The effects of hand placement on muscle activation during a closed kinetic chain exercise in physically active females

Kelli J. Stoelting

The University of Toledo

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The effects of hand placement on muscle activation during a closed kinetic chain exercise in physically active females

By

Kelli J. Stoelting, BS, ATC, EMT-B

Submitted as partial fulfillment of the requirements for

the Masters of Science Degree

in Exercise Science

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College of Health Science and Human Service

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College of Graduate Studies

The University of Toledo

May 2008
An Abstract of

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Kelli J. Stoelting, ATC

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Rehabilitation of the shoulder can be a complex process with an approach that is constantly changing. In order to be successful in the rehabilitation process, a complete understanding of the cause of injury and an accurate diagnosis is required. Researchers are constantly testing new ideas and working to improve the current protocols. Knowing
and understanding the movements of the shoulder complex and being aware of the muscles involved in this movement is vital to producing a solid rehabilitation protocol. Finding exercises that patients can perform on their own can be beneficial as well, especially when working with busy athletes or patients that may not have regular access to the clinician. One specific exercise, the push-up plus, is a great scapular stabilizing exercise that has been used clinically. Various hand placements during the push-up plus, however have not been thoroughly researched. The purpose of this study was to compare three different hand placements (normal, narrow, and wide) in a push-up plus to determine the average EMG activity in each using healthy female subjects. The female subjects’ results will be compared to a previous study which looked at the EMG activity in male subjects only for future investigations. A better understanding of the muscle activation involved in this exercise will allow clinicians to apply the correct techniques to the corresponding population they are working with. Twenty female subjects were recruited from a university setting and were tested performing the push-up plus in different hand positions (normal, narrow, and wide) while electromyography (EMG) of the serratus anterior (SA), middle (MT) and lower trapezius (LT) was assessed. Five trials for each hand placement were performed in a randomized order. The exercises were divided into three phases: 1) push-up phase, 2) plus phase 3) push-up plus phase. Each EMG signal collected during the push-up plus was normalized using the MVC average EMG signals. This allowed the trials to be expressed in percentages of each subject’s MVC trials. The data for each muscle was processed in SPSS v14.0 (SPSS Inc. Chicago, IL) for Windows statistical program. The independent variables were hand placement (Normal, Narrow, and Wide) and Exercise (Push-Up, Plus, and Push-Up Plus).
The dependant variables were the average peak EMG activation of the three muscles (middle trapezius, lower trapezius, and serratus anterior). For each dependent variable, a separate two-within factor (Exercise and Hand Placement) repeated measures analysis of variance was performed. Significance was set a priori at $p<0.05$. For the trials showing statistical significance, a Scheffe’s post-hoc testing was applied. The findings of this study showed that there was marked muscle activation in the Serratus Anterior during all three phases of the exercise with the push-up portion of the exercise being the highest. For the hand position, there was marked activity for all hand placements with the Wide hand placement being the highest. The other two muscles, middle and lower trapezius showed moderate but not significant results for position and for exercise. This study suggests that the push-up plus is a good exercise if the clinician is focusing on the Serratus Anterior, but other exercises may be more well suited for the athlete if the goal is to strengthen the Middle or Lower Trapezius. Future studies may include a comparison between males and females during the push-up plus, and a comparison of the push-up plus to other upper body exercises.
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Chapter 1

Introduction

Rehabilitation of the shoulder can be a complex process with an approach that is constantly changing. In order to be successful in the rehabilitation process, a complete understanding of the cause of injury and an accurate diagnosis is required. Researchers are constantly testing new ideas and working to improve the current protocols. Knowing and understanding the movements of the shoulder complex and being aware of the muscles involved in this movement is vital to producing a solid rehabilitation protocol. Finding exercises that patients can perform on their own can be beneficial as well, especially when working with busy athletes or patients that may not have regular access to the clinician.

Many researchers have found optimal exercises for strengthening the glenohumeral muscles. Exercises such as scapation or flexion, horizontal abduction in external rotation, and the press-up have been found to be the core exercises in a glenohumeral strengthening program. Strengthening the glenohumeral musculature is important for proper shoulder functioning; however, one focus of shoulder rehabilitations recently is the scapular stabilizers. A force couple composed of the upper and lower trapezius, serratus anterior and the levator scapulae act together to help rotate and elevate
the scapula upward.\textsuperscript{8} Strengthening these muscles, specifically the trapezius and serratus anterior can provide added scapular control.\textsuperscript{6} For athletes who participate in overhead throwing activities, for example, the stability of the scapular muscles is vital to avoid symptomatic arm function.\textsuperscript{10} One strengthening exercise that is currently being used in clinics is the push-up plus. This is a regular push-up with the plus being scapular protraction to end the upward movement. There are many variations that can be done with the push-up plus. As demonstrated by Ludewig et al\textsuperscript{6}, a progression of the push-up plus can be done starting as a wall push-up, and moving on to an elbow push-up plus, knee push-up plus, and eventually a standard push-up plus. This movement can be further progressed to using a chair or even a stability ball to support the feet. An unstable surface can be placed under the hands once the patient is competent with the previously mentioned progression. With so many variations of the push-up plus, it is important to know which muscles will be most affected with the basic movement. Knowing where to place the hands to gain the most muscle activation can be beneficial to the clinician when trying to regain muscle strength and functionality.

In a study by Gilbert et al\textsuperscript{5}, it was found that the specific placement of the hands during a push-up exercise influenced the activation of the scapular stabilizing muscles (specifically the serratus anterior, middle trapezius and lower trapezius). They compared muscle activation during a normal (48 cm), narrow (25.5 cm), and a wide (70.5 cm) hand placement, as well as between the three specific portions of the exercise (push-up, plus, and push-up plus). They used a previously published classification system by Decker et al\textsuperscript{1} which put the results in a minimal (0-20% of MVC), moderate (21-50% of MVC), or marked (over 50% MVC) category. Overall, they found that both hand placement and the
portion of the exercise (push-up, plus, or push-up plus) performed had separate significant impacts on muscle activation. They concluded that a clinician aiming to strengthen their male patient’s serratus anterior would be wise to choose a wide hand placement and the plus portion of the exercise. If the clinician’s goal was to strengthen specifically the middle trapezius or lower trapezius of the male patient, the researchers concluded that finding another exercise would better benefit the patient due to the overall low effect size found for these two muscles. Knowing these results for the male subjects, further study on female subjects is needed to determine if the previously mentioned results will remain the same or if they change with gender. This information will help ensure that the female patients as well as the male patients are doing the exercises that will best target their muscles.

**Significance of the Study**

Eventually, when compared to a current study (similar in format with a focus on male subjects), the data gathered in this study may help to further the understanding of the muscle performance of female subjects during scapulohumeral motions. The results will also help describe the muscle activation patterns when performing a push-up plus as a strengthening or rehabilitation exercise. Determining the best hand placement during the push-up plus exercise for females when completing a strengthening or rehabilitation program will also be explained.

**Statement of the Problem**

The push-up plus is a widely used exercise in clinical settings. The effect of the hand placement on the serratus anterior and trapezius muscle activity during the push-up plus has not yet been examined in a female population. A better understanding of the
muscle activation involved in this exercise will allow clinicians to apply the correct techniques to the corresponding population they are working with.

**Statement of the Purpose**

The purpose of this study was to compare three different hand placements (normal, narrow, and wide) in a push-up plus to determine the average EMG activity in each using healthy female subjects. The female subjects’ results will be compared to a previous study which looked at the EMG activity in male subjects only for future investigations.

**Hypothesis**

1) The wider hand placement will elicit more serratus anterior EMG activation than the normal or narrow hand placement.

2) The wider hand placement will elicit less middle and lower trapezius EMG activation than the normal or narrow hand placement.

3) The Push-up will elicit higher muscle activity in the MT and LT than the plus or the push-up plus

4) The plus only movement will elicit higher muscle activity in the serratus anterior than push-up or push-up plus
Chapter 2

Literature Review

Introduction

Researchers are always looking for ways to improve our knowledge through the use of experimentation. When it comes to shoulder research there have been many different approaches. First clinicians and researchers needed to understand the role of the shoulder and its structures. Once the fundamental movements were analyzed, researchers examined groups of muscles within the shoulder complex. One of the groups of muscles that has received most of the focus of researchers is the rotator cuff muscles. These muscles play an important role in the proper function of the shoulder complex. These muscles are also commonly injured, and understanding the role of these muscles could prevent injury. Recently there has been a shift to look at the scapular stabilizers and the role they play on shoulder injury. Proper movement of the scapula is vital for normal shoulder motion. If the scapula is not functioning properly the total movement that can be completed by the humerus alone is 120 degrees.\textsuperscript{11} This illustrates the vital role that the scapula plays in proper shoulder movement. The next step is to look at rehabilitation exercises that can result in improving proper scapular function. One of these exercises is the push-up plus.
The push-up has been demonstrated to be an effective exercise for upper body strengthening exercise, a measure of upper body strength, and used by most sports teams in the development of upper body strength. Additionally, the push-up has also been used as an effective rehabilitation exercise by some clinicians. The push up is versatile enough to be used in many different weight-bearing conditions to allow for a steady progression, and recently the plus portion has been added to make up the push-up plus. With this addition the push-up has become an even better upper body strengthening exercise by including some of the major scapular stabilizers.

**Shoulder Complex**

The shoulder complex allows a large degree of movement. To gain the extreme ranges of movement, the shoulder complex gives up some of the stability that can be found in other joints. The shoulder complex is made up of four joints and one articulation. There are three main bones of the shoulder complex: the clavicle, scapula, and humerus. The sternoclavicular joint is the only joint that attaches the shoulder complex to the thorax. This joint is comprised of the clavicle and the manubrium of the sternum. The clavicle is said to be the strut of the shoulder complex. The sternoclavicular joint allows the shoulder complex to move into elevation, depression, protraction, and retraction.\(^\text{12}\)

The next joint is the acromioclavicular joint. This joint is formed from the clavicle and the acromion process of the scapula. This joint contributes to the movements of scapular rotation, scapular winging, and scapular tipping. These movements are important in maintaining the space between the humerus and scapula during upper extremity movements.
The next joint, which is where most of the upper extremity movement takes place, is the glenohumeral joint. This joint is a ball and socket joint. The socket is the glenoid fossa of the scapula, which is a shallow socket and leads to some instability. The movement at this joint consists of flexion/extension, abduction/adduction, internal/external rotation, horizontal abduction/adduction, elevation, and circumduction. \(^\text{12}\)

**Scapulothoracic Articulation**

The scapulothoracic articulation is not considered a joint or true articulation because it is held to the thoracic cavity by soft tissues. Also it does not contain typical synovial joint characteristics, like fibrous, cartilaginous, or synovial tissues. \(^\text{12}\) The scapulothoracic articulation is divided into three layers. These layers are superficial, intermediate, and deep musculofascial layers. \(^\text{13}\) The superficial layer consists of the latissimus dorsi and trapezius, the intermediate layer consists of the rhomboid major and minor, and the levator scapula, and the deep layer consists of the subscapularis and serratus anterior.

**Scapular Stabilizers**

Many authors have stated that the primary stabilizer for the scapula is the serratus anterior. \(^\text{13,14,15}\) The serratus anterior divides the scapulothoracic articulation further into two distinct spaces. The subscapularis space is posterior to the serratus anterior and the serratus anterior space is anterior to the serratus anterior. \(^\text{13}\) The serratus anterior originates on ribs one through nine and inserts on the scapula from the superior angle down the medial border to the inferior angle. \(^\text{16}\) The serratus anterior is unique in the fact that it has seven to ten digitations on to the ribs. These digitations are fingerlike divisions of the muscle. Because of these digitations, the serratus anterior is divided into three
different sections. These sections are upper, middle, and lower serratus anterior. The upper serratus anterior is found on the first and second ribs and inserts on the superior angle of the scapula. Its primary role is to stabilize the scapula during humeral elevation and is grouped with the middle and lower serratus anterior.\textsuperscript{13} The next two to three digitations make up the middle serratus anterior. The middle serratus anterior inserts along the vertebral border of the scapula.\textsuperscript{14, 17} The action of this portion of the serratus anterior is mainly scapular abduction and protraction movements.\textsuperscript{17} However, it can also assist in upward rotation. The upper and middle digitations of the serratus anterior contribute to the first 30 degrees of scapular upward rotation.\textsuperscript{18} The lower serratus anterior makes up the last three to five digitations and inserts along the inferior angle of the scapula. The main function of the lower serratus anterior is upward rotation.\textsuperscript{17} The lower digitations of the serratus anterior control the scapular upward rotation from 30 to 60 degrees of rotation.\textsuperscript{18}

The upper trapezius originates at the occipital protuberance and attaches to the ligamentum nuchae down to the 7\textsuperscript{th} cervical spinous process. The insertion of this muscle is at the distal one third of the clavicle, acromion process, and scapular spine. The major movements of the upper trapezius are elevation of the scapula, upward rotation and adduction.\textsuperscript{12, 16} This muscle does not play an important role in the movement of the scapula when compared to the serratus anterior; but it has been reported when the serratus anterior is weak, there is more activity in the upper trapezius.\textsuperscript{19, 20} However, during a push-up plus the upper trapezius activity is relatively low.\textsuperscript{6}

The Middle trapezius originates on the spinous processes of the 7\textsuperscript{th} cervical vertebra to the 7\textsuperscript{th} thoracic verterbra. Some of the middle trapezius also originates on the
ligamentum nuchae.\textsuperscript{16} It attaches to the scapula along the spine of the scapula and acromion process. The main function of this muscle is scapular retraction and fixation of the thoracic spine.\textsuperscript{12} This is important during upward rotation of the scapula because it allows the inferior angle to rotate outwardly while the superior angle and spine are fixed.

The lower trapezius is the lowest portion of the trapezius and originates on the 7\textsuperscript{th} to the 12\textsuperscript{th} thoracic vertebra. Like the middle trapezius the lower trapezius inserts on the spine of the scapula. It also has the same movements as the middle trapezius, with the addition of depression of the scapula.\textsuperscript{12}

**Scapular Movement**

Ludwig et al\textsuperscript{21} has conducted a tremendous amount of research on the scapula and has termed the movements of the scapula. There are three major three-dimensional movements of the scapula that play a major role in its functioning. These movements are also important in preventing injuries. The movements revolve around three axes of the scapula. The first axis is perpendicular to the plane of the scapula and controls upward and downward rotation. The next axis runs parallel to the spine of the scapula, which involves anterior and posterior tipping. The final axis runs vertical to the scapula. Movements about this axis are termed internal and external rotation, or also commonly known as adduction and abduction. The serratus anterior has also been found to contribute to these movements, with it being the main contributor to posterior tipping of the scapula.\textsuperscript{19}

**Shoulder Dysfunctions**

Shoulder dysfunctions are debilitating musculoskeletal injuries that disrupt normal daily living functions. In 2003 alone about 13.7 million people went to the
doctor's office for a shoulder problem. Of that 13.7 million, 3.7 million visits were for shoulder and upper arm sprains and strains.\textsuperscript{22} This affects people ages 18-40,\textsuperscript{15,23,24} especially overhead athletes like baseball, softball, tennis, and swimming, but it also affects workers that have to work overhead like construction workers.\textsuperscript{25} Because this can affect so many people there has been a lot of research conducted to examine the shoulder. Inman et al\textsuperscript{26} performed the first major study on the shoulder and the role of the scapula by observing and examining the function of the shoulder complex. From here the researchers have looked at the role of the rotator cuff, scapula and scapular stabilizers, internal structures like labrum, and support systems. Some of the common injuries seen in the shoulder are glenohumeral instabilities and impingement. Improper functioning of the scapula has been linked to these injuries.

A current clinical belief is that when weakness is present in the scapular musculature this will affect normal scapular positioning. It has been suggested that if excess motion of the scapula occurs, this might place increased stress on the glenohumeral capsular structures and lead to increased glenohumeral instabilities.\textsuperscript{27} The scapula plays a role in providing a stable base for the humerus. If this shallow glenoid fossa is not positioned properly then instability will result. This emphasizes the important role of the delicate balance or rhythm of the scapula and the humerus.

Impingement is an injury that affects the rotator cuff muscles, but researchers are unsure about the exact cause of this injury. However, they do know if the motion of the scapula does play an important role in impingement. Some of the contributors to impingement are thought to be a result of glenohumeral instability, posterior capsule tightness, and scapulothoracic weakness, which also contributes to shoulder instability.\textsuperscript{28}
The motions of the scapula that relate to impingement are decreased scapular upward rotation and posterior tipping, which both happen during humeral elevation. This happens because these motions allow the greater tuberosity to come into close contact with the coracocromial arch. Upward rotation is thought to lead to impingement because a decrease in this motion leads to a decrease in the subacromial space. The serratus anterior plays an important role, because when early fatigue sets in there is an increase of stress on the anterior restraints. This also can decrease the space between the acromion and humeral head, and lead to the development of rotator cuff tendonitis. The serratus anterior allows the acromion to rotate clear of the humerus with a posterior tipping motion preventing impingement.

Ludewig et al, looked at four different push-up exercises and the activity of the serratus anterior, upper trapezius, and the ratio of the two. The serratus anterior is of main concern because of the important role that it plays in maintaining the position of the scapula. The upper trapezius was examined because of the role it plays when the serratus anterior is weak. The ratio of upper trapezius to serratus anterior was examined to find exercises that maximally elicit the serratus anterior while minimally activating the upper trapezius. This study is also unique in the fact that they used both healthy and shoulder dysfunction subjects. The four exercises that were used were the standard push-up plus, a knee push-up plus, elbow push-up plus, and a wall push-up plus. The only exercises that have been previously studied were the standard and knee push-up plus. These four exercises where chosen because they are variations of the standard push-up plus and can be used effectively in the clinical setting. There was a steady progression of muscle activity in both groups of subjects, moving from the wall push-up plus, elbow push-up
plus, knee push-up plus, and finally the standard push-up plus (p<0.05). The upper trapezius to serratus anterior ratio was found to be low during all exercises except the wall push-up plus (p<0.01).

Lear and Gross\textsuperscript{15} examined a further progression of the Ludewig et al\textsuperscript{6} protocol by comparing the push-up plus to a push-up plus with feet elevated and a push-up plus with hands on a mini trampoline and feet elevated. The muscles that were measured were the upper trapezius, lower trapezius, and serratus anterior. Additionally they measured shoulder width by looking at the interacromial shoulder width, which is the distance between the lateral borders of the acromion process. In this study, the subjects were allowed to select a pace that could be reproducible for the push-up plus exercises. The results of this study demonstrated that by raising the feet during a push-up plus, the serratus anterior activity increased significantly, but when placing the hands on the mini trampoline there was no significant increase (p<0.05).

Eksrom et al\textsuperscript{17} examined a cadaver dissection of the serratus anterior muscle to gain knowledge on the role of the two separate parts. Nine manual muscle tests were performed to look at the muscle activity of the upper and lower parts during the test. The push-up plus resulted in the highest activation of both the upper (78 +/- 24 %MVIC) and lower (72 +/- 17 %MVIC) serratus anterior. The push-up plus elicited the highest activation of the upper serratus anterior, while the shoulder abducted to 125 degrees in the plane of the scapula elicited the greatest activation of the lower serratus anterior (81 +/- 16 %MVIC). Overall, there seemed to be strong activity of the serratus anterior when it was either abducted or flexed to 125 degrees. Maximal protraction was needed to elicit the muscle activity in the push-up plus and shoulder flexed to 125 degrees. Upward
rotation was present in all of these movements. The results of this study demonstrated that upward rotation creates significantly more activation in the lower serratus anterior and that protraction increases upper serratus anterior, but these relationships were not statistically significant.

Moseley et al\(^3\) examined 16 shoulder exercises and seven different muscles (upper, middle, and lower trapezius, levator scapulae, rhomboids, middle and lower serratus anterior, and pectoralis minor). Two of the exercises for the serratus anterior were the push-up plus and a push-up with hands apart. The authors do not state how far apart the hands were during the push-up with hands apart. The differences in the serratus anterior activity during these two exercises were 46% difference in percentage of exercise duration in the lower serratus anterior and 7% of difference in percentage of exercise duration between the middle serratus anterior. Peak activity was 3% of the MMT for the lower serratus anterior and 23% of the MMT in the middle serratus anterior. The push-up plus elicited more peak activity and a longer duration of activity then the push-up with hands apart. The push-up plus and the push-up with hands apart were ranked fifth and sixth for the middle serratus anterior and they were ranked fourth and fifth for the lower serratus anterior.

Tucker et al\(^{31}\) examined a new rehabilitation device the Cuff Link®, and the muscles that are activated while using the device. There were four variations to the counterclockwise rotation of the Cuff Link®. The muscles that were measured were the anterior deltoid, upper trapezius, serratus anterior, and pectoralis major. Three different weight-bearing positions were measured; non-weight-bearing, partial weight-bearing and full weight-bearing. One unique procedure of this study was the use of 75% of the
subject’s height to normalize the vertical hand placement during the weight-bearing condition. The 75% of height was the distance between the toes and hands, which allowed the subjects to find their optimal angle at the shoulder. Previous studies have used other methods to put the subject in the desired position.\textsuperscript{3, 6, 15} The limitation to these techniques was that the subjects could shift to their optimal position and not maintain the desired measurement. The results of the Tucker et al\textsuperscript{31} study was that the anterior deltoid, serratus anterior, and pectoralis major all significantly increased activity as weight-bearing increase, with the serratus anterior showing the most activity.

**Conclusion**

The important role the scapula plays in shoulder function has been demonstrated. The anatomy of the shoulder joint allows for a highly movable joint, at the expense of stability. If the kinetic link is not working properly, injury may likely result. The scapular stabilizers play an important role in preventing injury. The serratus anterior is the main stabilizer of the scapula and plays an important role in preventing injuries like glenohumeral instability and impingement by moving the acromion process out of the way of the humeral head. One way to strengthen the serratus anterior is with the use of the push-up plus and Cuff Link®. The main muscles used during these exercises during weight-bearing are the serratus anterior and trapezius (upper, middle, and lower). However, it has been show that with both the Cuff Link® and push-up plus that the upper trapezius is not active.\textsuperscript{6, 31} More research needs to be performed in this area to help the huge population of overhead athlete and workers that are affected by these injuries. It can also help the clinicians develop more efficient prevention and rehabilitation strategies for shoulder injuries.
Chapter 3

Methods

Subjects

19 healthy physically active female athletes were recruited from The University of Toledo campus community for this study. The subjects had a mean age of 20.737 ± 2.306 which is a common age range in athletes for shoulder injury to occur. The mean mass was 139.158 ± 18.136 lbs. and the mean height was 64.974 ± 2.419 inches. This study was approved by The University of Toledo Human Subject Review Committee prior to the start of testing.

The subjects were screened (using a health history form) for shoulder problems that may have caused their activities of daily living to become reduced. The subjects were also screened for health problems such as heart disorders, high blood pressure, respiratory disorders, and pregnancy. Any subjects who had previous experience with the push-up plus as a rehabilitation exercise were excluded from the study. Subjects needed to be able to perform at least 10 push-up pluses with good form. Good form was determined by the primary investigator. Any questions that the subjects had about this study were answered to their contentment. The subjects each signed an informed consent form before beginning the study.
Instrumentation

A Noraxon Teleomyo Telemetry Electromyography unit (Noraxon USA Inc. Scottsdale, AZ) was used to collect the EMG data. Three leads and seven pre-gelled rectangular (2.5 cm x 4 cm) disposable bipolar silver-silver chloride electrodes (Danlee Medical Products, Inc.) were used to collect the data. A Noraxon receiver/amplifier (Noraxon USA Inc. Scottsdale, AZ) was used to allow the EMG signal to be telemetered and passed through an A/D converter. A Dell personal computer was also used in conjunction with the previously mentioned equipment. The video data was recorded on a Sony digital 8 handycam DCR-TRV 140 NTSC (Sony Corporation of America, New York, NY) and then sent to the Dell personal computer. To collect the data at a sampling rate of 1000 Hz, the Noraxon MyoVideo v1.5.04 was used. The data was smoothed and rectified using a moving windows at 50 ms, and then copied to be analyzed using the Noraxon MyoResearch v2.11 software. Instruments that were also be used include a goniometer, calculator, tape, and a tape measure, a scale with a height arm, a 10.2 cm. block, a treatment table and a metronome.

Procedures

The subjects were asked to complete the previously mentioned health history form which included a scale for the subjects to rate their level of activity. This scale had a 1-4 ranking (one = no activity, two = low activity, three = moderate activity, and four = high activity). The subjects who fit the qualifications were asked to read and sign a consent form. To keep confidentiality within the study, the subjects were each assigned a number as means of identification. After signing the required forms, the subjects were each asked to warm up on an Upper Body Ergometer for 5 minutes. Next, they were
asked to perform push-up pluses to see if they could complete 10 while keeping good
form. The subjects were asked to come back to the Motion Analysis Laboratory the next
day at approximately the same time to begin the actual trials. The placement sites for the
electrodes were shaved and debrided using a very fine sandpaper to help decrease the
amount of electrical impedance. The area was then cleaned with a 70% isopropyl alcohol
solution. The appropriate motor points were chosen by referencing literature by
Basmajian\textsuperscript{32}. Motor points on the right side of the body included the one midway
between the medial border of the scapula and spinous process of the vertebrae in the
thoracic region. This corresponded to the middle trapezius. The lower trapezius motor
point was immediately medial to the scapula’s inferior angle. This was located lateral to
the T7 vertebra. For the Serratus Anterior, the placement spot was above the inferior
angle of the scapula along the midline of the torso. A ground electrode was placed on the
ulnar process of the right arm.

The subjects were allowed to practice each of the three hand placements and then
rest for 1 minute. After this rest period, they each completed a maximal voluntary
contraction (MVC) for the middle trapezius, lower trapezius and serratus anterior. The
angle of the arm during the MVC testing of the serratus anterior was 125° in the scapular
plane\textsuperscript{33} as measured using a standard goniometer. The subjects’ arm was also internally
rotated in the thumb down position and force was applied downward into extension. The
contraction for the middle trapezius was measured with the subject lying prone and their
right arm hanging at a 90° angle off the table edge. The arm was abducted and externally
rotated with the thumb pointing up. The lower trapezius was measured in a similar
manner except that the arm was abducted and externally rotated at a 125° angle (thumb
The force was applied downward in the direction of horizontal adduction for both middle and lower trapezius. Each contraction was held for 5 seconds while the EMG data was recorded. The MVC for each muscle was done 3 times each with a 1 minute rest in between each.

After recording the MVC’s, the subjects’ height was found using a standard height scale. The distance between the feet and hands when doing the push-up plus was normalized to 75% of their height using methods used by Tucker, et al.\textsuperscript{31} The hand placement trials were randomized for each subject, and they were given 5 practice repetitions to review proper technique before beginning the actual testing. Tape was placed on the floor to ensure proper hand and foot placement during each trial. They were asked to keep their index fingers on the hand placement tape and to keep their toes on the foot placement line (not past it). They were also asked to keep pace with a metronome set at 60 bpm. The subjects completed 5 trials for each of the three hand placements with a one minute rest in between each. A 10.2 cm block was placed under the subject’s body so that they knew how far to lower themselves. To complete the push-up plus, the subject’s started with their arms extended, lowered themselves to the block, pushed themselves back up, protracted the scapula, then retracted the scapula. After they had completed all testing, they were given 5 minutes to complete a cool down of their choice.
Analysis

The data was recorded on the Myosoft program and processed using the Myoresearch program. The Independent variables for this study were hand placement (with three levels: Normal, Narrow and Wide) and exercise (also with three levels: push-up, push-up plus, and plus). The dependant variables were the average EMG activation of the middle trapezius, lower trapezius and serratus anterior. A two-way repeated measures ANOVA (3x3) was performed using SPSS v15.0 (SPSS Inc. Chicago, IL.) statistical program and statistical significance was set a priori at p < 0.05. For the significant interactions, a Scheffe post-hoc test was applied.
Chapter 4

Results

Statistical Analysis

The data for each muscle was processed in SPSS v15.0 (SPSS Inc. Chicago, IL) for Windows statistical program. The independent variables included hand placement (Normal, Narrow, and Wide) and exercise (Push-up, Plus, and Push-up Plus). The dependant variables included the average peak EMG activation of the serratus anterior, middle trapezius, and lower trapezius. For each dependant variable, a separate two-within factor (exercise and hand placement) repeated measures analysis of variance was performed. Significance was set a priori at p<0.05. In the event of statistical significance, a Scheffe post-hoc test was performed.

Results

Serratus Anterior (ST)

The interaction between the Exercise and Hand Placement was not statistically significant ($F_{4,72} = 0.611; p<0.656$) (Figure 1). The means and standard errors are presented in Table 1. Statistically significant main effects were observed for Exercise ($F_{2,36} = 15.429; p<0.001$) and Position ($F_{2, 36} = 9.570; p<0.001$). For Exercise, the push-up exercise presented with a significantly greater average SA activation ($92.764 \pm 12.185$...
% MVC) than the Push-up Plus (85.075 ± 10.592 % MVC) or the Plus (69.040 ± 8.051 % MVC) exercise (Figure 2).

For Position, the Wide hand placement produced a greater activation (89.897 ± 10.827 % MVC) when compared to the Normal (79.978 ± 9.678 % MVC) and Narrow (77.005 ± 10.225 % MVC) hand placements (Figure 3). Also, the Normal position showed a greater activation when compared to the Narrow position.

*Middle Trapezius (MT)*

The interaction between the Exercise and Position was not statistically significant (F4, 72 = 0.289; p=0.884) (Figure 4). The means and standard error can be found in Table 2. There was a nearly significant main effect for Position (F2, 36 =3.012; p=0.062) while Exercise showed no significance (F2, 36 = 0.644; p=0.531).

For Exercise, there was no statistical significance (F2, 36 =0.644; p=0.531) for muscle activation found in the Push-up (33.583 ± 3.744 % MVC), Plus (38.025 ± 6.567 % MVC) and Push-up Plus (34.983 ± 4.103 % MVC) hand positions.

For Position, there was no statistical significance found for muscle activation in the Normal (35.438 ± 4.643 % MVC), Narrow (38.768 ± 5.445 % MVC) and Wide (32.385 ± 3.677 % MVC) hand placements. There was however, a small observable difference found between the Wide and the Narrow placement.

*Lower Trapezius (LT)*

The interaction between Exercise and Position was not statistically significant (F4, 72 = 0.671; p= 0.614) (Figure 5). The means and standard errors can be found in Table 3.

For Exercise, there was no statistical significance (F2, 36 = 1.600; p = 0.216) for muscle activation found in the Push-up (27.241 ± 2.857% MVC), Plus (31.975 ± 4.769 % MVC)
MVC), or Push-up Plus (27.705 ± 2.171 % MVC). When compared to the Push-up and the Push-up Plus, the Plus exercise showed a slightly greater activation.

For Position, there was no statistical significance (p = 0.077) found for muscle activation in the Normal (29.631 ± 2.677 % MVC), Narrow (30.461 ± 3.652 % MVC), or Wide (26.829 ± 3.038 % MVC) hand placement. The Normal and Narrow positions showed the greatest activation when compared to the Wide placement.

**Figure 1: SA Exercise x Hand Placement Interaction (F<sub>4, 72</sub> = 0.611; p<0.656)**

![Graph showing SA Exercise x Hand Placement Interaction](image)

**Table 1: SA Exercise x Hand Placement Interaction (F<sub>4, 72</sub> = 0.611; p<0.656)**

<table>
<thead>
<tr>
<th></th>
<th>Push-up</th>
<th>Plus</th>
<th>Push-up Plus</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>91.936 ± 11.974</td>
<td>65.028 ± 7.627</td>
<td>82.969 ± 10.224</td>
<td></td>
</tr>
<tr>
<td>Narrow</td>
<td>86.826 ± 12.342</td>
<td>64.581 ± 8.105</td>
<td>79.607 ± 10.748</td>
<td>0.656</td>
</tr>
<tr>
<td>Wide</td>
<td>99.531 ± 12.676</td>
<td>77.510 ± 9.503</td>
<td>92.649 ± 11.195</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2: SA Exercise Main Effect ($F_{2, 36} = 15.43; p<0.001$)

* Push-up >Plus and Push-up Plus

Figure 3: SA Position Main Effect ($F_{2, 36} = 9.570; p<0.001$)

* Wide and Normal >Narrow
# Wide > Normal
Table 2: MT Exercise x Hand Placement Interaction (F_{4, 72} = 0.289; p=0.884)

<table>
<thead>
<tr>
<th></th>
<th>Push-up</th>
<th>Plus</th>
<th>Push-up Plus</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>32.648 ± 3.704</td>
<td>38.844 ± 7.001</td>
<td>34.822 ± 4.303</td>
<td>0.884</td>
</tr>
<tr>
<td>Narrow</td>
<td>36.961 ± 4.598</td>
<td>41.164 ± 8.546</td>
<td>38.178 ± 4.986</td>
<td></td>
</tr>
<tr>
<td>Wide</td>
<td>31.14 ± 3.617</td>
<td>34.066 ± 5.070</td>
<td>31.948 ± 3.560</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4: MT Exercise x Hand Placement Interaction (F_{4, 72} = 0.289; p=0.884)
Table 3: LT Exercise x Hand Placement Interaction ($F_{4, 72} = 0.671; p=0.614$)

<table>
<thead>
<tr>
<th></th>
<th>Push-up</th>
<th>Plus</th>
<th>Push-up Plus</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow</td>
<td>28.763 ± 2.894</td>
<td>32.598 ± 5.695</td>
<td>30.022 ± 3.341</td>
<td></td>
</tr>
<tr>
<td>Wide</td>
<td>24.806 ± 2.656</td>
<td>29.354 ± 4.241</td>
<td>26.327 ± 2.879</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5: LT Exercise x Hand Placement Interaction ($F_{4, 72} = 0.671; p=0.614$)
Chapter 5

Discussion

Introduction

The purpose of this study was to compare three different hand placements during a push-up plus exercise among female subjects. Three scapular stabilizers were analyzed to find the average EMG activity, with the goal of determining the most effective hand placement during the exercise. The hand placements performed during the push-up plus trials included a normal, narrow, and wide hand placement. A comparison was also made between three separate phases of the push-up plus exercise. These phases included the push-up, the plus, and the push-up plus. The final results of this study partially support the hypotheses that the hand placement and the phase of the exercise affects muscle activation.

Muscle Activation

A maximal voluntary contraction was recorded prior to each muscle being tested so that there would be baseline significance to the recorded muscle activation. Three categories of muscle activation were applied to the results. These categories included minimal, moderate and marked muscle activity. Minimal muscle activation was based on a range from 0-20% MVC. Moderate muscle activity was said to be in the range of 21-50% MVC, and Marked included any muscle activity over 50% MVC.
Muscle activity for the Serratus Anterior (SA) during all three phases of the exercise can be considered to be in the marked category. The push-up portion main effect was recorded as the highest ($92.76 \pm 12.19\%$), followed by the push-up plus ($85.08 \pm 10.59\%$) and the plus ($69.04 \pm 8.02\%$). The serratus anterior muscle activity during the three hand positions can also be considered in the marked category. The Wide ($89.90 \pm 10.83\%$) hand placement recorded the highest activity followed by the Normal ($79.98 \pm 9.68\%$) placement and the Narrow ($77.01 \pm 10.23\%$).

The Serratus Anterior is considered by many researchers as the prime mover of the scapula due to its attachment on the scapula’s vertebral border and inferior angle. It can produce scapular upward rotation, posterior tipping, and external rotation all while stabilizing the vertebral border and inferior angle. It has been reported that glenohumeral instabilities or weakness may disrupt scapulohumeral rhythm. Through these studies, we gain an understanding of how important strengthening of the scapular stabilizers and glenohumeral musculature really is.

With the results found in our current study, it may be concluded that the serratus anterior in females can be most highly activated during the push-up portion of the exercise using a wide hand placement. The wide hand placement would generate force that goes in towards the body, causing the scapula to eccentrically load the serratus anterior. Because muscles generally produce greater force when in the eccentric position, this finding is not surprising. It also may be concluded that the push-up plus exercise may not be as beneficial to the female athlete for activating the serratus anterior as the regular standard push-up may be.
The Middle Trapezius (MT) demonstrated moderate muscle activity during all three phases of the exercise and the three hand positions with no statistically significant differences. During the exercise, the Plus portion had the most activation (38.02 ± 6.57), but the push-up (33.58 ± 3.74) and push-up plus (34.98 ± 4.10) portions were very similar in muscle activation, with all three in the Moderate category. The middle trapezius also showed moderate activation for the three hand placements. The Narrow (38.77 ± 5.45) hand placement generated the most MT muscle activation followed by the Normal (35.44± 4.64) and the Wide (32.39 ± 3.68), respectively. If the goal of the clinician is to strengthen the middle trapezius, the push-up plus exercise may not be their best option; but it also would seem that the exercise portion or hand position would not matter. As found by Moseley et al\textsuperscript{3}, options such as horizontal abduction in neutral and with external rotation, rowing, and extension are more apt to strengthen the middle trapezius. Another possibility would be scaption during which those authors found MT activation to be 91% of the MVC.\textsuperscript{1}

The Lower Trapezius (LT) also demonstrated moderate muscle activation during the exercise main effect and the hand position main effect, but like the MT, with no statistically significant differences in exercise phase or hand position. The exercise portion revealed the Plus (31.98 ± 4.77) to elicit the most activation. The Push-up (27.24 ± 2.86) and the Push-up Plus (27.71 ± 2.17) showed similar results. All fell into the moderate category. Due to the level of muscle activation found during the push-up plus exercise, other options should be considered when attempting to strengthen the lower trapezius. Strengthening the lower trapezius may be more efficient if the clinician
chooses exercises such as abduction, horizontal abduction with external rotation, rowing, flexion, and horizontal abduction in neutral.$^3$

**Clinical Implications**

The push-up plus has been recommended by many researchers as a beneficial strengthening tool during rehabilitation$^{3, 6}$ Previous studies have not considered the theory that females and males may not have similar results when completing the same exercise. Due to anatomical and overall strength differences in males and females, it is important to individualize rehabilitation programs to each gender. Our results suggest that the push-up portion alone may be the most helpful for serratus anterior strengthening in female athletes, while the plus portion of the exercise has been shown to benefit males the most.$^5$ Further comparison of these two groups is needed to correctly determine just how significant the differences really are between males and females.

**Limitations**

EMG results in this study may have been skewed slightly due to the interference of clothing rubbing over the electrodes. The female subjects were allowed to wear sports bras over the electrodes in comparison to male subjects that could be tested shirtless throughout a similar experiment.

A second limitation would be bust size. We used a 10.2 cm block to normalize the lowest point during the exercise so that comparisons could be made to a cohort group of male subjects that were tested with similar methods. The anatomical differences between male and female bust size may have limited how far the females had to lower themselves during the push-up. Males may have used more upper body strength to meet the height of the block where females may not have had to lower themselves quite as far to meet the
block. Related to potential limitations of bust sizes, there could have been variability among our sample of female subjects. Subjects who were of smaller size may have had to use more upper body strength to lower themselves to the block, where the larger sized females would not. We did not quantify this variable in this study, so we cannot confidently address if this was a factor that could have been included as a co-variate. On observation of our data, we would conclude that there was not an abnormally large amount of variability across the subjects. However, future research may need to quantify this factor.

**Conclusion**

This study demonstrates that each portion of the push-up plus exercise and the positioning of the hands does effect the muscle activation of scapular stabilizers that occurs during the movement, but only with the serratus anterior were these relationships statistically significant. Since the serratus anterior works with the trapezius to stabilize the scapula and control its rotation,² it is imperative that we learn how to target each muscle specifically during strengthening and rehabilitation sessions. Comparing healthy and unhealthy populations, as well as comparing males to females during the push-up plus exercise, may be helpful to validate the push-up plus as a beneficial rehabilitation tool for athletes with shoulder pathologies.
References


Appendix A

Health History Form
Project Title: The Effects of Hand Placement on Muscle Activation during a Closed Kinetic Chain Exercise in Physically Active Females

Subject’s Name: _____________________________ Date: ______________
Age: _________ Gender: _________
Height: _________ Weight: _________

Are you currently being treated for any illness or injury that may alter this study?

   yes _________ no _________

   If “yes” please explain: ________________________________
______________________________

Have you ever sustained a shoulder injury?

   yes _________ no _________

   If “yes” please describe injury: ________________________________
   Treatment: ________________________________
   Number of days inactive: ________________________________
   Any limitations: ________________________________

How would you rate your activity level? (circle one)

   1 2 3 4
   no activity low activity moderate activity high activity
Appendix B

Informed Consent Form for Human Research Study
1. This section provides an explanation of the study in which you will be participating:

A. The study in which I am participating is part of research intended to assess the effects of scapular muscles activity when exercising on the Cuff Link compared to a push-up plus in various hand positions.

B. If I agree to take part in this research, I certify that I have not had any shoulder injury, which includes impingement syndrome, functional shoulder instability, scapular winging, and a sprain or strain of the shoulder that has resulted in a loss of normal daily activities in the last year, and that I am not suffering from any diseases or illnesses that would prevent me from performing the study.

C. I will be asked to report to the Motion Analysis Research lab in the Health and Human Services building on the campus of the University of Toledo on two separate occasions. The first session will comprise of filling out a health history form, and I will be instructed and screened for the completion of the Cuff Link and push-up plus exercises.

D. I will report back to the Motion Analysis Research lab one more time for preparation and set up of the testing equipment. After this I will be randomly tested with two different Cuff Link protocols and three different push-up plus protocols.

E. During the exercise testing, I will have sensors attached my middle trapezius, lower trapezius, and serratus anterior that will measure the electrical activity of these muscles. These sensors will be attached to the
muscles in a manner that will be comfortable and not hinder my movement.

2. This section describes your rights as a research participant:

A. I understand that I may ask the investigator any questions about the research procedures, and these questions will be answered.

B. My participation in this research is confidential. Only the person in charge will have access to my identity and information that can be associated with my identity. In the event of publication of this research, no personally identifying information will be disclosed. To make sure my participation is confidential, only a code number will appear on the data collection sheet. Only the researchers can match my name with my code number.

C. My participation is voluntary. I am free to stop participating in the research at any time, or to decline to answer any specific questions without penalty.

D. I may contact the Office for Research, 2300 University Hall, University of Toledo, Toledo, OH 43606, (419) 530-2844, for additional information concerning my right as a research participant.

3. This section indicates that you are giving your informed consent to participate in the research:

Participant:

I agree to participate in the scientific investigation described above, as an authorized part of the education and research program of the University of Toledo.

I understand the information given to me, and I have received answers to any questions I may have had about the research procedure. I understand and agree to the conditions of this study as described.

To the best of my knowledge and belief, I have no physical or mental illness or difficulties that would increase the risk to me of participation in this study.

I understand that my participation in this study does not entitle me to any compensation, financial or otherwise.

I understand that my participation in this research is voluntary, and that I may withdraw from this study at any time by notifying the person in charge.
I am 18 years of age or older.

I understand that medical care is available in the event of injury resulting from research but that neither financial compensation nor free medical treatment is provided. I also understand that I am not waiving any rights that I may have against the University for injury resulting from negligence of the University or investigators.

I understand that I will receive a signed copy of this consent form.

_____________________________________________ ____________
Signature        Date

Researcher:

I certify that the informed consent procedure has been followed, and that I have answered any questions from the participant above as fully as possible.

_____________________________________________ ____________
Signature        Date