Spring 2016

Effects of Hand Position During a Push-Up on Scapular Kinematics

Tylre M. Arens
Western Washington University, arenst@students.wwu.edu

Effects of Hand Position During a Push-Up on Scapular Kinematics

By

Tylre M. Arens

Accepted in Partial Completion

Of the requirements for the Degree

Master of Science

Kathleen L. Kitto, Dean of the Graduate School

ADVISORY COMMITTEE

Chair, David N. Suprak, PhD

Jun San Juan, PhD

Lorrie Brilla, PhD

MASTER'S THESIS

Effects of Hand Position During a Push-Up on Scapular Kinematics

A Thesis
Presented to
The Faculty of
Western Washington University

Accepted in Partial Completion
Of the requirements for the Degree
Master of Science

Tylre M Arens
May, 2016

Abstract

The purpose of this study was to investigate the effect of hand position and elbow flexion angle on scapular kinematics in a traditional push up exercise. Sixteen healthy subjects (11 males, 5 females, age 20.50 ± 5.25 yrs.) participated in the study. Following a standardized warm-up subjects were instrumented. Kinematic data was collected via the Polhemus Fastrak magnetic tracking system. Following digitization, subjects assumed a push-up position. A 10-cm wood block was positioned on the floor to control for push-up depth. Subjects performed push-ups with their hands in a standard position, wide, and narrow. Subjects performed three repetitions of each condition to a 4-second count. During the concentric phase in each condition, mean scapular orientations were measured during an elbow extension range of motion (ROM) of 90º - 30º. There was no significant interaction between elbow flexion and hand position for scapular upward rotation (UR) (p = .938) and no main effect of elbow flexion for UR (p = .232). There was a main effect of hand position on UR (p < .001). Pairwise comparisons indicated that standard and narrow conditions showed greater UR than wide (p = .001 and p = .002, respectively). However, no significant difference was seen between standard and narrow conditions (p = .091). There was no significant interaction between elbow flexion and hand position for posterior tilt (PT) (p = .821). There was a main effect of hand position of on PT (p = .001). There was no significant main effect of elbow angle (p = .218). Narrow hand position and significantly higher PT than wide (p = .004). There was no interaction between elbow flexion and hand position on external rotation (ER) (p = .073). There were main effects of both hand position (p = .021) and elbow flexion (p < .001) on ER. ER decreased linearly with elbow extension (p < .001).

Key Words: Push-up, Scapula, Kinematics

Acknowledgements

I've always been one for brevity, so her it goes. First and foremost I would like to thank the faculty and staff of the Health and Human Development department at Western Washington University. Their dedication and support to the students has never ceased to amaze me. More specifically I would like to thank my committee; Dr. Dave Suprak, Dr. Jun San Jaun, and Dr. Lorrie Brilla. All three have helped shape me into the student and scholar I am today in their own unique way.

I would also like to thank all of my fellow graduate students, whom I've come to call friends. The countless hours we've spent together talking about homework, tests, labs, and everything in between is something that I will always appreciate. Without any of you, this whole program just wouldn't be the same.

Finally I would like to thank my family. Their unending love and support has always been a reminder that everything I have done up to this has all been worth it. I just hope that in the end I can return the favor. Thank you everyone for believing in me and knowing that I can accomplish whatever I set out to do.

Table of Contents

List of Figures

List of Appendices

Chapter I

The Problem and Its Scope

Introduction

The scapula is essential to arm movement, due to the scapula allowing the arm to have a large amount of freedom in movement. It is important to maintain proper boney alignment, joint function, and muscle activation during upper extremity movement in order to maintain proper scapular kinematics (Tsai, McClure, & Karduna, 2003). The scapula is described as having an articulation with thorax, to create the scapulothoracic joint (Inman, Saunders, & Abbott, 1944). The scapulothoracic joint provides scapular motion. Healthy scapular kinematics during arm elevation includes external rotation, upward rotation, and posterior tipping of the scapula (Kibler, Sciascia, Uhl, Tambay, & Cunningham, 2008). Unhealthy scapular kinematics includes internal rotation, downward rotation, and anterior tipping of the scapula. There are also scapular translations that include protraction, retraction, elevation, and depression (Kibler, Sciascia, Uhl, Tambay, & Cunningham, 2008). With the large range of motion the scapula has, it is important to track its movement during various tasks. One way to track kinematics of the scapula is through use of a magnetic tracking device to record the degrees of movement of the scapula about the thorax (Karduna, McClure, Michener, 2000). It is important to identify healthy scapular kinematics, as it will create a greater subacromial space. The greater the subacromial space will prevent the incidences of the head of humerus encroaching on the acromion of the scapula (Ludewig, Phadke, Braman, & Hassett, 2009).

The primary muscles that provide scapular movement are the upper trapezius, lower trapezius, rhomboid major, rhomboid minor, serratus anterior, levator scapulae, and pectoralis minor muscles (Paine & Voight, 2013). These muscles act together, in various force couples, to maintain healthy scapular kinematics during humeral elevation (Escamilla, Yamashiro, Paulos, & Andrews, 2012). When the muscles acting on the scapula are not functioning properly, it can lead to shoulder pathologies such as subacromial impingement (Michener, McClure, & Karduna, 2003). This has been seen with decreased activity of the serratus anterior, and increased activity in the upper trapezius (Michener et al., 2003). The rotator cuff muscles also play a role in preventing shoulder pathologies. The rotator cuff muscles, which include the supraspinatus, infraspinatus, teres minor, and subscapularis play an important role in keeping the humerus in appropriate alignment throughout humeral elevation (Inman, Saunders, & Abbott, 1944; Wilk, Arrigo, & Andrews, 1997). Because of the poor muscle function in unhealthy scapular kinematics, exercises in rehabilitation are used to help restore proper scapular kinematics.

The push up is a popular exercise that is used in strength and conditioning training (Kilinç, 2008) as well as in rehabilitation programs for shoulder dyskinesis, leading to overuse conditions such as subacromial impingement syndrome or other pathologies (Anderson, Jackson, Kropf, & Soderberg, 1984). The popularity of the push-up is due to its ability to target muscles that are important for scapular kinematics, such as the serratus anterior (Decker, Hintermeister, Faber, & Hawkins, 1999). When using push-ups in either strength training or rehabilitation settings, the position of the hands may alter muscle activation and scapular kinematics (Cogley, Arcambault, Fibeger, Koverman, Youdas, & Hollman, 2005; Borstad, & Ludewig, 2002). Hand positions that have been studied include internal/external rotation, wide, narrow, standard, as well as placing the hands on various surfaces (Donkers, An, Chao, & Morrey, 1993; Cogley, et al., 2003; Sandhu, Mahajan, & Shenoy, 2008; Lee S., Lee D., & Park J., 2013). Wide hand position is more effective at activating the pectoralis major muscle, while the narrow hand position is more effective at activating the triceps brachii muscle (Cogley, et al., 2003). Internal rotation will cause a higher activation of the serratus anterior muscle (Lee, S., Lee, D., Park, 2013). Unstable surfaces cause a higher activation of the anterior deltoid muscle (Sandhu, Mahajan, & Shenoy, 2008). None of the previously mentioned hand positions have been examined in conjunction with scapular kinematics. Humeral position, including elevated, neutral, and at the side has also been observed during push-ups (Suprak, Bohannon, Morales, Stroschien, & San Juan, 2013). The position of the humerus has an effect on proper scapular kinematics. During increased humeral elevation there is an increase in scapular anterior tilt (Suprak, Bohannon, Morales, Stroschien, & San Juan, 2013). Hand position has an effect on muscle activation of the muscles of the shoulder (Cogley, Archambault, Fibeger, Koverman, Youdas, & Hollman, 2005). Muscles involved during a push up include the serratus anterior, upper trapezius, lower trapezius, pectoralis major, triceps brachii, anterior deltoid, and biceps brachii (Sandhu, Mahajan, & Shenoy, 2008; de Oliveira, de Morais Carvalho, de Brum, 2008; Cogley, Archambault, Fibeger, Koverman, Youda, & Hollman, 2005; Decker, Tokish, Ellis, Torry, & Hawkins, 2003). Overall there has been no research, to our knowledge, of the effects that hand position has on scapular kinematics. Although there has been research on muscle activation during push-up exercises, they have not observed the muscle activation at different degrees of elbow flexion.

Purpose of the Study

The purpose of this study was to investigate the effects of push-up variation (traditional vs. modified), hand position (standard vs. narrow vs. wide), and elbow angle (5° increments from 90° flexion to full extension) on scapular kinematics (posterior tilt, upward rotation, and external rotation) in a healthy population.

Hypothesis

The hypothesis was that the narrow and standard hand positions would elicit significantly increased scapular upward rotation, posterior tilting and external rotation, as compared to the wide hand position. Furthermore, as the elbow extends there will and increase in internal rotation, upward rotation, and posterior tilt.

Significance of the Study

The role of the push-up exercise in both rehabilitation and strength training settings has been well-documented in the research. Scapular kinematics has also been described during humeral elevation. However, scapular kinematics has not been observed during a push-up exercise. Furthermore, there has been little research investigating the role that various hand positions have on scapular kinematics and muscle activation across the range of motion. This is due to the hand positions' effect on the humerus during humeral elevation, and in turn, the humerus effect on the scapular kinematics. The change in scapular kinematics should then have an effect on the muscles involved in the push-up, therefore changing the muscle activation. Results from this study will help increase the understanding of how scapular kinematics and scapular and glenohumeral stabilizing muscle activation patterns can be affected by various hand positions at different elbow angles during a push-up exercise in a healthy population. This can lead to more effective use of the push-up exercise in strength and conditioning, and rehabilitation settings.

Limitations

1. The age range of this study was limited to college age, which limits its application to a wider population.
2. There were no subjects with any shoulder pathology, so the results are limited to individuals with healthy shoulders.
3. The participants may not have been familiar with the various hand positions, which may have affected their performance.

Definition of Terms

Acromion process – A boney landmark on the scapula that articulates with the lateral clavicle, and is above the humerus (Schuenke, Schult, &Schumacher, 2014).

Horizontal abduction - A motion of the arm moving away from the midline of the body in the transverse plane relative to the ground (Hamill & Knutzen, 2006; McGinnis, 2013).

Horizontal adduction - A motion of the arm moving toward the midline of the body in the transverse plane relative to the ground (Hamill & Knutzen, 2006; McGinnis, 2013).

Humeral elevation -Motions that include flexion or abduction of the arm, or any movements that move the arm away from the center line of the body (Shevlin et al., 1969)

Infraspinatus- A muscle that attaches to the infraspinatous fossa of the scapula, and the posterior portion of the greater tubercle of the humerus. It assists in external rotation of the humerus (Schuenke, Schult, &Schumacher, 2014).

Lower trapezius - A muscle that attaches to the transvers processes of T5-T12 and the inferior angle of the scapula. It assists in scapular depression and upward rotation (Schuenke, Schult, &Schumacher, 2014).

Modified push-up - Modified push-ups are performed with the knees in a position of flexion so that the knees are on the ground. The hands are positioned at shoulder width apart with the middle finger directly below the shoulder. The motion that is performed is similar to the traditional push-up (Suprak, Dawes, & Stephenson 2011).

Serratus anterior – A muscle that attaches to ribs 1-8 and the medial anterior scapular border. It assists with protraction and upward rotation of the scapula (Schuenke, Schult, &Schumacher, 2014).

Scapular kinematics - Movement of the scapula with respect to the thorax including upward/downward rotation, anterior/posterior tipping, and external/internal rotation (Huang et al., 2013; Michener et al., 2003).

Scapular translations - Multi-planar scapular motions that include protraction/retraction, and elevation/depression (Michener et al., 2003).

Scapulohumeral rhythm – The combination of the motion between the scapula and humerus in order to accomplish humeral elevation (Magee, 2008).

Subacromial impingement syndrome - Decrease in the space between the acromial arch and the humeral head. This can be through the tendon of the long head of the biceps brachii, the tendon of the supraspinatus or glenoid labrum (Neer, 1983).

Traditional push-up - An upper extremity exercise that is performed with the hips and knees fully extended and feet on the ground. The hands are positioned slightly wider than shoulder width, with the index finger aligned with the acromion process (Suprak, Bohannon, Morales, Stroschein, & San Juan, 2013).

Upper trapezius – A muscle attaches to the acromion process and external occipital protuberance that assists in scapular elevation and upward rotation (Schuenke, Schult, &Schumacher, 2014).

Chapter II

Review of Literature

Introduction

There is little known about the effectiveness of various types of push-up exercises and how they will affect scapular kinematics and the muscles acting on the scapula. The research in this literature review will focus on what the effects of different types of push up exercises on the humeral and scapular kinematics that include their interaction and the difference between healthy and unhealthy scapular kinematics, muscle activation, and the push-up exercise itself. Muscle activation will also be explored with respect to how different muscles will affect scapular kinematics and humeral elevation.

Scapular and Humeral Kinematics

Scapular kinematics describes how the scapula moves about the thorax. Different types of scapular movement includes upward/downward rotation, internal/external rotation, and anterior/posterior tilting (Karduna et al, 2000; Borstad & Ludewig 2002). The scapula also has two translations that are described as elevation/depression, and protraction/retraction, which include the scapular motions described (Kibler et al, 2008). When describing scapular kinematics, it is important to recognize how the humerus moves in conjunction with the scapula

The humerus has three degrees of freedom in the cardinal planes, which are abduction/adduction, flexion/extension, and internal/external rotation (Ludewig, & Cook, 2002). Along with the movements in the planes there is also a superior/inferior and anterior/posterior translations of the humeral head within the glenohumeral joint capsule (Ludewig, & Cook, 2002). Humeral positioning and motion also have an effect on scapular kinematics.

The humerus is attached to the scapula at the glenohumeral joint, which is a ball and socket joint, and is also inferior to the subacromial space, which involves the superior portion of the humeral head, the anterior, and superior portion of the acromion, as well as the acromioclavicular ligament and acromioclavicular joint (Neer, 1972). Because it is a ball and socket joint, and due to the fact the glenoid fossa is shallow, it has motions in the three cardinal planes, as well as elevation and depression in all planes (Perry, 1978). In order to allow for full shoulder range of motion, there is a 2:1 ratio that contributes to humeral elevation and scapular motion, which is described as there is two degrees of humeral elevation for one degree of scapular upward rotation throughout the range of motion (Perry, 1978). Scapulohumeral rhythm has been further broken down into three phases (Magee, 2008). Phase one is described as 30° abduction with minimal scapular motion. Phase two includes 40° humeral abduction with 20° scapular upward rotation. Phase three includes 60° humeral abduction and 90° humeral external rotation, as well as 30° of scapular upward rotation. In a healthy population, the scapula will posteriorly tip as well as externally rotate during humeral elevation (Ludewig & Cook, 2000). The motion of the scapula is important to allow the humerus to continue to elevate. Without scapular motion, the humerus would come into contact with the acromion process of the scapula, effectively reducing its range of motion. Since the scapula moves, the humerus is able to move, un-impinged from the scapula.

The humeral elevation angle also has an effect on important scapular mover muscles (Hardwick, Beebe, McDonnell, & Land 2006). As the humerus elevates, it causes scapular upward rotation, which is controlled in varying degrees by the trapezius muscles as well as the serratus anterior muscle (Perry, 1978). In healthy subjects, the serratus anterior and trapezius muscles will act synergistically to create upward scapular rotation, while keeping it externally rotated and posteriorly tilted (Borstad & Ludewig, 2002; Karduna, McClure, & Michener 2000; Perry, 1978). Since the scapula has such a large amount of motions, there are a number of problems that can occur. Due to the large amount of problems that can occur, it is important to recognize unhealthy scapular kinematics as well.

Unhealthy Scapular Kinematics

Since the scapula and humerus work in such close relationship, any sort of abnormalities in muscle action or altered scapulohumeral rhythm can result in scapular dyskinesis, which can be defined as altered scapular motion or position (Kibler, et al. 2013; Michener, McClure, Karduna, 2003). Scapular dyskinesis can lead to overuse injury, such as subacromial impingement syndrome (SAIS), which can be described as the narrowing of the subacromial space, resulting in the encroachment of the subacromial tissues on the humeral head during joint movement (Kibler, et al. 2013; Michener, McClure, Karduna, 2003). Subacromial tissues include the tendon of the biceps brachii long head, supraspinatus tendon, subacromial bursa, and the capsule of the glenohumeral joint (Kibler, et al. 2013; Michener, McClure, Karduna, 2003). When considering individuals with subacromial impingement, or other pathologies within the shoulder, there seems to be a consensus in the literature that there are kinematic changes that occur (Ludewig et al., 2009). The common theme in changes that occur at the scapula include increased anterior tipping, internal rotation, and decreased upward rotation during humeral elevation, which become more prominent in unhealthy scapular kinematics. These changes in scapular kinematics contribute to a decrease in the subacromial space, which increase the chances of subacromial impingement occurring (Ludewig et al., 2009; Michener, McClure, & Karduna, 2003).

Glenohumeral kinematics may also contribute to shoulder pathologies (Michener, McClure, & Karduna, 2003). The head of the humerus may superiorly translate during humeral elevation, which will also contribute to a decrease in the subacromial space. (Michener, McClure, & Karduna, 2003). The decrease in subacromial space is caused by the rotator cuff not functioning properly, and not pulling the humeral head back into the glenoid fossa (Inman, Saunders, Abbott, 1944).With all the motions of the scapula and humerus, whether healthy or unhealthy, it is important to identify the muscles acting on them in order to determine what to work on during rehabilitation.

Stabilizing muscles of the scapula. The scapula's only bony attachment to the body is via the acromioclavicular ligament, therefore, acromioclavicular joint is an inherently unstable joint. The only stability that the scapula receives is from the muscles acting on it, as well as the ligaments at the acromioclavicular joint (Pain & Voight, 2013). The muscles involved in the support of the scapula include the serratus anterior, rhomboids major and minor, trapezius, and levator scapulae (Pain & Voight, 2013; Ludewig, Cook, & Nawoczenski, 1996). The serratus anterior muscle plays a vital role in scapular kinematics. Its primary role is to assist in upward rotation and protraction of the scapula in order to keep it against the thorax during humeral elevation (Pain & Voight, 2013). It is also involved in scapular posterior tilt and external rotation (Ludewig, Cook, & Nawoczenski, 1996). The rhomboids, both major and minor, assist the scapula in retraction, as well as downward rotation (Pain & Voight, 2013). The trapezius is composed of three different divisions, characterized by differing fiber directions; the lower, upper and middle fibers. The upper fibers assist in elevation and upward rotation of the scapula, the middle fibers assist in retraction, and the lower fibers assist in upward rotation as well as depression (Pain & Voight, 2013).The levator scapulae assists in elevation and downward rotation (Pain & Voight, 2013). A high activation of the serratus anterior activation coupled with a high activation of the lower trapezius help the scapula to maintain healthy scapular kinematics, as detailed earlier (Ludewig & Cook, 2000). In contrast, a having a higher upper trapezius activation compared to the serratus anterior can lead to unhealthy scapular kinematics, as detailed earlier (Ludewig et al, 2004).

Stabalizing muscles of the humerus. There are also a number of muscles that originate from the scapula, that act on the humerus. These muscles are known as the rotator cuff, and consist of the supraspinatus, infraspinatus, subscapularis, and teres minor. The supraspinatus works to abduct the humerus, while keeping the humeral head in the glenoid fossa throughout abduction (Inman, Saunders, & Abbott, 1944). The subscapularis works primarily as an internal rotator for the humerus. Both the teres minor and infraspinatus work as external rotators for the humerus. All the rotator cuff muscles work to stabilize the humerus through all motions of the humerus, minimizing superior humeral head translation during humeral elevation (Inman, Saunders, & Abbott, 1944; Wilk, Arrigo, & Andrews, 1997). With the amount of muscles acting on the humerus and scapula, it is important to identify exercises to help encourage activation, or strengthen the muscles.

Shoulder rehabilitation exercises

Due to the prevalence of injuries that occur in the shoulder, and the role of proper scapular kinematics in shoulder health, as well as alterations that often accompany shoulder injuries, it is important to develop exercises that specifically target the shoulder musculature, and restore healthy scapular kinematics. The various exercises focus on improving strength and activation patterns of the muscles that are involved in scapular and humeral kinematics. Some such exercises are detailed below.

Wall slide. The wall slide exercise involves the participant leaning on the wall with their forearms flat against the wall and the elbow at 90°. From this position, the participant slides the forearms up the wall while maintaining normal scapular kinematics by focusing on preventing scapular elevation, and anterior tilt. This exercise is used to help promote serratus anterior, upper and lower trapezius muscle activation and healthy scapular kinematics, specifically upward rotation, and external rotation. (Hardwick, Beebe, McDonnell, & Lang, 2006).

Arm raise overhead. This exercise is performed while prone, with the participant raising the arm in the scapular plane while focusing on using the lower trapezius. By doing so, it helps to encourage lower trapezius activation while promoting scapular posterior tilt (Ekstrom, Donatelli, & Soderberg, 2003).

Unilateral shoulder press. This exercise is performed similarly to a bench press, however one arm is used to press half the bar, while the other half is supported. This can also be performed using dumbbells. At the end of the press there is a plus phase of the press, which involves protraction of the scapula involved. The unilateral shoulder press has been shown to strengthen the serratus anterior muscle and to help promote upward rotation and posterior tilt (Ekstrom, Donatelli, & Soderberg, 2003).

Dynamic hug. The dynamic hug is performed by abducting the arms to 60° and horizontally adducting the arms against resistance. The scapula should reach full protraction. This exercise strengthens the upper trapezius, anterior deltoid, and serratus anterior muscles

(Decker, Hintermeister, Faber, & Hawkins, 1999). However, its primary purpose to help with activation of the serratus anterior (Decker, Hintermeister, Faber, & Hawkins, 1999).

Side lying external rotation. This exercise is performed by lying on the side and externally rotating the arm that is not resting on the table with resistance. This exercise is used to help strengthen the rotator cuff, specifically the teres minor and infraspinatus muscles (Ingwersen et al., 2015)

Push-up. Push-ups are an exercise that is effective in shoulder rehabilitation, and health. It is commonly used due to its effectiveness of either strengthening, or targeting activation of muscles that act on the scapula and humerus (Anderson, Jackson, Kropf, & Soderberf, 1984; Decker et al., 2003; Escamilla, Yamashiro, Paulos, & Andrews, 2012). Muscles that the push-up can target include the anterior deltoid, pectoralis major, serratus anterior, and upper trapezius muscles (Gouvali, & Boudolos, 2005; Park, & Yoo, 2011; Sandhu, Mahajan, & Shenoy, 2008). There is also a variety of ways to perform the push-up, such as a variation on hand position and a stable or unstable surface type. The variety of applications make it applicable in a number of settings (Cogely, et al., 2005; Sandhu, Mahajan, & Shenoy, 2008).

Push-up Type

The push-up is a popular mode of exercise for the upper body due to its ease of implementation, and it can be performed in various ways, and settings such as strength training or rehabilitation programs (Kibler & McMullen, 2003; Decker, Hintermeister, Faber, & Hawkins, 1999; Harman, et al, 2008; Gabbett, Johns, & Riemann, 2008). Push up variations include traditional push up, modified push up, wall push up, and any one of those on a stable or unstable surface (Suprak, Dawes, & Stephenson, 2011; Marshall & Murphy, 2006; Park & Yoo, 2011). Each of these push-up variants are detailed below.

Traditional push-up. Traditional push-ups are performed with the hips and knees fully extended and feet on the ground. The hands are positioned slightly wider than shoulder width, with the index finger aligned with the acromion process (Suprak, Bohannon, Morales, Stroschein, & San Juan, 2013). The push-up consists of two phases; the downward, eccentric phase and the upward, concentric phase. During the downward phase, an action of flexion is performed at the elbows until approximately 90 degrees, and horizontal abduction at the shoulder, until the torso is close to ground (Marshal & Murphy, 2006). During the upward phase an action of extension is performed at the elbows until they are completely extended, and horizontal adduction occurs at the shoulder (Marshal & Murphy, 2006).

Modified push up. Modified push-ups are performed with the knees in a position of flexion so that the knees are on the ground. The hands are positioned at shoulder width apart with the middle finger directly below the shoulder. The motion that is performed is similar to the traditional push-up (Suprak, Dawes, & Stephenson 2011, San Jan, Suprak, Roach, & Lyde, 2015). A push-up plus can be performed from the upward phase by fully protracting the scapula (Lehman, Gilas, & Patel, 2008; Lunden, Braman, LaPrade, & Ludewig, 2010; Maenhout, Van Praet, Pizzi, Van Herzeele, & Cools, 2010)

Wall push up. The wall push-up is traditionally used in a rehabilitation setting, as opposed to a strength training programs and is performed similarly to a traditional push up, except for the motion is pushing away from a wall instead of away from the floor (Hardwick, Beebe, McDonnell, & Lang, 2006).

Stable vs unstable surfaces. Different surfaces, such as Swiss balls, BOSU balls, or medicine balls, may elicit different activation patterns throughout each aforementioned push-up type. These changes involve different muscle activations with muscles around the shoulder and elbow such as the upper trapezius, serratus anterior, pectoralis major, deltoids, and triceps. (Oliveira, Carvalho, & Brum, 2006; Lee at al., 2013).

Although there has been a vast amount of studies done on muscle activity during a push-up, few have investigated muscle activity throughout the range of motion of a push-up. Furthermore, there has been little research on scapular kinematics, and no research on the effect of hand position on scapular kinematics.

Hand Position

There is a variety of ways to position one's hands during a push-up that can alter the effects of the exercise. The different hand positions that have been studied in the literature are a wide hand stance, narrow hand stance, and neutral or self-selected hand stance (Cogley et al, 2005). Each position can elicit different effects on muscle activity, such as a greater amount of triceps brachii activation with a narrow hand position, or greater amount pectoralis major activation with a wide hand position (Cogley et al, 2005; Lee, Lee, & Park, 2008; Ludewig et al. 2009). Scapular-humeral kinematics, which describes the way in which the humerus moves about the scapula during elevation, may also be altered based and hand position (Cogley et al, 2005; Lee, Lee, & Park, 2008; Ludewig et al. 2009).

The hands can be internally or externally rotated as well, which increases serratus anterior activation during external rotation (Lee, Lee, & Park, 2008). Although push-ups can be performed in a variety of hand positions, there has been little research on the hand positions effect on scapular kinematics and muscle activation throughout the range of motion of the push-up.

Wide Hand Position. A wide hand position is typically thought of for use in its effectiveness to activate the pectoralis major muscle (Cogley et al, 2005). It is performed similarly to the traditional push up, except with the hands placed wider than shoulder width. One study performed the wide hand push up with the hands 20 cm wider than neutral, and found that the wide hand position had significantly greater EMG in the pectoralis major muscle when compared to narrow base hand position (Cogley et al, 2005). Another study did their hand placement at 150% of shoulder width (Gouvali & Boudolos, 2005). Gouvali & Boudolos found no significant increase in the pectoralis major muscle in the wide hand position when compared to the narrow hand position. Furthermore, they found there was no difference in ground reaction force between a wide and narrow hand position.

Narrow Hand Position. Narrow hand position is typically used when trying to elicit a greater activation in the triceps brachii muscles (Cogley et al, 2005). It is performed similarly to the traditional push-up, except the hands are placed narrower than shoulder width. It has been seen with the hands placed together, has found that a narrow hand position elicits a greater amount of triceps activation when compared to a wide hand position (Cogley et al, 2005). Another study investigated the hands placed at 50% of shoulder width, and found that there was no significant difference in tricep brachii muscle activation when compared to the wide hand postion, and there was no significant difference in ground reaction force when compared to the wide hand position (Gouvali & Boudolos, 2005).

Internal Rotation. Performed similarly to a traditional push-up, however the hands are internally rotated 90 degrees (Lee, Lee, & Park, 2008). Lee et al. (2008) found that internal rotation significantly reduced serratus anterior activation during a push-up.

External Rotation. Performed similarly to a traditional push-up, however the hands are externally rotated 90 degrees (Lee, Lee, & Park, 2008). Lee et al. (2008) found that external rotation significantly increased serratus anterior activation during a push-up.

Muscle activity during push-ups

Activation patterns of agonist and stabilizer muscles at the shoulder are determined by various factors, such as the position of the scapula and humerus. This is due, in part, to the degree of the elbow flexion through the different phases of a push-up, as well as the amount of humeral elevation, or horizontal adduction occurring (San Juan, Suprak, Roach, & Lyda, 2015; Sandhu, Mahajan, & Shenoy, 2008; Marshall & Murphy, 2005; Jeonh, Hung, & Shim, 2014). The pectoralis major has a higher activation with a wide hand stance, while the triceps are more active during a narrow hand stance (Cogley, et al., 2005) The anterior deltoid has have a greater amount of activation on an unstable surface compared to a stable surface (Sandhu, Mahajan, & Shenoy, 2008). The serratus anterior has a large amount of activation in all push up conditions, while different surfaces affect the part of the serratus anterior that is most active (Lear & Gross, 1998; Harwick, Beebe, & Lang, 2006; de Oleveira, de Morais, & de Brum, 2008; Hardwick, Beebe, McDonnell, & Lang, 2006; Ludewig, Cook, & Nawoczenski, 1996). Muscles that can also be active include the upper trapezius and lower trapezius (Lear & Gross, 1998; Park & Yoo, 2011). The lower trapezius muscle a greater amount of activity on unstable surfaces, while the upper trapezius muscle has a higher amount of activation on stable surfaces (Park & Yoo, 2011).

The position of the scapula and humerus can affect the amount of force a muscle can produce (Berthonnaud, Morrow, Herzberg, & An, 2010). This change in force is due to the fact that different joint angles will change the length of the muscle, which in turn, can affect the amount of tension it produces, as well as its moment arm at the joint (Balle, Magnusson, & McHugh, 2014). This change of length in the muscle can change the degree of muscle activation (Mohamed, Perry, & Hislop, 2002). There are certain muscles that have a greater amount contribution to healthy scapular kinematics during a push up. The muscles are listed below.

Serratus Anterior. The serratus anterior plays a vital role in push-ups because of its role in scapular kinematics (Lear & Gross, 1998; Hardwick, Beebe, McDonnell, & Lang, 2006). Push-ups or other exercises that utilize a high amount serratus anterior activation can help improve scapular kinematics because of types of scapular motions they cause (Hardwick, Beebe, McDonnell, & Lang, 2006). The serratus anterior helps with scapular external rotation, upward rotation, and posterior tilt and stabilizes the scapula against the thorax during humeral movements (Kibler et al., 2008).

Triceps Brachii. The tricpes brachii muscle is important in a push-up exercise in that it is the primary muscle in elbow extension, and is most active during a narrow base hand position (Cogley et al, 2005). Marcolin, et al., (2015) found similar data showing that the triceps have a higher activation to during elbow extension, and during a narrow hand position. However, this study only included eight participants, but they did find significance. This shows that hand position has an effect on muscle activation.

Pectoralis major. The pectoralis major is active throughout a push-up exercise due to the horizontal adduction motion, and is most active during a wide hand position push-up, more specifically during the up phase of the push-up (Cogley et al., 2005). This shows that hand position has an effect on muscle activation.

Anterior deltoid. The anterior deltoid muscle is also active throughput push-ups due to its nature as an arm extensor and arm horizontal abductor (Uhl, Carver, Mattacola, Mair, & Nitz, 2003). Deltoid muscle activation increases a push up on an unstable surface, when compared to a push up performed on a stable surface (Calatayud, et al., 2014)

Upper trapezius/Lower trapezius. The upper and lower trapezius have an important role in scapular kinematics (Ludewig et al, 2004). High upper trapezius activation can cause excessive elevation throughout a push up, and can contribute to subacromial impingement due to its role in scapular elevation and anterior tipping (Lunden, Braman, LaPrade, & Ludewig, 2010; Ludewig et al, 2004). While an increased lower trapezius activation helps with scapular depression, it allows for a greater amount of clearance in the subacromial space for the greater tubercle of the humerus to pass under (Michener, McClure, & Karduna, 2003). The upper trapezius has a higher activation on stable surfaces, while the lower trapezius has a lower activation on unstable surface push-ups (Park & Yoo, 2011).

Rotator Cuff. Rotator cuff muscles have been recognized to have a role in the push-up exercise (Decker, Tokish, Ellis, Torry, & Hawkins, 2003; Uhl, Carver, Mattacola, Mair, &Nitz, 2003; Swanik, K., Bliven, Swanik, C., 2011) However, the role of the rotator cuff muscles has not been observed in different hand positions.

Summary

It is evident from the literature that there is a wide variety of applications for push-ups in both strength training programs and rehabilitation. There have been studies that have identified the important prime movers and stabilizers during push-up exercises that include the serratus anterior, pectoralis major, anterior deltoid, upper and lower trapezius, and supraspinatus. The remainder of the rotator cuff, being the infraspinatus, teres minor, and subscapularis, also help with humeral stabilization. Hand position has also shown to affect muscle activation. However, there is little known about the role of the specific muscles through a push-ups range of motion and hand position’s effect on scapular kinematics.

Chapter III

Methods and Procedures

Introductions

This study was designed to investigate the effects of changing hand position on scapular kinematics during a traditional push-up. Differences in scapular kinematics were measured during a single session involving six different push up conditions. These conditions consisted of traditional push-up with narrow, wide and standard hand positions, and modified push-ups with narrow, wide, and standard hand positions.

Description of the Study Sample

The study sample consisted of 16 healthy, college aged participants (11 males, 5 females, age 20.5 $\pm$ 5.25 years) with no history of shoulder injury. Participants were excluded from the study if they have had a surgery to the shoulder, or had an injury that required rehabilitation. Furthermore, participants were excluded if they have any neurological disorders, or are currently involved in any overhead activities. Participants were recruited from Western Washington University Kinesiology classes, and from posted flyers on the WWU campus. The Human Subjects Review Committee of Western Washington University approved this experiment.

Design of the Study

Participants completed testing in a single session. The order of the type of push-up performed was randomized via a Balanced Latin Square design. All subjects performed the push-up exercise in each of the previously described conditions. Each subject was instructed on how to perform each variation of the push-ups.

Data Collection Procedures

Subjects were assigned a number for identification purposes and an informed consent form was completed. Anthropometrics (height and weight) were collected using a standard stadiometer. Prior to instrumentation, each participant performed a set of warm ups consisting of pendulum arm swings wall push-ups.

Scapular kinematic instrumentation. The Polhemus Fastrak 3Space magnetic tracking system (Polhemus Inc., Colchester, VT, USA), integrated with customized LabVIEW software (National instruments, Austin, TX, USA), was used to collect the scapular kinematic data for all conditions. The system includes the transmitter, three receivers, and digitizer. The transmitter was used to create a global coordinate system as a point of reference for the anatomical coordinate system. One receiver was fastened to the distal ulna, just proximal to the styloid, with the use of double-sided tape, and covered with pre-wrap and athletic tape. A second receiver was placed on the scapula using a custom-machined scapula tracker. The third receiver was placed approximately 2.5 cm inferior to sternal notch and attached via double-sided tape and micropore tape. To define the 3-dimensional anatomical coordinate system of the scapula, the Polhemus digitizing stylus was used to digitize the spinous process of C7, T1, and T8, the sternal notch, sternoclavicular joint on the dominant side, the dominant acromioclavicular joint, the origin of the spine and inferior angle of the dominant scapula, the medial and lateral epicondyles of the dominant humerus, and the radial and ulnar styloid processes on the dominant forearm. Dominate side was self-reported by asking participant which arm they would throw a ball with. The center of the humeral head was calculated using a least squares algorithm and was defined as the point that moved the least during several small arcs of motion (Harryman et al,, 1992).

Measurement techniques and procedures.

Warm up. The warm up consisted of pendulum swing of both arms using the body to move the arms at the glenohumeral joint passively as opposed to actively using their muscles to move them to prevent fatigue of the muscles used for the testing procedure. The participants swung their arms in a circle, forwards and backwards, and side to side. Fifteen repetitions of each swing were done on each arm. Wall push-ups were performed by standing at arm's length to the wall, and placing the middle finger under the acromion process. The participants then moved themselves closer to the wall via forearm flexion and humeral horizontal abductions, followed by moving themselves away from the wall via forearm extension and humeral horizontal adduction.

Push-ups. Each participant completed six variations of push-ups. These variations included a traditional push-up with the feet on the ground and the hand placed wide, narrow, or standard. The other three variations were modified push-ups with the knees on the ground and the hands in either wide, narrow, or standard. In the standard hand position, the hands were positioned on the ground with the third digit of each hand under the respective acromion. In the narrow hand positions, the hands were placed so that the distance between the third digits was 50% that in the standard position. During the wide hand position, the hands were placed wider than shoulder width, so that the distance between the third digits was 150% that in the standard position. The push-ups were performed with three repetitions each with a minute of rest between sets in order to reduce the effects of fatigue. Each push-up was performed to match a count of two seconds during the eccentric phase and two seconds during the concentric phase.

Experimental protocol. Each participant completed data collection in a single session. The order of push-ups was randomized, and one subject was collected at a time. After an explanation of testing procedures and an informed consent was completed, the warm up was implemented. Polhemus trackers were instrumented, and calibrated. After instrumentation, the participants were familiarized with the push-up types, and how they were performed. Following the familiarization, the participants performed the push-ups protocol. After the testing procedures, the participant was de-instrumented and cleaned of any electrode residue.

Data Analysis

There were two independent variables in this study: hand placement (standard vs. narrow vs. wide), and elbow extension angle (5° increments across the elbow extension ROM). Dependent variables included scapular movement (posterior tilt, upward rotation, and external rotation. Three two-way repeated measures analyses of variance (ANOVA) were conducted to evaluate the effects of hand position, and elbow angle of each of the dependent variables. Simple effects analyses were conducted in the case of significant interactions. Post-hoc analyses were conducted in the case of non-significant interactions and significant main effects. The significance level was set at $p < .007$, after a Bonferroni correction for three ANOVAs. Effect size was measured using partial eta squared.

Chapter IV

Results and Discussion

Introduction

This study tested the hypothesis that a narrow hand position during a push-up exercise would elicit a greater amount of scapular upward rotation, external rotation, and posterior tilting when compared to standard and wide hand positions. The independent variables consisted of hand position, and elbow angle at every 5° increments of elbow flexion. The dependent variables included scapular kinematics: upward/downward rotation, internal/external rotation, anterior/posterior tilting. Three two-way repeated measures analysis of variance (ANOVA) was performed to compare hand position and elbow angle on scapular kinematics.

Results

Mauchly's test of spherecity showed that spherecity was assumed for hand positions. Spherecity was not assumed for elbow flexion, so Greenhouse-Geisser was used. There was no significant interaction between elbow flexion and hand position for scapular upward rotation (UR) (F[24, 360] = 0.592 , p = .938, $\eta^2 = 0.038$). There was also no main effect of elbow flexion for UR (F[1.158, 17.371] = 1.5610, p = 0.232, η^2 = 0.094). However, there was a main effect of hand position on UR (F[2, 30] = 12.505, $p < .001$, η^2 = .455). Pairwise comparisons indicated that standard and narrow conditions showed greater UR than wide (p = .001 and p = .002, respectively). However, no significant difference was seen between standard and narrow conditions (p = .091) (Figure 1).

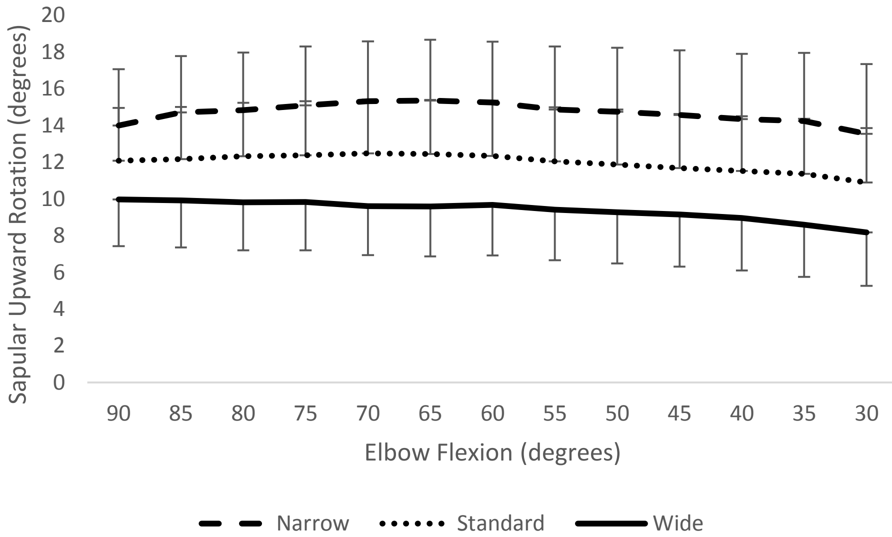

Figure 1. Scapular upward rotation (mean ± SEM) across elbow flexion angle for each hand position.

Mauchly’s test of sphericity was not significant for either hand position of elbow angle, therefore Greenhouse-Geisser was used. There was no significant interaction between elbow flexion and hand position for posterior tilt (PT) (F[24, 360] = 0.730, p = .821, η^2 = 0.046). There was a main effect of hand position of on PT (F[1.288, 19.317] = 8.565, p = .001, η^2 = 0.363), indicating that the narrow hand position showed significantly higher PT than wide (p = .004) There was no significant main effect of elbow angle (F[1.304, 9.560] = 1.306, p = .218, η^2 = 0.080) (Figure 2).

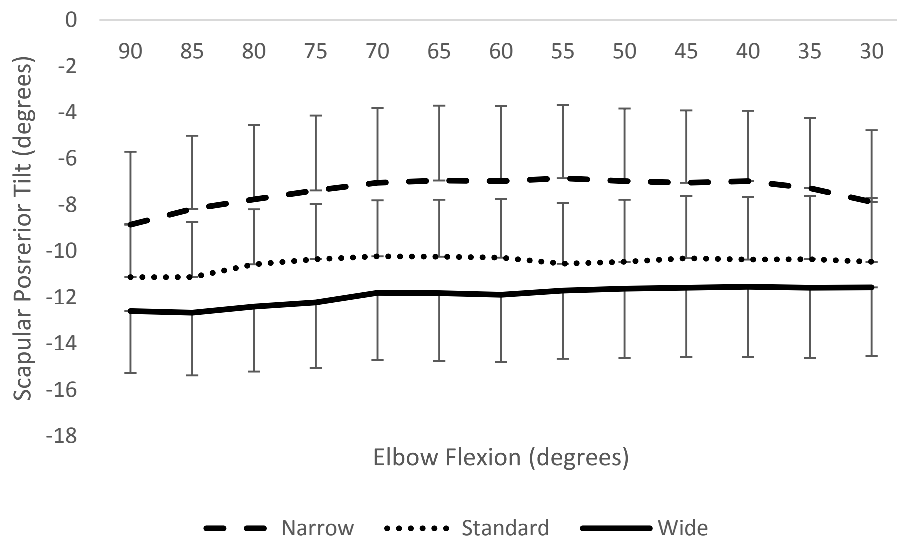

Figure 2. Scapular posterior tilt (mean ± SEM) across elbow flexion angle for each hand position.

Mauchly's test of spherecity showed spherecity was assumed for hand position, but not for elbow angle, therefore Greenhouse-Geisser was assumed. There was no interaction between elbow flexion and hand position on external rotation (ER) (F[24, 360] = 1.471, p = .073, η^2 = 0.089). There were main effects of both hand position (F[2, 30] = 4.411, p = .021, η^2 = 0.227) and elbow flexion (F[1.136, 17.03] = 36.57, p < .001, η^2 = 0.709) showing the narrow hand position having the greatest amount of ER. A linear trend analysis revealed that ER decreased linearly with elbow extension (p < .001) (Figure 3).

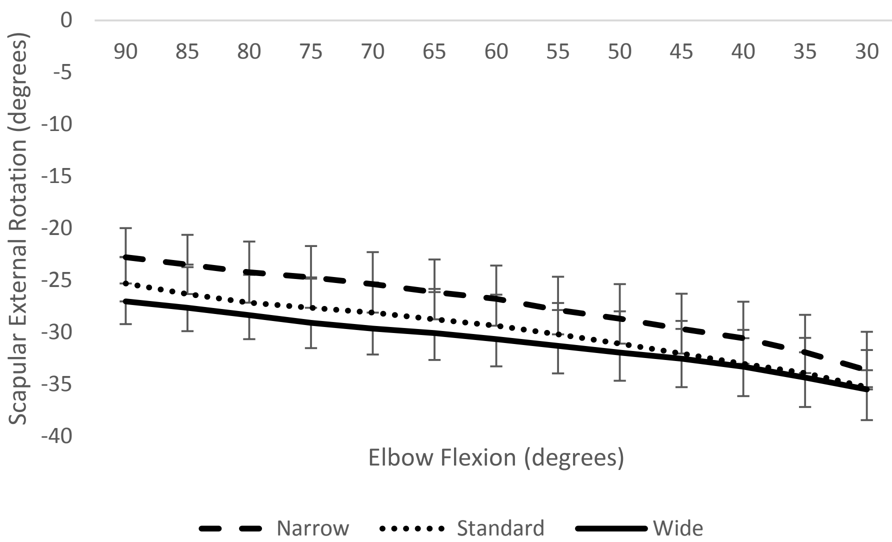

Figure 3. Scapular external rotation (mean ± SEM) across elbow flexion angle for each hand position.

Discussion

The push-up exercise is a commonly used exercise in both strength training and rehabilitation settings due to its effectiveness at targeting prime movers and scapular stabilizers, specifically the serratus anterior. Muscle activation during push-ups has been investigated with traditional push-ups, as well as push-up variations, such as changing hand positions, or during a modified push up. Although there is a vast amount of literature investigating the effect of the push-up on muscle activity, there has been little research on how push-ups affect scapular kinematics. Suprak et al. (2013) found that during a push-up exercise in a healthy population, with the hands placed in a similar position to the current study, a healthy scapular position was upward rotation, external rotation, and posterior tilt. This is important to identify in order to display when an individual may need shoulder rehabilitation or to increase the effectiveness of exercises for the shoulder. The few studies that have investigated scapular kinematics during a push-up involved wall push-ups, as well as the effect of humeral elevation (Lunden, Braman, LaPrade, & Ludewig, 2010; Suprak, et al., 2013).

Push-ups can be performed with variable hand position, and this may affect muscle lengths and activations, and thus, kinematics. Therefore, the purpose of this study was to investigate the effects of hand position during a push-up exercise on scapular kinematics. The tested hypothesis was that a wide hand position would have a significantly less amount of scapular upward rotation, external rotation, and posterior tilt. Conversely, a narrow hand position would theoretically have the greatest amount of scapular upward rotation, external rotation, and posterior tilt. The current data seemed to support the experimental hypothesis with the narrow hand position having a significantly greater amount of scapular upward rotation, external rotation, and posterior tilt. The narrow hand position had significantly higher upward rotation and posterior tilt when compared to the wide hand position, however there was no significant difference between the narrow and standard hand positions.

Other studies that investigated scapular kinematics have done so during either a wall push-up exercise or manipulating the humeral position during a push-up. Lunden et al. (2010) reported that during a wall push-up there was significantly higher downward rotation and internal rotation when compared to a standard push-up. The current study also shows the scapula in a position of internal rotation, however, the amount of internal rotation was decreased with the narrow hand position when compared to the wide hand position. Furthermore, the current study also demonstrated that a traditional push places the scapula in a position of upward rotation throughout the exercise, with the greatest degree in the narrow hand position. Lunden et al. also reported there was no difference in posterior tilt between a wall push-up and a traditional push-up. This is similar to the present results, as there was no difference in posterior tilt between the narrow and standard hand position, however, there was significantly less posterior tilt during the narrow when compared to the wide hand position. The differences between the Lunden study and the present study is due to the different loading patterns during a wall push-up when compared to a traditional push-up. Although the Lunden study compared their standard push-up to a wall push-up, they did not manipulate hand positions. They also investigated scapular position during static trials, whereas the present study tracked the position through a dynamic range of motion.

Suprak, et al. (2013) investigated the effects of humeral elevation during a push-up on scapular kinematics. They compared the differences between having the arms at the side, in a self-selected position, or elevated. Their data showed a greater amount of scapular posterior tilt, external rotation, and upward rotation while the arms were either placed at the side, or at a self-selected position, when compared to a greater amount of humeral elevation. The findings in the current study are in accordance to those from Suprak et al. in that there was an increase in scapular posterior tilt, upward rotation, and external rotation with the narrow hand position. Although this study did not control for humeral elevation, it was observed that the narrow hand position caused the participants to place the arms closer to their sides with an average humeral elevation of 37.70°, while the wide hand positions caused a greater amount of humeral elevation with an average of 55.73° of humeral elevation. These values compare to the standard hand position with an average of 46.90° of humeral elevation. When comparing Suprak et al. with the current study, there is an implication for the importance of both hand position and humeral elevation during a push-up. Because of this, a study investigating both humeral position and hand position should be performed to identify if there is an interaction between the two manipulations and, if combined, can achieve a more optimal scapular position.

In the present study, there was less posterior tilt, external rotation, and upward rotation during the wide hand position push-up when compared to the standard and narrow hand positions. This may be due to a difference in muscle activation patterns, and different loads occurring during push-up, which may affect the scapular movers during different humeral positions. A study by San Juan et al. (2015) found that a traditional push-up elicits higher EMG value in the upper trapezius, lower trapezius, serratus anterior, and infraspinatus muscles when compared to modified push-ups. Furthermore, they found that there was greater amount of ground reaction force during a traditional push-up compared to a modified push up. It has also been identified that a greater amount of body mass is supported during a traditional push-up when compared to a modified push-up (Suprak, Dawes, & Stephenson, 2001). Marcolin, et al. (2015) found that there was greater muscle activation of the serratus anterior as well as the transverse trapezius muscles during a narrow hand position push up when compared to standard and wide hand positions. An increase in serratus anterior activation causes the scapula to achieve a greater amount of scapular upward and external rotation. This can be compared to the present results, since the narrow hand position caused the greatest amount of scapular upward rotation, as well as external rotation. The findings in the literature about EMG activation and amount of load on the body during a push-up may have implications on scapular kinematics.

The greater amount of external rotation of the scapula during the narrow hand position condition may due to an increase in serratus anterior muscle and other scapular stabilizer activation. While the greater amount of posterior tilt may be explained by a greater activation of the lower trapezius muscle. Furthermore, the increased in upward rotation may be accounted for by an increase in the scapula upward rotators, such as the lower trapezius or serratus anterior. Although the aim of rehabilitation exercise is to decrease the amount of activation in the upper trapezius muscle due to its role in anterior tilt, the ratio of the upper trapezius and lower trapezius, or upper trapezius and serratus anterior may have been within a healthier range during the narrow and standard hand position, while the wide hand position may have had a less favorable ratio. Because of this, the hands should be placed at least below the acromion process or narrower in order to rehabilitate the scapular movers, or to prevent shoulder pathology. Furthermore, a wide hand position should be avoided to ensure the scapula is not placed in a poor position. Overall, a study should be performed to make a direct comparison between scapular kinematics and muscle activation of the scapular movers to better determine the cause of the difference in scapular kinematics during different exercises.

Chapter V

Summary Conclusions, and Recommendations

Summary

Scapular kinematics are important to investigate, and track, due to the scapula having such an important role in humeral motion. With the scapula moving in the three cardinal planes of motion with internal/external rotation, upward/downward rotation, and anterior/posterior tilt, there are many ways that the scapula can exhibit improper kinematics. Improper scapular kinematics can lead to shoulder pathologies, such as subacromial impingement syndrome, rotator cuff pathology, and instability. There are multiple exercises that can be employed to strengthen and coordinate the scapular stabilizers/movers, including the serratus anterior, upper trapezius, lower trapezius, and rhomboid muscles. One such commonly utilized exercise is the push-up.

A popular exercise for shoulder rehabilitation, or shoulder conditioning is the push-up due to its effectiveness at targeting the scapular stabilizing muscles, as well as its ease of implementation. The push-up can be altered in a variety of ways. It can be performed traditionally, with the feet on the ground, and the hands below the shoulders, the hand position can be manipulated to be more wide or narrow, as well as superior or inferior to the shoulder. Other variations include modified, where the knees are placed on the ground, or the push-up can be performed on a variety of surfaces, such as a Swiss ball, or a BOSU ball instead of a flat surface.

This study investigated the effects hand position during a push-up exercise on scapular kinematics. The hand positions included standard (middle finger below the acromion) wide (150% further than standard), and narrow (50% closer than standard). There was an increase in scapular upward rotation, external rotation, and posterior tilt in the narrow hand position when compared to the wide hand position. There was no difference between the narrow and standard hand positions.

Conclusions

The experimental hypothesis was supported, in that a narrow hand position push-up resulted in the greatest amount of scapular upward rotation, external rotation, and posterior tilt as compared to standard and wide hand positions. Therefore, a narrow hand position may be recommended when performing push-ups in order to promote healthy scapular positioning.

Recommendations

Push-ups have been well studied when looking at activation of muscles acting on the arm, such as the pectoralis major, deltoid, or triceps brachii muscles, as well as muscles acting on the scapula, such as the serratus anterior, upper trapezius, and lower trapezius muscle (Cogley, et al. 2005; Sandhu et al., 2008; Park & Yoo, 2011). There is, however, little research that has been done on investigating push-ups effect on scapular kinematics. Understanding how various push-up conditions can affect scapular kinematics on a healthy population can help determine to type of push-up that should be implemented either as preventive care, in order to decrease risk of shoulder pathologies, or in a rehabilitation setting to help return the shoulder to a healthy state.

From the results of this study, a narrow hand position should be used in both strength and conditioning setting as well as in preventive care to help keep the scapula in a healthy range of motion. It would be beneficial, however, to test the effectiveness of changing hand position during a push-up on a population with unhealthy shoulders. This can further determine specifically what types of exercises should be implemented to help restore healthy kinematics to the scapula. This could be done as an intervention study that measures scapular kinematics before and implementing a push-up exercise regimen and investigating the changes in kinematics over time. Although this study has implications to muscle activation during a push-up, it is difficult to determine without actually investigating muscle activation with EMG. Future studies should investigate muscle activation patterns through the push-ups' range of motion, specifically on scapular movers, with different hand placement positions.

References

Anderson, D. S., Jackson, M. F., Kropf, D. S., & Soderberg, G. L. (1984). Electromyographic analysis of selected muscles during sitting push-ups. Effects of position and sex. *Physical Therapy*, *64*(1), 24–28.

Berthonnaud, E., Morrow, M., Herzberg, G., An, K.-N., & Dimnet, J. (2010). Biomechanical model predicting values of muscle forces in the shoulder girdle during arm elevation. *Journal of Mechanics in Medicine & Biology, 10*(4), 643–666. doi:10.1142/s0219519410003629

Borstad, J. D., & Ludewig, P. M. (2002). Comparison of scapular kinematics between elevation and lowering of the arm in the scapular plane. *Clinical Biomechanics, 17*(9/10), 650.

Borstad, J. D., & Ludewig, P. M. (2005). The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. *Journal of orthopaedic & sports physical therapy*, *35*(4), 227-238. doi:10.2519/jospt.2005.35.4.227

Cogley, R. M., Archambault, T. A., Fibeger, J. F., Koverman, M. M., Youdas, J. W., & Hollman, J. H. (2005). Comparison of muscle activation using various hand positions during the push-up exercise. *Journal of Strength & Conditioning Research*, *19*(3), 628–633. doi:10.1519/15094.1

Decker, M. J., Hintermeister, R. A., Faber, K. J., & Hawkins, R. J. (1999). Serratus anterior muscle activity during selected rehabilitation exercisees. *The American Journal of Sports Medicine*, *27*(6), 784–791. doi:10.1097/00005768-199705001-00237

Decker, M. J., Tokish, J. M., Ellis, H. B., Torry, M. R., & Hawkins, R. J. (2003). Subscapularis muscle activity during selected rehabilitation exercises. *The American Journal of Sports Medicine*, *31*(1), 126–134.

de Oliveira, A. S., de Morais Carvalho, M., & de Brum, D. P. C. (2008). Activation of the shoulder and arm muscles during axial load exercises on a stable base of support and on a medicine ball. *Journal of Electromyography & Kinesiology*, *18*(3), 472–479. doi:10.1016/j.jelekin.2006.09.009

Donkers, M. J., An, K. N., Chao, E. Y., & Morrey, B. F. (1993). Hand position affects elbow joint load during push-up exercise. *Journal of Biomechanics*, *26*(6), 625–632. doi:10.1016/0021-9290(93)90026-b

Gabbett, T. J., Johns, J., & Riemann, M. (2008). Performance changes following training in junior rugby league players. *Journal of Strength & Conditioning Research*, *22*(3), 910–917.

Gouvali, M. K., & Boudolos, K. (2005). Dynamic and electromyographical analysis in variants of push-up exercise. *Journal of Strength and Conditioning Research*, *19*(1), 146–151. doi:10.1519/14733.1

Hamill, J., & Knutzen, K. M. (2006). *Biomechanical Basis of Human Movement*. Lippincott Williams & Wilkins.

Hardwick, D. H., Beebe, J. A., McDonnell, M. K., & Lang, C. E. (2006). A comparison of serratus anterior muscle activation during a wall slide exercise and other traditional exercises. *The Journal of Orthopaedic and Sports Physical Therapy*, *36*(12), 903–910. doi:10.2519/jospt.2006.2306

Harman, E. A., Gutekunst, D. J., Frykman, P. N., Nindl, B. C., Alemany, J. A., Mello, R. P., & Sharp, M. A. (2008). Effects of two different eight-week training programs on military physical performance. *Journal of Strength and Conditioning*, *22*(2), 524–534. doi:10.1519/JSC.0b013e31816347b6

Harryman, D. T., Sidles, J. A., Harris, S. L., & Matsen, F. A. (1992). The role of the rotator interval capsule in passive motion and stability of the shoulder. *The Journal of Bone and Joint Surgery. American Volume*, *74*(1), 53–66.

Huang, C. K., Siu, K. C., Lien, H. Y., Lee, Y. J., & Lin, Y. H. (2013). Scapular kinematics and muscle activities during pushing tasks. *Journal of Occupational Health*, *55*(4), 259–266. doi:10.1539/joh.12-0105-OA

Ingwersen, K. G., Christensen, R., Sørensen, L., Jørgensen, H. R. I., Jensen, S. L., Rasmussen, S., … Juul-Kristensen, B. (2015). Progressive high-load strength training compared with general low-load exercises in patients with rotator cuff tendinopathy: study protocol for a randomised controlled trial. *Trials*, *16*(1), 1–11. doi:10.1186/s13063-014-0544-6

San Juan, J. G., Suprak, D. N., Roach, S. M., & Lyda, M. (2015). The effects of exercise type and elbow angle on vertical ground reaction force and muscle activity during a push-up plus exercise. *BMC Musculoskeletal Disorders*, *16*(1), 1–9. doi:10.1186/s12891-015-0486-5

Karduna, A. R., McClure, P. W., & Michener, L. A. (2000). Scapular kinematics: effects of altering the Euler angle sequence of rotations. *Journal of Biomechanics*, *33*(9), 1063–1068. doi:10.1016/s0021-9290(00)00078-6

Karduna, A. R., McClure, P. W., Michener, L. A., & Sennett, B. (2001). Dynamic Measurements of Three-Dimensional Scapular Kinematics: A Validation Study. *Journal of Biomechanical Engineering*, *123*(2), 184. doi:10.1115/1.1351892

Kibler, W. B., & McMullen, J. (2003). Scapular dyskinesis and its relation to shoulder pain. *The Journal of the American Academy of Orthopaedic Surgeons*, *11*(2), 142–151. doi:10.5435/jaaos-20-06-364

Kilinç, F. (2008). An intensive combined training program modulates physical, physiological, biomotoric, and technical parameters in women basketball players. *Journal of Strength and Conditioning Research*, *22*(6), 1769–1778. doi:10.1519/JSC.0b013e3181854bca

Knapik, J. J., Rieger, W., Palkoska, F., Camp, S. V., & Darakjy, S. (2009). United States army physical readiness training: rationale and evaluation of the physical training doctrine. *Journal of Strength*, *23*(4), 1353–1362. doi:10.1519/JSC.0b013e318194df72

Lear, L. J., & Gross, M. T. (1998). An electromyographical analysis of the scapular stabilizing synergists during a push-up progression. *Journal of Orthopaedic & Sports Physical Therapy*, *28*(3), 146-157. doi:10.2519/jospt.1998.28.3.146

Lee, S., Lee, D., & Park, J. (2013). The effect of hand position changes on electromyographic activity of shoulder stabilizers during push-up plus exercise on stable and unstable surfaces. *Journal of Physical Therapy Science*, *25*(8), 981–984. doi:10.1589/jpts.25.981

Lehman, G. J. (2007). An unstable support surface is not a sufficient condition for increases in muscle activity during rehabilitation exercise. *The Journal of the Canadian Chiropractic Association*, *51*(3), 139–143.

Lehman, G. J., Gilas, D., & Patel, U. (2008). An unstable support surface does not increase scapulothoracic stabilizing muscle activity during push up and push up plus exercises. *Manual Therapy*, *13*(6), 500–506. doi:10.1016/j.math.2007.05.016

Lehman, G. J., MacMillan, B., MacIntyre, I., Chivers, M., & Fluter, M. (2006). Shoulder muscle EMG activity during push up variations on and off a Swiss ball. *Dynamic Medicine*, *5*, 7–7. doi:10.1186/1476-5918-5-7

Ludewig, P. M., Cook, T. M., & Nawoczenski, D. A. (1996). Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation. *Journal of Orthopaedic & Sports Physical Therapy*, *24*(2), 57-65. doi:10.2519/jospt.1996.24.2.57

Ludewig, P. M., & Cook, T. M. (2000). Alterations in Shoulder Kinematics and Associated Muscle Activity in People With Symptoms of Shoulder Impingement. *Physical Therapy*, *80*(3), 276–291.

Ludewig, P. M., & Cook, T. M. (2002). Translations of the humerus in persons with shoulder impingement symptoms. *The Journal of Orthopaedic and Sports Physical Therapy*, *32*(6), 248–259. doi:10.2519/jospt.2002.32.6.248

Ludewig, P. M., Hoff, M. S., Osowski, E. E., Meschke, S. A., & Rundquist, P. J. (2004). Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. *The American Journal of Sports Medicine*, *32*(2), 484–493. doi:10.1177/0363546503258911

Ludewig, P. M., Phadke, V., Braman, J. P., Hassett, D. R., Cieminski, C. J., & LaPrade, R. F. (2009). Motion of the shoulder complex during multiplanar humeral elevation. *The Journal of Bone and Joint Surgery. American Volume*, *91*(2), 378–389. doi:10.2106/JBJS.G.01483

Lunden, J. B., Braman, J. P., LaPrade, R. F., & Ludewig, P. M. (2010). Shoulder kinematics during the push-up plus exercise. *Journal of Shoulder and Elbow Surgery*, *19*(2), 216–223. doi:10.1016/j.jse.2009.06.003

Maenhout, A., Van Praet, K., Pizzi, L., Van Herzeele, M., & Cools, A. (2010). Electromyographic analysis of knee push up plus variations: what is the influence of the kinetic chain on scapular muscle activity? *British Journal of Sports Medicine*, *44*(14), 1010–1015. doi:10.1136/bjsm.2009.062810

Magee, D., J. (2007). *Orthopedic physical assessment* (5th ed.). Saunders Book Company

Marcolin, G., Petrone, N., Moro, T., Battaglia, G., Bianco, A., & Paoli, A. (2015). Selective Activation of Shoulder, Trunk, and Arm Muscles: A Comparative Analysis of Different Push-Up Variants. *Journal of athletic training*, *50*(11), 1126-1132.

Martins, J., Tucci, H. T., Andrade, R., Araújo, R. C., Bevilaqua-Grossi, D., & Oliveira, A. S. (2008). Electromyographic amplitude ratio of serratus anterior and upper trapezius muscles during modified push-ups and bench press exercises: *Journal of Strength and Conditioning Research*, *22*(2), 477–484. doi:10.1519/JSC.0b013e3181660748

McGuigan, M. R., Tatasciore, M., Newton, R. U., & Pettigrew, S. (2009). Eight weeks of resistance training can significantly alter body composition in children who are overweight or obese: *Journal of Strength and Conditioning Research*, *23*(1), 80–85. doi:10.1519/JSC.0b013e3181876a56

Michener, L. A., McClure, P. W., & Karduna, A. R. (2003). Anatomical and biomechanical mechanisms of subacromial impingement syndrome. *Clinical Biomechanics*, *18*(5), 369–379. doi:10.1016/s0268-0033(03)00047-0

Moseley, J. B., Jobe, F. W., Pink, M., & Perry, J. (1992). EMG analysis of the scapular muscles during a shoulder rehabilitation program. *Journal of the Canadian Chiropractic Association*, *36*(4), 244. doi: 10.1177/036354659202000206

Murphy, B., & Marshall, P. (2006). Changes in muscle activity and perceived exertion during exercises performed on a swiss ball. *Applied Physiology, Nutrition & Metabolism*, *31*(4), 376–383. doi:10.1139/H06-006

Neer, C. S. (1972). Anterior acromioplasty for the chronic impingement syndrome in the shoulder. *The Journal of Bone & Joint Surgery*, *54*(1), 41–50.

Paine, R., & Voight, M. L. (2013). The role of the scapula. *International Journal of Sports Physical Therapy*, *8*(5), 617–629.

Park, S., & Yoo, W. (2011). Differential activation of parts of the serratus anterior muscle during push-up variations on stable and unstable bases of support. *Journal of Electromyography and Kinesiology*, *21*(5), 861–867. doi:10.1016/j.jelekin.2011.07.001

San Juan, J. G., Suprak, D. N., Roach, S. M., & Lyda, M. (2015). The effects of exercise type and elbow angle on vertical ground reaction force and muscle activity during a push-up plus exercise. *BMC musculoskeletal disorders*, *16*(1), 23.

Sandhu, J. S., Mahajan, S., & Shenoy, S. (2008). An electromyographic analysis of shoulder muscle activation during push-up variations on stable and labile surfaces. *International Journal of Shoulder Surgery*, *2*(2), 30–35. doi:10.4103/0973-6042.40456

Sangwan, S., Green, R. A., & Taylor, N. F. (2015). Stabilizing characteristics of rotator cuff muscles: a systematic review. *Disability and Rehabilitation*, *37*(12), 1033–1043. doi:10.3109/09638288.2014.949357

Schuenke, M., Schulte, E., Schumacher, U. (2014). *Thieme atlas of anatomy general anatomy and musculoskeletal system* (5th ed.). New York, NY; Thieme Medical Publishers, Inc.

Shevlin, M. G., Lehmann, J. F., & Lucci, J. A. (1969). Electromyographic study of the function of some muscles crossing the glenohumeral joint. *Archives of Physical Medicine and Rehabilitation*, *50*(5), 264–270.

Suprak, D. N., Bohannon, J., Morales, G., Stroschein, J., & San Juan, J. G. (2013). Scapular kinematics and shoulder elevation in a traditional push-up. *Journal of athletic training*, *48*(6), 826-835.

Suprak, D. N., Dawes, J., & Stephenson, M. D. (2011). The effect of position on the percentage of body mass supported during traditional and modified push-up variants. *The Journal of Strength & Conditioning Research*, *25*(2), 497-503.

Suprak, D. N., Osternig, L. R., van Donkelaar, P., & Karduna, A. R. (2006). Shoulder joint position sense improves with elevation angle in a novel, unconstrained task. *Journal of Orthopaedic Research*, *24*(3), 559–568. doi:10.1002/jor.20095

Tsai, N. T., McClure, P. W., & Karduna, A. R. (2003). Effects of muscle fatigue on 3-dimensional scapular kinematics. *Archives of Physical Medicine and Rehabilitation*, *84*(7), 1000–1005. doi:10.1016/S0003-9993(03)00127-8

Uhl, T. L., Mattacola, C. G., & Johnson, D. L. (2002). Clinical assessment and rehabilitation of shoulder and knee sensorimotor control. *Orthopedics*, *25*(1), 75–78.

Uhl, T. L., Carver, T. J., Mattacola, C. G., Mair, S. D., & Nitz, A. J. (2003). Shoulder musculature activation during upper extremity weight-bearing exercise. *Journal of Orthopaedic & Sports Physical Therapy*, *33*(3), 109-117. doi:10.2519/jospt.2003.33.3.109

Appendix A

Anthropometric Survey and Experimental Checklist

	Check Off List			**Comments**
Date				Common Activities:
Time (Begun, Completed)				
Subject Number				
Height (in)				
Body Weight (lb)				
Age (yr)				
Gender	Male / Female			
Arm Tested	L / R			Injury History:
Consent Form Completed	Yes / No			
Warm-up Completed (both arms)	Yes / No			
Mark Key Landmarks	Yes / No			
Prep Skin Sites	Yes / No			
Sternal Sensor Attachment	Yes / No			
Scapular Sensor Attachment	Yes / No			
Forearm Sensor Attachment	Yes / No			
Transmitter Height Adjusted	Yes / No			
Digitize Bony Landmarks	Yes / No			
Humeral Head Translation (mm)				
Scapular Digitization Value (deg.)				
Subject Matrix Obtained	Yes / No			
Check Motion	Yes / No			
Mark ***hand*** positions on floor	Yes / No			
Mark ***block*** positions on floor	Yes / No			
Practice push-ups ***with*** count	Yes / No			
Collect each trial	Yes / No			
Condition Sequence:				
1				
2				
3				
4				
5				
6				

Appendix B

Western Washington University
Consent to Take Part In a Research Study
Project: Scapular kinematics and muscle activity during traditional and modified push-up variants

You are invited to participate in a research study conducted by Tylre M Arens, from the department of Health and Human Development at the Western Washington University. The purpose of this investigation is to study the movement of the shoulder blade during several variations of the push-up exercise. You were selected as a possible participant in this study because you have no history of shoulder pathology.

If you decide to participate, you understand that the following things will be done to you. You will be asked to fill out a brief form to provide basic information such as age, height and weight and which arm is your dominant arm. Non-invasive measurements will be made throughout the experiment. To perform these measurements, small sensors will be attached by straps or tape to your arm, breastbone and shoulder, as well as to the skin over certain muscles. You will be asked to perform several repetitions of the push-up exercise in various positions. These positions will consist of various hand positions on the floor, both supported on the feet and on the knees. The entire testing process should take about 90 minutes.

There is no direct benefit to you by participating in this study. However, you understand that information gained in this study may help in the understanding of the function of the shoulder, and may guide decisions made in prescribing strengthening and injury rehabilitation exercise.

Participation in any research study carries with it possible risks. Because multiple trials will be performed, there is a risk of muscle fatigue. However, precautions have been taken to minimize this risk. However, you may discontinue participation at any time during testing.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Subject identities will be kept confidential by coding the data with subject numbers, rather than names.

Your participation is voluntary. Your decision whether to participate will not affect your relationship with Western Washington University. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without penalty.

If you have any questions, please feel free to contact Dave Suprak, (360) 650-2586, Department of Physical Education, Health and Recreation, Western Washington University, Bellingham, WA, 98225. If you have questions regarding your rights as a research subject, contact the Ken Clark in the Office of Research and Sponsored Programs, Western Washington University, Bellingham, WA, 98225, (360) 650-4403. You have been offered a copy of this form to keep.

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you have received a copy of this form, that you are at least 18 years of age, and that you are not waiving any legal claims, rights or remedies.

Print Name____

Signature____

Date________________________

Appendix C

Raw Data

	Posterior Tilt												
	90	**85**	**80**	**75**	**70**	**65**	**60**	**55**	**50**	**45**	**40**	**35**	**30**
1	-7.569	-6.164	-4.058	-2.532	-2.603	-2.476	-2.269	-1.427	-0.898	0.016	0.44	0.218	0.214
2	-7.87733	-5.25267	-3.73833	-3.04	-2.09567	-1.458	-1.15467	-0.79733	-0.29833	0.826333	2.167	3.1705	3.813
3	22.612	23.395	23.972	24.4	24.53	24.537	24.308	23.115	20.784	18.311	16.064	13.802	10.51
4	-2.73333	-3.26867	-3.88467	-4.01	-3.86233	-4.445	-4.528	-5.04	-5.24	-6.877	-6.947	-8.1295	-8.161
5	-32.1595	-31.2885	-31.5045	-31.569	-30.682	-30.089	-29.544	-29.829	-30.52	-30.6395	-31.1825	-32.9963	-37.1527
6	-12.34	-11.374	-10.601	-9.938	-7.474	-7.416	-6.711	-7.004	-6.464	-6.484	-5.568	-5.295	-5.053
7	-9.963	-8.398	-8.242	-7.455	-7.167	-7.221	-7.031	-6.859	-6.525	-5.576	-5.744	-5.948	-6.996
8	-8.06	-7.436	-7.345	-6.992	-6.305	-4.647	-5.053	-5.32	-3.851	-2.688	-2.839	-3.171	-3.494
9	-25.187	-23.614	-22.772	-22.159	-22.077	-21.765	-21.508	-21.567	-21.378	-21.408	-21.238	-21.234	-20.479
10	-12.8885	-13.2105	-13.2165	-13.636	-13.6195	-13.9965	-14.3855	-11.733	-12.1213	-12.2893	-12.4077	-12.5783	-12.8597
11	-12.436	-12.18	-11.838	-10.16	-9.427	-9.667	-9.284	-9.432	-9.767	-9.559	-9.326	-8.516	-7.958
12	-20.8615	-21.0755	-20.5295	-20.343	-20.18	-20.5815	-21.4575	-19.0973	-19.727	-20.3433	-21.0147	-22.035	-22.5657
13	-2.906	-2.393	-2.12	-2.857	-3.105	-3.141	-3.272	-4.013	-4.574	-5.108	-6.118	-7.069	-8.77
14	1.777	2.543	2.7885	3.482	3.5425	3.8675	3.897	3.473	3.579	3.6655	3.4395	2.866	2.4585
15	4.396	5.188	5.896	6.574	6.443	6.869	6.847	7.217	7.595	8.267	8.605	8.418	8.508
16	-15.4823	-16.306	-16.9307	-17.7733	-18.6007	-19.5033	-20.4747	-21.3073	-22.1873	-22.7197	-19.9797	-17.9285	-17.8825
Mean	-8.85491	-8.17718	-7.75773	-7.37552	-7.04267	-6.9458	-6.97627	-6.85131	-6.97456	-7.03788	-6.97806	-7.27664	-7.86675
STD	3.15917	3.173823	3.209741	3.246775	3.228297	3.247632	3.253308	3.172949	3.152289	3.128172	3.05	3.027211	3.096306
	Upward Rotation												
	90	**85**	**80**	**75**	**70**	**65**	**60**	**55**	**50**	**45**	**40**	**35**	**30**
1	7.25	8.807	8.427	8.528	10.444	12.459	13.375	14.605	14.45	14.602	14	13.749	11.945
2	27.19333	28.23467	28.01033	29.138	29.36433	30.14333	30.16733	30.23133	30.43	30.66767	30.64367	30.565	29.474
3	29.655	31.483	33.963	36.809	37.573	39.184	39.357	40.136	40.857	41.695	42.87	42.974	43.542
4	32.35033	33.11867	33.07167	32.77967	32.954	32.73	31.808	32.2705	33.166	33.7065	33.0375	32.148	32.3375
5	-11.663	-10.7945	-10.6535	-10.0205	-9.957	-9.328	-10.1695	-10.15	-9.1215	-8.1835	-7.1105	-11.5303	-11.579
6	17.577	19.343	19.42	20.472	20.141	20.102	20.55	20.511	20.127	20.421	18.923	18.677	18.105
7	25.866	26.338	27.27	27.738	29.164	30.134	29.855	29.638	29.842	29.603	29.924	29.976	30.69
8	2.977	3.363	3.959	4.993	5.018	5.381	6.356	7.066	5.867	4.723	4.948	5.105	4.418
9	-2.159	-1.427	-0.955	-0.636	-0.355	-0.901	-0.839	-0.939	-1.288	-1.145	-2.016	-2.769	-4.765
10	16.215	15.6155	14.906	14.6055	13.5335	11.7655	11.69	6.140667	5.877667	5.376333	4.935	4.569667	3.875333
11	11.393	12.937	11.206	10.354	9.526	8.196	6.678	5.699	5.01	4.125	3.27	2.33	1.549
12	2.0455	3.263	3.036	2.456	2.7175	2.716	3.0985	-0.099	-0.30067	-0.52433	-0.27333	0.072667	-0.16667
13	20.514	20.541	20.784	20.94	20.805	19.726	19.114	19.279	18.745	17.38	16.555	14.74	11.855
14	18.368	18.3055	18.3285	18.01	18.2205	18.378	18.458	18.6885	18.33	18.1875	18.4145	18.298	17.6335
15	8.567	8.269	7.634	7.135	7.303	6.932	7.018	7.478	7.298	6.681	6.62	6.143	5.748
16	17.954	17.96833	18.876	18.13167	18.82567	18.07567	17.45267	17.355	16.80567	15.74467	14.919	22.891	22.1705
Mean	14.00645	14.71032	14.83019	15.08958	15.32984	15.35584	15.24806	14.86938	14.75595	14.56624	14.35374	14.24619	13.55201
STD	3.066976	3.074299	3.145238	3.221893	3.25543	3.317384	3.315692	3.441867	3.486864	3.529068	3.544471	3.713968	3.793618
	External Rotation												
	90	**85**	**80**	**75**	**70**	**65**	**60**	**55**	**50**	**45**	**40**	**35**	**30**
1	-43.22	-44.95	-46.558	-47.144	-48.108	-48.725	-49.102	-49.741	-50.436	-50.972	-51.129	-52.082	-53.269
2	-27.5	-27.9657	-28.6947	-29.4963	-30.066	-30.603	-31.1177	-31.9317	-32.7333	-34.1767	-35.7073	-37.1277	-39.02
3	-26.6	-27.72	-29.666	-31.779	-33.796	-35.725	-38.062	-39.985	-43.83	-48.03	-52.377	-58.047	-64.031
4	-8.03333	-8.71967	-9.19533	-9.427	-10.015	-10.6827	-11.3295	-12.027	-12.876	-15.246	-15.803	-18.026	-20.7365
5	-14.9455	-14.779	-14.885	-14.9455	-15.446	-16.0925	-15.969	-16.4235	-17.399	-18.38	-19.4325	-22.0307	-23.7293
6	-10.211	-10.043	-9.947	-9.453	-7.931	-7.554	-6.86	-6.873	-5.933	-5.716	-4.172	-4.156	-3.968
7	-22.756	-22.759	-23.086	-23.351	-23.458	-23.893	-24.32	-25.075	-25.421	-25.695	-26.058	-26.582	-27.442
8	-41.796	-42.527	-43.624	-44.554	-45.025	-45.86	-46.485	-47.198	-48.782	-49.468	-50.456	-51.731	-52.881
9	-26.117	-25.476	-25.392	-25.214	-25.212	-25.361	-26.096	-26.564	-27.477	-28.389	-29.118	-29.976	-31.176
10	-5.8425	-7.0205	-8.639	-9.784	-10.984	-12.639	-13.498	-18.3367	-19.048	-20.0543	-21.0363	-22.1633	-23.2967
11	-24.933	-26.312	-27.478	-28.048	-29.476	-31.231	-32.584	-33.631	-34.551	-35.172	-35.882	-37.436	-38.824
12	-25.3265	-26.672	-27.283	-27.8195	-28.751	-29.4075	-29.959	-32.7097	-33.1637	-33.9163	-34.8653	-35.7237	-36.35
13	-6.331	-6.758	-7.017	-6.927	-7.276	-7.724	-8.295	-8.39	-8.801	-9.236	-10.602	-13.287	-18.177
14	-25.9185	-26.7705	-27.087	-27.4395	-27.9295	-28.1445	-28.9275	-29.29	-29.5925	-30.156	-30.984	-31.6555	-33.3415
15	-25.106	-26.666	-27.261	-28.02	-28.893	-30.108	-30.831	-31.738	-32.551	-32.975	-33.669	-34.255	-35.25
16	-30.1013	-30.9263	-31.802	-32.2887	-33.6697	-34.6587	-35.1453	-36.0273	-36.7887	-37.3483	-38.147	-36.74	-36.9435
Mean	-22.7961	-23.504	-24.2259	-24.7307	-25.3773	-26.1506	-26.7863	-27.8713	-28.7114	-29.6832	-30.5899	-31.9387	-33.6522
STD	2.814885	2.876373	2.942579	3.006526	3.088239	3.130547	3.191446	3.200315	3.325383	3.390129	3.526655	3.604801	3.70338

Appendix D

Statistical Results

Tests of Within-Subjects Effects

Measure: External_Rotation

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Hand_Position	Sphericity Assumed	1354.943	2	677.471	4.411	.021	.227
	Greenhouse-Geisser	1354.943	1.626	833.546	4.411	.030	.227
	Huynh-Feldt	1354.943	1.795	754.809	4.411	.025	.227
	Lower-bound	1354.943	1.000	1354.943	4.411	.053	.227
Error(Hand_Position)	Sphericity Assumed	4607.568	30	153.586			
	Greenhouse-Geisser	4607.568	24.383	188.968			
	Huynh-Feldt	4607.568	26.926	171.118			
	Lower-bound	4607.568	15.000	307.171			
Elbow_Flexion	Sphericity Assumed	5205.329	12	433.777	36.567	.000	.709
	Greenhouse-Geisser	5205.329	1.136	4584.013	36.567	.000	.709
	Huynh-Feldt	5205.329	1.166	4463.523	36.567	.000	.709
	Lower-bound	5205.329	1.000	5205.329	36.567	.000	.709
Error(Elbow_Flexion)	Sphericity Assumed	2135.241	180	11.862			
	Greenhouse-Geisser	2135.241	17.033	125.358			
	Huynh-Feldt	2135.241	17.493	122.063			
	Lower-bound	2135.241	15.000	142.349			
Hand_Position * Elbow_Flexion	Sphericity Assumed	68.072	24	2.836	1.471	.073	.089
	Greenhouse-Geisser	68.072	1.652	41.216	1.471	.248	.089
	Huynh-Feldt	68.072	1.830	37.202	1.471	.247	.089
	Lower-bound	68.072	1.000	68.072	1.471	.244	.089
Error (Hand_Position*Elbow_Flexion)	Sphericity Assumed	693.930	360	1.928			
	Greenhouse-Geisser	693.930	24.774	28.011			
	Huynh-Feldt	693.930	27.447	25.282			
	Lower-bound	693.930	15.000	46.262			

Tests of Within-Subjects Effects

Measure: Posterior_Tilt

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Hand_Position	Sphericity Assumed	2234.935	2	1117.468	8.555	.001	.363
	Greenhouse-Geisser	2234.935	1.288	1735.508	8.555	.006	.363
	Huynh-Feldt	2234.935	1.357	1647.249	8.555	.005	.363
	Lower-bound	2234.935	1.000	2234.935	8.555	.010	.363
Error(Hand_Position)	Sphericity Assumed	3918.762	30	130.625			
	Greenhouse-Geisser	3918.762	19.317	202.871			
	Huynh-Feldt	3918.762	20.352	192.554			
	Lower-bound	3918.762	15.000	261.251			
Elbow_Flexion	Sphericity Assumed	95.234	12	7.936	1.306	.218	.080
	Greenhouse-Geisser	95.234	1.304	73.034	1.306	.279	.080
	Huynh-Feldt	95.234	1.377	69.145	1.306	.281	.080
	Lower-bound	95.234	1.000	95.234	1.306	.271	.080
Error(Elbow_Flexion)	Sphericity Assumed	1094.076	180	6.078			
	Greenhouse-Geisser	1094.076	19.560	55.935			
	Huynh-Feldt	1094.076	20.660	52.957			
	Lower-bound	1094.076	15.000	72.938			
Hand_Position * Elbow_Flexion	Sphericity Assumed	23.964	24	.998	.730	.821	.046
	Greenhouse-Geisser	23.964	3.193	7.506	.730	.547	.046
	Huynh-Feldt	23.964	4.157	5.765	.730	.580	.046
	Lower-bound	23.964	1.000	23.964	.730	.406	.046
Error (Hand_Position*Elbow_Flexion)	Sphericity Assumed	492.219	360	1.367			
	Greenhouse-Geisser	492.219	47.890	10.278			
	Huynh-Feldt	492.219	62.354	7.894			
	Lower-bound	492.219	15.000	32.815			

Tests of Within-Subjects Effects

Measure: Upward_Rotation

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Hand_Position	Sphericity Assumed	2924.177	2	1462.088	12.505	.000	.455
	Greenhouse-Geisser	2924.177	1.563	1870.406	12.505	.000	.455
	Huynh-Feldt	2924.177	1.713	1707.247	12.505	.000	.455
	Lower-bound	2924.177	1.000	2924.177	12.505	.003	.455
Error(Hand_Position)	Sphericity Assumed	3507.674	30	116.922			
	Greenhouse-Geisser	3507.674	23.451	149.575			
	Huynh-Feldt	3507.674	25.692	136.528			
	Lower-bound	3507.674	15.000	233.845			
Elbow_Flexion	Sphericity Assumed	134.787	12	11.232	1.560	.107	.094
	Greenhouse-Geisser	134.787	1.158	116.388	1.560	.232	.094
	Huynh-Feldt	134.787	1.194	112.873	1.560	.232	.094
	Lower-bound	134.787	1.000	134.787	1.560	.231	.094
Error(Elbow_Flexion)	Sphericity Assumed	1295.730	180	7.199			
	Greenhouse-Geisser	1295.730	17.371	74.591			
	Huynh-Feldt	1295.730	17.912	72.338			
	Lower-bound	1295.730	15.000	86.382			
Hand_Position * Elbow_Flexion	Sphericity Assumed	21.730	24	.905	.592	.938	.038
	Greenhouse-Geisser	21.730	2.974	7.306	.592	.622	.038
	Huynh-Feldt	21.730	3.791	5.732	.592	.661	.038
	Lower-bound	21.730	1.000	21.730	.592	.454	.038
Error (Hand_Position*Elbow_Flexion)	Sphericity Assumed	550.741	360	1.530			
	Greenhouse-Geisser	550.741	44.613	12.345			
	Huynh-Feldt	550.741	56.862	9.686			
	Lower-bound	550.741	15.000	36.716			