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The Effect of Serratus Anterior Fatigue on Scapular Kinematics

Nathan Curtis Harrison
nathanharrison7@msn.com

THE EFFECT OF SERRATUS ANTERIOR FATIGUE ON SCAPULAR KINEMATICS

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Nathan Curtis Harrison
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Dr. Mark Timmons, Committee Chairperson
Dr. William Garrett
Dr. Joseph Beckett

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APPROVAL OF THESIS

We, the faculty supervising the work of Nathan Curtis Harrison, affirm that the thesis, *The Effect of Serratus Anterior Fatigue on Scapular Kinematics*, meets the high academic standards for original scholarship and creative work established by the Master of Science in Exercise Science and the College of Health Professions. This work also conforms to the editorial standards of our discipline and the Graduate College of Marshall University. With our signatures, we approve the manuscript for publication.

		5-1-19
Dr. Mark Timmons, Department of Kinesiology	Committee Chairperson	Date
		5-1-19
Dr. William Garrett, Department of Kinesiology	Committee Member	Date
		5-1-19
Dr. Joseph Beckett, Department of Kinesiology	Committee Member	Date

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ABSTRACT

Background: Shoulder pain is a common occurrence in the general population. Pain has been associated with shoulder impairments and pathology. Associations between shoulder limitations, impairments, and mechanisms of injury and altered scapular motion appear in the literature. Fatigue of the scapular stabilizing muscles resulting from repeated arm motion has been reported to alter scapular kinematics, which could result in shoulder pathology, especially impingement.

Purpose: The purpose of this study was to examine the effects of fatigue of the serratus anterior muscle on scapular kinematics. The hypotheses were that there would be decreased posterior tilt and decreased upward rotation during arm elevation after selective fatigue of the serratus anterior.

Methods: Thirty participants (20 females, 10 males) were included in the investigation. Scapular kinematics and shoulder strength were measured prior to and immediately following a serratus anterior fatigue protocol. A two factor (Fatigue x arm elevation angle) repeated measures ANOVA was used to determine the effects of serratus anterior fatigue on scapular kinematics.

Results: There was no statistical significance in upward rotation of the scapula between pre- and post-fatigue conditions (ascending: p=0.188; descending: F p=0.798). Less scapular posterior tilt was found following the fatigue protocol between 60° - 90° and between 90° - 120° of arm elevation, during the ascent (p=0.004) and the descent (p=0.013). A statistical significance of fatigue by arm elevation angle was also found for clavicular elevation during the ascent (p=0.050) between 90° - 120° of arm elevation. A statistical significance of fatigue on internal rotation was found during the ascent (p=0.027). There was no statistical significance in clavicular protraction between pre- and post-fatigue conditions (ascending: F p=<0.001; descending: F p=<0.001).

Conclusions and Practical Relevance: Fatigue of the serratus anterior resulted in decreased scapular posterior tilt, and greater clavicular elevation at higher arm elevation angles along with greater scapular internal rotation. These findings are consistent with the scapular kinematic patterns associated with shoulder pain. Improving the endurance of the serratus anterior might reduce the scapular kinematics associated with mechanism of injury for the shoulder complex.

CHAPTER 1

INTRODUCTION

Shoulder pain is a common occurrence in the general population, with a point prevalence reported anywhere between 7-26% and a lifetime prevalence reported at the highest at 67% (Luime et al., 2004). Pain has been associated with shoulder impairments and pathology (Kibler, 1998). Altered scapular motion has been observed in patients with shoulder limitations, impairments, and mechanisms of injury (Borstad & Ludewig, 2002; Keshavarz, Bashardoust Tajali, Mir, & Ashrafi, 2017). However, reported differences are not the same in all subjects which makes it difficult to discern if shoulder pain is caused by the dysfunction, or if the dysfunction is caused by the pain. There needs to be further explanation into the causes of shoulder limitations, impairments, mechanisms of injury and pathology.

The shoulder girdle is extremely mobile, allowing problems to arise at any point in the shoulder system. Motion of the shoulder girdle is reliant on coordinated muscle activity causing the scapula to move in rhythm with the humerus, also called scapulohumeral rhythm (Keshavarz et al., 2017; Kibler, 1998). SHR is defined as the way in which the scapulothoracic, acromioclavicular, sternoclavicular, and glenohumeral joints all coordinate together resulting in a normal shoulder girdle movement. Normal scapular motion is characterized by internal and external rotation about the superior axis, anterior and posterior tilting about the lateral axis, and upward and downward rotation about the sagittal axis (Ludewig et al., 2009). Generally, the pattern of the scapula in the scapular plane during arm elevation is as follows: upward rotation, external rotation and posterior tilting, combined with clavicular elevation and retraction (Bourne, Choo, Regan, MacIntyre, & Oxland, 2007; Ludewig et al., 2009; McClure, Michener, Sennett, &

Karduna, 2001). The mechanisms leading to the reported changes in scapular kinematics have not been fully explored.

When shoulder kinematics are altered, dysfunction and impairment could be the result. Shoulder pain is a common symptom in individuals with altered scapular kinematics (Kibler, 1998). The altered kinematics which are associated with shoulder pain include increased and decreased upward rotation, increased internal rotation, decreased posterior tilt, and increased scapular elevation (Ludewig & Cook, 2000; McClure, Michener, & Karduna, 2006; Mell et al., 2005; Ogston & Ludewig, 2007; Seitz, McClure, Finucane, Boardman, & Michener, 2011). Common sources of shoulder pain as a result of altered scapular kinematics include rotator cuff pathology, subacromial impingement syndrome, and glenohumeral joint instability (Keshavarz et al., 2017). Altered kinematics resulting from serratus anterior fatigue, and ultimately dysfunction, could be the cause for scapular dysfunction in people with or without shoulder pain.

Limited bony attachment of the scapula makes it rely on muscular activation for stability and mobility (Kibler, 1998). The scapula and humerus are moved and stabilized by different groups of muscles, each performing specific tasks to keep the scapula and humerus in the correct position (Kibler, 1998). The glenohumeral muscles work together to stabilize and provide motion to the humerus. The extra-articular muscles of the shoulder, which originate on the trunk and insert on the humerus, work mainly to move the humerus through a range of motion. The parascapular muscles all work together to stabilize the scapula and provide it with movement. Of particular interest in the parascapular muscle group is the serratus anterior. The serratus anterior is important in the stabilization and motion for the scapula, providing a stable and moveable base of support for the arm during shoulder motion. As a stabilizer, the serratus anterior acts as a suction mechanism to keep the scapula close to the rib cage and prevent winging and posterior tilt (Peat, 1986). As a movement producer, the serratus anterior is responsible for protraction of the scapula. During elevation, the serratus anterior has been shown to have greater activation in the 60°-120° range in overhead athletes when compared to non-athletes (Habechian, Lozana, Cools, & Camargo, 2019). However, it has not been shown that serratus anterior activation is different in the general population following a fatigue protocol. Any alteration, including fatigue, in any of the stabilizing muscles can cause a dysfunction in scapular motion. Specifically, fatigue of the serratus anterior would hypothetically cause a decrease in posterior tilt and upward rotation.

Shoulder girdle muscle fatigue, which we are defining as a decrease in the function of a muscle, has been shown to alter scapulothoracic kinematics (Ebaugh, McClure, & Karduna, 2006a; McQuade, Hwa Wei, & Smidt, 1995; Tsai, McClure, & Karduna, 2003). Several studies have been performed examining the relationship between fatigue of the shoulder musculature and scapular kinematics (Ebaugh et al., 2006a; Ebaugh, McClure, & Karduna, 2006b; McQuade et al., 1995; Tsai et al., 2003). These papers agree that humeral motion is altered more when compared to scapular motion during an external rotation of the humerus fatigue protocol. The reported fatigue protocols incorporate multiple combinations of scapular movements producing a more general shoulder fatigue condition. Therefore, part of the purpose of this study was to fatigue a scapular specific muscle that does not directly affect humeral motion. There is a lack of research examining fatigue of the serratus anterior and its effect on scapular kinematics. Fatigue of the serratus anterior has been researched mainly in a push-up plus exercise (Piraua et al., 2014; Tsai et al., 2003). However, there is a lack of research on how to effectively isolate the serratus anterior to minimize variability in results of this study. There is a study on the fatigue of the teres minor and infraspinatus as it relates to scapular kinematics during external rotation of the humerus (Tsai et al., 2003). These studies reported that fatigue of the lower trapezius and teres minor resulted in increased scapular winging, a combination of increased scapular internal rotation and decreased scapular posterior tilt. However, there have been no studies examining overall scapula kinematics following an isolated serratus anterior fatigue protocol.

There is an immense amount of knowledge at a clinician's disposal to evaluate shoulder impairments. However, to this date, the serratus anterior and scapular kinematics have not been studied regarding muscle fatigue. Therefore, the purpose of this study was to examine the effects of fatigue of the serratus anterior on scapular kinematics.

Statement of the Problem

Shoulder injuries are a common occurrence in both athletic and general populations (Luime et al., 2004). Differing scapular kinematic patterns have been associated with increases in shoulder pain, impairment and limitations. The contraction of the serratus anterior produces scapular motion. However, the effect of serratus anterior fatigue on scapular motion has not been fully studied.

Research Question

Does fatigue of the serratus anterior have an impact on scapular kinematics in people with unimpaired shoulders?

Null Hypothesis

H_0: There will be no impact on scapular kinematics following selective fatigue of the serratus anterior.

Alternative Hypothesis

H_1: Following selective fatigue of the serratus anterior, the scapula will demonstrate decreased posterior tilt during arm elevation.

H_2: Following selective fatigue of the serratus anterior, the scapula will demonstrate decreased upward rotation during arm elevation.

Operational Definitions

Impairment: to diminish in function, ability, or quality. Restrictive in an individual parameter. Example, limitation in a specific range of motion (Nagi Model of Disablement - Jette, 1994).

Limitation: Limitation in performance at the whole person or organism level (Nagi Model of Disablement - Jette, 1994).

Fatigue: A reduction in a muscle's ability to produce force during arm elevation (McQuade, Dawson, & Smidt, 1998).

Limitations

1. Individual variability in the impact of the fatigue protocol.

Delimitations

1. The participants are 18-30 years old.
2. The data can only apply to people with unimpaired shoulders in the 18-30 range.

Assumptions

1. All patients gave maximum effort during the fatigue protocol.
2. All subjects have healthy, non-injured shoulders.

CHAPTER 2

LITERATURE REVIEW

Introduction

The purpose of this study was to examine scapular kinematics following serratus anterior fatigue. We hypothesized there would be decreased scapular posterior tilt and scapular upward rotation. This literature review will cover the existing documentation on the function of the shoulder. There will be a review of shoulder anatomy scapular kinematics, and shoulder muscle activity along with the concepts of muscle fatigue.

Humans depend on unimpaired arm motion during our everyday lives. Nearly all aspects of daily living involve some sort of arm activity, and a generous portion of those are overhead arm activities. Luime et al. (2004) performed a systematic review which included 17 studies which looked at shoulder pain prevalence. The overall point prevalence (ratio of population who has shoulder pain at the time of the study) from all the studies was reported at 6.9%-26%. Those studies also report a lifetime prevalence of shoulder pain at 6.7%-66.7%. That means that up to 2/3 of the general population will experience shoulder pain at some point in their lifetime. Additionally, in the span of one year they report that 5%-47% of the general population will experience shoulder pain, and 19%-31% of the general population will experience shoulder pain during a one month time period (Luime et al., 2004). It has been shown that individuals with shoulder pain have lower health related quality of life (Wylie, Bershadsky, & Iannotti, 2010). The high prevalence of shoulder pain along with the associated reduced health related quality of life calls for an improved understanding of the mechanisms leading to shoulder pain.

Shoulder Anatomy

The shoulder girdle has three skeletal components, the clavicle, scapula and humerus bones forming the scapulothoracic articulation, glenohumeral articulation, sternoclavicular articulation, and the acromioclavicular joints. The scapula is a flat triangular blade lying against the thoracic wall. Its triangle shape and its broad, thin nature allows it to glide smoothly on the thoracic wall and provides a large base for muscle attachment sites (Kibler, 1998). The scapula has almost no bony attachment to the rest of the body and serves as the bridge between the thorax and the arm, and is also the reason the scapula has a large range of motion (Kibler, Sciascia, & Wilkes, 2012). The complex skeletal anatomy of the shoulder girdle allows for a large range of motion at the shoulder complex.

Motion of the shoulder occurs at each of the four joints independently from the others. It is because of this limited bony attachment that the scapula relies on its muscular attachments to provide both motion and stability. Any alteration, including fatigue, in any of the stabilizing muscles can cause dysfunction in scapular motion and a loss of stability at the glenohumeral joint (McQuade et al., 1998).

Muscle

The scapula is the site of many muscle attachments that prove vital for the function of the shoulder (Kibler, 1998; Paine & Voight, 2013; Peat, 1986). Multiple muscle groups act on the shoulder and the scapula in order to provide the shoulder complex with its complex combination of motion and stability. First, the rotator cuff muscles, which all originate on the scapula and insert on the humerus. Activity of the rotator cuff results in stabilization of the humeral head within the glenoid cavity. The extra articular muscles, which originate on the trunk and insert on the humerus, work mainly to move the humerus. The parascapular muscles, which originate on the scapula and insert onto the trunk or thorax, work to stabilize and provide motion to the scapula (Kibler, 1998).

The rhomboid major originates from the second to the fifth thoracic vertebrae and inserts on the medial border of the scapula. The rhomboid minor originates from the spinous process of the seventh cervical and first thoracic vertebrae and inserts at the base of the spine of the scapula. The function of the rhomboids is to retract the scapula, as well as stabilize the medial border of the scapula (Paine & Voight, 2013). The trapezius muscle originates from the medial third of the superior nuchal line, external occipital protuberance, nuchal ligament, and spinous process of C7 to T12 vertebrae. The muscle inserts on the lateral third of the clavicle, acromion, and the spine of the scapula. The trapezius muscle is split into three divisions; upper, middle, and lower. The upper trapezius functions to upwardly rotate and elevate the scapula. The middle trapezius functions to retract the scapula and provide stability to the medial border of the scapula. The lower trapezius functions to depress and upwardly rotate the scapula. There are also small contributions to external rotation and posterior tilt during arm elevation (Paine & Voight, 2013). The serratus anterior originates from the first eight ribs, runs tight to the rib cage, and inserts on the anterior medial aspect of the scapula. The serratus anterior is divided into two portions; upper and lower. The upper portion is spread along the medial border of the scapula, while the lower portion inserts into the inferior angle of the scapula. The primary role of the serratus anterior is to provide stabilization for the scapula during arm elevation, and to pull the scapula forward and around the rib cage (Paine & Voight, 2013). The serratus anterior also helps to prevent posterior tipping and medial border protrusion due to its angle of pull. This mechanism allows the scapula to remain in close proximity to the thorax, but still allows for a smooth gliding motion during arm elevation. A loss in function of this mechanism could lead to an alteration in scapular kinematics such as a decrease in posterior tilt and decreased upward rotation.

As reported by Michener, Sharma, Cools, and Timmons (2016), there is a timing aspect between the scapular muscles which allows the scapula to move optimally. In their study, they found a disruption in timing between the lower trapezius (LT) and the serratus anterior (SA), as well as between the LT and upper trapezius (UT) in patients with subacromial pain syndrome (SAIS). They report a higher activity of the LT respective to the SA during the descending phase, and a subsequent higher activity of the SA respective to the LT during the ascending phase, all in patients with SAIS. As their conclusion pointed out, the LT is common to both scenarios and its importance can be implied from their results. Their results are similar to those found in prior studies (Cools, Declercq, Cambier, Mahieu, & Witvrouw, 2007; Ludewig & Cook, 2000).

Hwang, Kwon, Jeon, Kim, and Weon (2017) sought to describe the humeral-elevation angle at which the serratus anterior is most activated. Using the push-up plus exercise, they explored serratus anterior muscle activity at 60°, 90°, and 120° of humeral elevation. They also compared the ratios of serratus activity to upper trapezius and pectoralis major. The results of their study show a significant increase in serratus activity at 120° of humeral elevation when compared to 60° and 90°. They also showed that 120° of humeral elevation showed the least amount of activity in the upper trapezius and pectoralis major, suggesting isolated fatigue may be achieved most efficiently at that joint angle.

Inadequate serratus anterior activation has been proposed to reduce scapular upward rotation and posterior tilt and cause scapular dyskinesis (Ludewig & Reynolds, 2009). Scapular dyskinesis is thought to be caused by muscular weakness or shortening and by muscle activation deficiencies in the lower trapezius, upper trapezius, and serratus anterior. (Huang, Ou, Huang, &

Lin, 2015). Significantly decreased lower trapezius activity was found in patients with inferior angle prominence (anterior tipping) and medial border prominence (internal rotation). Also, serratus anterior activity has been found to be lower in patients with inferior angle prominence (anterior tipping) and medial border prominence (internal rotation). While lower trapezius and serratus anterior muscles decreased in activation, there was a subsequent increase in upper trapezius activation in the same patterns of dyskinesis. Their findings suggest the serratus anterior as a significant contributor to scapular motion in individuals with scapular dyskinesis. However, to the best of our knowledge, individuals with healthy shoulder girdles have yet to be studied regarding the serratus anterior.

Scapular Kinematics

Unimpaired shoulder function is dependent on unimpaired scapular motion. Scapular motion during arm elevation contributes to shoulder function by providing a stable glenohumeral articulation, increasing transverse plane motion (retraction and protraction), elevating the acromion arch (maintaining the width of the subacromial space) and by maintaining the length tension relationship of the shoulder musculature (Kibler, 1998; Solem-Bertoft, Thuomas, & Westerberg, 1993). Theoretically impairment of the scapular muscles, including fatigue, will decrease scapular motion resulting in decreased glenohumeral stability and increasing impingement of the structures of the subacromial space. However, the effect of fatigue of the scapular musculature has not been fully explored.

It is essential for clinicians to understand the biomechanics of shoulder motion before assessing for changes in kinematics, so the clinician can decide on treatment strategy once the shoulder is assessed. Although these articulations can move independently of each other, there are only rare cases in which that happens. Scapulohumeral rhythm (Codman, 1934) is the term for the relationship between the four articulations during arm elevation. Scapulohumeral rhythm is classically identified as the relationship between glenohumeral elevation and scapular upward rotation (Codman, 1934). Inman, Saunders, and Abbot (1944) described the relationship between scapular and glenohumeral motion as a 2:1 ratio. For example, if the arm is elevated 15 degrees, 10 degrees of that motion would occur at the glenohumeral joint and 5 degrees would occur at the scapula. However, they also described scapular motion in the first 30 degrees of elevation to be characteristic to each individual, and elevation past 30 degrees is fairly constant in the relationship between scapular and glenohumeral motion. Overall, to move the arm through a full range of motion requires the glenohumeral joint to contribute 100°-120° of elevation and the scapulothoracic articulation to contribute 50°-60° (Codman, 1934). Similarly, Borsa, Timmons, and Sauers (2003) reported scapular upward rotation as it relates to arm elevation. They found the scapula was consistently downwardly rotating during the first 30°, which leads us to believe it has a more stabilizing effect during early arm elevation. The most upward rotation of the scapula was found at 120° of arm elevation, which confirms the finding that scapula motion accounts for 100°-120° of arm elevation. However, Inman et al. (1944) only reported on scapular upward rotation. To understand the overall motion of the scapula a more complex model is needed (Inman et al., 1944).

Overall motion of unimpaired shoulders has been studied and reported by multiple authors (Inman et al., 1944; Ludewig et al., 2009) (Borsa et al., 2003; Lukasiewicz, McClure, Michener, Pratt, & Sennett, 1999). In Lukasiewicz et al. (1999) an orthopedic surgeon placed bone pins in the clavicle, scapula, and humerus to detect bone motion during multiplanar arm elevation. Results from their study show SHR ratios (humerus: scapula) of 2.1:1 for abduction, 2.4:1 for flexion, and 2.2:1 for scapular plane abduction (scaption). At 60° humeral elevation, more upward rotation was found in abduction than in flexion. At 90° and 120° of humeral elevation, more upward rotation was found in abduction than in flexion or scaption. Starting at rest, the scapula showed an average of 11° of upward rotation which then increased on average by 39° as scaption was performed. Internal rotation decreased as scaption was performed while posterior tilting increased throughout the motion. Their findings lend credence to the thought that serratus anterior activity is highest at 120° of humeral elevation in the plane of abduction because of its impact on upward rotation of the scapula.

The degree of tilt and rotation of the scapula has also been researched during arm elevation (Borsa et al., 2003; Borstad & Ludewig, 2002; Bourne et al., 2007; Ludewig et al., 2009). Ludewig et al. (2009) measured scapular internal/external rotation and posterior tilt at multiple arm elevation angles in the frontal and sagittal planes. Results from their study showed the scapula posteriorly tilted approximately 20°, upwardly rotated approximately 36°, and externally rotated approximately 3° in the sagittal plane. These numbers, except for external rotation, increased when arm elevation in the scapular plane was measured (posterior tilt ≈ 21°, upward rotation ≈ 41°, external rotation ≈ 1°). In the frontal plane the scapula moved similarly to the scapular plane posterior tilt approximately 21°, upward rotation approximately 42°, and external rotation approximately 1°. More scapular motion in the scapular plane suggests research on scapular kinematics be done in the scapular plane. Bourne et al. (2007) used bone pins to describe healthy motion of the scapula. Subjects in their study performed 4 different motions in an attempt to put the scapula through a full range of motion; glenohumeral abduction, forward reaching, glenohumeral horizontal adduction, hand behind the back (glenohumeral extension, adduction, and internal rotation). Scapula motion in the same study was measured using infrared light-emitting diodes which were attached to four bone pins placed by an orthopedic surgeon in the lateral scapular spine. Their findings are shown in Table 1.

Degrees of Scapular Motion in Specific Movements				
	Glenohumeral Abduction	**Forward Reaching**	**Glenohumeral Horizontal Adduction**	**Hand Behind the Back**
Downward Rotation	--	--	--	8° ± 4°
Upward Rotation	49° ± 7°	17° ± 3°	5° ± 2°	--
Posterior Tipping	44° ± 11°	5° ± 2°	--	--
Anterior Tipping	--	--	8° ± 3°	13° ± 3°
Internal Rotation	--	18° ± 6°	27° ± 6°	--
External Rotation	27° ± 11°	--	--	6° ± 5°

Table 1. **Scapular Kinematics in a Healthy Shoulder.**
Showing the results of the Bourne, Choo, Regan, MacIntyre, and Oxland (2007) study.

These findings corroborate the findings by Ludewig et al. (2009) because of their findings showing a greater level of upward rotation during glenohumeral abduction compared to the other motions assessed. Borsa et al. (2003), similarly to Ludewig et al. (2009), studied scapular upward rotation with a goniometer at multiple arm elevation angles in the scapular and frontal planes. Results from their study show a downward rotation of the scapula was found during arm elevation between resting position and 30° of arm elevation. Between 30°-120° they saw a consistent amount of upward rotation, with the maximal amount of upward rotation showing up at the 120° mark. Borsa et al. (2003) explains why there was consistent downward rotation during the first 30° of arm elevation. They describe a scapular setting period, which is defined as a period where scapular motion is variable. A setting phase in the scapula could be due to the weight of the arm, as well as the initial activation of the scapular musculature at the beginning of arm elevation. Unimpaired shoulder complex kinematics can also have some factors that contribute to differences in motion that are not considered an impairment or limitation.

Side dominance has been shown to have an impact on scapular kinematics. In healthy shoulders, Matsuki et al. (2011) showed a significant difference in upward rotation of the scapula in the dominant shoulder versus the non-dominant shoulder. The scapula started in a more downward rotation biased position (5°-10°) and increased upward rotation rate more than the non-dominant shoulder (44° ± 9° and 40°± 6°, respectively). Likewise, Oyama, Myers, Wassinger, Daniel Ricci, and Lephart (2008) reported differences in overhead athlete's scapular posture in the dominant side versus the non-dominant side at rest. Generally, the scapula was more internally rotated and protracted at rest in the dominant shoulder when compared to the non-dominant shoulder. However, Yoshizaki et al. (2009) reported no side differences in any scapular motions during arm elevation or lowering. The increased upward rotation rate reported by Matsuki et al. (2011) suggests an overall stronger serratus anterior in the dominant side compared to the non-dominant side. It is for that reason we assume that the non-dominant serratus anterior would be easier to fatigue and give us better results.

Scapulothoracic posture has also been shown to have an impact on scapular kinematics. Kebaetse, McClure, and Pratt (1999) designed a study which observed scapular position during shoulder abduction in a spine erect and slouched posture. Their results showed a significant decrease in posterior tilt of the scapula in the slouched posture. Likewise, Finley and Lee (2003) conducted a study which corroborated Kebaetse et al. (1999) findings by examining the effect of sitting posture and its impact on scapular kinematics. They used 16 adults with healthy, pain-free shoulders and observed their scapular kinematics using a real-time, 3-dimensional electromagnetic tracking device during humeral elevation in both an upright seated and a slouched seated posture. A significant decrease in posterior tilt and lateral rotation of the scapula was noted in the slouched posture, but there was no significant impact on the upward rotation between postures. These findings suggest more upward rotation, and thus greater activation of the serratus anterior if the subject is seated upright and erect when measuring scapular kinematics.

Scapular Kinematics and Shoulder Pain

Shoulder pain is a common symptom in individuals who have altered scapular kinematics (scapular dyskinesis) (Kibler, 1998). Kibler et al. (2012) defined scapular dyskinesis as a "general term that is used to describe loss of control of normal scapular physiology, mechanics, and motion." In a study from 2017, 67 individuals with shoulder pain were assessed for scapular dyskinesis using the scapular dyskinesis test (SDK) (Plummer, Sum, Pozzi, Varghese, & Michener, 2017). Scapular Dyskinesis was reported in 45 out of the 67 participants. Comparatively, the same study assessed 68 individuals without shoulder pain for scapular dyskinesis and reported 42 with scapular dyskinesis (Plummer et al., 2017). Altered kinematics resulting from serratus anterior fatigue, and ultimately dysfunction, could be the cause for scapular dyskinesis in people with or without shoulder pain.

Alterations in scapular kinematics have been linked to patients with multiple sources of shoulder limitations, impairments, and pathology (Borstad & Ludewig, 2002; Keshavarz et al., 2017). Common sources of shoulder limitations, impairments, and pathology as a result of altered scapular kinematics include rotator cuff pathology, subacromial impingement syndrome, and glenohumeral joint instability (Keshavarz et al., 2017). The altered kinematics related to these issues include increased and decreased upward rotation, increased internal rotation, decreased posterior tilt, and increased scapular elevation (Ludewig & Cook, 2000; McClure et al., 2006; Mell et al., 2005; Ogston & Ludewig, 2007; Seitz et al., 2011). Some of these alterations can lead to shoulder pathology, and some of them are normal for the patient. An improved understanding of the underling mechanisms leading to the identified scapular kinematics will help clinicians treat and prevent shoulder dysfunction. Abnormal scapular motions can contribute to shoulder disorders such as rotator cuff disease or subacromial impingement syndrome (Borstad & Ludewig, 2002).

Abnormalities of scapular kinematics leading to impingement syndrome are due to a reduction in subacromial space (Neer, 1972). The subacromial space is defined as the space between the most superior part of the humerus and the anterior edge and under surface of the anterior third of the acromion (Neer, 1972). The structures that pass through the space include; supraspinatus tendon, subacromial bursa, long head of the biceps brachii tendon, and the joint capsule (Michener, McClure, & Karduna, 2003).

Borstad and Ludewig (2002) performed a study comparing shoulders diagnosed with subacromial impingement syndrome (SAIS) and shoulders which were unimpaired. They found a significant difference in scapular posterior tilt and internal rotation at arm elevation angles above 80°. There was an increase in scapular internal rotation during the eccentric (lowering) phase, and an increase in anterior tilt during the same phase in the group diagnosed with SAIS. At arm elevation angles lower than 80° there were no significant differences between the SAIS group and the unimpaired group in any motion. The results of their study reveal altered scapular kinematics in the activation range of the serratus anterior, leading to the assumption that dysfunction of the serratus anterior can lead to SAIS.

Muscle Fatigue

Bigland-Ritchie, Dawson, Johansson, and Lippold (1986) defined neuromuscular fatigue as a decrease in capacity of a muscle to produce a level of strength or power. It is commonly discussed that there are two types of neuromuscular fatigue, central and peripheral. According to Gandevia (2001), central fatigue is defined as a progressive reduction in voluntary activation of muscle during exercise while peripheral fatigue is defined as fatigue produced by changes at or distal to the neuromuscular junction.

Skeletal muscles attached to the scapula are vital to the motion and rhythm of the scapula. If a muscle is fatigued, it has been shown to alter the motion of the scapula when compared to the non-fatigued state. Chen, Simonian, Wickiewicz, Otis, and Warren (1999) designed a muscle fatigue study and its impact on the humeral head as it moves in the glenoid. They described the level of fatigue achieved in their study as 30% torque as measured by a dynamometer when compared to the rested state. When the 30% fatigue was reached, they reported an average of 1.2 mm of inferior translation compared to the prefatigued state while the arm was rested at the side and reported a statistical significance in superior translation during humeral elevation. Their findings suggest a muscle fatigue level of 30% is sufficient for producing changes in the shoulder mechanism.

It has also been reported that as glenohumeral motion decreases, scapulothoracic motion tends to increase. Ebaugh et al. (2006a) designed a study testing shoulder girdle muscle fatigue and its impact on scapulothoracic and glenohumeral motion. Their results show an increase in upward rotation and external rotation of the scapula at 60°, 90°, and 120° of arm elevation in the scapular plane when compared to their baseline measurements. The increase in upward rotation is assumed to be because of a compensatory mechanism that takes over when the shoulder girdle becomes fatigued and still allows the person to elevate their arm over their head in a satisfactory manner. Their study brings up the question; what happens when the reciprocal is studied? What happens when the scapulothoracic musculature is fatigued? We hypothesize the scapula will act much the same as it did in the Ebaugh et al. (2006b) study.

Multiple studies have examined an external rotation fatigue protocol and its effect on scapular kinematics as well as muscle activation patterns (Ebaugh et al., 2006a; Joshi, Thigpen, Bunn, Karas, & Padua, 2011; Tsai et al., 2003). Results from these studies contradict each other, possibly due to their methods. Tsai et al. (2003) reported a decrease in scapular upward rotation post-fatigue, whereas Joshi et al. (2011) reported an increase in scapular upward rotation post-fatigue. Ebaugh et al. (2006b) reported an increase in lower trapezius activity and a decrease in infraspinatus activity post-fatigue, and Joshi et al. (2011) reported the opposite.

Tsai et al. (2003) studied changes in scapular kinematics following a selective fatigue of the main shoulder external rotators, the infraspinatus and teres minor muscles. Measurements using electromyography and three-dimensional analysis were made during maximal arm elevations in the scapular plane, which is 40° of horizontal adduction from the frontal plane. Their findings show a more internal rotation, anterior tilting, and downward rotation after the fatigue protocol.

To fatigue the serratus anterior, a standard way of testing must be made. It has been shown that the lowest activation ratio between the upper trapezius (UT) and the serratus anterior (SA) occurs during the standard push-up plus (SPP) exercise (Ludewig, Hoff, Osowski, Meschke, & Rundquist, 2004). They compared the SPP to the knee push-up plus (KPP), elbow push-up plus (EPP), and wall push-up plus (WPP). The KPP was identical to the standard push-up plus, except for the knees being the distal point of contact. The EPP was performed with the elbows and shoulders flexed at 90° and the elbows on the ground as the proximal point of contact; only the plus portion of the push-up plus was performed. The WPP was performed identical to the SPP except it was performed parallel to a wall with the hands on the wall.

There is some evidence which points to pain being a key sign of muscle fatigue. The theory behind this idea is that there is some nociceptive afferent input which helps to control the drive put behind a muscle to help prevent fatigue (Amann, Proctor, Sebranek, Pegelow, & Dempsey, 2009).

Conclusion

Humans depend on their shoulders to perform tasks specific to their activities of daily living. Normal scapular kinematics is necessary to inhibit pain and allow people to use their shoulder efficiently. Any alteration in scapular kinematics can lead to a decrease in function and an increase in pain. Dysfunction of the shoulder can lead to a decrease in quality of life. Prior research has been focused on the effects of pain on shoulder kinematics. However, there has been limited research done on fatigue protocols and their impact on shoulder kinematics. To our knowledge, no research has been conducted on the effects of serratus anterior fatigue and how it relates to scapular kinematics.

CHAPTER 3

METHODS

Purpose

The purpose of this study was to identify changes in scapular kinematics resulting from serratus anterior fatigue.

Null Hypothesis

H_0: There will be no impact on scapular kinematics following selective fatigue of the serratus anterior.

Alternative Hypothesis

H_1: Following selective fatigue of the serratus anterior, the scapula will demonstrate decreased posterior tilt.

H_2: Following selective fatigue of the serratus anterior, the scapula will demonstrate decreased upward rotation.

Participants

Power analysis conducted from pilot data revealed a sample size of 30 was adequate to detect a mean difference in posterior tilt position of 3.0° and standard deviation of 5.9°, setting $\alpha = 0.95$, $1-\beta = 0.80$. 31 participants were recruited for this study. One participant was excluded due to positive findings during the shoulder screening. All participants were recruited as a convenient sample from Marshall University.

Inclusion Criteria

Participants in this study were; 1) between the ages of 18 and 30 years, 2) Shoulder pain during arm elevation $\leq 2/10$, 3) Able to raise arm to at least 120° in the frontal and sagittal planes.

Exclusion Criteria

Participants were excluded if they met any of the following criteria; 1) Active or passive cervical spine range produces shoulder symptoms, 2) shoulder pain greater than 2/10, 2) history of shoulder injury within the past year, 3) history of shoulder surgery, 4) an overhead athlete (baseball, volleyball, swimming, etc.), 5) a history of systemic musculoskeletal disease.

IRB Approval

This study was approved (IRBNET # 1366374-1) by the Marshall University Institutional Review Board (IRB). (See Appendix A). All participants provided written informed consent prior to participation (See Appendix B).

Instrumentation

Three-dimensional (3D) Scapular kinematics were measured using the Ascension trackStar electromagnetic-based motion capture system (Ascension Technology, Shelburne, VT). It was used with Motion Monitor software (Innovative Sports Training, Inc, Chicago, IL) for collection of 3D kinematic data of the humerus, scapula, and trunk during the active arm elevation procedure. Validity and reliability of the system has been well established in participants with and without shoulder pain (Karduna, McClure, Michener, & Sennett, 2001; Michener, Elmore, Darter, & Timmons, 2016).

Measurements of force were made using a handheld dynamometer (microFET2, Hoggan Scientific LLC, Salt Lake City, UT).

Experimental design

This study used a within subject repeated measure design.

Protocol

Participants came to the research facility at the day and time agreed upon wearing clothes that allow easy access to the shoulder, upper back, and upper arm. The participant's maximal voluntary isometric (MVIC) strength was measured. The serratus anterior, deltoid, upper trapezius, and lower trapezius, along with the internal and external rotation strength were assessed. Participants then had 3-dimensional electromagnetic trackers attached to their body and the three-dimensional orientation of the trunk, shoulder and arm was digitized following the International Society of Biomechanics (ISB) protocol (Wu et al., 2005).

Participants performed two trials of five weighted arm elevations in the scapular plane as a baseline pre-fatigue measurement of scapular kinematics. Participants then performed the fatigue protocol until the serratus anterior was fatigued to 80% of the pre-fatigue serratus anterior MVIC. When serratus anterior punch strength reached 80% of the MVIC the participant then performed two more trials of five arm weighted arm elevations in the scapular plane.

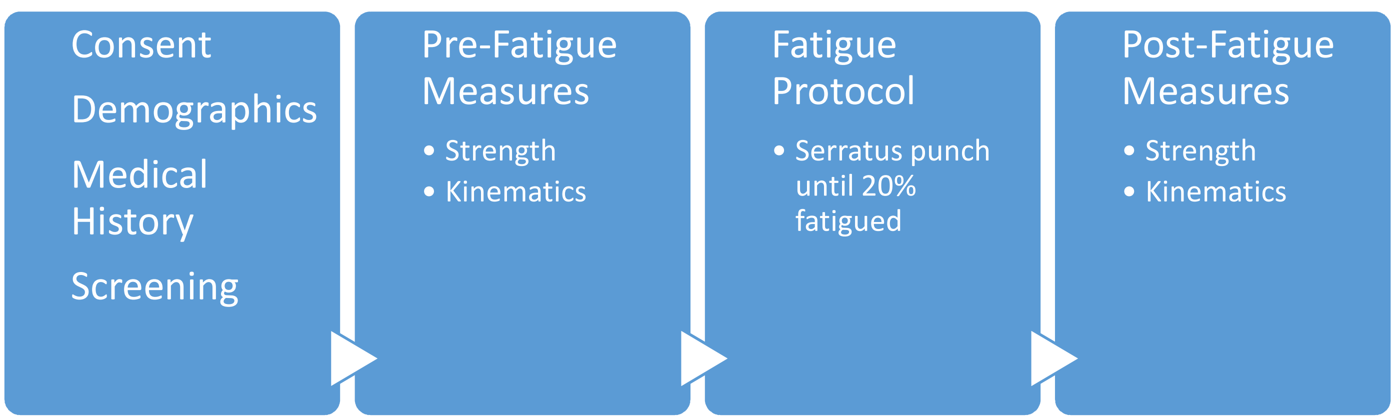

Figure 1. Methods Flowchart. A flowchart describing the methods used during the experiment.

Procedures

Demographics

Prior to any experimental protocol, the participant's demographic information was recorded. Their height (170.7 ± 10.6cm), weight (75.2 ± 18.4Kg), age (21.5 ± 3.5 years), sex (20 female, 10 male), side dominance (26 right, 2 left, 2 ambidextrous), and shoulder range of motion (table 2) were recorded. For the purposes of this study, we used the non-dominant side scapular kinematic for analysis. Participants also completed the PENN, DASH, and GROF.

	Right ER	Right IR	Right ABD	Right FLEX	Left ER	Left IR	Left ABD	Left FLEX
Mean	99.7	53.0	155.6	158.9	99.1	53.3	152.9	159.4
Std. Dev.	11.4	10.3	8.3	9.2	10.9	9.9	11.3	8.8

Table 2. **Shoulder Range of Motion of Participants.**

Electromagnetic Tracking

Three Dimensional (3D) Scapular Kinematics: The Ascension trackStar electromagnetic-based motion capture system (Ascension Technology, Shelburne, VT) was used with the Motion Monitor software (Innovative Sports Training, Inc, Chicago, IL) for collection of 3D kinematic data of the humerus, scapula and trunk during the active arm elevation procedure. A transmitter secured on a plastic support platform 115cm above the floor produces an electromagnetic field. The sensors attached to the bony segments receive the emitted signals. The 3 sensors are attached to the participant's skin. One sensor was affixed with adhesive tape over the third thoracic vertebrae to capture upper trunk movement. A second was affixed with adhesive tape over the posterior-lateral acromion for tracking scapular motion. The third sensor was fixed over the posterior aspect of the distal humerus midway between the medial and lateral epicondyles (Figure 3). The 3 sensors are used to track scapular and humeral motion relative to the trunk. A digitizing wand is connected to a 4th sensor position of the Ascension trackStar and is used to digitize skeletal landmarks of the participant. The participant was positioned while standing with their feet shoulder-width apart and holding their arms at their side. A local coordinate system for each rigid segment was created using the digitized landmarks. The trunk was defined by digitizing the following points: seventh cervical spinous process, seventh thoracic spinous process, suprasternal notch, and the most caudal point of the xyphoid process. The root of the spine of the scapula, the inferior angle of the scapula, and the posterior-lateral acromion angle defined the scapula. The humerus was defined by the medial and lateral epicondyles, and the center of the humeral head; the center is approximated by moving the arm in a conical pattern, while recording the position of the humerus in each.

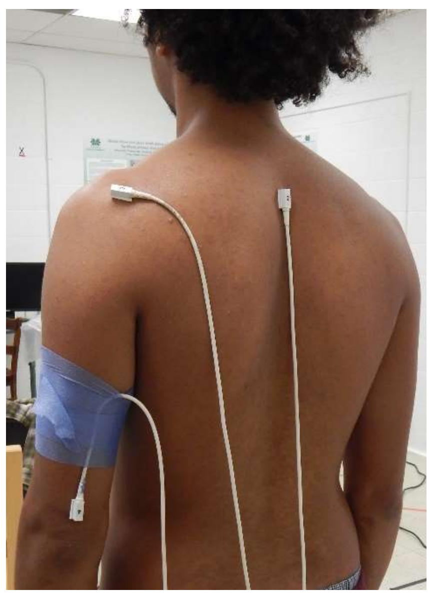

Figure 2. Electromagnetic Tracker Locations.
A photo showing the locations of the electromagnetic trackers. Photograph taken by Mark Timmons (2019).

Pilot testing in preparation for this investigation revealed good to excellent reliability (ICC = 0.66 – 0.94) for the all scapula kinematic measurements (Table 2). A sample size calculation using G*Power 3.13 software (Copyright 1992-2010 Unversitat Kiel) was conducted based on the minimal detectable change for the posterior tilt (SEM = 2.9°) measurement.

	Ext. Rot. (Asc.)	Ext. Rot. (Desc.)	Up. Rot. (Asc.)	Up. Rot. (Desc.)	Post. Tilt. (Asc.)	Post. Tilt. (Desc.)	Clav. Elev. (Asc.)	Clav. Elev. (Desc.)	Clav. Pro. (Asc.)	Clav. Pro. (Desc.)
SEM (degrees)	3.0	4.8	5.2	5.8	2.9	2.8	2.4	2.3	6.1	6.2
MDC (degrees)	8.3	6.7	7.8	8.2	4.2	3.9	3.5	3.3	8.7	8.8
ICC	0.916	0.948	0.916	0.887	.942	0.950	0.959	0.968	0.656	0.681

Table 3. ICC, SEM, and MDC Values.
A table showing the ICC, SEM, and MDC values for each motion measured.

Strength

Assessment of shoulder girdle muscle strength was performed using techniques described by Kendall F (1993). Specifically, strength was determined of the supraspinatus muscle and the motions of the shoulder; external rotation, internal rotation and shoulder adduction. Measurements of force were made using a handheld dynamometer (microFET2, Hoggan Scientific LLC, Salt Lake City, UT)

<u>External rotation</u>

External rotation strength was assessed by having the subject stand upright with their arm hanging in a relaxed slightly abducted position and with the elbow flexed to 90°. The examiner stood to the side of the subject with one hand stabilizing the subject's elbow. The subject was instructed to externally rotate their shoulder. The examiner resisted their motion.

<u>Internal rotation</u>

Internal rotation strength was assessed by having the subject stand upright with their arm hanging in a relaxed slightly abducted position with the elbow flexed to 90°. The examiner stood to the side of the subject with one hand stabilizing the subject's elbow, the examiner placed the handheld dynamometer at the subject's wrist. The subject was instructed to internally rotate their shoulder. The examiner resisted their motion.

Shoulder abduction

Shoulder abduction strength was assessed by having the subject stand with their arm at their side. The examiner stood in front of the subject, grasped the subject's wrist and passively abducted the subject's arm. The examiner placed the handheld dynamometer at the subject's wrist. The subject was instructed to abduct their arm. The examiner applied a force that resisted the subject's motion.

Lower Trapezius

The strength of the lower trapezius muscle was assessed by having the subject lay prone with their arm abducted to 120° and internally rotated. The examiner placed their hand at the level of the subject's elbow and applied an anterior directed force.

Serratus Anterior

The strength of the serratus anterior was assessed in two different manners. First a break test was performed by having the participant stand with their arm elevated to 120° in the scapular plane. The examiner placed their hand over the participant's elbow and applied a downward directed force. Second, the participant's serratus anterior strength was measured during a scapular protraction test. The participant was seated with their arm elevated to 120°. Their arm was held in extension. The participant was then instructed to punch forward while producing a maximal isometric scapular protraction contraction. (Figure 4)

Figure 3. Assessing Strength of the Serratus Anterior.
Two photos showing the two different methods of assessing strength of the serratus anterior. Photographs taken by Mark Timmons (2019).

Fatigue protocol

Before performing the fatigue protocol, the researchers showed the participants how to perform the “serratus punch” against TheraBand resistance. The punch motion is protraction of the scapula while keeping the arm fully extended and punching out without rotating the torso. The punch is the exercise used to fatigue the serratus anterior most efficiently (Hwang et al., 2017). The resistance of the TheraBand used for the fatigue exercise was dependent on the participant’s pre-test serratus anterior MVIC strength measurement. If the participant measured <30 pounds of force, the yellow band was used, ≥30 and <50 pounds of force, the green band was used, ≥50 pounds of force, the grey band was used. The TheraBand was attached to the wall and had a handle fixed to the end. The participant was seated on a stable wooden chair, with the trunk flexed to 90° and their feet comfortably resting on the floor. The participant’s shoulder was flexed to 120°and their elbow at 0° extension. To ensure the shoulder was flexed to 120°, the participant was put into position and one researcher placed their hands under the participants arm as a feedback mechanism for the participant. The participant was then given the handle end of the band and was then instructed to perform the “serratus punch” in sets of 15 repetitions until the serratus anterior measures at 80% decrease in serratus anterior MVIC strength (Figure 5). No more than four sets were performed.

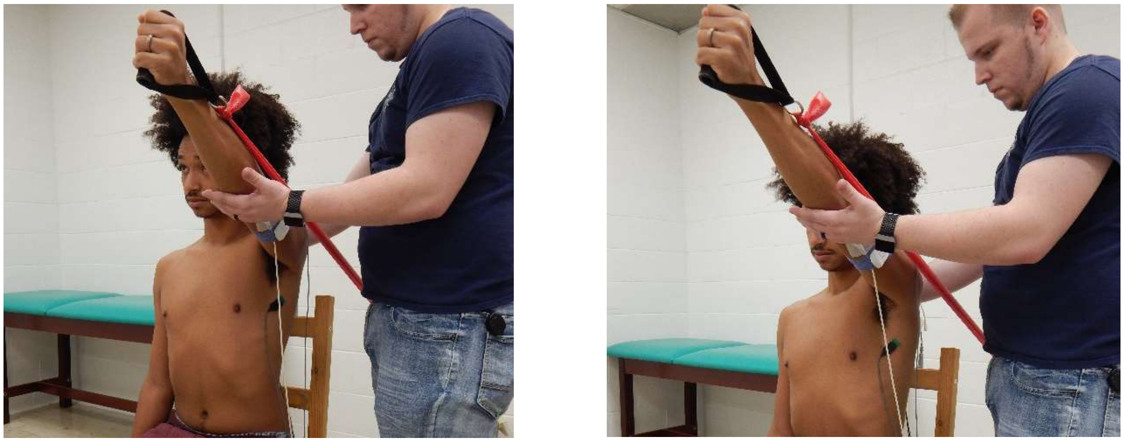

Figure 4. Serratus Anterior Punch.
Two photos showing the beginning (left) and ending (Krzesniak-Swinarska, Caress, & Cartwright, 2017) positions of the fatigue protocol. Photographs taken by Mark Timmons

Statistical Analysis

All subject and clinician generated data was recorded on paper documents and then entered into an electronic data for analysis. All statistical analysis was performed with SPSS 24.0 (SPSS, Chicago, Il). Descriptive means and standard deviations were reported for all demographic variables. Pre-fatigue / fatigues as well as pre and post lower trapezius training differences were explored in the patient reported measures (PRE, NPRS) using student t-test and analysis of variance (ANOVA) where appropriate. Repeated measures ANOVA was used to evaluate differences in kinematic data.

CHAPTER 4

RESULTS

Strength

The strength measurements for both the pre- and post-fatigue conditions are shown in Table 4. Strength decreased in all motions after the fatigue protocol with the greatest percentage decrease in abduction, lower trapezius, and serratus anterior strength. All decreases in strength were statistically significant. Serratus anterior punch MVIC decreased (18.5%, $p<0.001$) following the exercise bout.

	Pre-Fatigue Mean (lbs.)	Post-Fatigue Mean (lbs.)	Percent Change	t	p
External Rotation	18.6 ± 5.4	17.3 ± 5.5	-6.9%	2.952	.006
Internal Rotation	22.4 ± 7.4	20.6 ± 7.1	-8.0%	3.576	.001
Abduction	17.0 ± 6.2	13.8 ± 5.6	-18.8%	7.026	.000
Serratus Anterior	14.0 ± 5.6	12.7 ± 5.4	-9.3%	4.783	.000
Lower Trapezius	14.5 ± 3.9	13.1 ± 4.5	-9.7%	3.104	.004

Table 4. Strength Measures Pre- and Post-Fatigue.
A table showing the muscular strength measures pre- and post-fatigue.

The movement of the scapula and clavicle in the five motions measured before the fatigue protocol is listed in Table 5. The movement of the scapula and clavicle in the five motions measured after the fatigue protocol is listed in Table 6. Each of the five motions is reported separately in sections below.

Kinematics

	Upward Rotation		Internal Rotation		Posterior Tilt		Clavicular Elevation		Clavicular Protraction	
	Mean	Std. Dev.	Mean	Std. Dev,	Mean	Std. Dev.	Mean	Std. Dev	Mean	Std. Dev.
30°	-3.1	11.0	-14.0	10.2	-10.6	5.2	13.4	7.0	-26.1	10.9
60°	12.3	9.8	-12.4	10.8	-8.9	6.7	20.6	6.9	-27.7	9.3
90°	26.6	9.7	-12.4	11.7	-6.3	8.2	27.9	7.0	-29.9	7.3
120°	38.6	11.1	-15.0	12.9	-4.0	9.3	34.3	7.3	-33.0	5.9

Table 5: **Pre-Fatigue Scapular Kinematics.**
A table showing the pre-fatigue scapular kinematic measurements in degrees during arm elevation.

	Upward Rotation		Internal Rotation		Posterior Tilt		Clavicular Elevation		Clavicular Protraction	
	Mean	Std. Dev.	Mean	Std. Dev,	Mean	Std. Dev.	Mean	Std. Dev	Mean	Std. Dev.
30°	-4.5	13.2	-16.1	11.0	-9.2	8.8	12.6	7.7	-16.6	18.3
60°	11.0	11.9	-14.9	11.5	-8.4	9.0	20.0	7.7	-18.1	20.1
90°	25.3	11.2	-15.0	12.6	-7.1	9.3	27.4	7.7	-20.3	23.4
120°	38.2	12.6	-17.7	14.0	-5.8	10.0	34.6	8.0	-23.7	28.0

Table 6: **Post-Fatigue Scapular Kinematics**
A table showing the post-fatigue scapular kinematic measurements in degrees during arm elevation.

Upward Rotation

The upward rotation position of the scapula increased with increasing the arm elevation angle (Figures 5 and 6). Analysis revealed significant arm elevation angle main effect during both the ascending phase ($F_{(30,1)} = 846.091$, $p \leq 0.001$) and the descending phase ($F_{(30,1)} = 629.052$, $p \leq 0.001$). The upward rotation position of the scapula was greater at higher arm elevation angles (30° arm elevation = -3.8° ± 2.2°, 60° arm elevation = 11.6° ± 1.9°, 90° arm elevation = 26.0° ± 1.9°, 120° arm elevation = 38.4° ± 2.1°).

The fatigue main effect was not significant during either the ascending ($F_{(30,1)} = 1.817$, $p = 0.188$), or the descending ($F_{(30,1)} = 0.067$, $p = 0.798$) phase. The fatigue by arm elevation angle interaction was not significant during the ascending ($F_{(30,1)} = .938$ $p = 0.426$) or the descending ($F_{(30,1)} = 0.664$, $p = 0.577$) phases.

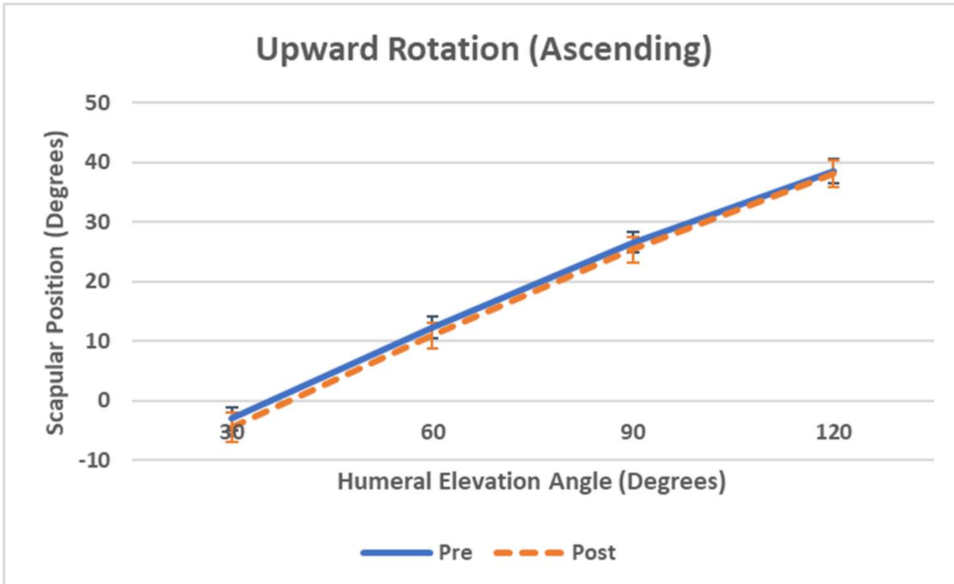

Figure 5: Upward Rotation in the Ascending Phase.
A line graph illustrating the upward rotation movement of the scapula during arm elevation in the ascending phase. Statistically significant greater scapular upward rotation was seen at successive arm elevation angles. Positive values represent upward rotation and indicate an upward rotated position. Error bars represent standard error.

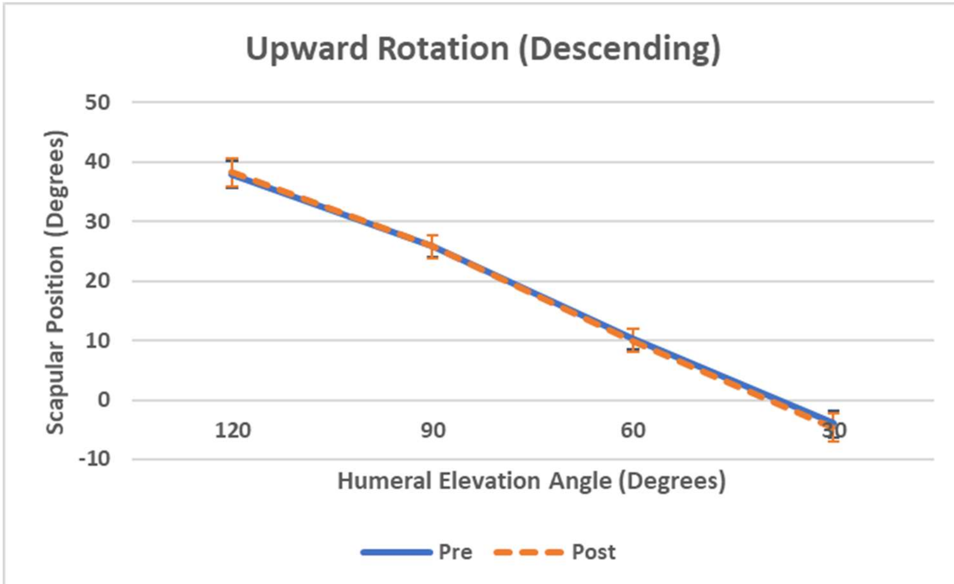

Figure 6: Upward Rotation in the Descending Phase.
A line graph illustrating the upward rotation movement of the scapula during arm elevation in the descending phase. Positive values represent upward rotation and indicate an upward rotated position. Error bars represent standard error.

Internal Rotation

The scapula initially moved into external rotation with increasing arm elevation angle; at 90° of elevation the scapula then moved back into internal rotation (Figures 7 and 8). Analysis revealed a significant arm elevation angle main effect during both the ascending phase ($F_{(30,1)}$ = 4.560, $p \leq 0.005$) and the descending phase ($F_{(30,1)}$ = 11.436, $p \leq 0.001$). The internal rotation position of the scapula was lesser at 60° and 90° of arm elevation, and greater at 30° and 120° of arm elevation (30° arm elevation = -15.8° ± 1.8°, 60° arm elevation = -13.7° ± 2.0°, 90° arm elevation = -13.7° ± 2.2°, 120° arm elevation = -16.4° ± 2.4°).

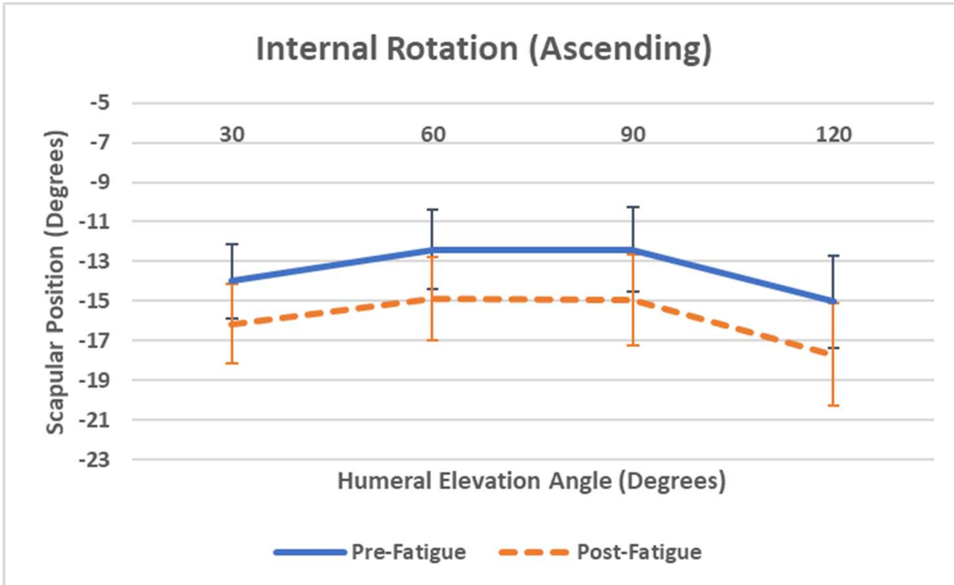

Figure 7: Internal Rotation in the Ascending Phase.
A line graph illustrating the internal rotation movement of the scapula during arm elevation in the ascending phase. A greater negative number indicates an internal rotated position whereas a less negative number indicates a less internal rotated position. Error bars represent standard error.

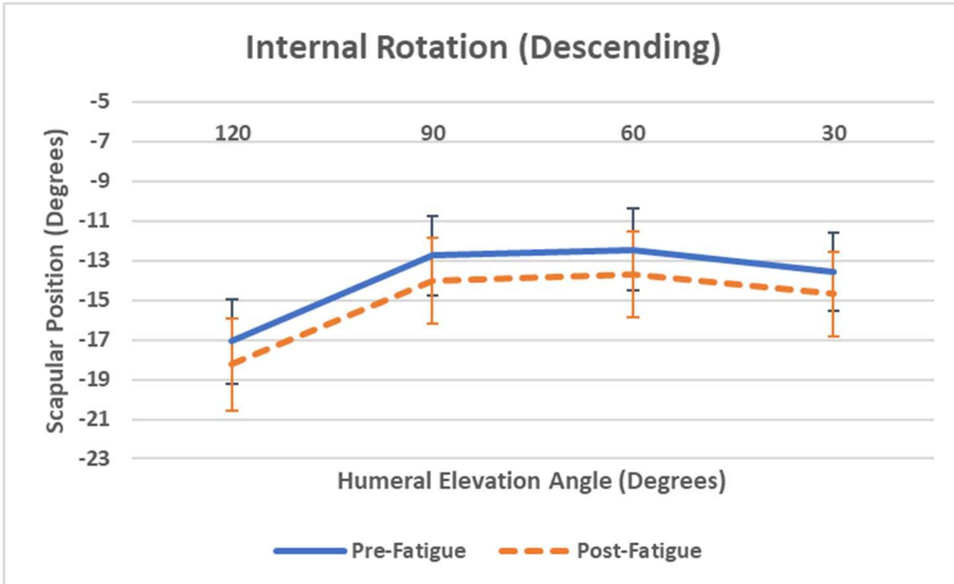

Figure 8: Internal Rotation in the Descending Phase.
A line graph illustrating the internal rotation movement of the scapula during arm elevation in the descending phase. A greater negative number indicates a more internal rotated position whereas a less negative number indicates a less internal rotated position. Error bars represent standard error.

Analysis revealed significant fatigue main effect on internal rotation position of the scapula during the ascending phase ($F_{(30,1)} = 5.393$, $p = 0.027$) (Figure 9), but not during the descending phase ($F_{(30,1)} = 0.759$, $p = 0.391$). There was not a significant fatigue by arm elevation angle interaction during the ascending phase ($F_{(30,1)} = .237$, $p = 0.870$) or the descending phase ($F_{(30,1)} = 0.019$, $p = 0.997$) on internal rotation position of the scapula.

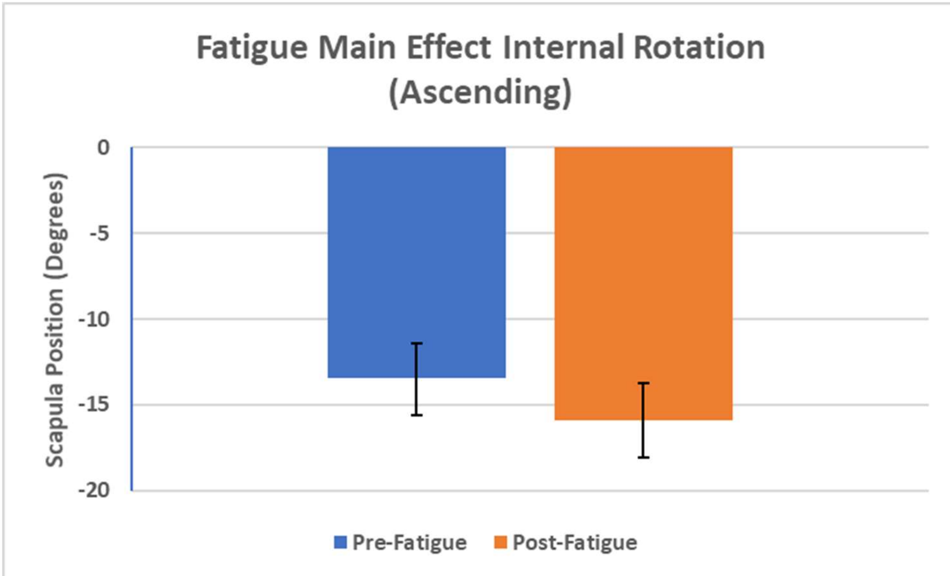

Figure 9: Internal Rotation Fatigue Effect.
A bar graph illustrating the main effect of fatigue on internal rotation motion of the scapula during arm elevation in the ascending phase. A greater negative number indicates a more internal rotated position whereas a less negative number indicates a less internal rotated position. Error bars represent standard error.

Posterior Tilt

The scapula was in an anterior tilted position throughout the entire range of motion, but during arm elevation the scapula moved towards less anterior tilt (Figures 10 and 11). Analysis revealed significant arm elevation angle main effect at all arm elevation angles during both the ascending phase ($F_{(30,1)} = 18.749$, $p \leq 0.001$) and the descending phase ($F_{(30,1)} = 22.530$, $p \leq 0.001$). The posterior tilt position of the scapula was less at lower arm elevation angles and greater at higher arm elevation angles (30° arm elevation = -9.9° ± 1.2°, 60° arm elevation = -8.6° ± 1.4°, 90° arm elevation = -6.7° ± 1.6°, 120° arm elevation = -4.9° ± 1.7°).

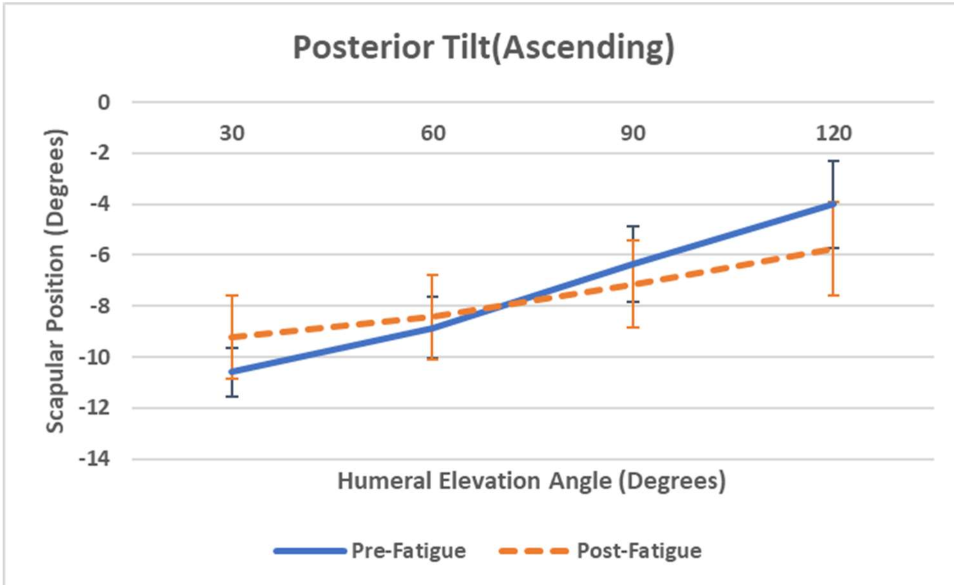

Figure 10: Posterior Tilt in the Ascending Phase.
A line graph illustrating the posterior tilt movement of the scapula during arm elevation in the ascending phase. A greater negative number indicates a less posterior tilted position whereas a less negative number indicates a more posterior tilted position. Error bars represent standard error.

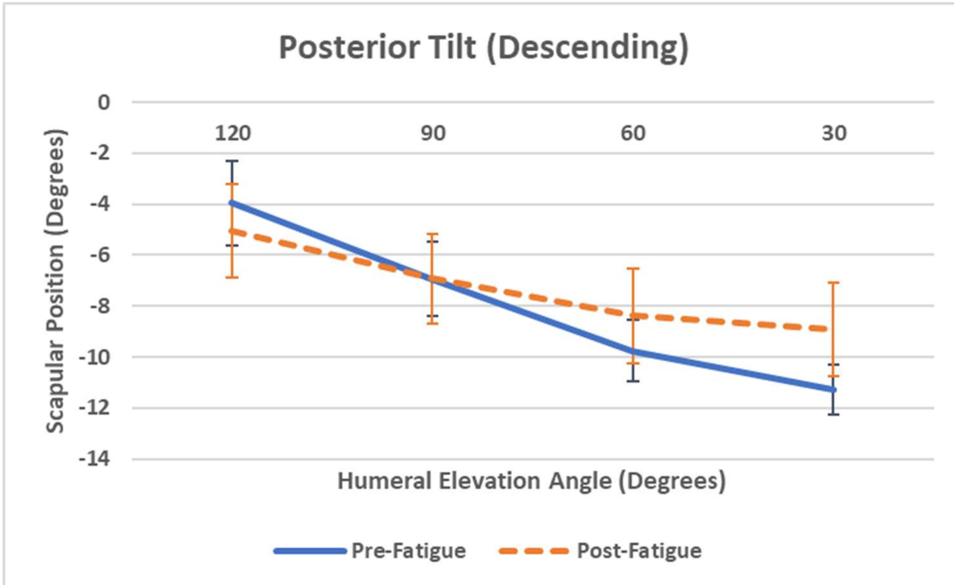

Figure 11: Posterior Tilt in the Descending Phase.
A line graph illustrating the posterior tilt movement of the scapula during arm elevation in the descending phase. A greater negative number indicates a less posterior tilted position whereas a less negative number indicates a more posterior tilted position. Error bars represent standard error.

The fatigue main effect for scapular posterior tilt was not significant for either the ascending ($F_{(30,1)} = 0.055$, $p = 0.816$) or descending ($F_{(30,1)} = 0.499$, $p = 0.486$) phases. A significant fatigue by arm elevation angle interaction effect was found for scapular posterior tilt position during the ascent ($F_{(30,1)} = 4.703$, $p = 0.004$) and during the descent ($F_{(30,1)} = 4.703$, $p = 0.013$). During the ascent in the pre-fatigued condition, the scapula moved towards posterior tilt at the higher arm elevation angles, while in the fatigued condition the scapula moved into more anterior tilt. In the pre-fatigue condition, the scapula experienced 2.5° ± 1.4° between the 60° and 90° arm elevation angles, and 2.3° ± 1.6° between the 90° and 120° arm elevation angles. In the fatigued condition, the scapula experienced -0.8° ± 1.7° between the 60° and 90° arm elevation angles, -1.7° ± 1.8° between the 90° and 120° arm elevation angles. During the descent in the pre-fatigued and post fatigue conditions, the scapula moved towards increasing anterior tilt with decreasing arm elevation angles. In the pre-fatigue condition the scapula experienced -1.4° ± 1.1° between the 120° and 90° arm elevation angles, 2.8° ± 1.3° between the 90° and 60° arm elevation angles. In the fatigued condition, the scapula experienced -0.5° ± 1.8° between the 120° and 90° arm elevation angles, and -1.4° ± 1.8° between the 90° and 60° arm elevation angles.

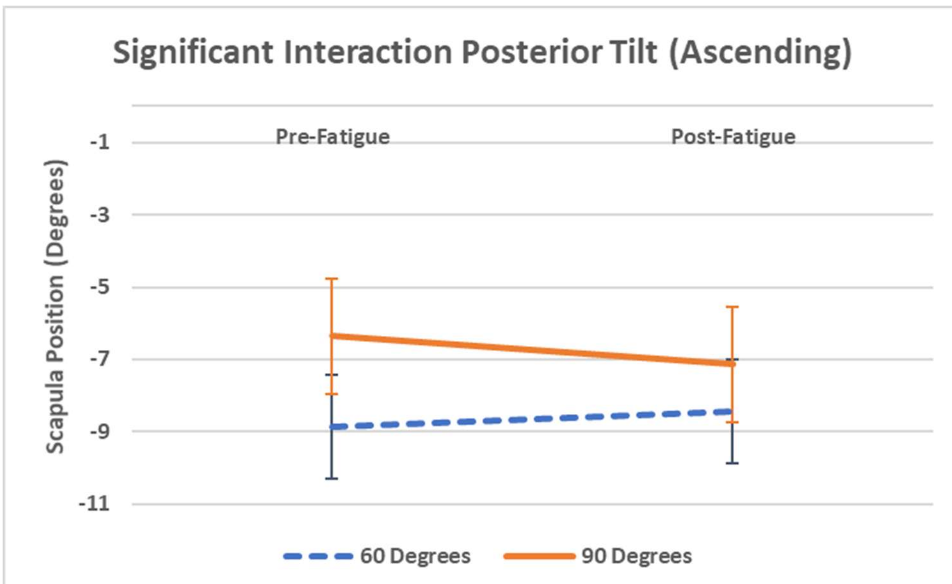

Figure 12: Posterior Tilt Significant Interaction 60-90°.
A line graph illustrating the effect of fatigue by arm interaction on posterior tilt position of the scapula during arm elevation. A greater negative number indicates a less posterior tilted position whereas a less negative number indicates a more posterior tilted position. Error bars represent standard error.

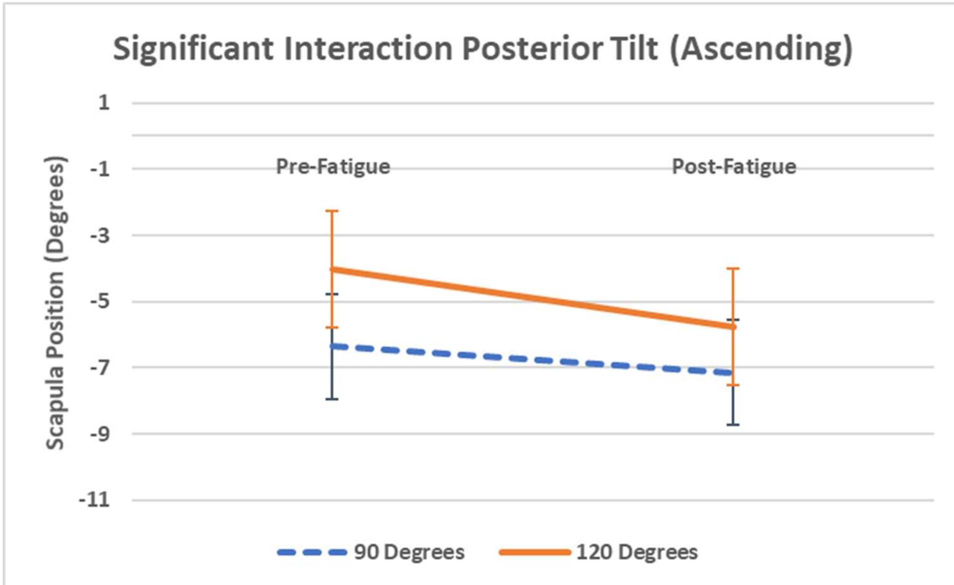

Figure 13: Posterior Tilt Significant Interaction 90-120°.
A line graph illustrating the effect of fatigue by arm interaction on posterior tilt position of the scapula during arm elevation. A greater negative number indicates a less posterior tilted position whereas a less negative number indicates a more posterior tilted position. Error bars represent standard error.

Clavicular Elevation

The elevation position of the clavicle increased with increasing the arm elevation angle (Figures 14 and 15). Analysis revealed significant arm elevation angle main effect at all arm angles during both the ascending phase ($F_{(30,1)} = 549.579$, $p \leq 0.001$) and the descending phase ($F_{(30,1)} = 444.926$, $p \leq 0.001$). The elevation position of the clavicle was lesser at lower arm elevation angles and greater at higher arm elevation angles (30° arm elevation = 13.0° ± 1.3°, 60° arm elevation = 20.3° ± 1.3°, 90° arm elevation = 27.6° ± 1.3°, 120° arm elevation = 34.5° ± 1.4°).

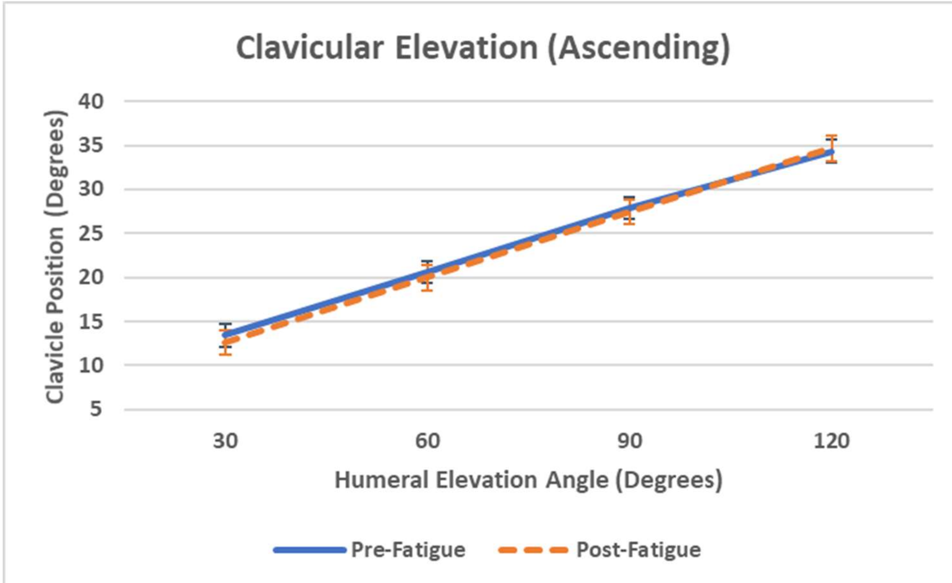

Figure 14: Clavicular Elevation in the Ascending Phase.
A line graph illustrating the elevation movement of the clavicle during arm elevation in the ascending phase. A higher number indicates a more elevated position whereas a lower number indicates a less elevated position. Error bars represent standard error.

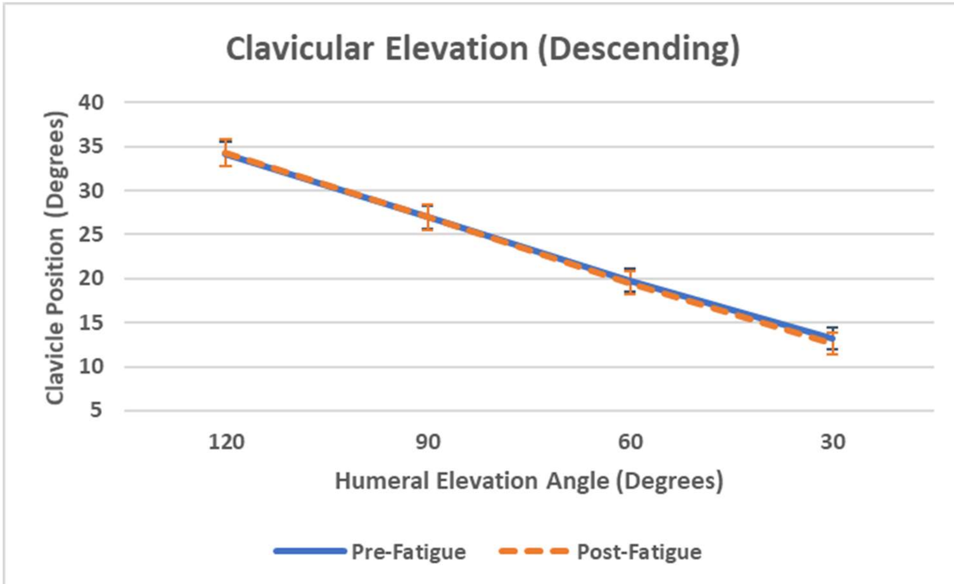

Figure 15: Clavicular Elevation in the Descending Phase.
A line graph illustrating the elevation movement of the clavicle during arm elevation in the descending phase. A higher number indicates a more elevated position whereas a lower number indicates a less elevated position. Error bars represent standard error.

Analysis revealed that fatigue did not have a significant main effect on elevation position of the clavicle (ascending: $F_{(30,1)} = 0.055$, $p = 0.816$, descending: $F_{(30,1)} = 0.055$, $p = 0.720$). However, there was a significant fatigue by arm elevation angle interaction ($F_{(30,1)} = 2.709$, $p = 0.050$) on elevation position of the clavicle. However, *Post-hoc* analysis found no significant interactions between the pre- and post-fatigue conditions on clavicular elevation angle at any arm elevation angles.

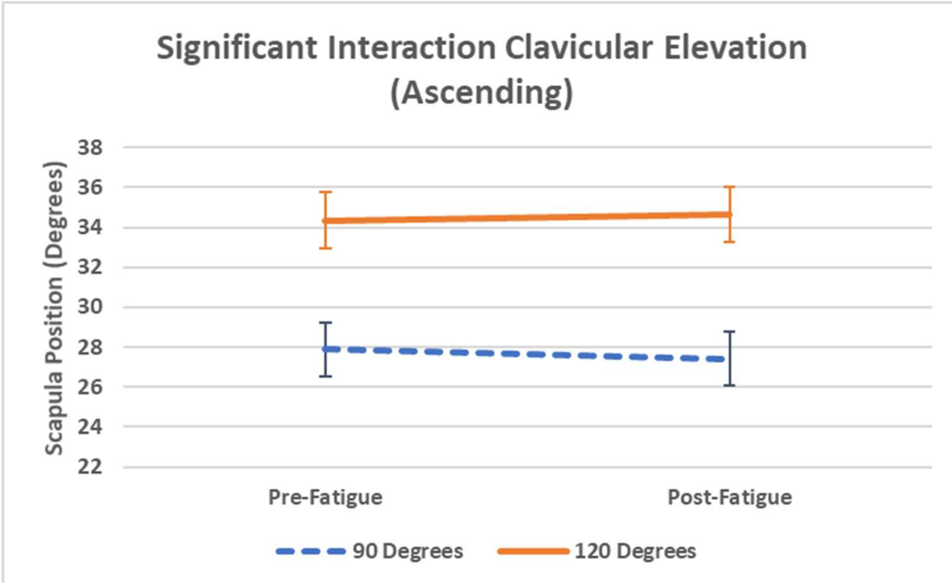

Figure 16: Clavicular Elevation Significant Interaction.
A line graph illustrating the effect of fatigue by arm interaction on elevation position of the clavicle during arm elevation. A higher number indicates a more elevated position whereas a lower number indicates a less elevated position. Error bars represent standard error.

Clavicular Protraction

The protraction position of the clavicle decreased with increasing the arm elevation angle (Figures 17 and 18). Analysis revealed significant arm elevation angle main effect at all arm angles during both the ascending phase ($F_{(30,1)} = 12.457$, $p \leq 0.001$) and the descending phase ($F_{(30,1)} = 9.371$, $p \leq 0.001$). The protraction position of the clavicle was greater at lower arm elevation angles and lesser at higher arm elevation angles (30° arm elevation = -21.4° ± 1.2°, 60° arm elevation = -22.9° ± 1.5°, 90° arm elevation = -25.1° ± 2.0°, 120° arm elevation = -28.4° ± 2.7°).

Analysis revealed that neither fatigue (ascending: $F_{(30,1)} = 1.817$, $p = 0.188$, descending: $F_{(30,1)} = 3.574$, $p = 0.069$) nor the fatigue by arm elevation interaction (ascending: $F_{(30,1)}= .938$, $p = 0.426$, descending: $F_{(30,1)} = 0.837$, $p = 0.477$) had a significant effect on protraction position of the clavicle.

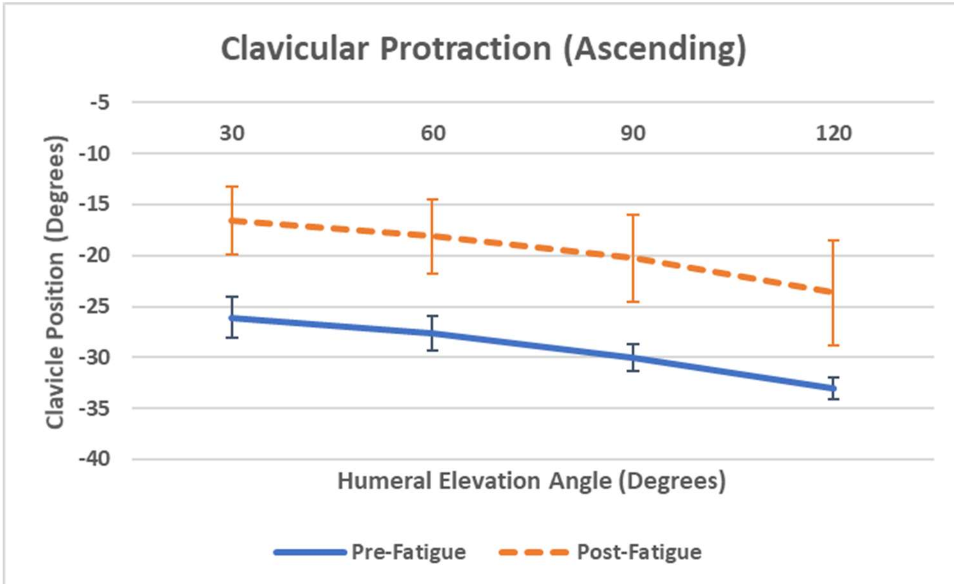

Figure 17: Clavicular Protraction in the Ascending Phase.
A line graph illustrating the protraction movement of the clavicle during arm elevation in the ascending phase. A greater negative number indicates a less protracted position whereas a less negative number indicates a more protracted position.

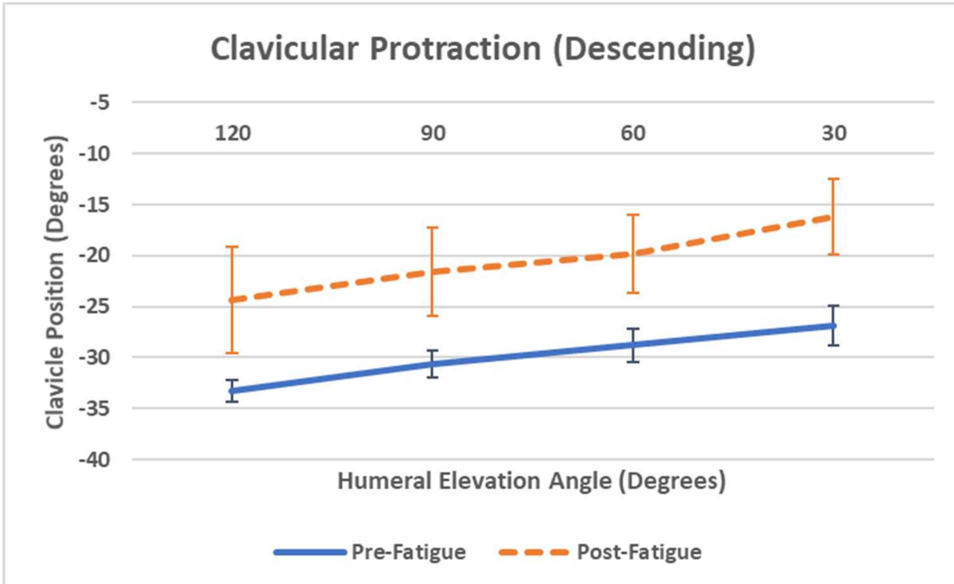

Figure 18: Clavicular Protraction in the Descending Phase.
A line graph illustrating the elevation movement of the clavicle during arm elevation in the ascending phase. A greater negative number indicates a less protracted position whereas a lesser negative number indicates a more protracted position.

CHAPTER 5

DISCUSSION

The purpose of this study was to examine the effects of the serratus anterior fatigue on scapular kinematics. The alternative hypotheses were that following selective fatigue of the serratus anterior, the scapula would demonstrate decreased posterior tilt and decreased upward rotation during arm elevation. The scapula demonstrated decreased posterior tilt but did not demonstrate decreased upward rotation. Posterior tilt of the scapula decreased significantly less between 60° and 90° as well as between 90° and 120° of arm elevation after the selective fatigue protocol. Fatigue of the serratus anterior led to a less robust posterior tilt motion of the scapula. The scapula essentially remained at a constant position in terms of posterior tilt position throughout the entire range of motion when compared to the pre-fatigue posterior tilt position. Participants demonstrated less posterior tilt of the scapula during arm elevation likely due to the decrease in contribution of serratus anterior muscle force resulting from the 20% reduction of its MVIC. The serratus anterior is the muscle primarily responsible for posterior tilt of the scapula during arm elevation at the arm angles where we saw the greatest effect. The serratus anterior was unable to fully contribute force and posteriorly tilt the scapula, leading to less posterior tilt after the fatigue protocol. Upward rotation of the scapula decreased, but not to a statistically significant extent at any arm angle. Participants also demonstrated a significant increase in clavicular elevation between 90° and 120° arm elevation. Overall, the significant results found in this study were found at arm angles of 60° and above because the serratus anterior is most active at higher arm elevation angles. The greatest significance was found at higher arm elevation angles, which is where the serratus anterior was fatigued. We did achieve fatigue of the serratus anterior, although not to the level of our goal. However, the level of fatigue that we did achieve had an effect on scapular kinematics.

Participants in this study demonstrated a decrease in all strength measurements taken. The largest decreases in strength measurements were found in abduction (18.8%), lower trapezius (9.7%), and the serratus anterior statue of liberty position (9.3%). We anticipated we would find a greater decrease in the abduction and serratus anterior strength. Our findings showed a decrease in strength of all motions measured are consistent with other shoulder fatigue studies (Joshi et al., 2011; McQuade et al., 1998; Tsai et al., 2003). The previous studies found a decrease in shoulder and scapular musculature caused an alteration in scapular kinematics. The altered scapular kinematics described in previous studies include; increased upward rotation, decreased upward rotation, reduced posterior tilt, and reduced external rotation, are consistent in describing scapular dyskinesis. Specifically, reduced posterior tilt has been associated with rotator cuff pain and subacromial impingement syndrome (Timmons et al., 2012). We believe that we saw a decrease in strength in all motions because of compensatory mechanisms during the serratus punch. In the first set of the serratus punch exercise, all participants seemed to do a good job of maintaining the correct technique and not compensating. By the final set the participants performed, their technique was faulty and compensatory motions were noted in almost all participants. There was typically an increase in a shoulder shrug during the punch, which would lead to the fatigue of the upper trapezius and a decrease in abduction strength. The lower trapezius could have been fatigued due to it trying to substitute for the serratus anterior during posterior tilt of the scapula. The results of the current study show the reduction in strength of the shoulder musculature and subsequent alteration of scapular kinematics can cause shoulder pain, limitations, and pathology.

Before the fatigue protocol was initiated, scapular kinematics were measured to establish a baseline measurement to compare the fatigue condition to. Our measurements for scapular kinematics before the fatigue protocol are found in Table 1. Our findings of pre-fatigue scapular kinematics are consistent with Borsa et al. (2003) in showing the scapula starts in a more downward rotated position in the first 30° of arm elevation and then goes into a more upward rotated position with the greatest upward rotated position at 120° of arm elevation. However, the Borsa et al. (2003) study was a two-dimensional study, whereas the current study examined the scapula in three dimensions, so the results should be compared cautiously. Contrary to the current study and the Borsa et al. (2003) study, Lukasiewicz et al. (1999) reported upward rotation angle at rest, at 90° of arm elevation, and at maximal arm elevation. At rest the upward rotation angle was shown to be slightly over 10° on average between subjects. The current study found the upward rotation angle to be in the negatives (more downward rotation) at 30° of arm elevation, and then moving into a more upward rotated position as arm elevation angle increased. The difference seen in the two studies when compared to the current study could have been due to the static measurement performed in the Borsa et al. (2003) and Lukasiewicz et al. (1999) studies compared to the continuous motion measurement in the current study, which may better represent functional movement patterns. There is an agreement between the studies that says the upward rotation position of the scapula increases with an increase in arm elevation angle. Similarly, internal rotation and posterior tilt have been reported with differing starting positions but follow the same pattern as the current study as the arm is elevated. Internal rotation decreased as arm elevation angle increased, and posterior tilt increased as arm elevation angle increased (Lukasiewicz et al., 1999). Multiple other studies show similar results as the current study in healthy shoulders. Borstad and Ludewig (2002) reported upward rotation of the scapula to be at 22.5° at 60° of arm elevation and 40.7° at 120° of arm elevation. The current study found upward rotation of the scapula to be at 12.3° at 60° of arm elevation and 38.6° at 120° of arm elevation. The differences in upward rotation between the current study and Borstad and Ludewig (2002) studies are small; however, we do see a larger difference at the lower elevation angle of 60°, which evens out as you get closer to 120° of arm elevation. Borstad and Ludewig (2002) also reported on posterior tilt of the scapula during arm elevation. Results from the current study and Borstad and Ludewig (2002) are very similar regarding posterior tilt. Borstad and Ludewig (2002) report -10° of posterior tilt (in a more anterior tilted position) at 60° of arm elevation, and the current study reports -9° of posterior tilt at 60° of arm elevation. At 120° of arm elevation, Borstad and Ludewig (2002) report -8° of posterior tilt and the current study reports -4°. The pattern of scapular kinematics in a healthy, non-fatigued shoulder in the current study is consistent with the pattern of scapular kinematics in previous studies.

The findings of the current study report no statistically significant change in upward rotation of the scapula, which is not consistent with other studies. Previous studies show either an increase or a decrease in upward rotation. Tsai et al. (2003) reported a decrease in scapular upward rotation after an external rotation fatigue protocol, which is more in line with what previous studies have reported. Similarly, Ludewig and Cook (2000) reported a decrease in scapular upward rotation averaged across all arm phases during arm elevation in participants with impingement. Su, Johnson, Gracely, and Karduna (2004) also reported a significant decrease in upward rotation in their group of swimmers with impingement against their controls. Joshi et al. (2011) reported an increase in scapular upward rotation after an external rotation fatigue protocol. The difference in upward rotation between the current study and the aforementioned studies could be due to a difference in fatigue protocols. Both Tsai et al. (2003)

and Joshi et al. (2011) performed external rotation fatigue protocols to exhaustion, whereas the current study performed a selective serratus anterior fatigue protocol aimed to achieve 80% of the MVIC (Ludewig and Cook, 2000; Su et al., 2004). Also, as demonstrated in a study by Mura et al. (2003), a disruption in rotator cuff function, such as fatigue, would cause a superior translation of the humeral head. That super translation would need a subsequent increase in upward rotation to get the arm elevated over the head without impingement. The Su et al. (2004) and Ludewig and Cook (2000) studies were not fatigue studies, but they do report on scapular kinematics associated with impingement and how they are affected by exercise, which includes decreased upward rotation. The current study did not show a decrease in upward rotation, but did show a decrease in posterior tilt, and an increase in clavicular elevation and internal rotation.

In the current study, internal rotation of the scapula increased across all arm elevation angles. Increased internal rotation has been associated with shoulder impingement mechanisms (Ludewig & Cook, 2000), although not as often as decreased upward rotation and posterior tilt. In the Ludewig and Cook (2000) study, they reported an increase in internal rotation during arm elevation in the scapular plane when a load was applied to the arm. However, there were no differences when the arm was in the unloaded condition. Their findings are similar to that of the current study. The current study performed all measurements of scapular kinematics in a loaded condition (three- or five-pound dumbbells). Therefore, it is logical to assume that under loaded conditions, an impairment in the serratus anterior (fatigue) can lead to altered scapular internal rotation and an increase in the impingement mechanism.

Following the selective fatigue of the serratus anterior, there was shown to be a statistically significant decrease in posterior tilt of the scapula. The reported differences in posterior tilt are within the SEM, so these results need to be interpreted with caution. A decrease in posterior tilt is known to be a contributor to the impingement mechanism. Ludewig and Cook (2000) reported a decrease in posterior tilt of the scapula at arm elevation angles at and above 90° in participants that were diagnosed with shoulder impingement. At 120° of arm elevation, the scapula experienced a change of -6° (moving into anterior tilt) in posterior tilt in their impingement group compared to their control group. In the current study, the scapula experienced a change of -2° (moving into anterior tilt) in the fatigued condition compared to the non-fatigued condition. The results of the current study are similar to that of Laudner, Myers, Pasquale, Bradley, and Lephart (2006). They reported a change in posterior tilt between control and impingement groups at -3° at 120° of arm elevation. The previous findings, along with our own, show an impairment resulting in decreased posterior tilt of the scapula can lead to an increase in the impingement mechanism.

Following the selective fatigue of the serratus anterior, there was shown to be a statistically significant increase in elevation of the clavicle. The reported differences in clavicular elevation are within the SEM, so these results need to be interpreted with caution. It is important to note that an increase in clavicular elevation is consistent with mechanisms of impingement reported in other studies. Laudner et al. (2006) performed their study on scapular kinematics using throwers with impingement compared to a control group. They reported an increase in clavicular elevation in the impingement group when compared to the control group. They did not perform a fatigue study, but their findings of increased clavicular elevation in throwers with impingement are similar to our findings of clavicular elevation in participants with selective fatigue of the serratus anterior. The fatigued condition of the serratus anterior led to an impingement-like movement pattern of the clavicle.

The previous studies used fatigue protocols at lower arm elevation angles than the current study, which could account for the difference in results. The current study showed the most change in scapular and clavicular positioning following selective fatigue of the serratus anterior at arm elevation angles above 90°, with the greatest changes occurring at the 120° arm elevation angle. A possible reason for the change at higher arm elevation angles could be the serratus anterior is most active at 120° of arm elevation (Hwang et al., 2017). The fatigue protocol of the serratus anterior was executed at 120° of arm elevation in order to achieve the most selective fatigue possible, which could be why there was a significant change in scapular kinematics at higher arm elevation angles. The body was adapting to the fatigue of the serratus anterior and had to change the muscle activation pattern and intensity to get the participants' arms over their heads.

The findings of the current study are consistent with the reports of Minning, Eliot, Uhl, and Malone (2007) and Gerdle, Edstrom, and Rahm (1993). Minning et al. (2007) performed a study examining shoulder muscle fatigue-ability during a shoulder flexion isometric test. They used 60% of the participant's MVIC and held the participant in 90° of shoulder flexion for 5 minutes or until they failed holding the position. Results from their study show a high fatigue-ability of the deltoid muscle compared to the other muscles studied (upper trapezius, lower trapezius, and serratus anterior. They attribute the difference in fatigue-ability to primary fiber type and to the activation of the primary muscle responsible for that motion. They conclude, and although unproven, that type II muscle fibers logically fatigue at a faster rate than type I fibers. They also attribute the fatigue-ability of the middle deltoid to its primary role in shoulder flexion. The results of their study could explain the level of fatigue reached in the serratus anterior in the current study (18.5% of the MVIC). However, Minning et al. (2007) used an isometric fatigue protocol at 90° of arm elevation, whereas the current study used an isotonic fatigue protocol at 120° of arm elevation. There could be differences in static versus dynamic fatigue-ability of the shoulder musculature as well as introducing a muscular timing aspect with the dynamic fatigue protocol. The timing aspect of the scapular musculature was likely disrupted after the fatigue protocol. After fatigue, the serratus anterior was inhibited to an extent, which required other muscles such as the upper and lower trapezius to be activated to get the arm elevated over the head in a satisfactory manner. The increase in clavicular elevation without an increase in upward rotation of the scapula leads us to believe the upper trapezius substituted for the serratus anterior at higher arm elevation angles. The upper trapezius inserts into the lateral portion of the clavicle, and when contracted can produce upward rotation of the scapula, so the upper trapezius could have substituted for the serratus anterior to upwardly rotate the scapula but also elevated the clavicle; however, shoulder muscle activation was not reported for this study.

Individual variability in response to the fatigue protocol played a role in this study. Our first limitation stated there could be individual variability in response to the fatigue protocol. The mean fatigue percentage of the serratus punch motion reached 18.5% ($p<0.001$) following the exercise bout. All participants showed a reduction in MVIC of the serratus anterior after the selective fatigue protocol. During the study, there were some individuals who were able to be fatigued to 80% of the MVIC of the serratus anterior, and there were others who did not fatigue to 80% even after four sets of 15 repetitions of the serratus punch. A reason for the variability in the response to fatigue of the serratus anterior could be individual differences in muscular training and endurance, specifically of the serratus anterior. Minning et al. (2007) discusses another possible reason for differences in fatigue-ability of specific muscles could be fiber type. Although unjustified, it is logical to believe that type II muscle fibers would fatigue at a faster rate than type I muscle fibers. Thus, it would follow a logical sequence to believe the serratus anterior has more type I muscle fibers than type II, leading it to fatigue at a slower rate than other muscles. The delimitations still apply as well. This study cannot be generalized to any other population other than the general population between the age of 18-30 with non-impaired shoulders because this study was only performed on that population. There have been no studies examining the effects of serratus anterior fatigue on scapular kinematics in populations outside the age range of 18-30 with or without impaired shoulders.

Recommendations for Further Research

Future research should focus on collecting kinematic data of the scapula following muscle fatigue on impaired shoulders. Further research beyond that should focus on other parascapular musculature as well as focusing on the dominant shoulder. The collection of both kinematic and electromyography data following fatigue in future studies of different parascapular musculature will allow the clinician to further understand the mechanisms of injury following inhibition or partial inhibition of certain muscles. We would expect an injured muscle to act much like a fatigued muscle, with reduced contractile force and movement production. Future research should also focus on implementing a muscular endurance-strengthening program with follow up after the program to see if there are any changes following the program.

Conclusion

Following selective fatigue of the serratus anterior, the scapula demonstrated decreased posterior tilt and increased clavicular at arm elevation angles at and above 60°. The scapula also demonstrated less internal rotation throughout the entire arm elevation arc. If clinicians focus on muscular endurance strengthening of the serratus anterior as well as other parascapular musculature, the occurrence of shoulder pain, pathology, and reinjury rated could subsequently decrease.

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APPENDIX A: OFFICE OF RESEARCH INTEGRITY APPROVAL LETTER

MARSHALL UNIVERSITY
www.marshall.edu

Office of Research Integrity
Institutional Review Board
One John Marshall Drive
Huntington, WV 25755

FWA 00002704

IRB1 #00002205
IRB2 #00003206

December 28, 2018

Mark Timmons, PhD
Marshall University, Dept. of Kinesiology

RE: IRBNet ID# 1366374-1
At: Marshall University Institutional Review Board #1 (Medical)

Dear Dr. Timmons:

Protocol Title:	[1366374-1] The Effects of Serratus Anterior Muscle Fatigue on Scapular Kinematics, Subacromial Space Width, and Muscle Function in Participants without Shoulder Pain.
Expiration Date:	January 28, 2020
Site Location:	MU
Submission Type:	New Project APPROVED
Review Type:	Expedited Review

In accordance with 45CFR46.110(a)(4)(6)(7), the above study was granted Expedited approval today by the Marshall University Institutional Review Board #1 (Medical) Chair for the period of 12 months. The approval will expire January 28, 2020. A continuing review request for this study must be submitted no later than 30 days prior to the expiration date.

If you have any questions, please contact the Marshall University Institutional Review Board #1 (Medical) Coordinator Trula Stanley at (304) 696-7320 or stanley@marshall.edu. Please include your study title and reference number in all correspondence with this office.

- 1 -

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APPENDIX B: INFORMED CONSENT

Informed Consent to Participate in a Research Study

The Effects of Serratus Anterior Muscle Fatigue on Scapular Kinematics, Subacromial Space Width, and Lower Trapezius Muscle Function in Participants without Shoulder Pain.

Mark K Timmons PhD ATC, Principal Investigator

Marshall University IRB

Approved on:	12-28-18
Expires on:	12-28-19
Study number:	1366374

Introduction

You are invited to be in a research study. Research studies are designed to gain scientific knowledge that may help other people in the future. You may or may not receive any benefit from being part of the study. There may also be risks associated with being part of research studies. If there are any risks involved in this study then they will be described in this consent. Your participation is voluntary. Please take your time to make your decision, and ask your research doctor or research staff to explain any words or information that you do not understand.

Why Is This Study Being Done?

The purpose of this study is to increase the understanding over how muscle fatigue effects the shoulder motion.

How Many People Will Take Part In The Study?

About 30 people will take part in this study. A total of 50 subjects are the most that would be able to enter the study.

What Is Involved In This Research Study?

During the study, you will first fill out a questionnaire about your shoulder, then the researcher will perform a brief examination of your shoulder. After the examination, the researcher will use an ultrasound machine to make several images of the shoulder of the arm that you use to write or throw a ball. During the ultrasound imaging, you will need to wear a sleeveless or tank top shirt. During the ultrasound, imaging you will be asked to sit down and your arm will be placed in several positions, you will also be asked to perform several contractions of your shoulder muscles. After the ultrasound imaging is complete, the researcher will place several small sensors around your shoulders. These sensors will measure your shoulder motion and muscle activity. The researcher will then ask you to raise your arm over your head 5 times while the motion of your shoulder and activity of your muscles are measured. You will hold a small weight in your hands while you raise your arm. You will perform several maximal contraction of your shoulder muscles and then perform several arm elevation exercises that will produce fatigue of your shoulder muscles. After the fatigue exercise, the motion of your shoulder and the ultrasound imaging will be repeated. The questionnaires, shoulder examination, motion testing and ultrasound imaging will take about 90 minutes to complete.

How Long Will You Be In The Study?

Subject's Initials ________

You will be in the study for one testing sessions that will take about 90 minutes to complete.

You can decide to stop participating at any time. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff to discuss what follow up care and testing could be most helpful for you.

The study principal investigator may stop you from taking part in this study at any time if he/she believes it is in your best interest; if you do not follow the study rules; or if the study is stopped.

What Are The Risks Of The Study?

Being in this study involves some risk to you. You should discuss the risk of being in this study with the study staff.

You should talk to your study doctor about any side effects that you have while taking part in the study.

Risks and side effects related to the testing session include increased shoulder pain, muscle soreness, muscle fatigue and reduced shoulder strength. These risks and side effects are temporary and are no greater than the risks associated with any physical exercise program. These side effects can be reduced by stretching exercises, and applying either moist heat or ice. **If you experience pain that you would describe as being more than 7 out of 10 you should stop the testing session contact your doctor.**

There may also be side effects that we cannot predict. You should tell the research staff about all the medications, vitamins and supplements you take and any medical conditions you have. This may help avoid side effects, interactions and other risks. There are no funds available for compensation for any injury that occurs because of your participation in this study. The participant or their insurance will be responsible for the cost of treatment.

Are There Benefits To Taking Part In The Study?

If you agree to take part in this study, there may or may not be direct benefit to you. We hope the information learned from this study will benefit other people in the future. The benefits of participating in this study may be: You will gain information about the function of your shoulder.

What Other Choices Are There?

You do not have to take part in this study.

What About Confidentiality?

We will do our best to make sure that your personal information is kept confidential. However, we cannot guarantee absolute confidentiality. Federal law states that we must keep your study records private. Nevertheless, certain people other than your researchers may also need to see your study records. By law, anyone who looks at your records must keep them completely confidential.

Those who may need to see your records are:

Subject's Initials ________

- Certain university and government people who need to know more about the study. For example, individuals who provide oversight on this study may need to look at your records. These include the Marshall University Institutional Review Board (IRB) and the Office of Research Integrity (ORI). Other individuals who may look at your records include: *the federal Office of Human Research Protection*, This is done to make sure that we are doing the study in the right way. They also need to make sure that we are protecting your rights and your safety.

If we publish the information we learn from this study, you will not be identified by name or in any other way.

What Are The Costs Of Taking Part In This Study?

There are no costs to you for taking part in this study. All the study costs, including any study medications and procedures related directly to the study, will be paid for by the study. Costs for your regular medical care, which are not related to this study, will be your own responsibility.

Will You Be Paid For Participating?

You will not be paid for your participation in this project.

Who Is Funding This Study?

This study is being sponsored by Marshall University School of Kinesiology

What Are Your Rights As A Research Study Participant?

Taking part in this study is voluntary. You may choose not to take part or you may leave the study at any time. Refusing to participate or leaving the study will not result in any penalty or loss of benefits to which you are entitled. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff first to learn about any potential health or safety consequences.

Whom Do You Call If You Have Questions Or Problems?

For questions about the study or in the event of a research-related injury, contact the study investigator, Mark K Timmons ATC, PhD at (304)696-2925. You should also call the investigator if you have a concern or complaint about the research.

For questions about your rights as a research participant, contact the Marshall University IRB#1 Chairman Dr. Henry Driscoll or ORI at (304) 696-7320. You may also call this number if:

- You have concerns or complaints about the research.
- The research staff cannot be reached.
- You want to talk to someone other than the research staff.

You will be given a signed and dated copy of this consent form.

Subject's Initials ________

SIGNATURES

You agree to take part in this study and confirm that you are 18 years of age or older. You have had a chance to ask questions about being in this study and have had those questions answered. By signing this consent form, you are not giving up any legal rights to which you are entitled.

____
Subject Name (Printed)

______________________________ ____________
Subject Signature Date

______________________________ ____________
Person Obtaining Consent Date

______________________________ ____________
Principal Investigator Date

Subject's Initials ________