can create disordered mechanics which can result in pain, or the disordered mechanics can be the response to that injury contributing to scapular dyskinesis (Kibler et al., 2013). Scapular dyskinesis can lead to a variety of shoulder dysfunctions including: abnormal stresses on the glenohumeral joint, altered kinematics, altered muscle activation, shoulder and neck pain and altered scapular motion or position (Schory et al., 2016; Kibler et al., 2013). For example, abnormal stresses on the glenohumeral joint can lead to injury of the rotator cuff muscles and injury or tears to the glenoid labrum (Kibler et al., 2013).

In addition to the injuries mentioned above, altered muscular activation can lead to the altered kinematics of the scapula. The altered kinematics, specifically the altered scapular motion and position, can lead to increased risk of impingement. Symptoms of internal impingement result from the compression of the rotator cuff between the posterior superior glenoid labrum and the humeral head during humeral elevation and internal rotation, decreased subacromial space, reduced rotator cuff strength and increased strain on the anterior glenohumeral ligaments (Kibler et al., 2013; Prentice, 2011). The consequences of scapular dyskinesis, as mentioned above, can create pain or injuries in the shoulder which can further decrease normal upper extremity function and can lead to increased dysfunction (Kibler et al., 2013).

There is also the possibility that scapular dyskinesis could be due to an injury of the shoulder in which the pathomechanics created the dysfunction (Kibler et al., 2013).

For example, Kibler et al. (2013) described five possible causes of scapular dyskinesis, as follows: Bony causes, joint causes, neurological causes, soft tissue mechanisms and alterations in muscle activation. The bony causes can include thoracic kyphosis (which is described as an abnormally large thoracic angle creating the appearance of a 'hump' in the upper back), or a clavicle fracture from non-union or a shortened mal-union (Watkins, 1999). As previously described, acromioclavicular joint instability, arthrosis or glenohumeral joint internal derangement (described as joint mal-alignment) can also contribute to scapular dyskinesis due to the inherent joint components. The authors also described neurological causes including cervical radiculopathy, long thoracic or spinal accessory nerve palsy. The inflexibility and intrinsic muscle problems of the shoulder complex are the primary soft tissue mechanisms leading to scapular dyskinesis (Kibler et al., 2013).

The last category of causes the authors described is alterations in muscle activation. These alterations are often decreased serratus anterior activation and strength, and the alteration of the force-coupling of the upper trapezius and lower trapezius. In the altered force-coupling there is often a delayed lower trapezius activation which alters the upward rotation and posterior tilt. These variations create the abnormal movement of the scapula which can then lead to increased pain or injury as described above. Though the altered force coupling of upper trapezius and lower trapezius was mentioned as a common abnormality, the coupling of the activation of upper trapezius and serratus anterior are arguably the most impactful to normal shoulder function (Kibler & Sciascia, 2015).

2.4 Rehabilitation of Shoulder Injuries

Shoulder rehabilitation is most often focused on addressing the above-mentioned abnormalities to treat scapular dysfunction (Schory et al., 2016; Lin & Karduna, 2016). To effectively treat scapular dyskinesis, the emphasis should be on restoring the balance of muscle forces that allow for correct scapular motion and position (Kibler et al., 2013). The rehabilitation of the muscles should include: regaining strength in muscles, improving activation of muscles and selective relaxation of muscles (Kibler et al., 2013). One of the more complex aspects of this type of rehabilitation is addressing the coordinated activation patterns of muscles and improving the neuromuscular control. Mottram (1997) stressed the importance of regaining neuromuscular control in correcting shoulder dysfunction because it allows for normal coordination of the various joints and muscles contributing to upper extremity movement (Mottram, 1997).

So far, this review has covered the normal anatomy and musculature of the shoulder complex, the causes of scapular dyskinesis and its implications and common rehabilitation concepts in shoulder rehabilitation. The aforementioned works have suggested that when addressing a disordered muscular function of the shoulder, rehabilitation must assess the cause and outcome of the disorder and aim to alleviate those components of the disorder. Furthermore, rehabilitation should focus on increasing lower trapezius and serratus anterior activation while reducing upper trapezius activation (Kibler et al., 2013). The previous sections have established the importance of proper rehabilitation of shoulder complex disorders. The following sections will dissect specific components of common rehabilitation techniques and evaluate various methods for efficacy and effectiveness in the treatment of scapular dyskinesis.

2.5 Biofeedback

Feedback is an essential aid in rehabilitation, primarily to address the aforementioned concerns (Antunes et al., 2016; Weon et al., 2011). Magill and Anderson (2014) provide a detailed explanation of the different types of feedback. In one case, feedback can be task-intrinsic, in which the sensory-perceptual components of the skill give information on the performance of the task. This type of feedback is internal to the subject performing the skill, and the visual, auditory, proprioceptor and tactile components of that skill allow the subject to obtain information about the performance and outcome of the task. Task-intrinsic feedback is present in most skills as it provides information about the natural aspects of performing the skill. Another type of feedback that can be given in addition to the task-intrinsic feedback is augmented feedback. Augmented feedback is also called extrinsic feedback and includes information about the performance or outcome of the skill that is given from an external source, supplementing the intrinsic feedback. Augmented feedback can be given as knowledge of results, where information about the outcome of the skill is provided, or knowledge of performance where information about the performance of the skill, most commonly the movement characteristics, is provided to the subject. Augmented feedback in the form of knowledge of performance is a common practice in rehabilitation settings because the movement characteristics or patterns are often more important to focus on than the outcome of the skill (Giggins et al., 2013).

Various feedback techniques have been used in rehabilitation settings to correct the abnormal functioning of the musculoskeletal components of a joint. For example, a common practice for implementing feedback into rehabilitation is through the use of

biofeedback. Giggins et al., (2013) described biofeedback as a technique used to provide real-time biological information as feedback to subjects not otherwise available. Biofeedback in rehabilitation can be either physiological by measuring the neuromuscular, the respiratory or the cardiovascular system; or biomechanical by measuring movement, postural control or force. Biofeedback is used throughout rehabilitation and training and is delivered either as a quantitative measure displayed on a device such as heart rate monitors or as a transformed variable presented to the subjects as an auditory, visual or tactile signal (Giggins et al., 2013). Various feedback techniques have been used in rehabilitation and many appear to be effective at improving multiple physiological and biomechanical abnormalities. The following will examine the most commonly used technique.

2.6 EMG Biofeedback

Giggins et al. (2013) examined the uses of biofeedback in rehabilitation to determine the effectiveness and influences of biofeedback. In the evaluation of the various biofeedback techniques used in rehabilitation the researchers found that the most widely used form of biofeedback in rehabilitation is electromyography (EMG) biofeedback. EMG biofeedback provides real-time augmented visual feedback concerning the timing and intensity of muscle activation. This method has been used to enhance muscle activity in weak muscles or to reduce muscle activity in an overactive or spastic muscle. EMG biofeedback has been used to improve rehabilitation of various conditions including post anterior cruciate ligament surgery, knee osteoarthritis, neck pain, patellofemoral pain and post-stroke to name a few (Giggins et al., 2013). This

technique has been found to be effective at improving specific aspects of shoulder function and recovery. Examples of studies are detailed below.

Holterman et al. (2010) demonstrated that EMG biofeedback can be used to learn selective activation of a shoulder muscle. The researchers investigated the ability of subjects to consciously activate specific intramuscular aspects of the serratus anterior following a familiarization and practice session with EMG biofeedback. The researchers explored the idea that the lower trapezius and serratus anterior make up the lower scapula rotation force couple in which activation of one will synergistically activate the other. This coupling of the muscles would allow for a reduction of the activation of the upper trapezius which then could lead to a more balanced control of the scapula. The study allowed for a ten-minute familiarization and a one-hour practice session with the EMG providing real-time biofeedback. At the end of this session six of the nine subjects were able to selectively activate at least one part of the serratus anterior. The results of their study indicated that EMG biofeedback has the possibility to be used to improve neuromuscular control of scapular muscles after a short training session.

Lim et al. (2014) also set out to determine if EMG biofeedback could be used to improve control of certain scapular muscles. The results of their study indicated that EMG biofeedback can be used to change the muscle activation ratios of specific muscle groups. The researchers were interested in investigating the ability to alter antagonistic muscle ratios with the use of EMG biofeedback. Specifically, the researchers examined the use of EMG biofeedback to reduce posterior deltoid and increase infraspinatus activation during normal shoulder rehabilitation exercises. The subjects were given ten minutes to familiarize themselves with the activities and then performed the exercises

with and without the EMG biofeedback. The researchers concluded that EMG biofeedback was effective at changing the muscle activation amplitudes and ratios during external rotation exercises. Their study indicated that the addition of EMG biofeedback allowed for better performance of exercises, though it did not address the actual learning or retention of these improvements.

Research has investigated the short-term "performance" improvements from EMG biofeedback, but retention tests are needed to determine if this technique actually leads to an improved ratio in the long-term learning of this improvement (Lim et al., 2014; Giggins et al., 2013). Ma et al. (2011) were able to use EMG as a tool to reduce upper trapezius activation during typing with a six month follow up. Their results suggested the possibility for the effects from EMG biofeedback to be retained, though their research did not explore the use of EMG biofeedback in conjunction with exercises to alter activation ratios.

2.7 Summary

In summary, the normal function of the shoulder complex stems from the varying differences in the articular surface interactions of the three joints in the complex. The lack of congruence in the shoulder joint creates an inherent instability that is countered by various ligaments and muscles that are coupled to increase stability to carry out movement of the upper extremity. Disordered force-coupling of various muscles of the shoulder complex (most commonly an over-activation of the upper trapezius and under-activation of the serratus anterior) can lead to scapular dyskinesis which can lead to injuries of the glenohumeral joint capsule and should be addressed in rehabilitation. Shoulder rehabilitation is most effective when focused on treating the underlying causes

of the injury and this is often in the form of addressing the disordered force-coupling of the scapular stabilizing muscles (most importantly the serratus anterior and upper trapezius). Rehabilitation often utilizes various types of feedback to improve these desired outcomes. A common form of feedback is the utilization of biofeedback which provides real-time information to the subject that would otherwise be unknown. A subcategory of biofeedback is the use of EMG biofeedback as a way to show a visualization of the amplitude and timing of the activation of muscle fibers during movements.

EMG biofeedback is well researched and has been found to be helpful in the treatment of various musculoskeletal disorders. For example, Huang et al. (2013) examined the prospect of utilizing EMG biofeedback as a means for subjects to increase the motor control ability of shoulder stabilizer muscles while receiving muscle activation information from EMG biofeedback. The researchers determined that EMG biofeedback is effective at decreasing the activation of upper trapezius and increasing the activation of serratus anterior and the middle and lower trapezius muscles (Huang et al., 2013). In addition, Giggins et al. (2013) conducted a literature review investigating the ability of biofeedback to improve the effects of rehabilitation. In their review, they determined that EMG biofeedback is effective at aiding in the rehabilitation of anterior cruciate ligament reconstruction, quadriceps exercises and decreasing neck pain (Giggins et al., 2013).

Taken together, the research examined suggests that EMG biofeedback can be utilized as a method to improve shoulder function. Specifically, EMG biofeedback may be a viable means to improve neuromuscular control of the scapular stabilizer muscles. This improvement in neuromuscular control would address the common concern in

rehabilitation; an altered force-coupling of scapular muscles specifically the over-activation of the upper trapezius and under-activation of the serratus anterior during upper extremity movements.

Chapter 3: Methods

The purpose of this study was to determine if EMG biofeedback could be an effective tool to improve scapular control by decreasing the upper trapezius to serratus anterior activation ratio. A secondary purpose of this study was to determine if any observed changes in the activation ratio would be retained beyond the time frame of the implementation of the EMG biofeedback. The upper trapezius to serratus anterior activation ratio was examined and the changes to this ratio were analyzed along with the individual changes in muscle activity. It was hypothesized that the utilization of EMG biofeedback twice a week for four weeks would significantly decrease the upper trapezius to serratus anterior muscle activation ratio during common scapular rehabilitation exercises. Additionally, it was hypothesized that the decrease in the ratio would be present at the end of the treatment period of four weeks as well as after a two-week retention period.

3.1 Subjects

This study consisted of twenty subjects who were recruited from the California Polytechnic State University campus. Subjects were eligible for inclusion in this study if they were college aged (18-25 years), had the ability to perform shoulder rehabilitation exercises, and have not been told by a medical professional that they were unable to participate in physical activity. Subjects were excluded from this study if they met any of the following criteria: a recent (within the last two years) shoulder injury, recent (within the last two years) participation in shoulder rehabilitation, or the having other conditions which would limit the ability to perform shoulder rehabilitation exercises. Additionally, subjects were excluded from participation in this study if they participated in or had the

intention to participate in upper extremity focused weight training two or more days a week during the course of the study.

3.2 Procedures

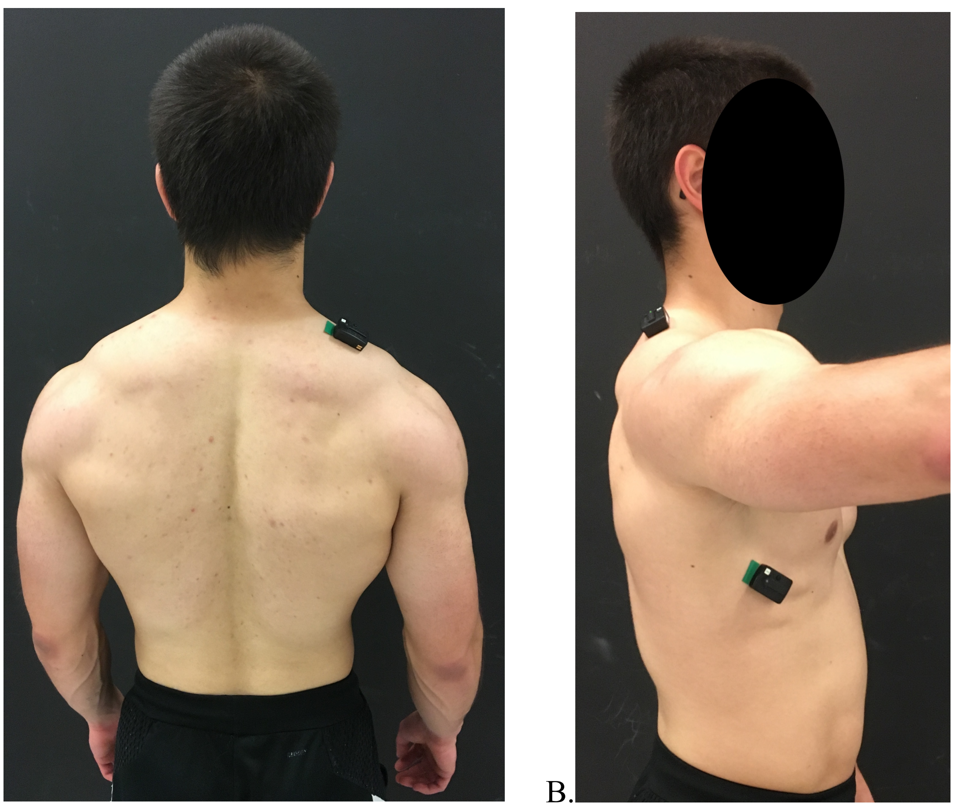
3.2.1 Pre-Participation Screening

Subjects interested in participating were interviewed in person (or via phone or email) to establish initial eligibility for the study. Inclusion and exclusion criteria were discussed including the following requirements; being college aged (18-25 years), having the ability to perform shoulder rehabilitation exercises, not having been told that they are unable to participate in physical activity, not having a recent shoulder injury, not having participated in shoulder rehabilitation within the last two years, not having other conditions which would limit the ability to perform shoulder rehabilitation exercises and not participating in upper extremity focused weight training exercises more than twice a week during participation. If the criteria for participation were met the subjects were instructed to come to the facility and demonstrate their ability to perform the three exercises consistent with the inclusion criteria. Those who met all criteria signed the informed consent form.

3.2.2 EMG Data Collection

Each participant performed a baseline EMG test for all three exercises during their first testing session. EMG data were collected using Delsys Trigno wireless EMG system (Delsys acquisition software version 4.3) and were analyzed with the Delsys analysis software (version 4.3). Before placing the electrodes, the skin was cleaned with isopropyl alcohol/skin prep (Ekstrom, Soderberg, & Donatelli, 2005). As shown in **Figure 3.1**, one electrode was placed on the upper trapezius midway between the C7

vertebrae and the acromion process parallel to the muscle fibers (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000; Ekstrom et al., 2005). Another electrode was placed on the serratus anterior below the axilla on the mid-axillary line anterior to the latissimus dorsi and posterior to the pectoralis major parallel to the muscle fibers (Ludewig, Hoff, Osowski, Meschke, & Rundquist, 2004). Signals were tested within the Delsys acquisition software (version 4.3) to ensure correct electrode placement and sufficient strength of signal.



A. B.

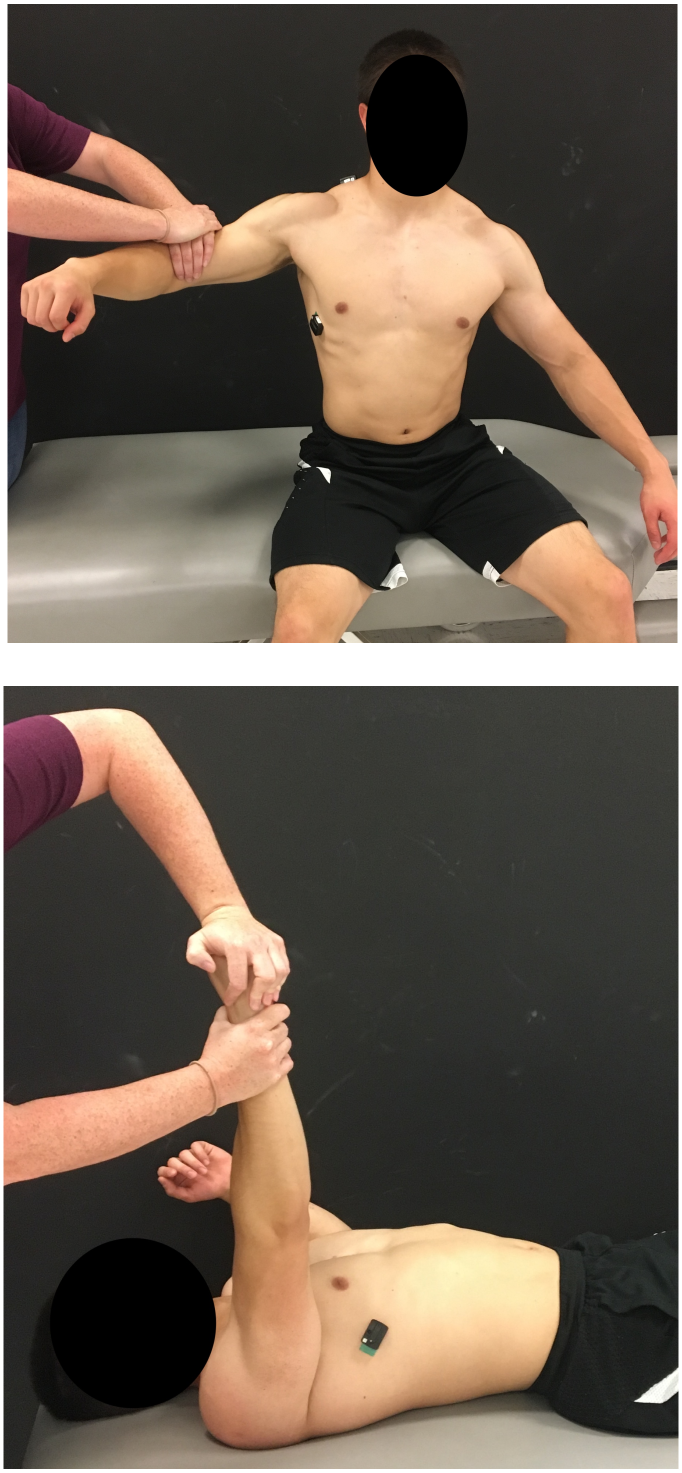
Figure 3.1: Visual Depiction of Electrode Placement A. depicts the upper trapezius electrode placement, and **B.** shows the placement on the serratus anterior.

3.2.3 MVC Tests

Maximal voluntary contraction (MVC) tests were conducted to normalize the data to a percentage of each subject's MVC to allow comparison across subjects. MVC’s were performed on the upper trapezius and serratus anterior of the dominant upper limb on

each subject. Descriptions and examples of the MVC tests are depicted in **Figure 3.2** and **Table 3.1**. Each muscle's MVC was collected three times and the highest value obtained was used as the MVC measure. The MVC protocol for the serratus anterior was implemented according to previous research by Ekstrom et al. (2004). To measure the serratus anterior MVC the subjects were lying on the training table in the supine position with their elbow fully extended and shoulder flexed to 90 degrees in slight protraction. The subjects were instructed to resist maximally against scapular retraction by pushing up against the force applied by the researchers at the hand (Decker, Hintermeister, Faber, & Hawkins, 1999).

Measurement of the upper trapezius MVC was performed with the subject seated in a backless chair with their shoulder abducted to 90° and their elbow at full extension. The subjects were instructed to resist the maximal resistance applied superior to the elbow during shoulder abduction (McLean, Chislett, Keith, Murphy, & Walton, 2003). Subjects performed each MVC test three times for three seconds each repetition. They were given thirty seconds of rest in between each repetition. The highest of the three trials for each muscle was selected as the MVC value. The data collected was used to normalize the root mean square data to a percentage of the maximal voluntary contraction (%MVC). After baseline MVC values were collected, the subjects were instructed on the proper technique in performing the three exercises: Side-lying external rotation, side-lying flexion, and forward flexion in scaption (standing Y) as described in the following section.



A.

B.

Figure 3.2: Example of MVC Tests A. shows the hand placement for the upper trapezius MVC with the subject resisting maximal shoulder abduction. **B.** shows the MVC for the serratus anterior with the subject resisting maximal scapular retraction.

Table 3.1. Description of the Electrode Placement and MVC Testing Procedures.

Electrode Placement	
Upper Trapezius	Midway between C7 vertebrae and the acromion process
Serratus Anterior	Inferior to axilla on mid axillary line, anterior to latissimus dorsi, posterior to pectoralis major
MVC Test Procedure	
Upper Trapezius	Seated in chair without support, shoulder abducted to 90° and elbow extended. Resisted maximal shoulder abduction (force applied superior to elbow)
Serratus Anterior	Lying in supine position with elbow extended and shoulder flexed to 90°. Resisted maximal retraction (force applied at hand)

3.2.4 Exercises

On the first visit, the subjects were instructed on the correct mechanics in performing the three exercises. The exercises selected were based off previous research which established their usefulness in treating shoulder dysfunctions (**Table 3.2**). The exercises performed were: side-lying external rotation, side-lying flexion and forward flexion in scaption (standing Y) (Lin & Karduna, 2016; Schory et al., 2016; Moseley Jr., Jobe, Pink, Perry, & Tibone, 1992). The exercises were demonstrated to the subjects as are shown in **Figures 3.3 and 3.4**. Side-lying external rotation was performed with the subject lying on the non-dominant side on an examination table. A towel was placed under the elbow of the dominant side and a weight was given to perform the exercises. The weight used for each exercise was based on previous research by Cools et al. (2007) in which the sex and weight of the subject determine the weights used as shown in **Table 3.3** (Cools et al., 2007). Side-lying external rotation was performed with the subject

lying on their non-dominant side on an examination table. The subject held the appropriate weight in the dominant hand with the elbow flexed to 90° and the shoulder in a neutral position. The subject then externally rotated the shoulder through their entire range of motion. Side-lying flexion was performed with the subject lying on the non-dominant side on an examination table. The subject held a weight (based on body weight) with their elbow fully extended and their shoulder in the neutral position resting on their side. The subject then moved their shoulder in flexion through their entire range of motion (at least 120°). Standing Y exercise was performed with the subject standing with their arm in a neutral position holding an appropriate weight. The subject would then raise their arm in the scapular plane to at least 120° keeping their elbow extended.

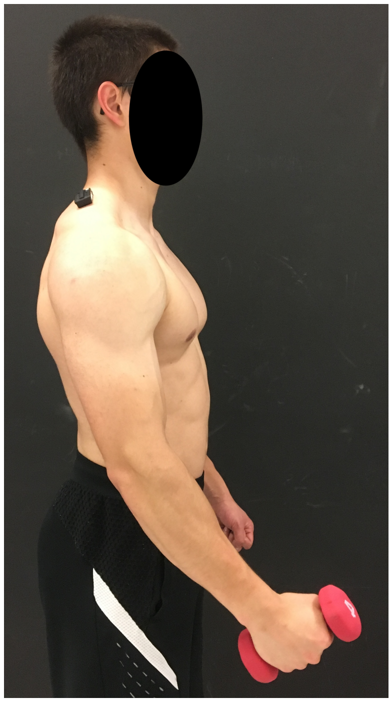
Once the proper mechanics of the exercises were described and demonstrated by the researcher, the subjects performed 10 sample repetitions of the exercises without weights, and verbal feedback was given to help ensure consistency of movement. In order to control for dynamic effects (rate of muscular contraction), subjects were then instructed to perform three repetitions of each exercise in time with a metronome set to 40 beats per minute (bpm) for the standing Y and 50 bpm for the side-lying external rotation and side-lying forward flexion. The ordering of the exercises was randomly allocated using a random number generator to prevent a bias or practice effect.

Table 3.2. Description of Exercises Detailing Body and Upper Extremity positioning and movement performed.

Exercise	Body Position	Upper Extremity Position	Movement Performed
Side-lying external rotation	Side-lying on non-dominant side	Elbow flexed to 90°, shoulder in neutral position	Externally rotating shoulder through whole ROM
Side-lying Flexion	Side-lying on non-dominant side	Elbow fully extended, shoulder in neutral position	Move shoulder through flexion to 120°
Forward flexion in scaption(standing Y)	Standing	Elbow extended, shoulder in neutral position, thumb superior	Raise arm in scapular plane to 120°, keeping elbow extended

Table 3.3. Description of Weights Used for Each Exercise Based on Weight and Sex.

Exercise	Male Subject Weight			Female Subject Weight		
	50-59 kg	60-69 kg	70-85 kg	50-55 kg	56-64 kg	65-75 kg
Side-lying external rotation	2.5	3	3.5	2.5	3	3
Side-lying flexion	2.5	3	3.5	2	2.5	3
Forward flexion in scaption (standing Y)	3	3.5	4	3	3.5	4

A. 

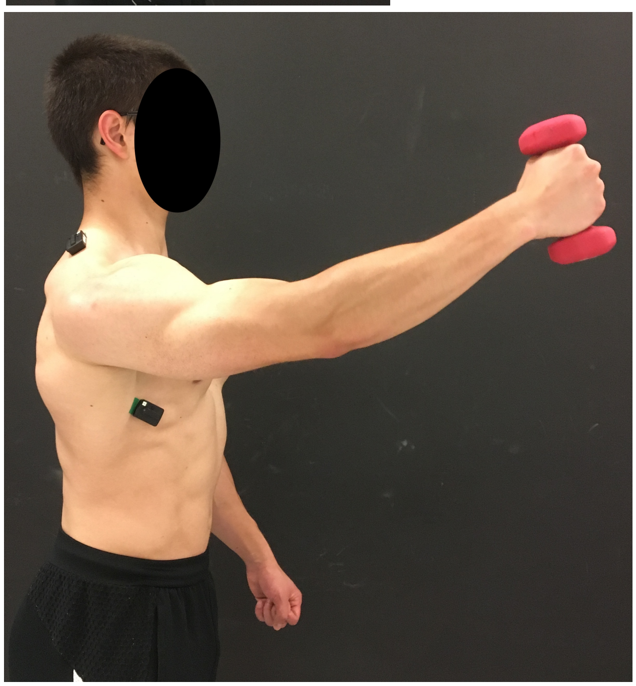
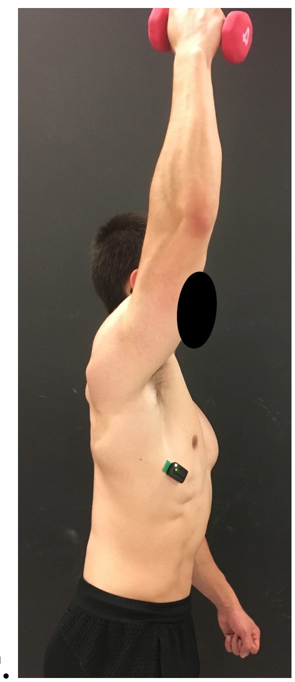
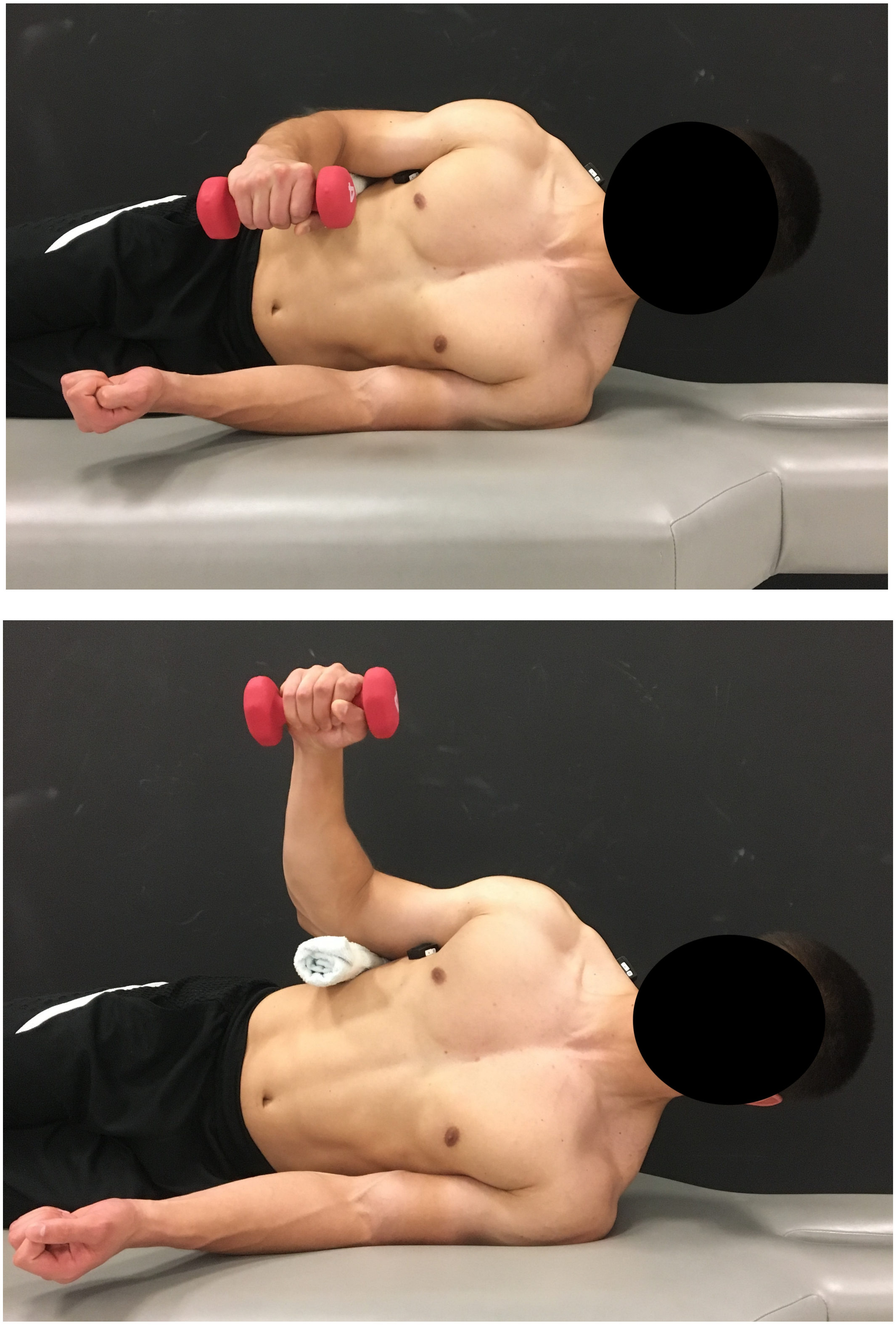
B.  C. 

Figure 3.3: Forward Flexion in Scaption (Standing Y) A. indicates the starting position **B.** indicates the middle position **C.** indicates the ending position. The same joint movement occurs while side-lying in side-lying forward flexion exercise.



A.

B.

Figure 3.4: **Side-Lying External Rotation Exercise A.** shows the starting position and **B.** shows the ending position of full external shoulder rotation

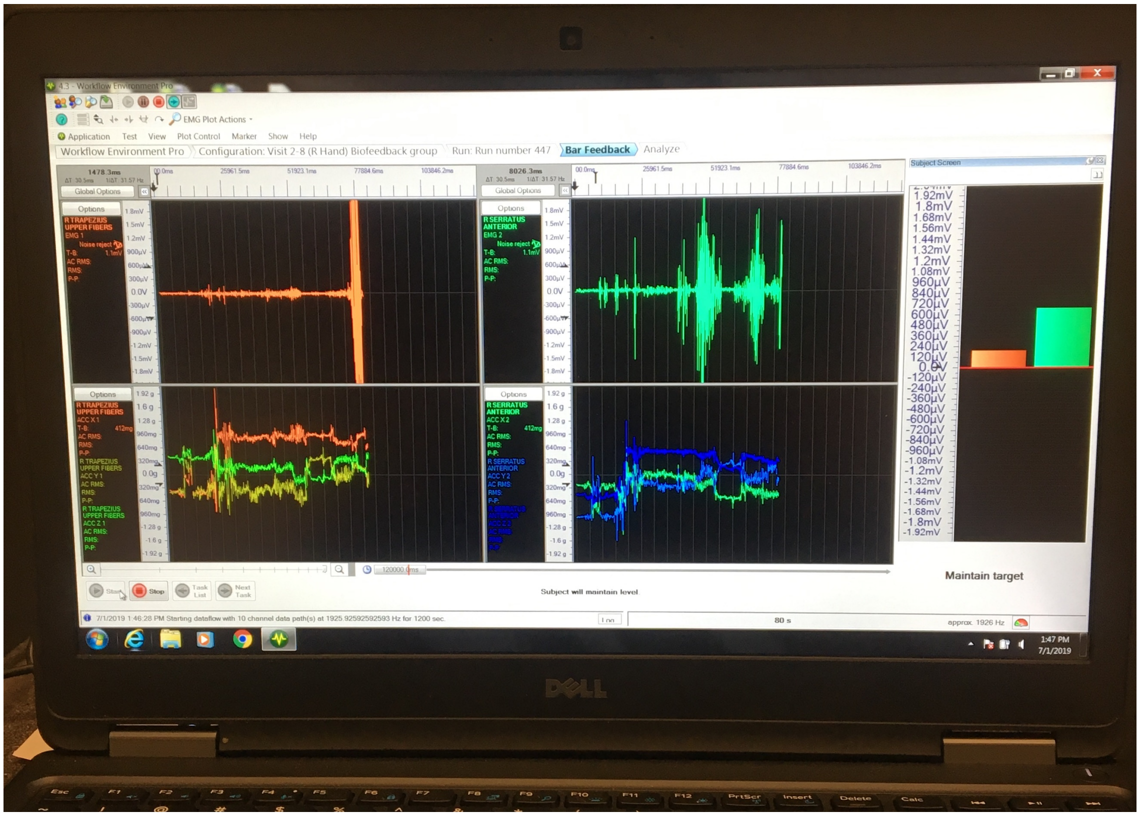


Figure 3.5: Computer Display Visible to Subjects. The top left box is the RMS of the upper trapezius activation over time, the middle box on the top is the RMS of the serratus anterior activation over time. The far-right rectangle is an output of the activation of the upper trapezius (left) and the serratus anterior (right) in real time.

<u>3.2.5 EMG Biofeedback</u>

The EMG biofeedback group (N=15) performed the experimental protocol testing with EMG biofeedback twice a week for four weeks. Electrodes were placed on the upper trapezius and serratus anterior of the dominant side. On the first day, each subject in this group was given ten minutes to familiarize themselves with the biofeedback program, specifically the changes to the feedback with different motions and muscular activations (Holterman et al., 2010). The purpose of the ten-minute familiarization period was for the subjects to understand the relationship between their movements and the changes to the EMG output. In order to maximize the potential of the subjects in learning this relationship, a structured and controlled procedure was followed during this period. This

procedure included various movements and exercises (see **Appendix A**) the subjects were instructed to perform and practice in order to facilitate learning the relationship between movement and EMG output.

Each subject in the EMG biofeedback group then performed three sets of ten repetitions of each of the three exercises at their own pace. Specific exercise sequences were created and the order of the exercises was scheduled on each day to eliminate an order effect. The EMG biofeedback was visible as a real-time root mean square output on a computer monitor visible to the subjects as seen in **Figure 3.5**. As the subjects were performing the exercises, they were given instructions to increase the activation of the serratus anterior and decrease the upper trapezius activation by altering the activation output appropriately on the display. The researcher answered any questions regarding the exercise technique or biofeedback display on each day of testing. The exercises were also reviewed weekly to ensure that all techniques were correct, and questions were answered.

The exercise only group (N=5) also performed the exercises with the supervision of the researchers twice a week for four weeks without the EMG biofeedback display. The subjects in this group performed three sets of ten repetitions of each exercise each day. The orders of the exercises were the same as the EMG biofeedback group to keep any fatigue or practice effect consistent for both groups.

3.2.6 Protocol

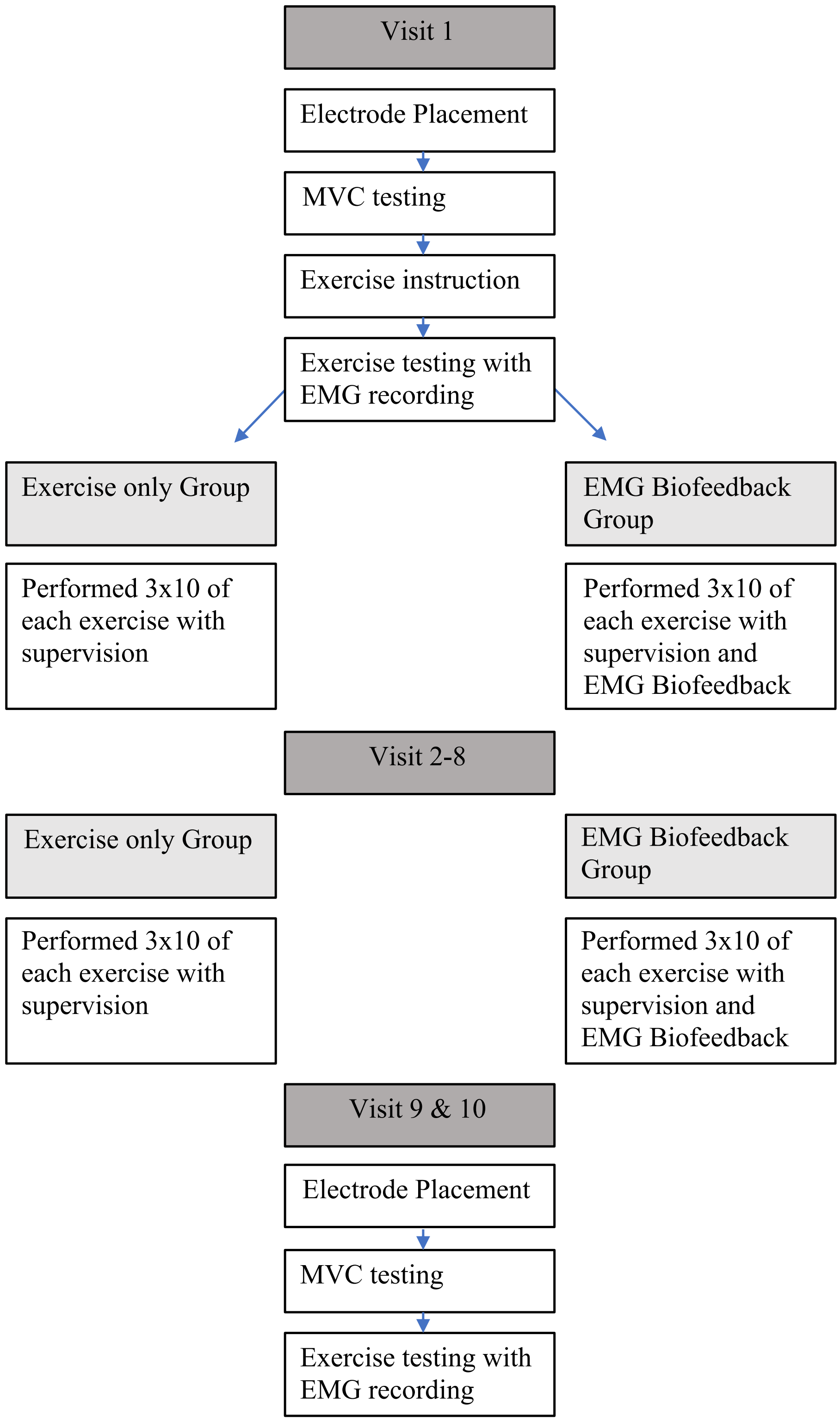
Prior to arrival, subjects were randomly assigned to either the exercise only group or the EMG biofeedback group using a random number generator. After the eligibly of the subject was established during the pre-participation discussion, subjects were instructed to arrive at Cal Poly Human Performance Laboratory in clothing suitable for

exercise and access to the electrode sites. The subjects were also instructed to refrain from extraneous exercise on the days they visited the laboratory. Upon arrival to the laboratory, subjects were evaluated for their ability to safely perform the three exercises by the researcher. They were then instructed to read and sign the informed consent. Each subject was then fitted with the EMG electrodes on the upper trapezius and serratus anterior on the dominant side of their body. Data were collected on all subjects on the first visit, after four weeks of training, and after a two-week retention period (see **Table 3.4**). On these testing days, the skin was prepped, and the electrodes were placed on the muscles according to the recommendations mentioned above. MVC values were measured on each subject for both the upper trapezius and the serratus anterior. The exercises were described to each subject and they were then instructed to perform three repetitions of each exercise in time with the metronome to collect the RMS data to calculate the activation ratio later. The electrodes were removed from those in the exercise only group, and they were instructed to perform three sets of ten repetitions of each exercise and were reminded to ask any questions needed for the understanding of the exercises. The EMG biofeedback group participated in the ten-minute familiarization period with the biofeedback. They then performed the same amount of exercises but were instructed to increase the amount of serratus anterior activation and decrease the upper trapezius activation by attempting to raise or lower the activation lines on the computer screen, respectively. Once the exercises were completed, the electrodes were removed and all subjects were given instructions on when to return.

All subjects returned twice a week for four weeks and performed the exercises with the supervision of the researcher to ensure proper form, compliance and

understanding of the exercises. The days in which the subjects performed the exercises without collecting data the exercise only group performed the exercises in the laboratory without any electrode placement. The EMG biofeedback group was fitted with the electrodes then performed one MVC on each muscle which was needed for EMG biofeedback output. They were then instructed to perform the exercise with the same cues to increase the serratus anterior and decrease upper trapezius activation through the influence of EMG biofeedback. There was no recording of data on these days. The electrodes were removed from the subjects and they were given any necessary further instructions. **Table 3.4** details the protocol of expectations of each group at each visit.

Table 3.4. Flowchart Depicting the Procedures Each Group Followed at Each Visit.



3.3 Data Analysis

Raw EMG was processed using Delsys analysis software (version 4.3). Root Mean Square (RMS) of these data was calculated and these data were normalized to the MVC for each muscle on each day. The mean RMS was displayed as a percentage of the MVC for each muscle in each exercise. The ratio was calculated by dividing the RMS upper trapezius value by the RMS serratus anterior value. The calculated ratio value was measured as a baseline on the first day, after the four-week program and again following a two-week retention period.

The percent change was calculated for the upper trapezius to serratus anterior ratio and for each individual muscle. The percent change was calculated by comparing the measure on visit one to visit nine as well as visit nine to visit ten. The data were analyzed in this manner to take into account the between subject differences in the percent MVC values at baseline. Main effects of group (exercise only vs. EMG biofeedback), exercise (side-lying external rotation, side-lying flexion and forward flexion in scaption) and subject were analyzed along with the interaction of group and exercise. A multi-factor analysis of variance (ANOVA) was performed for each variable (ratio, upper trapezius activation and serratus anterior activation) for each percent change (visit one to visit nine and visit nine to visit ten) to determine if there was a significant change in the upper trapezius to serratus anterior activation ratio, the upper trapezius values or the serratus anterior values after implementing EMG biofeedback into the training regimen. The values were analyzed using Minitab with a level of significance set at 0.05.

Chapter 4: Results

4.1 Results

Subject characteristics for Age (years), Height (in), and Weight (lbs.) are reported in **Table 4.1**. The subjects were randomly assigned to either the EMG biofeedback group (n=15) or the exercise only group (n=5). More subjects were assigned to the EMG biofeedback group than the exercise only group in order to gain as much insight about the response to the EMG biofeedback as possible. All subjects in both groups completed all ten visits in the six weeks.

Table 4.1: General Subject Demographics. Standard deviation is in parentheses.

Variable	All (n=20)	Females (n=10)	Males (n=10)
Age (year)	21.75 (1.77)	23.56 (1.75)	22.3 (1.70)
Height (in)	66.9 (2.81)	65 (2.49)	68.8 (1.55)
Weight (lbs.)	152.2 (33.89)	132.8 (15.53)	171.6 (36.71)

<u>4.1.1 Generalized Linear Models</u>

Percent change for each variable (ratio, upper trapezius, and serratus anterior) was calculated in order to take into account the between subject differences in values. The percent change from visit one compared to visit nine (end of the fourth week), and from visit nine to visit ten (end of the sixth week) were calculated and analyzed for each variable. The standardized residuals and FITS were calculated for the data, and outliers were removed to allow for the data to meet the requirements of an ANOVA. A multi-factor ANOVA was used to determine the effects of group and exercise as well as the interaction of group and exercise on the percent change of each variable. Two ANOVA's were performed on each variable to examine the percent change from visit one to visit nine as well as from visit nine to visit ten (six ANOVA's in total). Subject was also used

as a factor with the expectations that the subject is significant as they are independent subjects. The significance level was set at 0.05. Tukey post hoc testing was performed on significant results. Results from the statistical tests can be seen in **Table 4.2**, and each percent change value is depicted in **Table 4.3.**

Table 4.2: Results of Statistical Tests. Values presented are the p-values from the multi-factor ANOVAs performed. 9:1 compares the values on visit one to visit nine, 10:9 compares values on visit nine to visit ten. *indicates a significance level below 0.05

Factors	Ratio 9:1	Ratio 10:9	UT 9:1	UT 10:9	SA 9:1	SA 10:9
Group	0.084	0.065	0.007 *	0.358	0.000 *	0.001 *
Exercise	0.606	0.202	0.002 *	0.175	0.002 *	0.053
Subject	0.000	0.000	0.000	0.031	0.000	0.000
Group*Exercise	0.438	0.449	0.567	0.437	0.553	0.049 *

Table 4.3: Percent Change Values. 9:1 indicates the percent change from visit one to visit nine, 10:9 indicates percent change value from visit nine to visit ten. UT is upper trapezius, SA is serratus anterior, Ratio is the upper trapezius to serratus anterior ratio. The Exercises listed are side-lying external rotation as ER, standing Y in scaption as Y, side-lying forward flexion as FF. The values represent the percent change in each exercise for all subjects. *indicates a significance level below 0.05

Group/ Exercise Comparison	Ratio 9:1	Ratio 10:9	UT 9:1	UT 10:9	SA 9:1	SA 10:9
Exercise only	-17	4	27*	-20	29*	-12*
EMG Biofeedback	-35	10	-10*	-12	196*	14*
ER	-21	-10	46*	-25	139	9
Y	-24	20	-8	-20	78*	-11
FF	-32	11	-12	-4	118	5

4.1.2 Ratio

It was hypothesized that performing common shoulder rehabilitation exercises with EMG biofeedback twice a week for four weeks would significantly decrease the upper trapezius to serratus anterior muscle activation ratio. It was also hypothesized that the decrease in this ratio would be present at the end of the treatment period of four weeks as well as after a two-week retention period.

There was no significant effect of group [EMG biofeedback, Exercise only] ($p=0.084$) or Exercise ($p=0.606$) on the percent change of the upper trapezius to serratus anterior ratio from visit one to visit nine. There was no interaction between group and exercise ($p=0.438$). As shown in **Table 4.3**, there was a decrease in the ratio for both groups. Though not significant, there was a trend of more of a decrease in the EMG biofeedback group compared to the exercise only group. As seen in in **Figure 4.1**, the EMG biofeedback group changed by an average of -35 percent while the exercise only group changed by -17 percent.

Similarly, when comparing the ratio on visit ten to visit nine, there was no effect of group ($p=0.652$) nor exercise ($p=0.202$). There was no interaction between group and exercise ($p=0.449$). The EMG biofeedback group had more of an increase in the ratio (10%) compared to the exercise only group (4%). This suggests that any change in the ratio after the two-week retention period was not statistically significantly different between groups.

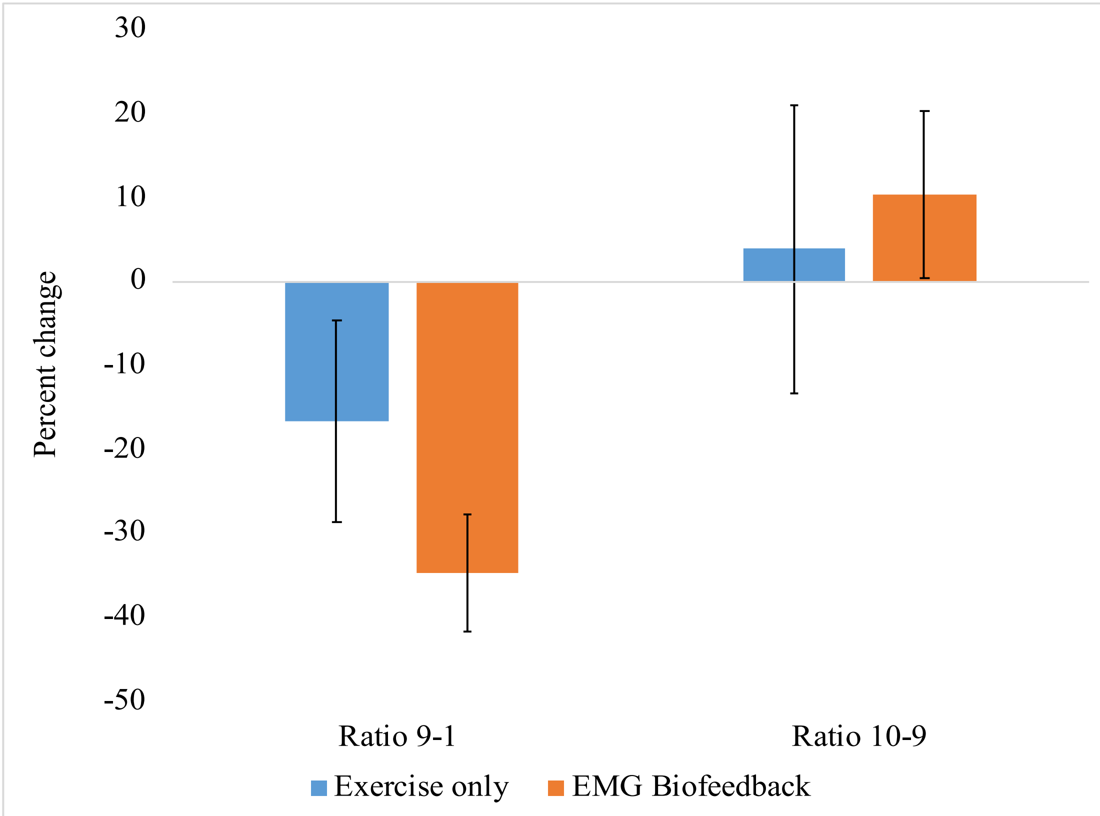


Figure 4.1: Graphical Representation of the Percent Change in the Upper Trapezius to Serratus Anterior Ratio. Ratio 9-1 is the percent change from visit one to visit nine, Ratio 10-9 is the percent change from visit nine to visit ten. Error bars are standard errors.

4.1.3 Individual Muscle Changes

The change in the upper trapezius to serratus anterior ratio was hypothesized to take place by decreasing the activation of the upper trapezius and increasing the serratus anterior activation through the use of EMG biofeedback. These individual muscle activation changes were analyzed to determine if EMG biofeedback could significantly alter the individual muscle activation.

There was a main effect of group (p=0.007), and exercise (p=0.002) on the upper trapezius muscle activation value comparing visit one to visit nine. This suggests that EMG biofeedback significantly decreases the upper trapezius activation after four weeks of use when compared to the exercise only group. As shown in **Table 4.3**, **t**he EMG

biofeedback group had a decrease in upper trapezius activation (-10%) compared to the exercise only group (27%). This also indicates that the exercises used had different effects on the upper trapezius activation with side-lying external rotation having an increase in activation while the side-lying forward flexion and standing Y had an average decrease.

When comparing the upper trapezius activation value from visit nine to visit ten, there was no significant effect of group (p=0.358), exercise (p=0.175), nor was there an interaction between group and exercise (p=0.437). As depicted in **Table 4.2,** these results indicate that having EMG biofeedback had no effect on the changes in the upper trapezius activation from visit 9 to visit 10.

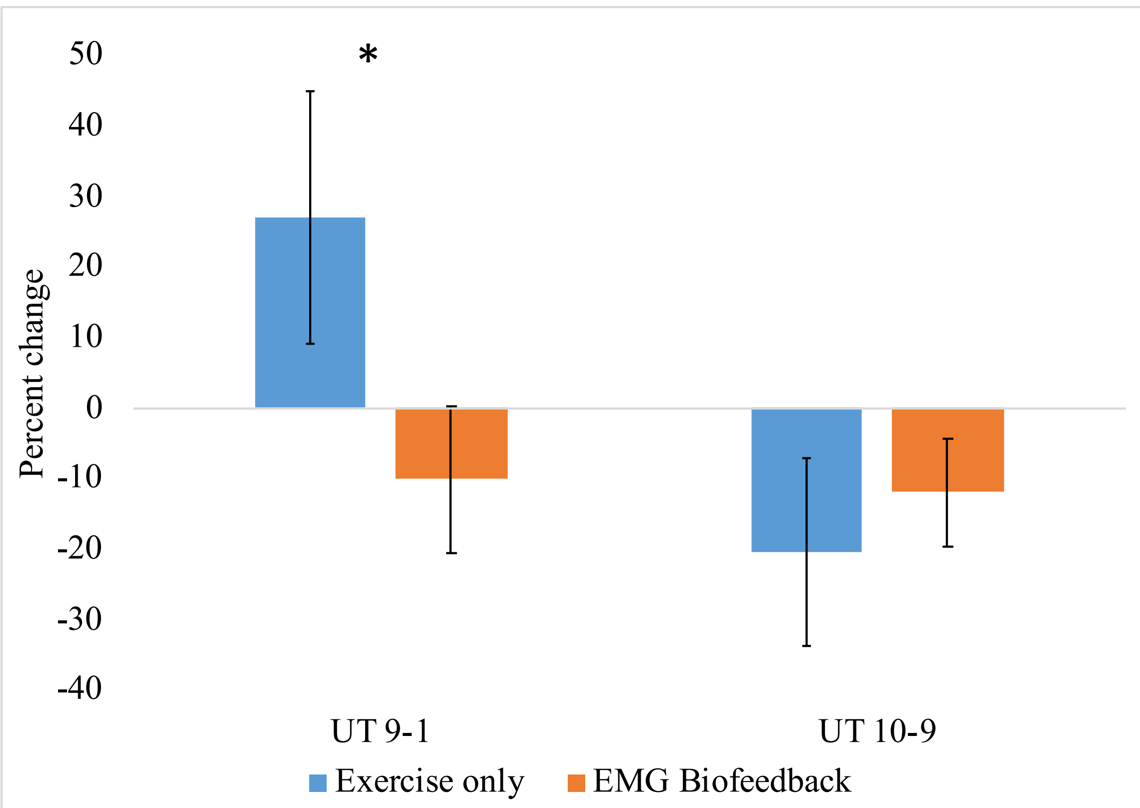


Figure 4.2 Graphical Representation of the Percent Change in the Upper Trapezius (UT) Activation. UT 9-1 is the percent change from visit one to visit nine, UT 10-9 is the percent change from visit nine to visit ten. Error bars are standard errors. *indicates a significance level below 0.05 for the main effect of group.

There was a main effect of group ($p<0.000$) and exercise ($p=0.002$) on the serratus anterior muscle activation values comparing visit one to visit nine. This suggests that, as expected, performing shoulder exercises with EMG biofeedback increases the activation of the serratus anterior more than performing the exercises without it. The EMG biofeedback group (196%) had more of an increase in activation compared to the exercise only group (29%), though both groups did see an increase.

As shown in **Figure 4.3**, there was a main effect of group ($p=0.001$) and group*exercise interaction ($p=0.049$) on the serratus anterior activation when comparing visit nine to visit ten. The effect of exercise ($p=0.053$) failed to reach significance. The significant main effect of group indicated that there is a difference in the retention of the altered serratus anterior muscle activation with the exercise only group decreasing (-12%) in activation while the EMG biofeedback group had a slight increase (14%).

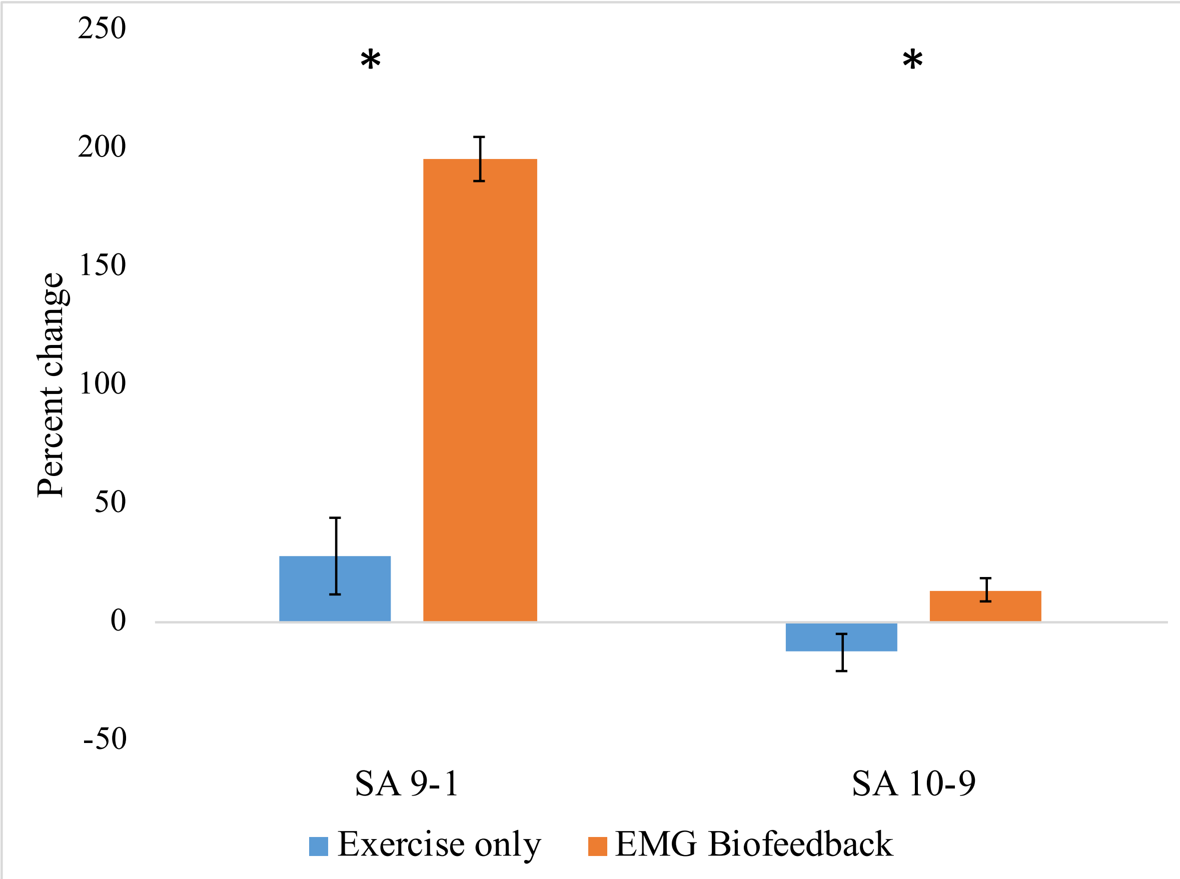


Figure 4.3: Graphical Representation of the Percent Change in the Serratus Anterior (SA) Activation. SA 9-1 is the percent change from visit one to visit nine, SA 10-9 is the percent change from visit nine to visit ten. Error bars are standard errors. *indicates a significance level below 0.05 for the main effect of group.

4.1.4 Exercises

Though not part of the original hypotheses, there was some effect of exercise on the changes in ratio and individual muscle activations as depicted in **Table 4.2** and **Table 4.3**. There were significant effects of exercise in two of the factors analyzed, however there was no significant effect of exercise in ratio comparing visit one to visit nine ($p=0.606$), ratio comparing visit nine to visit ten ($p=0.202$), upper trapezius comparing visit nine to visit ten ($p=0.175$), nor serratus anterior comparing visit nine to visit ten ($p=0.053$). There was a main effect of exercise in upper trapezius comparing visit one to visit nine ($p=0.002$) and serratus anterior comparing visit one to visit nine ($p=0.002$).

For the upper trapezius comparing visit nine to visit one, average differences indicated that the side-lying external rotation had an increase in upper trapezius activation (46%) while the other two exercises had a decrease. For the serratus anterior comparing visit one to visit nine, the standing Y had less of an increase (78%) when compared to side-lying external rotation (139%) and side-lying forward flexion (118%). This suggests that the changes seen were affected by the exercises performed.

Chapter 5: Discussion and Conclusion

5.1 Discussion

The purpose of this study was to determine if EMG biofeedback could be used to improve scapular control by decreasing the upper trapezius to serratus anterior activation ratio. A secondary purpose of this study was to determine if these predicted improvements in the ratio can be retained beyond the timeframe in which the treatment is provided. It was hypothesized that the utilization of EMG biofeedback for four weeks would significantly decrease the upper trapezius to serratus anterior muscle activation ratio during common scapular rehabilitation exercises. It was also hypothesized that the decrease in the ratio would be present at the end of the treatment period of four weeks as well as after a two-week retention period. The results of this study do not directly support the hypotheses as there was no significant effect of group (EMG biofeedback and exercise only) on the upper trapezius to serratus anterior activation ratio. There was also no significant effect of group when examining the ratio on visit nine and visit ten. This indicates that the change in the ratio during the two-week retention was not significantly different for each condition. The specifics of the findings are discussed below.

5.1.1 Muscle Activation Changes

The force coupling of the upper trapezius and serratus anterior has been shown to be essential to healthy shoulder function as it allows for normal scapular stabilization and motion (Kibler & Sciascia, 2015). When the coupling of this musculature is altered, there can be a loss of control resulting in abnormal scapular motion and position, or scapular dyskinesis (Kibler et al., 2013). A common abnormal coupling is the overactivation of the upper trapezius and inhibition of the serratus anterior, the ratio in which this research was focused. EMG biofeedback was used in this research to attempt to decrease this ratio

during common shoulder exercises to reduce the risk of trauma to the shoulder complex (Schory et al., 2016; Kibler et al., 2013). The EMG biofeedback group performed three common shoulder rehabilitation exercises twice a week for four weeks while receiving real-time biofeedback presented on a computer screen and attempting to decrease the upper trapezius activation and increase the serratus anterior activation. The exercise only group performed the same amount and frequency of exercises with the only difference being that they performed the exercises without any augmented feedback.

Though there was a trend indicating more of a decrease in the ratio in the EMG biofeedback group compared to the exercise only group, the differences were not enough to be statistically significant. Therefore, the results of this study did not support the hypothesis as there was no statistically significant decrease in the upper trapezius to serratus anterior ratio after four-weeks of EMG biofeedback when compared to the exercise only group. These data suggest that EMG biofeedback is effective at decreasing this ratio, but the difference was not enough to elicit statistical significance. This lack of significance is not in line with the findings of previous research examining shoulder muscle ratios (Huang et al., 2013; Lim et al., 2014).

The lack of significance in the ratio could be due to a number of factors including the small number of subjects in the exercise only group (n=5) compared to the EMG biofeedback group (n=15). Each subject's data had a large impact on the outcome due to the small number of subjects in the exercise only group. This could have led to the lack of significance in some instances and is a possibility of low statistical power (no power analysis was conducted). Another reason that could explain the lack of significance in the ratio is that the subjects in this study were free from shoulder pathologies. The healthy

subjects could have already had upper trapezius to serratus anterior ratios that were desirable, and therefore were not able to elicit much of a change.

Testing on subjects with scapular dyskinesis or some other shoulder pathology may have had more of a response in the desired direction. There also could have been a learning effect in the maximal voluntary contraction tests. The EMG biofeedback group had to perform one MVC for each muscle each day that they performed the exercises. This was necessary for the Delsys analysis software to display the biofeedback output on the computer. These subjects may have improved their ability to activate each muscle which would have registered as a lower percent of their MVC even if the absolute activation was larger. Some subjects may not have been as successful at maximally activating the muscles during the MVC which would show that the activation in the exercises was much greater than it actually was. This problem was observed on a few subjects showing abnormally high percent MVC values. During these instances, the unusual values for the subjects were discarded for analysis.

The data recorded on the tenth visit was analyzed and compared to the ninth visit to determine if the change seen on these two days was different between the groups. There was no significant difference in the change in ratio between groups on visit ten compared to visit nine. The EMG biofeedback group had more of an increase in the ratio compared to the exercise only group, but the difference between these groups was not significant. This suggests that there was a slight increase of the ratio during the two-week retention, but that the change in the ratio was not different for each group. This implies that though there was a slight increase in the ratio during the retention period, EMG biofeedback does not appear to be a major determinant.

The change in the ratio was hypothesized to be due to a decrease in the upper trapezius activation and an increase in the serratus anterior activation. To determine if changes occurred to the individual muscle activation, these data were also analyzed . The upper trapezius activation comparing visit nine to visit one did show a significant change due to group. The EMG biofeedback group had a decrease in upper trapezius activation where the exercise only group had an increase in the activation.

This decrease in the activation of the upper trapezius through the use of EMG biofeedback was similar to previous research in which the ability to selectively activate and relax muscles through EMG biofeedback was examined (Huang et al., 2013; Ma et al., 2011). Though previous literature has addressed the ability to perform changes in muscle activation while utilizing the EMG biofeedback, little research about the ability to retain these changes exists (Lim et al., 2014). This study examined the effectiveness of EMG biofeedback on the ability to retain the changes. This decrease in the upper trapezius activation suggests that using EMG biofeedback twice a week for four weeks leads to the ability to learn to alter muscle activation.

Both groups had a slight decrease in upper trapezius activation from the ninth to tenth visit, but the changes were similar. This shows that after two weeks of no exercise or EMG biofeedback, both groups had a decrease in the upper trapezius activation. This indicates that there was less of an ability to retain the changes in muscle activation than expected. This could be due to previous established motor patterns the subject returned to after the treatment, or too much reliance on the feedback.

Selective activation of the serratus anterior as shown by an increase in the amplitude of activation has been examined in previous research. Holterman et al. (2010)

demonstrated the effectiveness of EMG biofeedback at improving the ability for subjects to selectively activate specific parts of the serratus anterior. This study utilized the same ideals, but also sought to determine if this ability to alter the activation could be learned when EMG biofeedback was not available to the subjects. The results of this study suggest that four weeks of EMG biofeedback significantly increased the activation of the serratus anterior more than just performing the exercises. This significant increase supports the idea that EMG biofeedback can lead to the ability to alter the activation of shoulder musculature in specific shoulder rehabilitation exercises. This is especially important because these changes affect long-term rehabilitation of shoulder injuries and their role in decreasing the prevalence of shoulder injuries and pain.

The EMG biofeedback group continued to have an increase in the serratus anterior activation from visit nine (end of week four) to visit ten (end of week six), while the exercise only group had a slight decrease in the activation. These data suggest that there was a greater ability to continue to activate the serratus anterior due to EMG training. The ability to retain the improvements, as discussed with the upper trapezius changes, suggest a true learning of the skill. The implications of these findings are discussed below.

5.1.2 Implications

The upper trapezius to serratus anterior ratio was not found to be significantly decreased through a four-week EMG biofeedback protocol but individual muscle differences were significantly changed in the desired direction. In a rehabilitation setting where the desired outcome would be an alteration in muscle activation, EMG biofeedback can be used to increase the effectiveness of common shoulder rehabilitation

exercises. This study demonstrates that exercises alone can produce a trend towards an alteration in muscle activation but adding in EMG biofeedback can increase these changes using the same frequency and duration of exercises. The alterations may have a protective effect on the shoulder. For example, various researchers have suggested that the over-activation of the upper trapezius and under-activation of the serratus anterior can lead to scapular dyskinesis, and in turn shoulder pain or injuries (Kibler et al., 2013; Prentice, 2011). If EMG biofeedback can improve the activation of each of these muscles, the altered kinematics may be addressed and the subsequent pain and injuries may be avoided. In order to determine the effectiveness of this treatment at altering the kinematics, pain, injuries and dyskinesis, further research should address these specific components in affected populations.

5.1.3 Limitations

The sample size of 20 subjects taken from a convenience sample limits the ability to make population assumptions. Having more subjects with a wider variety of age and previous exercise experience would have allowed for the researchers to gain insight into the effectiveness of this method. Subjects in this study were healthy individuals without shoulder injuries or recent shoulder rehabilitation. This only allows for the ability to make assumptions about the efficacy of this treatment to healthy individuals. Another limitation is the use of the metronome during the measuring of the RMS values and not during the other sessions. The assumption had to be made that the subjects performed the exercises at the same rate during the practice sessions.

5.1.4 Future Studies

Future research should perform a similar protocol on individuals with shoulder injuries to determine how EMG biofeedback can be used to alter muscle activation ratios in those who already have scapular dyskinesis or other shoulder pathologies. More research should be done to elucidate a healthy or ideal upper trapezius to serratus anterior ratio in the future. The starting ratio was not assessed in terms of need for a decrease and should be considered before further attempts are made using this methodology.

Only a retention test was performed in this research to evaluate learning. Transfer tests would be beneficial in the future to determine if the learned ability to alter muscle activation could be used in new environments and transfer to more real-world situations. Adding in additional common shoulder rehabilitation exercises to be practiced with EMG biofeedback, or as a means to assess the changes in muscle activation in exercises not being practiced would allow researchers to determine how permanent these changes are. The three exercises used in this study were chosen based on their reported effectiveness at treating shoulder dysfunctions, but there are many other exercises that are used in rehabilitation. The addition of other exercises including, diagonal exercises, dynamic hug, prone flexion and abduction in scapular plane which have been shown to elicit high EMG activity in various muscles is recommended to determine the effectiveness of this protocol in other components of shoulder rehabilitation (Schory et al., 2016).

5.2 Conclusion

Shoulder pain is a complex issue which affects a majority of the general population at some point in their lifetime (Singh et al., 2015). Shoulder pain can be due to altered force coupling of shoulder musculature which can create abnormal scapular

motion termed scapular dyskinesis (Kibler et al., 2013). Often, over-activation of the upper trapezius and under-activation of the serratus anterior can lead to scapular dyskinesis or shoulder pain. Rehabilitation of shoulder injuries often focuses on correcting the upper trapezius to serratus anterior ratio (Kibler & Sciascia, 2015).

The current research examined the effectiveness of using EMG biofeedback as a tool to correct this muscle activation ratio during common shoulder rehabilitation exercises to determine if this would be an effective tool for shoulder rehabilitation. The results of this current study are unable to support the hypothesis that a four-week EMG biofeedback intervention can decrease the upper trapezius to serratus anterior ratio more than performing the exercises alone. Though the data was unable to support this, there was a trend in the data which suggests that EMG biofeedback does decrease the ratio and future studies with more subjects or a population with shoulder injuries may be able to support this hypothesis. While the ratio was not significantly altered in this study, changes in individual muscle activations were significantly altered through the use of EMG biofeedback. These data support the notion that EMG biofeedback can be used as a tool to alter the ability to selectively activate shoulder musculature when used twice a week for four weeks. The results of this research support the idea that subjects are able to learn to selectively activate shoulder muscles and that this learning can be retained at different rates than if they were to perform only the exercises without adding in the biofeedback. The retention of this ability is something that has not been examined thoroughly in previous works and should also be considered in future research.

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Appendix A
EMG Familiarization Protocol

The **EMG biofeedback group** will be given the opportunity to examine to EMG biofeedback display and will have 10 minutes to get acquainted with the Delsys acquisition software (version 4.3).

- The 10 minutes gives the subject the ability to understand the relationship between their movements and the output on the display.
- During these 10 minutes they will be given a list of movements to perform for 1 minute each to ensure consistent understanding of the relationship.
  - The remaining time will be spent on their free ability to explore movements and the effect on the EMG.
  - The movements are:
    - Shoulder shrug
    - External rotation
    - Forward flexion
    - Abduction
    - Protraction and retraction
    - Overhead press
    - Rows
    - Extension

Appendix B

Informed Consent Form

INFORMED CONSENT TO PARTICIPATE IN A RESEARCH PROJECT, "Examining the effectiveness of electromyography (EMG) biofeedback at improving the upper trapezius to serratus anterior muscle activation ratio"

A research project on the effectiveness of electromyography (EMG) biofeedback in altering shoulder muscle activation is being conducted by Julia Holton, a graduate student in the Department of Kinesiology and Public Health at Cal Poly, San Luis Obispo, under the supervision of Dr. Robert Clark. The purpose of the study is to determine if EMG biofeedback could be an effective tool to improve scapular control by decreasing the upper trapezius to serratus anterior activation ratio.

You are being asked to take part in this study by participating in various shoulder exercises and well as maximal voluntary contractions (MVC) for the serratus anterior and upper trapezius. The serratus anterior is the muscle which connects your shoulder blade to your ribs and allows you to punch your arm straight out in front of you. The upper trapezius connects the back of your head and neck to your shoulder and collar bone and is the muscle which allows you to shrug your shoulders. Two EMG electrodes will be placed on your shoulder area. One will be placed on the upper trapezius between the shoulder and the neck. The other will be placed below the arm pit on the serratus anterior. You will be asked to perform a maximal voluntary contraction in which you will resist a force placed on your arm by a researcher. You will then be given instructions on the three exercises that you will be performing, all of which relate to shoulder rehabilitation. You will perform each exercise three times so data can be collected. You will then be asked to return to the research area twice a week for four weeks and perform each exercise 30 times under the supervision of the researchers

Your participation will take approximately 6 weeks with visits twice a week for the first four weeks, then one additional visit in the sixth week. Each visit will take approximately twenty minutes to complete. Please be aware that you are not required to participate in this research and you may discontinue your participation at any time without.

The possible risks associated with participation in this study include: skin irritation or discomfort from the electrode placement may occur, though proper skin preparations will be conducted to minimize this risk. Joint or muscle pain attributed to performing shoulder rehabilitation exercises may occur, though the exercises were chosen based on previous research on commonly performed shoulder rehabilitation exercises for all levels of functionality. Additionally, psychological stress or discomfort may occur due to discomfort in performing exercises or frustration at lack of progress during the course of the experiment, and any exercise protocol has the potential to produce problems as serious as heart attack and death though the nature of the exercises being performed are not expected to be at an intensity to cause this kind of harm. If you should experience Emotional distress or physical discomfort, please be aware that you may contact Cal Poly Health Services at (805)756-1211 or by visiting building 27 for assistance. Outside of Cal Poly, you can contact Sierra Vista Hospital by calling (805)546-7650 or 911 for emergencies as well as visiting the hospital at 1010 Murray Avenue in San Luis Obispo, California.

Your confidentiality will be protected by a coding your identity and keeping the coded ID number separate from any other data that is collected and stored. The data stored is kept in a locked area with very limited access. The data kept in the computer will be coded to your ID number and will have no distinguishing characteristics to you as a subject. Potential benefits associated with the study include improving the strength and activation of shoulder musculature and increasing the knowledge of shoulder musculature and how to selectively activate said musculature. In addition, as an incentive, you will receive $30 worth of gift cards to Starbucks throughout your participation in this research.

If you have questions regarding this study or would like to be informed of the results when the study is completed and if the study is published, please feel free to contact Julia Holton at jeholton@calpoly.edu. If you have concerns regarding the manner in which the study is conducted, you may contact Dr. Michael Black, Chair of the Cal Poly Institutional Review Board, at (805) 756-2894, mblack@calpoly.edu, or Ms. Debbie Hart, Compliance Officer, at (805) 756-1508, dahart@calpoly.edu.

If you agree to voluntarily participate in this research project as described, please indicate your agreement by signing below. Please keep one copy of this form for your reference and thank you for your participation in this research.

________________________________ ______________

Signature of Volunteer Date

________________________________ ______________

Signature of Researcher Date

Appendix C

Subject Demographic Questionnaire

Name	
Age	
Sex	
Height	
Weight	
Dominant Arm	LEFT / RIGHT
Have you had any recent (within 2 years) Shoulder injuries or Physical therapy for a shoulder injury?	YES / NO
Email Address	
Contact Phone number	

Appendix D
Data

Subject	Exercise	Ratio (9-1)/1_1	Ratio (10-9)/9_1	UT (9-1)/1_1	UT (10-9)/9_1	SA (9-1)/1_1	SA (10-9)/9_1	Group
1	ER	24.802	-13.650	40.000	34.483	12.178	55.741	EMG
1	FF	-45.934	-44.964	-21.073	-38.350	45.983	12.018	EMG
1	Y	-35.134	-33.483	-35.248	-37.185	-0.175	-5.565	EMG
2	ER	27.439	-61.252	95.146	-36.318	53.129	64.348	EMG
2	FF	-8.402	-3.498	36.508	8.140	49.029	12.059	EMG
2	Y	24.099	17.357	31.917	13.131	6.300	-3.601	EMG
3	ER	-48.124	292.677	-24.542	*	-67.125	39.486	EMG
3	FF	-66.020	261.164	24.016	*	-65.540	24.597	EMG
3	Y	-46.002	210.129	61.528	*	-60.504	24.497	EMG
4	ER	-95.260	*	-91.316	*	83.214	13.918	EMG
4	FF	-25.875	10.308	-9.979	30.716	21.445	18.501	EMG
4	Y	-69.178	31.282	-63.911	18.909	17.090	-9.425	EMG
5	ER	6.671	-46.128	31.707	-25.926	23.470	37.500	EMG
5	FF	-28.895	-38.790	-33.291	-38.041	-6.183	1.224	EMG
5	Y	4.143	-25.821	-25.898	-22.024	-28.846	5.119	EMG
6	ER	-63.342	-15.104	4.878	-12.791	186.102	2.725	Control
6	FF	-80.099	-50.196	-54.961	-37.931	126.311	24.627	Control
6	Y	15.140	-47.700	7.273	-51.365	-6.833	-7.009	Control
7	ER	*	-82.276	*	-84.157	-9.682	-10.608	Control
7	FF	-27.623	33.928	-24.818	20.451	3.876	-10.063	Control
7	Y	-29.557	82.243	-30.874	25.692	-1.870	-31.031	Control
8	ER	-62.560	*	4.455	*	178.991	-35.270	EMG
8	FF	-45.264	174.807	-38.971	40.964	11.498	-48.704	EMG
8	Y	-69.935	31.523	-59.347	-12.435	35.219	-33.423	EMG
9	ER	-12.415	-56.475	68.041	-71.350	91.861	-34.175	EMG
9	FF	-24.551	-52.952	57.917	-69.393	109.302	-34.946	EMG
9	Y	-59.713	-39.613	-39.110	-63.608	51.142	-39.736	EMG
10	ER	-49.383	26.719	214.815	-24.559	*	-40.466	Control
10	FF	*	*	49.395	8.833	*	*	Control
10	Y	*	*	59.837	-43.140	*	*	Control
11	ER	-93.394	-54.748	-26.100	-25.575	1018.750	64.469	EMG
11	FF	-98.126	-32.223	-78.132	-27.184	1066.667	7.433	EMG
11	Y	-95.828	-2.310	-89.832	-33.000	*	-31.416	EMG
12	ER	-65.106	-5.808	-33.333	0.820	91.054	7.036	EMG
12	FF	-89.628	-29.099	-81.071	-6.918	82.493	31.285	EMG
12	Y	-78.674	-48.183	-69.261	-31.169	44.139	32.835	EMG
13	ER	111.866	-83.742	*	-73.970	72.591	60.108	EMG
13	FF	44.098	-72.858	38.061	-70.221	-4.189	9.717	EMG
13	Y	-8.959	-37.187	-6.172	-49.224	3.062	-19.163	EMG
14	ER	-48.325	46.036	-3.704	-3.077	86.350	-33.631	EMG
14	FF	-67.836	48.500	-40.123	4.124	86.159	-29.883	EMG
14	Y	-83.609	62.464	-67.898	-13.973	95.855	-47.048	EMG
15	ER	-91.650	*	87.143	-15.267	*	*	EMG
15	FF	-91.400	*	-25.000	-25.385	*	*	EMG
15	Y	-91.645	*	24.013	*	1384.375	*	EMG
16	ER	72.382	-14.383	68.333	-19.802	-2.349	-6.329	Control
16	FF	30.206	-1.464	48.069	-5.215	13.719	-3.807	Control
16	Y	13.965	11.375	-17.899	-7.808	-27.960	-17.223	Control
17	ER	141.990	-39.344	103.226	-10.317	-16.019	*	EMG
17	FF	*	-34.726	-33.333	39.041	-18.349	113.011	EMG
17	Y	*	-73.664	104.324	-38.046	-55.624	135.248	EMG
18	ER	-21.125	-27.446	41.515	-38.544	79.417	-15.297	Control
18	FF	4.696	-9.363	10.143	8.417	5.203	19.617	Control
18	Y	*	*	*	-43.392	*	*	Control
19	ER	-91.181	-12.736	-92.755	22.034	-17.850	39.845	EMG
19	FF	-74.148	-24.283	-81.926	-26.096	-30.088	-2.394	EMG
19	Y	-64.291	58.839	-78.931	64.698	-40.999	3.689	EMG
20	ER	-52.223	-24.204	40.391	-16.241	193.843	10.506	EMG
20	FF	-80.757	76.577	-36.477	75.910	230.105	-0.378	EMG
20	Y	-87.522	1.180	-72.702	17.517	118.767	16.147	EMG

Appendix E

Statistical Output from Minitab

General Linear Model: Ratio (9-1)/1_1 versus Subject, Group, Exercise

Method

Factor coding	(-1, 0, +1)
Rows unused	20

Factor Information

Factor	Type	Levels	Values
Subject(Group)	Fixed	20	6(Control), 7(Control), 10(Control), 16(Control), 18(Control), 1(EMG), 2(EMG), 3(EMG), 4(EMG), 5(EMG), 8(EMG), 9(EMG), 11(EMG), 12(EMG), 13(EMG), 14(EMG), 15(EMG), 17(EMG), 19(EMG), 20(EMG)
Group	Fixed	2	Control, EMG
Exercise	Fixed	3	ER, FF, Y

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Group	1	2313	2312.6	3.18	0.084
Exercise	2	739	369.5	0.51	0.606
Subject(Group)	18	112053	6225.2	8.57	0.000
Group*Exercise	2	1233	616.6	0.85	0.438
Error	30	21785	726.2		
Total	53	150720			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
26.9478	85.55%	74.46%	*

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-25.74	5.04	-5.10	0.000	
Group					
Control	9.00	5.04	1.78	0.084	1.23
Exercise					
ER	4.88	7.32	0.67	0.510	2.65
FF	-6.42	6.57	-0.98	0.337	2.08
Subject(Group)					
6(Control)	-26.0	15.1	-1.72	0.095	1.57

7(Control)	-12.8	19.4	-0.66	0.515	2.07
10(Control)	-30.8	25.3	-1.22	0.233	2.63
16(Control)	55.6	15.1	3.68	0.001	1.57
1(EMG)	16.0	15.1	1.06	0.299	1.89
2(EMG)	49.1	15.1	3.25	0.003	1.89
3(EMG)	-18.6	15.1	-1.23	0.227	1.89
4(EMG)	-28.7	15.1	-1.90	0.067	1.89
5(EMG)	28.7	15.1	1.90	0.067	1.89
8(EMG)	-24.5	15.1	-1.62	0.115	1.89
9(EMG)	2.5	15.1	0.17	0.869	1.89
11(EMG)	-61.0	15.1	-4.04	0.000	1.89
12(EMG)	-43.1	15.1	-2.85	0.008	1.89
13(EMG)	83.7	15.1	5.54	0.000	1.89
14(EMG)	-31.9	15.1	-2.11	0.043	1.89
15(EMG)	-56.8	15.1	-3.76	0.001	1.89
17(EMG)	165.2	26.0	6.34	0.000	3.66
19(EMG)	-41.8	15.1	-2.77	0.010	1.89
Group*Exercise					
Control ER	-6.69	7.32	-0.91	0.368	2.66
Control FF	-2.76	6.57	-0.42	0.678	2.08

Regression Equation

Ratio (9-1)/1_1 = -25.74 + 9.00 Group_Control - 9.00 Group_EMG + 4.88 Exercise_ER
- 6.42 Exercise_FF + 1.54 Exercise_Y - 26.0 Subject(Group)_6(Control)
- 12.8 Subject(Group)_7(Control) - 30.8 Subject(Group)_10(Control)
+ 55.6 Subject(Group)_16(Control) + 14.0 Subject(Group)_18(Control)
+ 16.0 Subject(Group)_1(EMG) + 49.1 Subject(Group)_2(EMG)
- 18.6 Subject(Group)_3(EMG) - 28.7 Subject(Group)_4(EMG)
+ 28.7 Subject(Group)_5(EMG) - 24.5 Subject(Group)_8(EMG)
+ 2.5 Subject(Group)_9(EMG) - 61.0 Subject(Group)_11(EMG)
- 43.1 Subject(Group)_12(EMG) + 83.7 Subject(Group)_13(EMG)
- 31.9 Subject(Group)_14(EMG) - 56.8 Subject(Group)_15(EMG)
+ 165.2 Subject(Group)_17(EMG) - 41.8 Subject(Group)_19(EMG)
- 38.8 Subject(Group)_20(EMG) - 6.69 Group*Exercise_Control ER
- 2.76 Group*Exercise_Control FF + 9.45 Group*Exercise_Control Y
+ 6.69 Group*Exercise_EMG ER + 2.76 Group*Exercise_EMG FF
- 9.45 Group*Exercise_EMG Y

Fits and Diagnostics for Unusual Observations

Obs	Ratio (9-1)/1_1	Fit	Resid	Std Resid		
10	-95.3	-51.9	-43.4	-2.05	R	
18	15.1	-31.8	46.9	2.69	R	
28	-49.4	-49.4	-0.0	*		X

37	111.9	60.6	51.3	2.42	R	
39	-9.0	41.1	-50.0	-2.36	R	
46	72.4	37.0	35.3	2.03	R	
48	14.0	49.8	-35.9	-2.06	R	
49	142.0	142.0	-0.0	*		X

R Large residual
X Unusual X

Normplot of Residuals for Ratio (9-1)/1_1
Residuals vs Fits for Ratio (9-1)/1_1

General Linear Model: Ratio (10-9)/9_1 versus Subject, Group, Exercise

Method

Factor coding	(-1, 0, +1)
Rows unused	22

Factor Information

Factor	Type	Levels	Values
Subject(Group)	Fixed	19	6(Control), 7(Control), 10(Control), 16(Control), 18(Control), 1(EMG), 2(EMG), 3(EMG), 4(EMG), 5(EMG), 8(EMG), 9(EMG), 11(EMG), 12(EMG), 13(EMG), 14(EMG), 17(EMG), 19(EMG), 20(EMG)
Group	Fixed	2	Control, EMG
Exercise	Fixed	3	ER, FF, Y

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Group	1	303	302.8	0.21	0.652
Exercise	2	4927	2463.7	1.69	0.202
Subject(Group)	17	267973	15763.1	10.81	0.000
Group*Exercise	2	2400	1200.1	0.82	0.449
Error	29	42289	1458.2		
Total	51	318595			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
38.1869	86.73%	76.66%	*

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	7.06	7.14	0.99	0.330	
Group					
Control	-3.25	7.14	-0.46	0.652	1.29

Exercise					
ER	-16.78	9.28	-1.81	0.081	2.01
FF	4.20	9.16	0.46	0.650	2.01
Subject(Group)					
6(Control)	-41.5	21.4	-1.94	0.062	1.56
7(Control)	7.5	21.4	0.35	0.729	1.56
10(Control)	49.2	34.2	1.44	0.160	2.38
16(Control)	-5.3	21.4	-0.25	0.806	1.56
1(EMG)	-41.0	21.3	-1.92	0.064	1.87
2(EMG)	-26.1	21.3	-1.23	0.230	1.87
3(EMG)	244.3	21.3	11.46	0.000	1.87
4(EMG)	6.8	26.0	0.26	0.794	2.31
5(EMG)	-47.2	21.3	-2.22	0.035	1.87
8(EMG)	89.2	26.0	3.43	0.002	2.31
9(EMG)	-60.0	21.3	-2.81	0.009	1.87
11(EMG)	-40.1	21.3	-1.88	0.070	1.87
12(EMG)	-38.0	21.3	-1.78	0.085	1.87
13(EMG)	-74.9	21.3	-3.51	0.001	1.87
14(EMG)	42.0	21.3	1.97	0.058	1.87
17(EMG)	-59.6	21.3	-2.79	0.009	1.87
19(EMG)	-3.0	21.3	-0.14	0.887	1.87
Group*Exercise					
Control ER	-9.53	9.28	-1.03	0.313	1.99
Control FF	-2.48	9.16	-0.27	0.788	2.01

Regression Equation

Ratio (10-9)/9_1 = 7.06 - 3.25 Group_Control + 3.25 Group_EMG - 16.78 Exercise_ER
+ 4.20 Exercise_FF + 12.58 Exercise_Y - 41.5 Subject(Group)_6(Control)
+ 7.5 Subject(Group)_7(Control) + 49.2 Subject(Group)_10(Control)
- 5.3 Subject(Group)_16(Control) - 9.9 Subject(Group)_18(Control)
- 41.0 Subject(Group)_1(EMG) - 26.1 Subject(Group)_2(EMG)
+ 244.3 Subject(Group)_3(EMG) + 6.8 Subject(Group)_4(EMG)
- 47.2 Subject(Group)_5(EMG) + 89.2 Subject(Group)_8(EMG)
- 60.0 Subject(Group)_9(EMG) - 40.1 Subject(Group)_11(EMG)
- 38.0 Subject(Group)_12(EMG) - 74.9 Subject(Group)_13(EMG)
+ 42.0 Subject(Group)_14(EMG) - 59.6 Subject(Group)_17(EMG)
- 3.0 Subject(Group)_19(EMG) + 7.5 Subject(Group)_20(EMG)
- 9.53 Group*Exercise_Control ER - 2.48 Group*Exercise_Control FF
+ 12.01 Group*Exercise_Control Y + 9.53 Group*Exercise_EMG ER
+ 2.48 Group*Exercise_EMG FF - 12.01 Group*Exercise_EMG Y

Fits and Diagnostics for Unusual Observations

Obs	Ratio (10-9)/9_1	Fit	Resid	Std Resid		
19	-82.3	-15.0	-67.3	-2.53	R	
23	174.8	106.2	68.6	2.64	R	
24	31.5	100.1	-68.6	-2.64	R	
28	26.7	26.7	0.0	*		X

R Large residual
X Unusual X

General Linear Model: UT (9-1)/1_1 versus Subject, Group, Exercise

Method

Factor coding	(-1, 0, +1)
Rows unused	3

Factor Information

Factor	Type	Levels	Values
Subject(Group)	Fixed	20	6(Control), 7(Control), 10(Control), 16(Control), 18(Control), 1(EMG), 2(EMG), 3(EMG), 4(EMG), 5(EMG), 8(EMG), 9(EMG), 11(EMG), 12(EMG), 13(EMG), 14(EMG), 15(EMG), 17(EMG), 19(EMG), 20(EMG)
Group	Fixed	2	Control, EMG
Exercise	Fixed	3	ER, FF, Y

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Group	1	13215	13215.2	8.26	0.007
Exercise	2	24487	12243.7	7.65	0.002
Subject(Group)	18	111893	6216.3	3.89	0.000
Group*Exercise	2	1848	923.8	0.58	0.567
Error	33	52789	1599.7		
Total	56	211470			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
39.9959	75.04%	57.64%	25.33%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	8.48	6.46	1.31	0.199	
Group					
Control	18.58	6.46	2.87	0.007	1.05

Exercise					
ER	37.32	9.54	3.91	0.000	2.10
FF	-16.46	8.79	-1.87	0.070	1.88
Subject(Group)					
6(Control)	-41.3	21.2	-1.95	0.060	1.40
7(Control)	-31.1	25.9	-1.20	0.238	1.68
10(Control)	81.0	21.2	3.81	0.001	1.40
16(Control)	5.8	21.2	0.27	0.787	1.40
1(EMG)	4.7	22.3	0.21	0.836	1.87
2(EMG)	64.6	22.3	2.89	0.007	1.87
3(EMG)	30.4	22.3	1.36	0.182	1.87
4(EMG)	-45.0	22.3	-2.01	0.052	1.87
5(EMG)	0.9	22.3	0.04	0.967	1.87
8(EMG)	-21.2	22.3	-0.95	0.350	1.87
9(EMG)	39.0	22.3	1.75	0.090	1.87
11(EMG)	-54.6	22.3	-2.44	0.020	1.87
12(EMG)	-51.1	22.3	-2.29	0.029	1.87
13(EMG)	39.6	27.3	1.45	0.157	2.33
14(EMG)	-27.1	22.3	-1.22	0.233	1.87
15(EMG)	38.8	22.3	1.74	0.092	1.87
17(EMG)	68.2	22.3	3.05	0.004	1.87
19(EMG)	-74.4	22.3	-3.33	0.002	1.87
Group*Exercise					
Control ER	10.22	9.54	1.07	0.292	2.10
Control FF	-5.04	8.79	-0.57	0.571	1.88

Regression Equation

UT (9-1)/1_1 = 8.48 + 18.58 Group_Control - 18.58 Group_EMG + 37.32 Exercise_ER
- 16.46 Exercise_FF - 20.86 Exercise_Y - 41.3 Subject(Group)_6(Control)
- 31.1 Subject(Group)_7(Control) + 81.0 Subject(Group)_10(Control)
+ 5.8 Subject(Group)_16(Control) - 14.3 Subject(Group)_18(Control)
+ 4.7 Subject(Group)_1(EMG) + 64.6 Subject(Group)_2(EMG)
+ 30.4 Subject(Group)_3(EMG) - 45.0 Subject(Group)_4(EMG)
+ 0.9 Subject(Group)_5(EMG) - 21.2 Subject(Group)_8(EMG)
+ 39.0 Subject(Group)_9(EMG) - 54.6 Subject(Group)_11(EMG)
- 51.1 Subject(Group)_12(EMG) + 39.6 Subject(Group)_13(EMG)
- 27.1 Subject(Group)_14(EMG) + 38.8 Subject(Group)_15(EMG)
+ 68.2 Subject(Group)_17(EMG) - 74.4 Subject(Group)_19(EMG)
- 12.8 Subject(Group)_20(EMG) + 10.22 Group*Exercise_Control ER
- 5.04 Group*Exercise_Control FF - 5.19 Group*Exercise_Control Y
- 10.22 Group*Exercise_EMG ER + 5.04 Group*Exercise_EMG FF
+ 5.19 Group*Exercise_EMG Y

Fits and Diagnostics for Unusual Observations

Obs	UT (9-1)/1_1	Fit	Resid	Std Resid	
7	-24.5	47.4	-72.0	-2.29	R
10	-91.3	-28.0	-63.3	-2.01	R
28	214.8	155.6	59.3	2.12	R
50	-33.3	46.6	-80.0	-2.54	R

R Large residual

Normplot of Residuals for UT (9-1)/1_1
Residuals vs Fits for UT (9-1)/1_1
Tukey Pairwise Comparisons: Exercise
Grouping Information Using the Tukey Method and 95% Confidence

Exercise	N	Mean	Grouping	
ER	18	45.7985	A	
FF	20	-7.9798		B
Y	19	-12.3741		B

Means that do not share a letter are significantly different.

General Linear Model: UT (10-9)/9_1 versus Subject, Group, Exercise

Method

Factor coding	(-1, 0, +1)
Rows unused	6

Factor Information

Factor	Type	Levels	Values
Subject(Group)	Fixed	19	6(Control), 7(Control), 10(Control), 16(Control), 18(Control), 1(EMG), 2(EMG), 4(EMG), 5(EMG), 8(EMG), 9(EMG), 11(EMG), 12(EMG), 13(EMG), 14(EMG), 15(EMG), 17(EMG), 19(EMG), 20(EMG)
Group	Fixed	2	Control, EMG
Exercise	Fixed	3	ER, FF, Y

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Group	1	765.9	765.9	0.87	0.358
Exercise	2	3257.2	1628.6	1.85	0.175
Subject(Group)	17	32179.6	1892.9	2.15	0.031
Group*Exercise	2	1497.9	749.0	0.85	0.437
Error	31	27323.0	881.4		
Total	53	64040.0			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
29.6882	57.33%	27.06%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-16.13	4.53	-3.56	0.001	
Group					
Control	-4.23	4.53	-0.93	0.358	1.01
Exercise					
ER	-8.49	6.47	-1.31	0.199	1.66
FF	11.92	6.36	1.87	0.071	1.70
Subject(Group)					
6(Control)	-13.7	15.3	-0.89	0.379	1.60
7(Control)	7.7	15.3	0.50	0.620	1.60
10(Control)	0.7	15.3	0.05	0.962	1.60
16(Control)	9.4	15.3	0.61	0.544	1.60
1(EMG)	-1.8	16.6	-0.11	0.915	1.87
2(EMG)	6.9	16.6	0.42	0.681	1.87
4(EMG)	36.0	20.3	1.78	0.085	2.32
5(EMG)	-16.8	16.6	-1.01	0.320	1.87
8(EMG)	25.5	20.3	1.26	0.218	2.32
9(EMG)	-56.2	16.6	-3.39	0.002	1.87
11(EMG)	-16.7	16.6	-1.01	0.322	1.87
12(EMG)	-0.5	16.6	-0.03	0.975	1.87
13(EMG)	-52.6	16.6	-3.17	0.003	1.87
14(EMG)	7.6	16.6	0.46	0.650	1.87
15(EMG)	-10.0	20.3	-0.49	0.625	2.34
17(EMG)	8.8	16.6	0.53	0.600	1.87
19(EMG)	32.1	16.6	1.94	0.062	1.87
Group*Exercise					
Control ER	-7.13	6.47	-1.10	0.279	1.66
Control FF	7.35	6.36	1.15	0.257	1.70

Regression Equation

UT (10-9)/9_1 = -16.13 - 4.23 Group_Control + 4.23 Group_EMG - 8.49 Exercise_ER
+ 11.92 Exercise_FF - 3.43 Exercise_Y - 13.7 Subject(Group)_6(Control)
+ 7.7 Subject(Group)_7(Control) + 0.7 Subject(Group)_10(Control)
+ 9.4 Subject(Group)_16(Control) - 4.2 Subject(Group)_18(Control)
- 1.8 Subject(Group)_1(EMG) + 6.9 Subject(Group)_2(EMG)
+ 36.0 Subject(Group)_4(EMG) - 16.8 Subject(Group)_5(EMG)
+ 25.5 Subject(Group)_8(EMG) - 56.2 Subject(Group)_9(EMG)

- 16.7 Subject(Group)_11(EMG) - 0.5 Subject(Group)_12(EMG)
- 52.6 Subject(Group)_13(EMG) + 7.6 Subject(Group)_14(EMG)
- 10.0 Subject(Group)_15(EMG) + 8.8 Subject(Group)_17(EMG)
+ 32.1 Subject(Group)_19(EMG) + 37.6 Subject(Group)_20(EMG)
- 7.13 Group*Exercise_Control ER + 7.35 Group*Exercise_Control FF
- 0.22 Group*Exercise_Control Y + 7.13 Group*Exercise_EMG ER
- 7.35 Group*Exercise_EMG FF + 0.22 Group*Exercise_EMG Y

Fits and Diagnostics for Unusual Observations

Obs	UT (10-9)/9_1	Fit	Resid	Std Resid	
1	34.5	-15.0	49.5	2.14	R
19	-84.2	-28.3	-55.9	-2.58	R
56	-26.1	24.8	-50.9	-2.18	R
57	64.7	17.0	47.7	2.05	R

R Large residual

Normplot of Residuals for UT (10-9)/9_1
Residuals vs Fits for UT (10-9)/9_1

Comparisons for UT (10-9)/9_1
Tukey Pairwise Comparisons: Group
Grouping Information Using the Tukey Method and 95% Confidence

Group	N	Mean	Grouping
EMG	39	-11.9036	A
Control	15	-20.3541	A

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: Exercise
Grouping Information Using the Tukey Method and 95% Confidence

Exercise	N	Mean	Grouping
FF	19	-4.2122	A
Y	18	-19.5566	A
ER	17	-24.6178	A

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: Group*Exercise
Grouping Information Using the Tukey Method and 95% Confidence

Group*Exercise	N	Mean	Grouping
Control FF	5	-1.0890	A
EMG FF	14	-7.3353	A
EMG ER	12	-13.2653	A
EMG Y	13	-15.1103	A
Control Y	5	-24.0028	A
Control ER	5	-35.9704	A

Means that do not share a letter are significantly different.

General Linear Model: SA (9-1)/1_1 versus Subject, Group, Exercise

Method

Factor coding	(-1, 0, +1)
Rows unused	7

Factor Information

Factor	Type	Levels	Values
Subject(Group)	Fixed	19	6(Control), 7(Control), 16(Control), 18(Control), 1(EMG), 2(EMG), 3(EMG), 4(EMG), 5(EMG), 8(EMG), 9(EMG), 11(EMG), 12(EMG), 13(EMG), 14(EMG), 15(EMG), 17(EMG), 19(EMG), 20(EMG)
Group	Fixed	2	Control, EMG
Exercise	Fixed	3	ER, FF, Y

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Group	1	226261	226261	173.47	0.000
Exercise	2	19304	9652	7.40	0.002
Subject(Group)	17	3745580	220328	168.92	0.000
Group*Exercise	2	1576	788	0.60	0.553
Error	30	39131	1304		
Total	52	3859603			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
36.1158	98.99%	98.24%	*

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	112.07	6.34	17.68	0.000	
Group					
Control	-83.48	6.34	-13.17	0.000	1.07
Exercise					
ER	27.37	8.64	3.17	0.004	2.00
FF	6.25	8.64	0.72	0.475	2.00
Subject(Group)					
6(Control)	73.3	18.6	3.95	0.000	1.31
7(Control)	-31.1	18.6	-1.68	0.104	1.31
16(Control)	-34.1	18.6	-1.84	0.076	1.31
1(EMG)	-176.2	20.3	-8.70	0.000	1.89

2(EMG)	-159.4	20.3	-7.87	0.000	1.89
3(EMG)	-259.9	20.3	-12.83	0.000	1.89
4(EMG)	-155.0	20.3	-7.65	0.000	1.89
5(EMG)	-199.4	20.3	-9.84	0.000	1.89
8(EMG)	-120.3	20.3	-5.94	0.000	1.89
9(EMG)	-111.4	20.3	-5.50	0.000	1.89
11(EMG)	835.3	24.9	33.60	0.000	2.36
12(EMG)	-123.0	20.3	-6.07	0.000	1.89
13(EMG)	-171.7	20.3	-8.47	0.000	1.89
14(EMG)	-106.1	20.3	-5.24	0.000	1.89
15(EMG)	1212.6	35.0	34.62	0.000	3.69
17(EMG)	-225.5	20.3	-11.13	0.000	1.89
19(EMG)	-225.2	20.3	-11.11	0.000	1.89
Group*Exercise					
Control ER	7.42	8.64	0.86	0.398	2.00
Control FF	2.44	8.64	0.28	0.779	2.00

Regression Equation

SA (9-1)/1_1 = 112.07 - 83.48 Group_Control + 83.48 Group_EMG + 27.37 Exercise_ER
+ 6.25 Exercise_FF - 33.62 Exercise_Y + 73.3 Subject(Group)_6(Control)
- 31.1 Subject(Group)_7(Control) - 34.1 Subject(Group)_16(Control)
- 8.0 Subject(Group)_18(Control) - 176.2 Subject(Group)_1(EMG)
- 159.4 Subject(Group)_2(EMG) - 259.9 Subject(Group)_3(EMG)
- 155.0 Subject(Group)_4(EMG) - 199.4 Subject(Group)_5(EMG)
- 120.3 Subject(Group)_8(EMG) - 111.4 Subject(Group)_9(EMG)
+ 835.3 Subject(Group)_11(EMG) - 123.0 Subject(Group)_12(EMG)
- 171.7 Subject(Group)_13(EMG) - 106.1 Subject(Group)_14(EMG)
+ 1212.6 Subject(Group)_15(EMG) - 225.5 Subject(Group)_17(EMG)
- 225.2 Subject(Group)_19(EMG) - 14.6 Subject(Group)_20(EMG)
+ 7.42 Group*Exercise_Control ER + 2.44 Group*Exercise_Control FF
- 9.86 Group*Exercise_Control Y - 7.42 Group*Exercise_EMG ER
- 2.44 Group*Exercise_EMG FF + 9.86 Group*Exercise_EMG Y

Fits and Diagnostics for Unusual Observations

Obs	SA (9-1)/1_1	Fit	Resid	Std Resid		
18	-6.8	58.4	-65.2	-2.71	R	
22	179.0	95.2	83.8	2.95	R	
23	11.5	79.0	-67.5	-2.38	R	
45	1384.4	1384.4	-0.0	*		X

R Large residual
X Unusual X

Comparisons for SA (9-1)/1_1

Tukey Pairwise Comparisons: Group
Grouping Information Using the Tukey Method and 95% Confidence

Group	N	Mean	Grouping	
EMG	42	195.548	A	
Control	11	28.585		B

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: Exercise
Grouping Information Using the Tukey Method and 95% Confidence

Exercise	N	Mean	Grouping	
ER	18	139.437	A	
FF	18	118.314	A	
Y	17	78.449		B

Means that do not share a letter are significantly different.

General Linear Model: SA (10-9)/9_1 versus Subject, Group, Exercise

Method

Factor coding	(-1, 0, +1)
Rows unused	7

Factor Information

Factor	Type	Levels	Values
Subject(Group)	Fixed	19	6(Control), 7(Control), 10(Control), 16(Control), 18(Control), 1(EMG), 2(EMG), 3(EMG), 4(EMG), 5(EMG), 8(EMG), 9(EMG), 11(EMG), 12(EMG), 13(EMG), 14(EMG), 17(EMG), 19(EMG), 20(EMG)
Group	Fixed	2	Control, EMG
Exercise	Fixed	3	ER, FF, Y

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Group	1	4997	4996.7	14.85	0.001
Exercise	2	2184	1092.0	3.25	0.053
Subject(Group)	17	54448	3202.8	9.52	0.000
Group*Exercise	2	2255	1127.6	3.35	0.049
Error	30	10095	336.5		
Total	52	72072			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
18.3435	85.99%	75.72%	*

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF

Constant	0.70	3.41	0.21	0.839	
Group					
Control	-13.16	3.41	-3.85	0.001	1.29
Exercise					
ER	8.03	4.42	1.82	0.079	2.03
FF	3.84	4.39	0.88	0.388	2.00
Subject(Group)					
6(Control)	19.2	10.3	1.87	0.071	1.56
7(Control)	-4.8	10.3	-0.46	0.645	1.56
10(Control)	-26.5	16.4	-1.61	0.117	2.38
16(Control)	3.3	10.3	0.32	0.748	1.56
1(EMG)	6.9	10.2	0.67	0.507	1.86
2(EMG)	10.4	10.2	1.02	0.317	1.86
3(EMG)	15.7	10.2	1.53	0.136	1.86
4(EMG)	-6.2	10.2	-0.61	0.549	1.86
5(EMG)	0.8	10.2	0.07	0.942	1.86
8(EMG)	-53.0	10.2	-5.18	0.000	1.86
9(EMG)	-50.1	10.2	-4.91	0.000	1.86
11(EMG)	-0.4	10.2	-0.04	0.972	1.86
12(EMG)	9.9	10.2	0.96	0.342	1.86
13(EMG)	3.0	10.2	0.30	0.769	1.86
14(EMG)	-50.7	10.2	-4.96	0.000	1.86
17(EMG)	119.1	12.5	9.53	0.000	2.31
19(EMG)	-0.1	10.2	-0.01	0.989	1.86
Group*Exercise					
Control ER	-9.57	4.42	-2.17	0.038	2.02
Control FF	9.59	4.39	2.18	0.037	2.00

Regression Equation

SA (10-9)/9_1 = 0.70 - 13.16 Group_Control + 13.16 Group_EMG + 8.03 Exercise_ER
+ 3.84 Exercise_FF - 11.87 Exercise_Y + 19.2 Subject(Group)_6(Control)
- 4.8 Subject(Group)_7(Control) - 26.5 Subject(Group)_10(Control)
+ 3.3 Subject(Group)_16(Control) + 8.7 Subject(Group)_18(Control)
+ 6.9 Subject(Group)_1(EMG) + 10.4 Subject(Group)_2(EMG)
+ 15.7 Subject(Group)_3(EMG) - 6.2 Subject(Group)_4(EMG)
+ 0.8 Subject(Group)_5(EMG) - 53.0 Subject(Group)_8(EMG)
- 50.1 Subject(Group)_9(EMG) - 0.4 Subject(Group)_11(EMG)
+ 9.9 Subject(Group)_12(EMG) + 3.0 Subject(Group)_13(EMG)
- 50.7 Subject(Group)_14(EMG) + 119.1 Subject(Group)_17(EMG)
- 0.1 Subject(Group)_19(EMG) - 5.1 Subject(Group)_20(EMG)
- 9.57 Group*Exercise_Control ER + 9.59 Group*Exercise_Control FF
- 0.02 Group*Exercise_Control Y + 9.57 Group*Exercise_EMG ER
- 9.59 Group*Exercise_EMG FF + 0.02 Group*Exercise_EMG Y

Fits and Diagnostics for Unusual Observations

Obs	SA (10-9)/9_1	Fit	Resid	Std Resid		
28	-40.5	-40.5	0.0	*		X
31	64.5	31.1	33.4	2.32	R	
33	-31.4	1.6	-33.1	-2.29	R	
34	7.0	41.3	-34.3	-2.38	R	

R Large residual
X Unusual X

Comparisons for SA (10-9)/9_1
Tukey Pairwise Comparisons: Group
Grouping Information Using the Tukey Method and 95% Confidence

Group	N	Mean	Grouping	
EMG	41	13.8596	A	
Control	12	-12.4579		B

Means that do not share a letter are significantly different.