ACUTE EFFECTS OF POSTURE SHIRT USE ON SCAPULAR KINEMATICS AND ROUNDED SHOULDER POSTURE IN COLLEGE STUDENTS

John Peter Manor

A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Arts in the Department of Exercise & Sport Science in the College of Arts & Sciences.

Chapel Hill
2013

Approved by:

Joseph B. Myers

Meredith Petschauer

Elizabeth Hibberd

ABSTRACT

John Peter Manor: Acute Effects of Posture Shirt Use on Scapular Kinematics and Rounded Shoulder Posture in College Students
(Under the direction of Joseph B. Myers)

Posture shirts are used as an adjunct to traditional therapies to correct rounded shoulder posture, however there is no current literature to indicate their use. The purpose of this study was to evaluate the acute effects of posture shirt use on scapular kinematics and rounded shoulder posture in college students. Participants with rounded shoulder posture were recruited and put through a postural assessment and an electromagnetic assessment of scapular kinematics under three test conditions. No significant differences were found between the posture shirt and the control conditions with posture or kinematic assessment. A significant decrease in forward shoulder angle was found between the sham shirt and the control and posture shirt conditions. Additionally, a significant increase in protraction was found between the sham condition and the control and posture shirt conditions at high levels of humeral elevation.

PREFACE

The manuscript for this thesis, located in chapter IV, was prepared for submission to the Journal of Sport Rehabilitation. At the time of submission of this thesis, the manuscript had not been submitted for review or published in whole or in part.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Shoulder injuries are common throughout the student population with some estimates ranging from 26 to 35% (Katz, Amick et al. 2000; Schlossberg, Morrow et al. 2004; Bruls, Bastiaenen et al. 2013). Additionally, shoulder injuries account for 8-20% of all sport related injuries (Powell and Barber-Foss 1999). These estimates were further supported by the 2007 Injury Surveillance System (ISS) employed by the National Collegiate Athletic Association, which found that between 6% and 20% of all injuries were shoulder injuries in sports such as football, men's lacrosse, baseball, wrestling, volleyball, and softball (Agel, Palmieri-Smith et al. 2007; Agel, Ransone et al. 2007; Dick, Ferrara et al. 2007; Dick, Romani et al. 2007; Dick, Sauers et al. 2007; Marshall, Hamstra-Wright et al. 2007).

Many shoulder injuries are chronic in nature and may be classified as overuse injuries with shoulder impingement syndrome being one of the most common (Griegel-Morris, Larson et al. 1992). Shoulder impingement syndrome is the compression of and damage to soft tissue structures beneath the subacromial arch (Neer 1972); which can be debilitating and often painful (Corso 1995; Ludewig and Cook 2000). Other shoulder pathologies may include myofascial pain or thoracic outlet syndrome (Langford 1994; Ferrante 2004). Myofascial pain, which can be very painful, may be the result of muscle weakness or biomechanic abnormalities which can lead to repetitive microtrauma (Simons and Travell 1981; Langford 1994). Thoracic outlet syndrome can cause symptoms such as numbness, decreased sensation and decreased blood flow to the extremities (Ferrante 2004). All of these injuries have been attributed in the literature to rounded shoulder posture, muscular imbalances, and altered kinematics (Greenfield, Catlin et al. 1995; Brossmann, Preidler et al. 1996).

Rounded shoulder posture is often described in tandem with shoulder pathology as it can be identified clinically when the tip of the acromion process presents protracted relative to other body landmarks (Griegel-Morris, Larson et al. 1992). Rounded shoulder posture is thought to be caused by an increase in scapular anterior tipping, internal rotation and protraction as well as a decrease in upward rotation (Ludewig and Cook 2000; Borstad 2006; Thigpen, Padua et al. 2010). These changes in shoulder posture have been associated with shoulder pathology such as impingement syndrome (Lukasiewicz, McClure et al. 1999); and persons with rounded shoulder posture have been shown to exhibit an increased incidence of interscapular pain (Griegel-Morris, Larson et al. 1992). This is important to athletes, as it has been shown that even healthy athletes may present with increased shoulder protraction and anterior tipping on their dominant side (Oyama, Myers et al. 2008). Rounded shoulder posture may be the result of a combination of altered scapular kinematics or muscular imbalance (Finley and Lee 2003; Thigpen, Padua et al. 2010).

Altered scapular kinematics refers to changes in scapular internal/external rotation, upward/downward rotation, and anterior/posterior tipping, as well changes in scapular elevation/depression and protraction/retraction during shoulder motion (Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000; Thigpen, Padua et al. 2010). It has been found that persons with symptoms of shoulder impingement presented with changes in shoulder motion, in that they had increased anterior tipping and greater upward rotation (Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000). These changes in kinematics may be an attempt to minimize pain in a symptomatic shoulder and may be the result of muscular imbalances (Kebaetse, McClure et al. 1999; Ludewig and Cook 2000; Lewis, Green et al. 2005).

Muscle imbalances such as tightness, weakness, over activity, or under activity can play an important role in shoulder motion, position, and may predispose someone to pathology (Kebaetse, McClure et al. 1999; Lewis, Green et al. 2005). Tightness or over activity of the anterior muscles combined with weakness or under activity of the posterior musculature of the shoulder girdle may lead to a relative protraction, anterior tipping or downward rotation of the shoulder (Ludewig and Cook 2000; Thigpen, Padua et al. 2010). These muscle imbalances may result in either static changes in shoulder position, i.e. rounded shoulder posture, or they may result in kinematic changes to the shoulder (Langford 1994; Finley and Lee 2003).

With rounded shoulder posture and altered scapular kinematics being linked to shoulder pathology in the literature many clinicians have sought to correct these abnormalities (Wang, McClure et al. 1999; Lynch, Thigpen et al. 2010; Wong, Coleman et al. 2010). Many different means of posture correction have been examined in the literature, including stretching of tight structures, strengthening of weak and lengthened structures, and the use of manual therapy (Wang, McClure et al. 1999; Kluemper, Uhl et al. 2006; Lynch, Thigpen et al. 2010; Wong, Coleman et al. 2010).

Clinicians have also attempted the use of external support to correct rounded shoulder posture as traditional rehabilitation can take extended periods of time (Wang, McClure et al. 1999; Kluemper, Uhl et al. 2006; Lynch, Thigpen et al. 2010). One such device is the

Scapular Stabilizing System (S3) brace (Alignmed, Santa Ana, CA) which manually retracts the scapula using non-elastic bands embedded into the shirt (Apparel 2012). While there has been limited research on the use of posture braces, evidence has suggested that the S3 brace acutely decreased forward shoulder angle (rounded shoulder posture) (Cole, Prentice et al. 2008).

The S3 brace, designed to be manipulative, is only recommended to be worn 2-4 hours each day (Apparel 2012). Recently released, a corrective Posture Shirt (Alignmed, Santa Ana, CA), may provide longer lasting relief as it can be worn for extended periods of time (Apparel 2012). However, there is no current literature that confirms this assumption. If poor scapular kinematics and rounded shoulder posture can be acutely corrected through the use of posture shirts, it may be possible to reduce the incidence of shoulder pain. Additionally, posture shirts may provide a useful adjunct to current therapies by providing temporary relief for sufferers of shoulder pain while other rehabilitative techniques take longer to be effective.

PURPOSE

Posture is shown in the literature to be a contributor to shoulder pain. This is particularly important to college students who may be predisposed to postural abnormalities due to the nature of their schooling or active lifestyle. The purpose of this study was to determine if application of the corrective posture shirt, as compared to a sham and control, has an effect on scapular kinematics or posture in college students with rounded shoulder posture. Comparing the treatment to the sham and control will determine if any changes shown were due to the application of the posture shirt. If effective, posture shirts may provide temporary relief of symptoms related to rounded shoulder posture. This may allow continuation of daily activities in a pain free manor; or for the correction of posture and kinematics or relief of symptoms while performing traditional rehabilitation exercises.

RESEARCH QUESTIONS

RQ1: What are the acute effects of posture shirt use on forward shoulder angle (FSA) in college students?

RQ2: What are the effects of posture shirt use on scapular kinematics during an elevation task in the scapular plane in college students with rounded shoulder posture?

RQ2.1: What is the effect on anterior/posterior tipping?

RQ2.2: What is the effect on upward/downward rotation?

RQ2.3: What is the effect on internal/external rotation?

RQ2.4: What is the effect on elevation/depression?

RQ2.5: What is the effect on protraction/retraction?

INDEPENDENT VARIABLES

1. Condition (treatment, sham, control)
    a. Treatment – posture shirt
    b. Sham – non-corrective shirt
    c. Control – no shirt

DEPENDENT VARIABLES

1. Forward shoulder angle as measured by a lateral photograph.

2. Scapular anterior and posterior tipping during an elevation task.

3. Scapular upward and downward rotation during an elevation task.

4. Scapular internal and external rotation during an elevation task.

5. Scapular elevation and depression during an elevation task.

6. Scapular protraction and retraction during an elevation task.

HYPOTHESES

RH1: Forward shoulder angle (FSA) will be decreased at rest when wearing the posture shirt as compared to the sham and control conditions.

H_O: $\mu_{FSA\ Control} = \mu_{FSA\ Sham} = \mu_{FSA\ Treatment}$

H_A: $\mu_{FSA\ Control} = \mu_{FSA\ Sham} < \mu_{FSA\ Treatment}$

RH2: Scapular kinematics will be different when wearing the posture shirt as compared to the sham and control conditions.

RH2.1: Posture shirt use will result in increased posterior tipping (PT) of the scapula.

H_O: $\mu_{PT\ Control} = \mu_{PT\ Sham} = \mu_{PT\ Treatment}$

H_A: $\mu_{\text{PT Control}} = \mu_{\text{PT Sham}} < \mu_{\text{PT Treatment}}$

RH2.2: Posture shirt use will result in increased upward rotation (UR) of the scapula.

H_O: $\mu_{\text{UR Control}} = \mu_{\text{UR Sham}} = \mu_{\text{UR Treatment}}$

H_A: $\mu_{\text{UR Control}} = \mu_{\text{UR Sham}} < \mu_{\text{UR Treatment}}$

RH2.3: Posture shirt use will result in increased external rotation (ER) of the scapula.

H_O: $\mu_{\text{ER Control}} = \mu_{\text{ER Sham}} = \mu_{\text{ER Treatment}}$

H_A: $\mu_{\text{ER Control}} = \mu_{\text{ER Sham}} < \mu_{\text{ER Treatment}}$

RH2.4: Posture shirt use will result in increased depression (SD) of the scapula.

H_O: $\mu_{\text{SD Control}} = \mu_{\text{SD Sham}} = \mu_{\text{SD Treatment}}$

H_A: $\mu_{\text{SD Control}} = \mu_{\text{SD Sham}} < \mu_{\text{SD Treatment}}$

RH2.5: Posture shirt use will result in increased retraction (SR) of the scapula.

H_O: $\mu_{\text{SR Control}} = \mu_{\text{SR Sham}} = \mu_{\text{SR Treatment}}$

H_A: $\mu_{\text{SR Control}} = \mu_{\text{SR Sham}} < \mu_{\text{SR Treatment}}$

NULL HYPOTHESES

1. Posture shirt use will not result in acute improvements in Forward Shoulder Angle.

2. Posture shirt use will not result in acute changes in scapular kinematics.

OPERATIONAL DEFINITIONS

1. Rounded shoulder posture: A person will be defined as having rounded shoulder posture if they present with a Forward Shoulder Angle (FSA) greater than or equal to 52°, as described by Thigpen et al (2010).
2. Corrective posture shirt: A cotton/polyester blend shirt, with non-elastic bands of fabric sewn in, which is designed to provide mechanical and neurological feedback to the wearer and encourages a change in posture.
3. Sham treatment: The use of a non-corrective shirt that is similar in appearance and feel to the corrective shirt, without the inclusion of the corrective bands.

ASSUMPTIONS

1. Participant had no prior experience with posture corrective devices.
2. Participant did not know the difference between the corrective and non-corrective shirts.

DELIMITATIONS:

1. Participants were truthful about their injury history.
2. Analysis was only performed on the participant's dominant arm.
3. Participants had pre-existing rounded shoulder posture.

LIMITATIONS

1. College students between the ages of 18 and 25 may not represent all people between the ages of 18 and 25
2. Data was taken in a laboratory setting and may not represent a clinical setting.
    a. May have affected how each participant performs the task.

3. Participants were attached to electromagnetic tracking system.

    a. May have affected how each participant performs the task.

4. Counterbalanced research design may have allowed participants to glean information from each external device placed on them.

    a. May discern which shirt was the posture shirt and which was the sham.

    b. May have affected how each participant performs the task.

CHAPTER II

REVIEW OF THE LITERATURE

Shoulder injuries are a common occurrence with some estimates ranging from 20 to 30% of injuries (van der Windt, Koes et al. 1995; Katz, Amick et al. 2000; Agel, Palmieri-Smith et al. 2007; Agel, Ransone et al. 2007; Dick, Ferrara et al. 2007; Dick, Romani et al. 2007; Dick, Sauers et al. 2007; Bruls, Bastiaenen et al. 2013). Many times these injuries are classified as being overuse injuries, including impingement, which has been described as one of the most common contributors to shoulder pain (Griegel-Morris, Larson et al. 1992; Bigliani and Levine 1997; Feleus, Bierma-Zeinstra et al. 2008). Impingement syndrome can be extremely debilitating due to the constant sensation of pain (Corso 1995). Other pathologies may include rotator cuff tendonitis, myofascial pain and thoracic outlet syndrome (Neer 1972; Simons and Travell 1981; Ferrante 2004). Also commonly associated with shoulder pathology is rounded shoulder posture and altered scapular kinematics, as they are thought to be contributing factors of shoulder pain (Griegel-Morris, Larson et al. 1992; Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000; Borstad 2006; McClure, Michener et al. 2006; Tate, McClure et al. 2008; Kalra, Seitz et al. 2010). Some studies have suggested that increased scapular protraction, anterior tipping, increased internal rotation, and increased upward rotation may be some of the altered kinematic factors present in people with shoulder pathology (Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000; Borstad 2006; McClure, Michener et al. 2006). The kinematic changes may be due to many factors, including altered muscle function, muscle imbalance, habit or fatigue (Wang, McClure et al. 1999; Ludewig and Cook 2000; Hibberd, Oyama et al. 2012). These kinematic differences may present themselves clinically as rounded shoulder posture (RSP) (Kibler, Sciascia et al. 2008; Thigpen, Padua et al. 2010), which, along with thoracic kyphosis and forward head posture (FHP), have been shown to be associated with an increased incidence of interscapular pain which can be debilitating, resulting in loss of work or removal from activity (Griegel-Morris, Larson et al. 1992).

With rounded shoulder posture being identifiable clinically, it has also been suggested that it could be corrected through the use of modalities such as strengthening, stretching, and manual therapy (Wang, McClure et al. 1999; Kluemper, Uhl et al. 2006; Lynch, Thigpen et al. 2010; Wong, Coleman et al. 2010). It has also been examined if external means of correction are effective, such as corrective braces. One such device is the Scapular Stabilizing System (S3) brace (Alignmed, Santa Ana, CA) which has been found effective in acutely reducing rounded shoulder posture (Cole, Prentice et al. 2008). This brace is designed to manually retract the scapula through the use of non-elastic straps (Apparel 2012) If rounded shoulder posture is corrective through the physical act of repositioning the scapula, then improving posture may reduce the incidence of shoulder pain in a population that experiences a large number of shoulder injuries. Recently a new form of corrective garment has been released, a Posture Shirt (Apparel 2012); but there has been no research to determine its effectiveness. If the new corrective shirt is found effective at correcting rounded shoulder posture then it would prove a valuable adjunct to current therapies.

SHOULDER INJURIES

Impingement Syndrome

Shoulder impingement is the most commonly reported cause of shoulder pain among an active population (Griegel-Morris, Larson et al. 1992; van der Windt, Koes et al. 1995; Bigliani and Levine 1997). Shoulder impingement is a catch all term that may include pathologies such as rotator cuff tendonitis or bursitis and is thought to be caused by decreased subacromial space between the coracoacromial arch and the underlying tissues including the subacromial bursa, the rotator cuff tendons and the long head of the biceps brachii (Neer 1972; Neer 1983; Graichen, Bonel et al. 1999). Impingement syndrome has many causes which may include anatomical variations in the acromion process, fatigue in the rotator cuff muscles, or poor scapular mechanics (Hawkins, Misamore et al. 1985; Hardy, Vogler et al. 1986; Graichen, Bonel et al. 1999; Neer 2005). The acromion may present in one of three shapes. Type 1 acromion may present as flat and may be associated with low incidence of impingement, a type 2 acromion may appear curved and associated with increased incidence of impingement, while a type 3, or hooked acromion may be associated with the greatest incidence of shoulder impingement syndrome (Bigliani and Levine 1997; Worland, Lee et al. 2003). Decreased upward rotation of the scapula or uncontrolled humeral motion, caused by weak or underactive scapular stabilizing or rotator cuff musculature, has been suggested to decrease the subacromial space and lead to impingement (Hawkins, Misamore et al. 1985; Graichen, Bonel et al. 1999; Reddy, Mohr et al. 2000). During shoulder elevation uncontrolled humeral motion may lead to humeral head superior translation thereby compressing the structures in the subacromial space (Allegrucci, Whitney et al. 1994; Graichen, Bonel et al. 1999). It is thought that the physical impingement of the rotator cuff tendons begins at approximately 30° of abduction and reach its maximum at 90° of abduction (Brossmann, Preidler et al. 1996) These altered kinematics may be present in someone who also exhibits rounded shoulder posture (Lukasiewicz, McClure et al. 1999; Borstad 2006; Thigpen, Padua et al. 2010).. The alterations in posture or scapular position may play a role in the incidence of impingement. If these biomechanical factors could be restored to their normal state it may be possible to reduce the incidence of impingement related pain.

Myofascial Pain

Myofascial pain is a very common pathology throughout the body, but can be especially aggravating for people who experience it in the shoulders (Gerwin, Dommerholt et al. 2004; Chen, Bensamoun et al. 2007; Bron, Dommerholt et al. 2011). Myofascial pain, also known as myofascial trigger points, are characterized by local points within a muscle group that are highly sensitive to pressure, can cause constant pain, and the compression of which can cause referred pain and muscle dysfunction (Ge, Fernandez-de-las-Penas et al. 2006; Bron, Dommerholt et al. 2011). Myofascial pain is thought to have multiple causes including repetitive microtrauma, muscle weakness, faulty biomechanics or generally poor posture (Simons and Travell 1981; Bron, Dommerholt et al. 2011). As such, therapeutic techniques such as strengthening and manual therapy have been suggested as effective techniques for correcting myofascial pain (Simons and Travell 1981; McPartland 2004). Lucas et al have shown that, in patients with abnormal shoulder muscle recruitment and movement patterns, normal movement could be restored following trigger point release and stretching (Lucas, Rich et al. 2010).

Thoracic Outlet Syndrome

Thoracic outlet syndrome (TOS) is another pathology that has been associated with rounded shoulder posture. Thoracic outlet syndrome can be broken into three classifications; neurogenic TOS in which there is compression of the brachial plexus, vascular TOS which includes compression of the subclavian blood vessels, and nonspecific-type, or common, TOS which may present as chronic pain or features suggestive of brachial plexus involvement (Wilbourn 1990; Ferrante 2004). Symptoms of TOS may include decreased blood flow, distal upper extremity edema, heaviness of the arms, and possibly numbness or tingling in the extremities (Urschel 1972; Huang and Zager 2004). Two common sites of compression are the anterior scalene muscles which may be tightened in someone who exhibits forward head posture, or in the subcoracoid space where the neurovascular structures pass between the coracoid process and pectoralis minor muscle, and the rib cage (Huang and Zager 2004). If the pectoralis minor muscle is overactive or tight, as in someone who exhibits rounded shoulder posture (Lewis and Valentine 2007), the scapula may present as being protracted. This may cause predisposition to thoracic outlet syndrome, as the neurovascular structures that pass beneath the subcoracoid space will be at increased risk of compression (Ferrante 2004). If rounded shoulder posture were to be corrected it may relieve some of the tension placed on these neurovascular structures and could possibly alleviate symptoms of thoracic outlet syndrome.

CAUSES OF SHOULDER PAIN

Muscle Imbalances

Proper function of all of the muscles of the shoulder girdle is important in the position, orientation, and motion of the shoulder with anterior/posterior and medial/lateral muscles being equal and opposite in strength in flexibility (Paine and Voight 1993; Inman, Saunders et al. 1996). However, changes in normal function may result in changes to shoulder kinematics (Wang, McClure et al. 1999; Finley and Lee 2003; Lucas, Rich et al. 2010). The anterior musculature of the shoulder, the pectoralis major, pectoralis minor and anterior deltoid, have a tendency to become over-active or tightened (Sahrman 2002; Wong, Coleman et al. 2010). Conversely, the stabilizers of the shoulder girdle, the rhomboids, serratus anterior, and the rotator cuff, are more prone to weakness and under-activity (Wang, McClure et al. 1999; Sahrman 2002). Changes to length tension relationships have been explored in the literature as fatigue, trauma, and/or painful conditions can result in inhibition of the muscles surrounding the shoulder girdle and changes to the kinematics of the shoulder (Fleisig, Barrentine et al. 1996; McQuade, Dawson et al. 1998). One study found that scapular kinematics were altered following an external rotator fatigue protocol. After the fatigue protocol the participants demonstrated increased upward scapular rotation and decreased lower trapezius activity which altered the force couples of the shoulder girdle (Joshi, Thigpen et al. 2011). Another study has shown that decreased pectoralis minor length led to changes in the resting position of the scapula including increased scapular protraction, increased internal rotation, and a decreased distance between the coracoid process and sternal notch (Borstad 2006). Positional alterations, such as scapular protraction, may result physiologic changes that may be seen clinically as postural changes (Sahrman 2002; Lucas, Rich et al. 2010; Thigpen, Padua et al. 2010) and may predispose someone to injury (Griegel-Morris, Larson et al. 1992).

Kinematics

To increase total motion of the shoulder girdle the scapula has motions in three dimensions including intern/external rotation, upward/downward rotation, anterior/posterior tipping, protraction/retraction, and elevation/depression (McClure, Michener et al. 2001; Myers, Laudner et al. 2005; Wu, van der Helm et al. 2005). These motions, in conjunction with glenohumeral motion, allow the shoulder to have extensive range of motion. Scapular and humeral kinematics are frequently measured using an electromagnetic or optoelectric motion capture system (Lukasiewicz, McClure et al. 1999; Karduna, McClure et al. 2001; Finley and Lee 2003; McClure, Michener et al. 2006; Joshi, Thigpen et al. 2011; Hibberd, Oyama et al. 2012). Electromagnetic motion capture systems use electromagnetic receivers, tethered to the participant and attached to significant bodily landmarks, to collect kinematic data in real time inside an electromagnetic field generated by a transmitter (McClure, Michener et al. 2001). For the measurement of humeral and scapular kinematics receivers are attached to the thorax, the scapula, and the humerus. Data collected from these receivers are then processed to obtain scapular position and orientation (McClure, Michener et al. 2001). This method of assessing kinematics has been shown to be precise, valid, and reliable in the determination of scapular motion (McClure, Michener et al. 2001; Myers, Jolly et al. 2006). Reliability and precision of the measurement of scapular kinematics using an electromagnetic tracking device are listed in Table 10 (Myers, Jolly et al. 2006). Optoelectric motion capture systems use infrared cameras and reflective markers placed on bodily landmarks to measure the position and orientation of the body in three dimensional space (Brochard, Lempereur et al. 2011). The reflection of the markers seen in multiple cameras allows for the triangulation of the marker's position; which in combination with data from other markers allows for the recreation of body segments (Brochard, Lempereur et al. 2011). For this study the use of an electromagnetic motion capture system is the most appropriate due to the application of an external appliance (posture or sham shirt) to the participant. The use of an optoelectric motion capture system would require the repeated removal and reapplication of the reflective markers and recalibration of the system, which may invalidate the data collected (Bourne, Choo et al. 2011; Chu, Akins et al. 2012).

With extensive motion available at the shoulder girdle, the scapula must have proper orientation relative to the trunk and humerus in order to facilitate efficient movement. Normal scapular resting orientation has been defined as having approximately 40° of internal rotation, 11° of upward rotation, and 10° of posterior tipping (Ludewig and Cook 2000). When moved into abduction, at 90° degrees abduction the orientation of the scapula was 22° of posterior tipping, 28° of upward rotation, and 41° of internal rotation. At maximal abduction the orientation of the scapula changed to 34° of posterior tipping, 40° of upward rotation, and 39° of internal rotation (Lukasiewicz, McClure et al. 1999). However, with injury, normal kinematics may be altered (Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000; Lewis, Green et al. 2005). In one study of participants with and without signs of shoulder impingement it was found that participants with symptoms of impingement syndrome demonstrated increased anterior tipping and elevation; which was thought to be due to weakness or inadequate firing of the glenohumeral muscles (Lukasiewicz, McClure et al. 1999). Another study found similar results with impingement participants showing greater scapular upward rotation and clavicular elevation and slightly greater posterior tipping than the control group; however, they found no changes in resting position of the participants (McClure, Michener et al. 2001). Observable changes in scapular kinematics or resting position can be generally defined as rounded shoulder posture, usually represented by excessive scapular protraction, anterior tipping, and internal rotation (Borstad 2006; Oyama, Myers et al. 2008; Thigpen, Padua et al. 2010).

Posture

Many ways of measuring posture have been cited in the literature. For overall posture, the use of a plumb line has been described (Griegel-Morris, Larson et al. 1992; Ono, Bastrom et al. 2012). The plumb line is aligned with various landmarks on the body and abnormal posture is identified by finding landmarks that fall outside the plumb line. Forward head posture has been defined as the tragus of the ear lying in front of the plumb line, and rounded shoulder posture is defined as the acromion process lying in front of the plumb line (Griegel-Morris, Larson et al. 1992). Other methods include the use of lateral radiographs, a double square, a Baylor square, and a measure of scapular position using a measuring tape (Peterson, Blankenship et al. 1997). The Baylor square involves the participant standing against a wall while the physical distance is measured from the spinous process of C7 to the anterior border of the acromion process (Peterson, Blankenship et al. 1997). The double square uses a modified carpenter's square, similar to the Baylor square, to measure the distance between the anterior border of the acromion process to the wall (Peterson, Blankenship et al. 1997). The scapular position measurement uses a tape measure to quantify the horizontal distance between the superior medial border of the scapula and the spinous process of the 3rd thoracic vertebra (Peterson, Blankenship et al. 1997). The radiographs are considered the most reliable measure, and the intratester reliability of the other measures makes them acceptable clinical measures of posture, even though they had only moderate correlation to the radiographs (Peterson, Blankenship et al. 1997). However, for this study, these methods of posture assessment may not be the most appropriate. The Baylor square and double square measurement tools would require moving the participant against a wall which could be hindered by the participant being tethered to the electromagnetic motion capture system. The measurement of scapular position with a measuring tape may be confounded by the application of a shirt to the participant, as this study measured reliability against bare skin; and radiographic assessment presents an unnecessary risk to the participants (Boice and Lubin 1997) as other clinical methods of posture assessment are reliable. Another such method of identifying and quantifying forward head and rounded shoulder posture (FHRSP) uses reflective markers placed on the spinous process of C7, the tragus of the ear, and the acromion process. A lateral photograph is taken and angles are measured between a vertical line at C7 and the markers at the tragus and acromion process (Thigpen, Padua et al. 2010). Using this method, forward head and rounded shoulder posture was calculated as forward shoulder angle (FSA) and forward head angle (FHA). Ideal values for FSA and FHA were found to be less than 36° and 22° respectively. Participants who were determined to have FHRSP possessed a FSA of greater than 52° and a forward head angle (FHA) of greater than or equal to 46° (Thigpen, Padua et al. 2010). This method of posture assessment has been shown to be reliable (Table 7) (Thigpen, Padua et al. 2010) and is most appropriate for this study as this method does not require a repositioning of the participant or removal of the electromagnetic hardware used for kinematic assessment. It is also possible that posture could be measured through the use of electromagnetic or optoelectric motion capture systems (Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000; McClure, Michener et al. 2001), however those systems are more commonly used to quantify kinematics instead of static position. The largest downside to each system as a tool for posture assessment is that they are not portable and can only be used in a laboratory setting.

Changes in rounded shoulder posture are often associated with overdeveloped or tight anterior musculature that “pulls” the shoulder forward into a protracted position (Borstad 2006). The anterior pull of the shoulder may put a constant stretch on the posterior musculature which may lead to weakening or lengthening of those muscles (Caldwell, Sahrmann et al. 2007). This constant stretch or constant stress of lengthened or tight musculature, common in rounded shoulder posture, may result in myofascial pain (Simons and Travell 1981). Rounded shoulder posture has often been associated with shoulder pathology, including impingement from decreased subacromial space (Bak and Fauno 1997; Borstad 2006), increased incidence of interscapular pain (Griegel-Morris, Larson et al. 1992; Bullock, Foster et al. 2005), and thoracic outlet syndrome (Langford 1994). Also associated with rounded shoulder posture are other postural abnormalities such as kyphosis or forward head posture (Griegel-Morris, Larson et al. 1992; Tovin 2006). Kyphosis is described as an abnormally large forward curvature of the thoracic spine, and forward head posture is described as anterior positioning of the head relative to other bodily landmarks (Carman, Browne et al. 1990). One study of 88 participants it was found that those presenting with kyphosis experienced an increased incidence of interscapular pain and those with forward head posture had an increased incidence of headaches, interscapular and cervical pain (Griegel-Morris, Larson et al. 1992). These increases in incidence of pain are likely caused by changes in muscle function such as the posterior musculature of the neck and back forced to constantly contract resulting in painful myofascial points or leading to headaches (Simons and Travell 1981; McPartland 2004). Postural and kinematic changes are also common in athletic populations that participate in overhead sports such as baseball, volleyball, swimming, and tennis (Beach, Whitney et al. 1992; Myers, Laudner et al. 2005; Kluemper, Uhl et al. 2006; Oyama, Myers et al. 2008; Laudner, Moline et al. 2010; Lynch, Thigpen et al. 2010; Hibberd, Oyama et al. 2012). Oyama et al. found that the dominant scapula for select baseball, tennis, and volleyball athletes was more internally rotated and anteriorly tipped. They also found that in tennis players, specifically, the scapula of the dominant arm was more protracted than the non-dominant one (Oyama, Myers et al. 2008). In baseball athletes it has been found that the dominant arm, the throwing arm, displays increased forward shoulder posture than the non-dominant arm (Laudner, Moline et al. 2010). Postural changes are not just common in throwing sports. Swimmers are also commonly affected by changes in posture due to the repetitive pushing and pulling nature of their sport (Lynch, Thigpen et al. 2010). Swimming places increased demand on the anterior musculature of the shoulder, causing them to become overactive and tight which can sometimes result in a forward head and rounded shoulder posture (Kluemper, Uhl et al. 2006). This postural change in swimmers, like that in other athletes, can result in changes in muscle function, decreased subacromial space, or increased incidence of shoulder pain.

CORRECTIVE TECHNIQUES

Many studies have looked at a variety of clinical techniques for altering rounded shoulder posture and scapular kinematics including stretching, strengthening, manual therapy, and bracing (Wang, McClure et al. 1999; Kluemper, Uhl et al. 2006; Cole, Prentice et al. 2008; Lynch, Thigpen et al. 2010; Wong, Coleman et al. 2010).

Strengthening

Strengthening exercises targeting posterior shoulder musculature such as the trapezius and rhomboids have been shown to be effective at reducing rounded shoulder posture (Wang, McClure et al. 1999; Kluemper, Uhl et al. 2006; Lynch, Thigpen et al. 2010). These studies used exercises such as scapular retraction, shoulder shrugs, and shoulder external rotation in an attempt to strengthen the posterior musculature. These exercises have been shown to activate the serratus anterior, upper trapezius, and lower trapezius at levels that have been shown to increase strength (Kibler, Sciascia et al. 2008). Kluemper et al. who employed a 6 week intervention program found that, between 2 groups of swimmers, the experimental group that strengthened as well as stretched showed significant improvements in rounded shoulder posture as compared to a control group that received no intervention (Kluemper, Uhl et al. 2006). Another study by Hibberd et al. found that, while not statistically significant, following a 6 week intervention period swimmers that performed scapular stabilizing exercises such as I's T's and W's displayed slightly increased shoulder flexion and abduction strength (Hibberd, Oyama et al. 2012). They posit that an increase in the intervention period may result in clinical significance. An increase in strength may result in increased neural activity of the muscle, altering kinematics and resulting in increased posterior tipping and scapular retraction (Wang, McClure et al. 1999). Also, it may result in increased stiffness or tightness that would create a posterior pull on the shoulder girdle, thereby reducing forward shoulder posture (Kluemper, Uhl et al. 2006).

Manual Therapy

Static stretching or manual therapy (massage) of anterior musculature has also been found to decrease rounded shoulder posture and scapular kinematics (Wang, McClure et al.

1999; Roddey, Olson et al. 2001; Kluemper, Uhl et al. 2006; Wong, Coleman et al. 2010). Stretching of anterior musculature such as the pectoralis minor muscle may increase the static length of the muscles and may decrease its stiffness; resulting in a relative laxity in the musculature. In a study by Wong et al. the combination of soft tissue massage and static stretching directed at the pectoralis minor muscle resulted in a decrease in rounded shoulder posture that persisted for two weeks following a sing treatment session (Wong, Coleman et al. 2010). Kluemper et al. found that the combination of static stretching of the pectoralis major and minor and strengthening using rubber tubing resulted in a decrease in forward shoulder posture (Kluemper, Uhl et al. 2006). This relative laxity may result in a decreased anterior pull on the shoulder girdle and may decrease rounded shoulder posture and may create less protraction during shoulder motion (Borstad 2006). However, static posture changes may not be the only effects of an intervention protocol. Wang et al. found that following a 6-week intervention protocol there were no significant changes to resting scapular position (rounded shoulder posture), but participants demonstrated an increase in scapular stability and altered scapulohumeral rhythm (Wang, McClure et al. 1999).

Bracing

In addition to altering soft tissue structures through the use of physical rehabilitation, some clinicians have utilized bracing to alter scapular position and kinematics. External bracing has been suggested to alter scapular kinematics and posture (Cole, Prentice et al. 2008). One such device is the S3 brace from Evidence Based Apparel. The brace is a shirt with bracing straps called “neural bands” built into the material and also external to the shirt that are adjustable (Apparel 2012). These straps provide mechanical tension across the shoulders and upper back resulting in a posterior force which is thought to decrease rounded shoulder posture by stretching the anterior shoulder musculature such as the pectoralis minor. It is also thought that the mechanical pressure of the shirt and its straps will "correct improper posture by re-educating and re-engineering the musculoskeletal system surrounding the shoulder and spine (Apparel 2012)." Although limited research has been performed to determine the effects of bracing, one study of 38 college athletes found that the use of the S3 braces resulted in acute reductions in forward shoulder angle and increased muscle activation of the trapezius muscle when compared to the control group without a brace, while performing select rehabilitation exercises (Cole, Prentice et al. 2008). It is also interesting to note that, in this study, there was minimal difference between the treatment group that wore the shirt as it was designed to and the sham group that wore the shirt incorrectly. Cole et al. postulated that this discrepancy was the result of the shirts' construction, meaning that the neural bands built into the shirt portion of the brace may still be effective even without the use of the straps that mechanically pull the shoulders posteriorly (Cole, Prentice et al. 2008). The posture braces, however, are not a perfect tool. The braces are recommended by the manufacturer to be worn only 2-4 hours each day. This limited amount of exposure to the brace may make it an ineffective tool in the correction of rounded shoulder posture.

POSTURE SHIRTS

Recently, there has been released a new line of corrective garments called posture shirts (Apparel 2012). These corrective shirts are a modification of the S3 brace that is designed for longer wear and to be more comfortable. The new posture shirt incorporates the same band technology as other posture braces; however the bands are not adjustable and are implanted within the shirt. The bands begin at the pectoralis muscle and traverse across the clavicle, over the shoulders, across the scapula, intersect at the spine and run to the end of the shirt (Apparel 2012). The posture shirt and the sewn in bands are theorized to work in a very similar fashion to the S3 brace by creating “a mechanical pull on the muscles, ligaments and tendons” and through “neurological signals to the brain” (Apparel 2012). These two mechanisms are thought to encourage the wearer to self-correct their posture, and “create a downward tilting of the scapula that creates more space in your shoulder joint” (Apparel 2012). The mechanical pull and increased neurological signals are theorized to provide a posterior force through the shoulder girdle and increase muscle activity of the posterior musculature of the shoulder girdle which might alter the wearer’s posture.

Although posture shirts are used by clinicians there have been no published studies on the effect of posture shirts as a therapeutic modality in the correction of rounded shoulder posture or scapular kinematics. Should studies confirm that posture shirts are effective at altering forward shoulder posture or scapular kinematics, it would legitimize the use of posture shirts as a simple, inexpensive, and valuable adjunct to current modalities used in treating poor posture.

INSTRUMENTATION

Clinical Assessment

For clinical measurement of posture a photographic method, shown to be reliable by Thigpen et al., will be used (Thigpen, Padua et al. 2010). This method involves the use of 3 reflective markers placed on the spinous process of C7, tragus, and the acromion process. With participants standing in front of a scaled backdrop, a measured distance away from both the backdrop and the camera, they are instructed to bend forward 3 times, reach overhead 3 times, and to stand in their natural posture looking at a fixed point directly ahead of them. A high definition lateral photograph is taken of the participant and image software is used to determine forward shoulder angle. The backdrop allows for a reference to true vertical so that angle measurements can be standardized between participants. The measured distances and fixed orientation of the camera and backdrop allow for more consistent measures as a rotation of the participant or a misplacement of the backdrop or camera may result in an apparent change in the participants forward shoulder angle. This method of postural assessment is preferable to other methods as it has been shown to be equally reliable or more reliable than other methods such as the Baylor square or double square (Peterson, Blankenship et al. 1997; Thigpen, Padua et al. 2010), and can be assessed without moving the participant or without the removal of electromagnetic motion tracking hardware as would be required for methods such as the pectoralis length test measurement (Lewis and Valentine 2007).

Laboratory Assessment

Electromagnetic motion capture system is used for laboratory assessment of kinematic upper extremity motion. Receivers are placed on bodily landmarks and other significant points are digitized to generate a three-dimensional representation of the participant. These points are analyzed for changes in position in both a world axis system and segment axis systems and are analyzed to obtain changes in position and orientation which allow the clinician to assess motion of the participant. As compared to video-based motion tracking systems, this method is preferable for this study, as the application of an external appliance to the body (posture or sham shirt) would require the removal and replacement of the reflective markers which could invalidate the data (Chu, Akins et al. 2012). Electromagnetic motion tracking has been shown to be precise, valid, and reliable in the determination of scapular motion (McClure, Michener et al. 2001; Myers, Jolly et al. 2006).

CLINICAL RELEVANCE

The use of posture shirts, if effective, may prove an important therapeutic tool in the rehabilitation of people with rounded shoulder posture. The use of posture shirts may provide temporary relief of shoulder pain related to rounded shoulder posture by acutely altering forward shoulder position and scapular kinematics. These changes may allow the wearer to continue daily activities or competition while doing traditional rehabilitation, as traditional rehabilitation can take extended periods of time to be effective (Wang, McClure et al. 1999; Kluemper, Uhl et al. 2006; Hibberd, Oyama et al. 2012).

CHAPTER III

PARTICIPANTS

Forty nine participants were screened for this study with twenty four participants qualifying for participation. Participants were recruited from the general student population of the University of North Carolina at Chapel Hill. Participants were both males and females between the ages of 18 and 25 years old. Participants in this study also presented with a pre-existing rounded shoulder posture. This abnormality was identified during a pre-screening of the participant.

Participants were excluded from this study if they had a history of shoulder, neck, or back surgery, a history of scoliosis, if they were actively seeking regular treatment for shoulder pain, or if they had experienced shoulder pain or injury that resulted in the loss of practice or play time greater than three consecutive days in the previous three months.

INSTRUMENTATION

The Motion Monitor version 8.64 electromagnetic tracking software (Innovative Sports Training Inc., Chicago, IL) along with the MotionStar model 800 wide-range transmitter and miniaturized birds (Ascension Technologies Inc., Milton, VT) were used to collect scapular kinematics. The data was acquired through electromagnetic receivers for the calculation of receiver position and orientation relative to the electromagnetic transmitter. A wide-range direct current transmitter and four receivers were used for data collection, sampled at 100Hz.

Postural assessments were made using a lateral photograph taken with a Canon PowerShot SD1000 digital camera (Canon USA Inc., Lake Success, NY). Images were then downloaded into ImageJ. ImageJ is a photo-analysis program, developed by the National Institutes of Health (Bethesda, MD), which allows for identification of forward shoulder angle using an angle measurement tool.

DESIGN

The design of this study was a repeated measures intervention study with counterbalanced conditions, where each participant was tested four times under three unique conditions; control (no shirt), treatment and sham (test conditions). First every participant completed posture and kinematic measurement (testing) under the control condition, followed by testing under one of the test conditions (treatment or sham). The participant then completed testing under a second control condition followed by the other test condition, counterbalanced to the first (treatment or sham). Each participant had their kinematics and posture assessed at each phase of testing.

PROCEDURES

Participation in this study required two visits to the research lab. During the first visit to the Sports Medicine Research Laboratory (SMRL) each participant completed an informed consent form approved by the UNC Institutional Review Board (IRB) and a screening. For screening of posture, participants were equipped with reflective markers placed on the spinous process of C7, tragus, and the most anterior portion of the acromion process (Figure 1) and positioned in front of a scaled backdrop. Participants were instructed to touch their toes and reach overhead three times and then stand in their normal posture. A high definition lateral photograph was taken of the participant and uploaded to a computer. This process was repeated three times resulting in three photographs per participant. Using ImageJ the forward shoulder angle (FSA) was measured from the acromion process marker relative to a vertical line placed at C7 in each photograph (Figure 2). The measurements were averaged and a FSA for the participant was recorded. Participants with a FSA $\geq 52°$ were defined as having rounded shoulder posture (Thigpen, Padua et al. 2010).

If the participant qualified as having a FSA $\geq 52°$ they were called back to the SMRL for a second, testing, session and the collection of scapular kinematic and posture data. Each participant completed a shoulder elevation task in the scapular plane to assess scapular kinematics and posture under the three test conditions, performed in a counterbalanced order chosen at random; control, sham, and treatment. The control condition involved the participant wearing no shirt; males were bare skinned, females were in either a tank top shirt or sports bra. The sham condition involved the participant wearing a non-corrective shirt. The treatment condition involved the wearing of a posture shirt. The appropriate shirt was selected by a circumferential measurement of the participant's chest per the manufacturer's recommendations (Table 1).

Kinematics

Participants were fitted with electromagnetic tracking receivers that are used with the electromagnetic motion capture system to collect scapulothoracic and humerothoracic data which was analyzed to obtain scapular kinematics during a shoulder elevation task. The male participants removed their shirt, and female participants wore a tank top or sports bra to make receiver placement more accurate and secure. A total of 4 receivers were used for the scapular kinematics assessment. Electromagnetic receivers were placed on the spinous process of the seventh cervical vertebra (C7), the acromial angle of the acromion process, and the humeral shaft of the dominant arm (Figure 1) (Oyama, Myers et al. 2008). The receiver on C7 was placed over the spinous process, defined as the point with the least amount of soft tissue covering it. The receiver placed on the acromion processes was placed over the lateral one third of the process where the soft tissue is of least thickness (the acromial angle). The receiver placed on the humerus was placed on the posterior humerus, distal to the muscle belly of the triceps brachii. All receivers were secured by means of hypoallergenic tape. The receiver on the humeral shaft was also wrapped with foam under-wrap and then covered with athletic tape. The cables attached to each receiver were taped to the participant in such a way that the participant could don a shirt without disrupting the cables (Figure 1).

A fourth receiver was attached to the stylus and was used to digitize the anatomical landmarks of the upper arm, scapula, clavicle, and thorax (Table 2). Root of the spine of the scapula (TS), inferior angle (AI), and acromial angle (AA) were digitized on the scapula. Spinous process of the eighth thoracic vertebra (T8), the spinous process of the seventh cervical vertebra (C7), the suprasternal notch (IJ), and the xiphoid process (PX) were digitized on the thorax. The most dorsal point on the acromioclavicular joint (AC) and the most ventral point on the sternoclavicular joint (SC) were digitized on the clavicle. Medial (EM) and lateral (EL) epicondyles were digitized on the humerus with the glenohumeral joint center (GH) being defined through motion recordings. A least squares algorithm identified the glenohumeral joint center as the point that moves the least with respect to the scapula as the humerus is moved through short arcs of motion (Veeger 2000). Definition of joint coordinate systems and digitization of bodily landmarks was done according to the ISB recommendations on definitions of joint coordinate systems (Wu, van der Helm et al. 2005).

The local coordinate systems for the thorax, scapula, clavicle and humerus were constructed based on the digitization of these anatomical landmarks. The position and orientation of the scapula relative to the thorax were calculated based on these local coordinate systems (Wu, van der Helm et al. 2005; Myers and Jolly 2006).

After digitization, the participants were then instructed on a humeral elevation task in the scapular plane. Guidance for the task was provided by vertical posts positioned in front of the participant; that they used as a guide to their motion. The scapular plane was defined as 30 degrees anterior to the frontal plane for this study. Shoulder rotation was in the neutral position and the participant was instructed to maintain this position by keeping their thumbs pointing towards the ceiling (Figure 2). Each participant performed 15 elevations at a rate of 4 seconds per repetition, 2 seconds raising and 2 seconds lowering (Karduna, McClure et al. 2000; Hibberd, Oyama et al. 2012).

Photographic Posture Assessment

Photographic posture assessment was identical to the photographic screening procedure. Participants were equipped with three reflective markers placed on the spinous process of C7, tragus, and acromion process (Figure 1). With participants standing in front of a scaled backdrop they were instructed to bend forward three times, reach overhead three times, and to stand in their natural posture looking straight ahead at a fixed point. The participant completed this task three times and after each trial a high definition lateral photograph was taken of the participant and uploaded to a computer. Using ImageJ the forward shoulder angle (FSA) was measured in each photograph and averaged to obtain the participant's FSA. Forward shoulder angle was measured from a vertical line placed at C7 to the marker on the acromion process (Figure 2). Each test condition required the removal and reapplication of the reflective marker on the acromion process. To ensure accurate placement during each condition the marker was aligned with the most anterior prominence of the acromion process, identified through palpation of the area. Additionally, this marker was placed by the same clinician in an effort to standardize placement.

DATA REDUCTION

Kinematic Data Reduction

Raw kinematic data was filtered with a 10Hz Butterworth filter (Challis and Kitney 1983). Receiver position and orientation data of the thoracic, scapular, and humeral receivers were transformed into a local coordinate system for each of the respective segments. The coordinate systems used were in accordance with recommendations from the International Society of Biomechanics (Tables 3-6) (Wu, van der Helm et al. 2005). With the participant standing in anatomical position, the coordinate system for each segment was: vertical (y-axis), horizontal to the right (z-axis) and anterior (x-axis) (Figure 3). Euler angles (Y-X-Y order) were used to determine the position of the humerus relative to the thorax. The rotation sequence of the Euler angle was chosen from the recommendations of the International Shoulder Group (Wu, van der Helm et al. 2005). Humeral orientation was determined as rotation about the y-axis of the humerus (plane of elevation), rotation about the z-axis (elevation), and rotation about the y-axis (axial rotation). Using Matlab software (The MathWorks Inc., Natick, Massachusetts) humeral elevation angles of 30°, 60°, 90°, and 120° were identified relative to the thorax during the ascending phase of the elevation task. The time points at said humeral elevation angles were used for the assessment of scapular position and orientation. Scapular orientation and position data was not assessed above 120° of humeral elevation as it be shown to be unreliable (Karduna, McClure et al. 2001).

Euler angles (Y-X-Z order) were used to determine the scapular orientation, with respect to the thorax, at the time points identified for a given humeral elevation angle. Orientation of the scapula relative to the thorax was determined as rotation about the y-axis of the scapula (internal/external rotation), rotation about the z-axis of the scapula (upward/downward rotation) and rotation about the x-axis of the scapula (anterior/posterior tipping) (Figure 4). Scapular position (protraction/retraction, elevation/depression) was represented by clavicular kinematic measurements; not actual clavicular motions. Scapular protraction/retraction was calculated as the angle formed between the vector extending from the SC joint to the AC joint, projected onto the transverse plane of the thorax, relative to the frontal plane of the thorax. Scapular elevation/depression was calculated as the angle formed between the vector extending from the SC joint to the AC joint, projected onto the frontal plane of the thorax, relative to the transverse plane of the thorax.

Based on the recommendations from the ISB, scapular movements in internal rotation, downward rotation and posterior tipping directions were indicated by the positive numbers (Wu, van der Helm et al. 2005). Scapular upward rotation values were multiplied by -1 to make upward rotation a positive movement. This was done to make clinical interpretation easier. Using a MatLab software, mean scapular orientations and clavicular positions at 30°, 60°, 90° and 120° of humeral elevation during the ascending phase of the elevation task were calculated for statistical analyses by averaging the values from the middle 5 repetitions (of 15 total repetitions) of the shoulder elevation task. The first 5 repetitions and the last 5 repetitions were excluded from analysis to account for learning effects and fatigue respectively. Change scores were calculated for each kinematic variable at each level of humeral elevation by taking the difference between the control conditions, the difference between the sham condition and preceding control condition, and the difference between the treatment condition and the preceding control condition. These data were used in statistical analysis.

Photographic Data Reduction

Three photographs were taken of each participant under each test condition. The Forward Shoulder Angle was measured in each photograph. These data for each participant and condition were averaged and the means were used for statistical analysis of FSA.

STATISTICAL ANALYSIS

A power analysis of previous research revealed that a group size of 20 participants was necessary to yield a power rating of 0.87 (Wang, McClure et al. 1999). An a priori alpha level of 0.05 was set for all comparisons. Analyses were run using SPSS version 21 for Windows PCs. A one-way, repeated measures ANOVA was run with one within-subjects factor (condition) to compare forward shoulder angles between conditions. A post-hoc analysis with a Bonferroni correction was used to assess pair-wise comparisons of test conditions. Using change scores between the sham shirt, the posture shirt, and the two control conditions, two-way repeated measures ANOVAs were run with two within-subjects factors (condition and angle) to assess each kinematic variable including scapular upward rotation, internal rotation, posterior tipping, protraction, and elevation (Table 11). Post-hoc analyses with Bonferroni corrections of each ANOVA were used to assess main effects as well as interaction effects of condition and test angle. An a priori alpha level of 0.05 was set for all comparisons and all analyses were run using SPSS for Windows PCs (version 21.0, SPSS Inc., Chicago, IL). Bonferonni corrections were performed, adjusted for multiple comparisons, giving an adjusted alpha level of 0.0027 for all post-hoc testing.

CHAPTER IV: MANUSCRIPT

INTRODUCTION

Shoulder injuries are common throughout the student population with some estimates as high as 35% (Katz, Amick et al. 2000; Schlossberg, Morrow et al. 2004). Additionally, shoulder injuries account for 8-20% of all sport related injuries (Agel, Ransone et al. 2007; Dick, Ferrara et al. 2007). Many shoulder injuries are chronic in nature and may be classified as overuse injuries such as shoulder impingement syndrome, myofascial pain or thoracic outlet syndrome (Simons and Travell 1981; Griegel-Morris, Larson et al. 1992; Ferrante 2004). These injuries have been partially attributed in the literature to rounded shoulder posture, muscle imbalance, and altered scapular kinematics (Greenfield, Catlin et al. 1995).

Rounded shoulder posture has been linked to an increase in scapular anterior tipping, internal rotation and protraction as well as a decrease in upward rotation (Ludewig and Cook 2000; Borstad 2006; Oyama, Myers et al. 2008; Thigpen, Padua et al. 2010). These changes in shoulder posture have been associated with shoulder pathology such as impingement syndrome (Brossmann, Preidler et al. 1996; Lukasiewicz, McClure et al. 1999). In addition, persons with rounded shoulder posture have been shown to exhibit an increased incidence of interscapular pain (Griegel-Morris, Larson et al. 1992). Rounded shoulder posture may be the result of a combination of altered scapular kinematics and/or muscular imbalance (Finley and Lee 2003; Thigpen, Padua et al. 2010). Altered scapular kinematics include abnormal scapular orientations (scapular internal/external rotation, upward/downward rotation, and anterior/posterior tipping), and abnormal scapular position (elevation/depression and protraction/retraction) during shoulder motion (Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000; Thigpen, Padua et al. 2010). Often, persons with symptoms of shoulder impingement present clinically with changes in shoulder motion; specifically increased anterior tipping and greater upward rotation (Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000). These abnormal kinematics may be an attempt to minimize pain in a symptomatic shoulder and may result from muscular imbalances (Kebaetse, McClure et al. 1999; Ludewig and Cook 2000). Tightness or over activity of the anterior muscles combined with weakness or under activity of the posterior musculature of the shoulder girdle may lead to a relative protraction, anterior tipping or downward rotation of the shoulder (Ludewig and Cook 2000; Thigpen, Padua et al. 2010). These muscle imbalances may result in either static changes in shoulder position, i.e. rounded shoulder posture, or may result in kinematic changes to the shoulder (Langford 1994; Finley and Lee 2003).

With rounded shoulder posture and altered scapular kinematics being linked to shoulder pathology, clinicians have sought ways to correct these abnormalities (Wang, McClure et al. 1999; Lynch, Thigpen et al. 2010; Wong, Coleman et al. 2010). Many different means of posture correction have been examined in the literature, including stretching of tight structures, strengthening of weak and lengthened structures, and the use of manual therapy (Wang, McClure et al. 1999; Kluemper, Uhl et al. 2006; Lynch, Thigpen et al. 2010; Wong, Coleman et al. 2010). Clinicians have also attempted the use of external support to correct rounded shoulder posture as traditional rehabilitation can take extended periods of time (Kluemper, Uhl et al. 2006; Lynch, Thigpen et al. 2010). While there has been limited research on the use of posture braces, recent literature suggest evidence of bracing efficacy (Cole, Prentice et al. 2008). Recently, a corrective Posture Shirt (Alignmed, Santa Ana, CA) has been released which is designed to improve rounded shoulder posture through the use of specialized neural bands that extend across the superior shoulder girdle from pectorals to the spine. The neural bands are designed to improve posture through increased proprioception and manipulation of the scapula and muscles of the shoulder girdle (Apparel 2012), however there is little published evidence in favor of or against their efficacy.

The purpose of this study was to determine if application of the corrective posture shirt, as compared to a sham shirt and control (no shirt) condition, has an acute effect on scapular kinematics or posture in college students with rounded shoulder posture. Clinically, if excessive rounded shoulder posture and abnormal scapular kinematics can be acutely corrected through the use of posture shirts, it may be possible to reduce the incidence of shoulder pain and may provide a useful adjunct to current therapies by providing temporary relief for sufferers of shoulder pain while other rehabilitative techniques take longer to be effective. Additionally, if effective, posture shirts could be worn in conjunction with traditional therapies such as rehabilitation exercises as an additive benefit.

METHODS

Design

A repeated measures intervention study with counterbalanced conditions was used to determine how a posture shirt changes excessive forward shoulder posture and scapular movement patterns compared to both control and sham conditions.

Participants

Twenty-four participants with rounded shoulder posture, as defined as having a forward shoulder angle (FSA) greater than 52° (Thigpen, Padua et al. 2010), were identified through a screening process of forty-nine individuals. All participants were recruited from the general student body population at a large university and were between 18 and 25 years old. Three participants (2 females, 1 male) were excluded from final analysis for being clear outliers relative to the other participants. Final analysis included twenty-one participants (11 males, 10 females; age 20.8±1.7 y, height 173.2±11.9 cm, weight 74.7±14.5 kg) (Table 9). Participants were excluded from the study if they had a history of upper extremity surgery, history of scoliosis, active shoulder pain, or shoulder pain in the last three months that restricted activity for greater than three consecutive days.

Procedures

Lateral photographs were taken with a Canon PowerShot SD1000 digital camera (Canon USA Inc., Lake Success, NY) and the images were downloaded to ImageJ software (National Institutes of Health, Bethesday, MD) for analysis.

Kinematic assessment was performed using the MotionStar model 800 wide-range transmitter and miniaturized birds (Ascension Technologies Inc., Milton, VT). The device used an electromagnetic transmitter and 4 electromagnetic receivers, 3 of which were attached to the participant with the fourth being used for digitization of landmarks as described in previous literature (Meskers, Fraterman et al. 1999). The tracking device recorded position and orientation data of the receivers relative to the transmitter. All kinematic data were collected at 100 Hz and analysis was done using Motion Monitor version 8.64 electromagnetic tracking software (Innovative Sports Training Inc., Chicago, IL).

All participants underwent screening to identify excessive forward shoulder posture. Informed consent was obtained with a University Institutional Review Board form prior to screening. Participants completed a photographic posture screening to identify their FSA. The screening method consisted of the participant standing in front of a scaled backdrop a known distance away from a camera. Participants were equipped with three reflective markers, on the spinous process of the seventh cervical vertebra (C7), the most anterior border of the acromion process and on the tragus of the dominant side of the participant's body (Figures 2&3). Participants were instructed to touch their toes and reach overhead three times and then stand in their normal posture, at which time a high definition lateral photograph was taken. This procedure was repeated three times with three photographs used for calculation of FSA. Photographs were analyzed using the angle calculation function of the ImageJ software. Forward shoulder angle, defined as the angle formed between the reflective marker on the acromion process and a vertical line through the marker on the spinous process at C7 (Thigpen, Padua et al. 2010), was calculated for each photograph and averaged to determine participant eligibility (Figure 2). This measurement of posture, as described by Thigpen et al. (Thigpen, Padua et al. 2010), was used for identification of FSA and was shown to be reliable during pilot testing for this study (Intraclass Correlation Coefficient $(ICC)_{(3,1)}$=0.99, Standard Error of the Mean (SEM)=0.23°, Minimum Detectable Difference (MDD)=0.78°). This same manner of data collection was used during testing with those data used in statistical analysis of FSA.

Upon qualifying for continuation in the study with a forward shoulder angle greater than 52°, participants were called back to the research laboratory for additional posture and kinematic testing. Posture testing procedures were identical to the screening process. Kinematic assessment was done through electromagnetic motion tracking using 4 electromagnetic receivers. This method has been shown a precise, valid and reliable method of collection of scapular kinematics (McClure, Michener et al. 2001; Myers and Jolly 2006), Receivers were placed on the participant's dominant arm, as defined as the arm used to throw a ball, and being placed on the acromial angle where tissue was of the least thickness, the spinous process of C7, and mid-shaft of the posterior humerus. All receivers were secured with double-sided adhesive tape, as well as pre-wrap and athletic tap on the humeral receiver, to minimize receiver movement. The fourth receiver was used for digitization of anatomical landmarks on the thorax, scapula, clavicle, and upper arm. Digitized landmarks included the spinous process of the seventh cervical vertebra, spinous process of the eighth thoracic vertebra, suprasternal notch, xiphoid process, root of the spine of the scapula, scapular inferior angle, scapular acromial angle, sternoclavicular joint, acromioclavicular joint, and the medial and lateral epicondyles of the humerus. The glenohumeral joint center, defined as the point that moves the least with respect to the scapula as the humerus is moved through short arcs of motion (Veeger 2000), was estimated through a least squares algorithm. Construction of local coordinate systems were done using the digitized landmarks for each body segment; thorax, scapula, and humerus. Local coordinate systems were used for calculation of position and orientation of the scapula.

Participants completed an elevation task consisting of 15 repetitions of continuous bilateral full-shoulder elevation in the scapular plane, defined as 30 degrees anterior to the frontal plane verified with a goniometer. A guide was placed in front of the participant to ensure that their arms remained in the scapular plane (Figure 3) (Karduna, McClure et al. 2000; Hibberd, Oyama et al. 2012). The participant completed each cycle to the beat of a metronome with elevation taking two seconds and lowering taking two seconds.

Participants completed four posture and kinematic assessments under three conditions. Participants completed the test procedures first under a control condition with no shirt, second by a test condition (posture shirt or sham shirt); third under another control condition, and finally under the other test condition, counterbalanced to the first. The posture shirt condition involved the wearing of a specially designed shirt intended to assist the wearer in self-correcting their posture. The sham shirt was chosen as an analog to the posture shirt that provided no posture correction to the wearer. Both the sham shirt and posture shirt were fitted according to manufacturer recommendations using a circumferential measurement of the participant's chest which was compared to sizing charts from the respective manufacturer. The control conditions involved the participant wearing no shirt (males), or a tank top or sports bra (females). No electromagnetic receivers were removed during the testing process and only the reflective marker on the acromion process was removed to accommodate for the shirt conditions. To ensure proper replacement of the reflective marker on the acromion process all placements were done by the same clinician, and by palpating the most anterior border of the acromion process.

For kinematic data reduction the middle 5 repetitions (of 15 total repetitions) of the elevation task were used to account for a learning effect and fatigue. Raw kinematic data were filtered using a low-pass, 10Hz Butterworth filter; and reduced using Matlab software (The MathWorks Inc., Natick, Massachusetts). Position and orientation data from each receiver were used to construct local coordinate systems for the thorax, scapula and humerus; in accordance with International Society of Biomechanics (ISB) recommendations (Wu, van der Helm et al. 2005). With the participant standing in anatomic position each segment was defined as vertical (y-axis), horizontal to the right (z-axis) and anterior (x-axis). Scapular orientation was determined as rotation about the y-axis of the scapula (internal/external rotation), rotation about the z-axis of the scapula (upward/downward rotation), and rotation about the x-axis of the scapula (anterior/posterior tipping). Euler angles were used to determine scapular orientation with respect to the thorax and were chosen based on ISB recommendations (Wu, van der Helm et al. 2005). Scapular position (protraction/retraction, elevation/depression) were represented by clavicular kinematic measurements. Scapular protraction/retraction was calculated as the angle formed between the vector extending from the sternoclavicular joint to the acromioclavicular joint projected onto the transverse plane of the thorax, relative to the frontal plane of the thorax. Scapular elevation/depression was calculated as the angle formed between the vector extending from the sternoclavicular joint to the acromioclavicular joint, projected onto the frontal plane of the thorax, relative to the transverse plane of the thorax.

For each kinematic variable, mean position and orientation data were identified at 30°, 60°, 90°, and 120° of humeral elevation during the ascension phase of the elevation task. These data were further reduced by calculating change scores at each level of humeral elevation, for each kinematic variable, for the treatment condition (posture shirt) minus the preceding control condition, the sham condition minus the preceding control condition, and the difference between the two control conditions. These data were used in statistical analysis.

Statistical Analyses

A one-way, repeated measures ANOVA was run with one within-subjects factor (condition) to compare forward shoulder angles between conditions (posture shirt , sham shirt, control condition). A post-hoc analysis with a Bonferroni correction was used to assess pair-wise comparisons of test conditions. Using change scores between the sham shirt, the posture shirt, and the two control conditions, two-way repeated measures ANOVAs were run with two within-subjects factors (condition and angle) to assess each kinematic variable including scapular upward rotation, internal rotation, posterior tipping, protraction, and elevation. Post-hoc analyses with Bonferroni corrections of each ANOVA were used to assess main effects as well as interaction effects of condition and test angle. An a priori alpha level of 0.05 was set for all comparisons and all analyses were run using SPSS for Windows PCs (version 21.0, SPSS Inc., Chicago, IL). Bonferonni corrections were performed, adjusted for multiple comparisons and giving an adjusted alpha level of 0.0027 for all post-hoc testing.

RESULTS

A significant difference was found between postural analysis conditions for the forward shoulder angle ($F_{(4,92)}$=3.726, p=0.007)(Table 10). Post-hoc testing revealed that participants wearing the sham shirts demonstrated a significant decrease of 2.40° in FSA between the sham shirt and its preceding control condition as compared to the posture shirt and its preceding control condition and between the two control conditions (p=0.048)(Figure 6). No other significant differences were found between postural assessment conditions.

A significant interaction effect ($F_{(6,120)}$=3.776, p=0.002) was found for scapular protraction (Table 11). Post-hoc testing revealed a significant increase in protraction at 90° of elevation (Figure 7) between the sham shirt and the control ($t_{(20)}$=5.035, p<0.001), and at 120° of elevation (Figure 8), a significant increase in protraction between the sham shirt and both the control ($t_{(20)}$= - 4.070, p<0.001) and the posture shirt change scores ($t_{(20)}$=8.113, p=0.001) (Table 11). Finally, while there was a significant main effect ($F_{(3,120)}$=8.955, p<0.001)and significant interaction effect ($F_{(6,120)}$=3.479, p=0.003) for scapular internal rotation as well as a significant main effect ($F_{(3,120)}$=6.782, p=0.001) and interaction effect ($F_{(6,120)}$=4.504, p<0.001) for posterior tipping, post-hoc testing revealed no statistically significant changes in either kinematic variable. There were no significant findings for scapular upward rotation or elevation.

DISCUSSION

There were no statistically significant findings for the posture shirts with regard to forward shoulder angle or any of the scapular kinematics. This suggests that the posture shirts do not acutely alter rounded shoulder posture or scapular kinematics in any significant fashion. With no current literature on posture shirts, a comparison to literature on posture braces is the closest analogue available. One particular study assessed posture via forward shoulder angle and muscle activation through electromyographic analysis (EMG) while wearing a posture brace under various conditions (Cole, Prentice et al. 2008). The results of Cole et al,'s study demonstrated a significant decrease in forward shoulder angle (FSA) and a change in EMG activity for select muscles during rehabilitation exercises while wearing both a sham brace and treatment brace as compared to a control (no brace) condition. The decreases in FSA and increases in EMG activity that were seen in the sham condition, where the bracing straps were not placed correctly, suggest that the strapping procedures may not be necessary for changes in muscle activation or posture to occur. A parallel could be drawn between the sham condition employed by Cole et al. and the treatment condition (posture shirt) used in this study, in that the posture shirts do not employ bracing straps and are designed to obtain the same result as the posture braces. However, no change was found in FSA with posture shirt use in this study; and without EMG analysis in this study it is not possible to compare the EMG results found by Cole et al. The lack of significant change in FSA or kinematics in this study may be due to the differences in construction between the posture brace and the posture shirt, or the nature of the posture brace which is designed to be a tighter fitting and manipulative appliance. The posture shirt is designed for extended wear and may be looser fitting and more flexible than a brace. This may result in decreased acute effectiveness of the shirt's neural bands and could explain the lack of significant results in this study. Changes in FSA or kinematics are the desired effect of posture shirt use (Apparel 2012), and while no acute changes were found in this study, improvements in patient proprioception may still alter FSA or scapular kinematics with increased posture shirt wear time; however, further research is needed for confirmation of this hypothesis. Posture shirts continue to have anecdotal evidence with regard to improving posture and scapular kinematics and remain in use in clinics that specialize in rehabilitation, but that evidence could not be replicated by this study and may require further research to confirm.

The sham shirt, contrary to the posture shirt, was found to significantly decrease forward shoulder angle as compared to the treatment and control conditions (Figure 6); however the sham shirt also increased scapular protraction at higher angles of humeral elevation relative to both the control and treatment conditions (Figures 7&8). This suggests that while the posture shirt does not acutely alter rounded shoulder posture or scapular kinematics, the sham shirt may decrease rounded shoulder posture while simultaneously altering scapular kinematics in a sub-optimal fashion. With decreased rounded shoulder posture, the sham shirts may decrease a contributing factor to shoulder pain (Griegel-Morris, Larson et al. 1992; Borstad 2006). Conversely, the increased protraction at higher levels of humeral elevation could be detrimental to the patient as increased protraction has been shown to be a contributing factor to shoulder pathology (Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000). Finally, despite being statistically significant, these changes may not be clinically significant as they show a change of only a few degrees.

One thing to note about the shirts used in this study was that the sham shirts were more tightly fitted than the appropriately fitted posture shirts and may have been more restrictive, leading to the acute decrease in rounded shoulder posture by compressing the shoulder girdle to the trunk despite being fitted based on manufacturer’s recommendations. During the elevation task, the added restriction of the shirt may have led to increased muscle activity, pulling the scapula into increased protraction. An attempt to control for this was made by having the shirts fitted by a clinician trained in the application of external devices such as braces and by fitting both shirts according to manufacturer's recommendations.

Another thing to note about this study is that participants may have self-corrected their posture by simply being aware that they were participating in a posture related study, participants were given no verbal cueing as to how to improve their posture while standing or during the kinematic task. This is of particular importance to clinicians as instruction and verbal cueing are consistently used for training a patient to perform rehabilitative exercises correctly. The lack of verbal cueing in this study may provide additional insight as to why no significant results were found.

One significant limitation of this study was that the sham shirts were not a direct analog of the posture shirts and may have led to the participant knowing which shirt was designed to be corrective. This limitation was controlled through the use of the counterbalanced study in which one half of the participants completed the elevation task in the posture shirt prior to the sham shirt, and half of the participants completed the elevation task in the sham shirt prior to the posture shirt; however, with no true blinding the participants may have gleaned which shirt was corrective and which was not. Another limitation of this study was that the shirts were only worn acutely. These shirts are generally designed and prescribed for extended wear; however this study did not evaluate extended use. Also, there was no evaluation of electromyographic (EMG) activity in this study. Electromyographic activity has been shown to be altered while wearing an external appliance such as a posture brace (Cole, Prentice et al. 2008), and these effects may be present while wearing a posture shirt. An acute change in EMG activity may indicate that extended use of the posture shirts could produce lasting changes in muscle activity that may affect posture or alter scapular kinematics. Finally, this study was performed on an asymptomatic population that was free of shoulder pain. As the shirts are commonly used in a symptomatic population this study may not be generalizable to other populations.

This study is a preliminary assessment of the effects of posture shirt use on scapular kinematics and rounded shoulder posture. Additional studies may focus on the use of posture shirts during functional tasks, specifically concentrating on their effect on muscle activation and movement patterns. Those studies may focus on the use of a posture shirt as an adjunct to traditional therapies as a means to improve muscle function during rehabilitation exercises, in combination with verbal cueing, or as a palliative treatment for people with active shoulder pain, none of which were the focus of this study.

CONCLUSION

Being that this study shows no conclusive evidence linking posture shirt use to acute reductions in rounded shoulder posture or improvements in scapular kinematics, further study is needed to substantiate or refute the use of posture shirts as a viable clinical tool in reducing rounded shoulder posture or improving scapular kinematics.

FIGURES

Figure 1 - Receiver and reflective marker placement for humerus, scapula, tragus and spinous process of C7

Figure 2 – Participant performing elevation task while equipped with electromagnetic motion tracking system

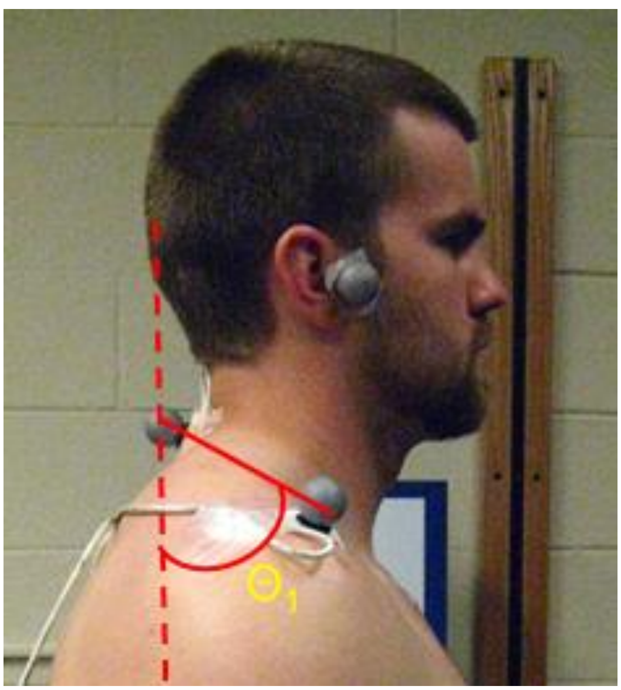

Figure 3- Forward shoulder angle (Θ_1) assessment using ImageJ software

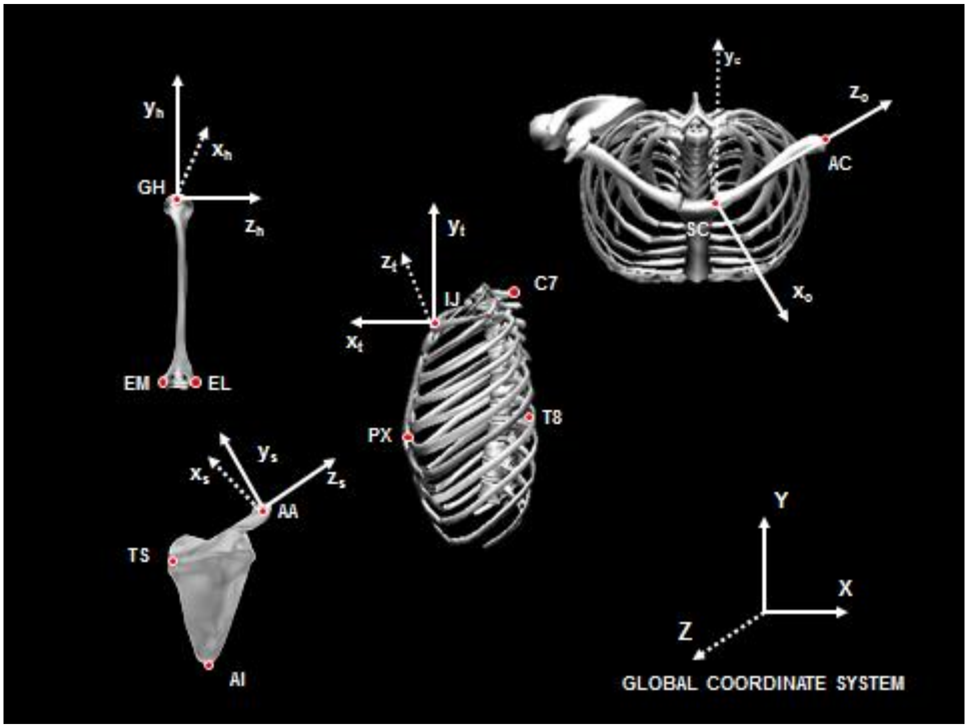

Figure 4 - Coordinate systems of the thorax, scapula, clavicle, and humerus.

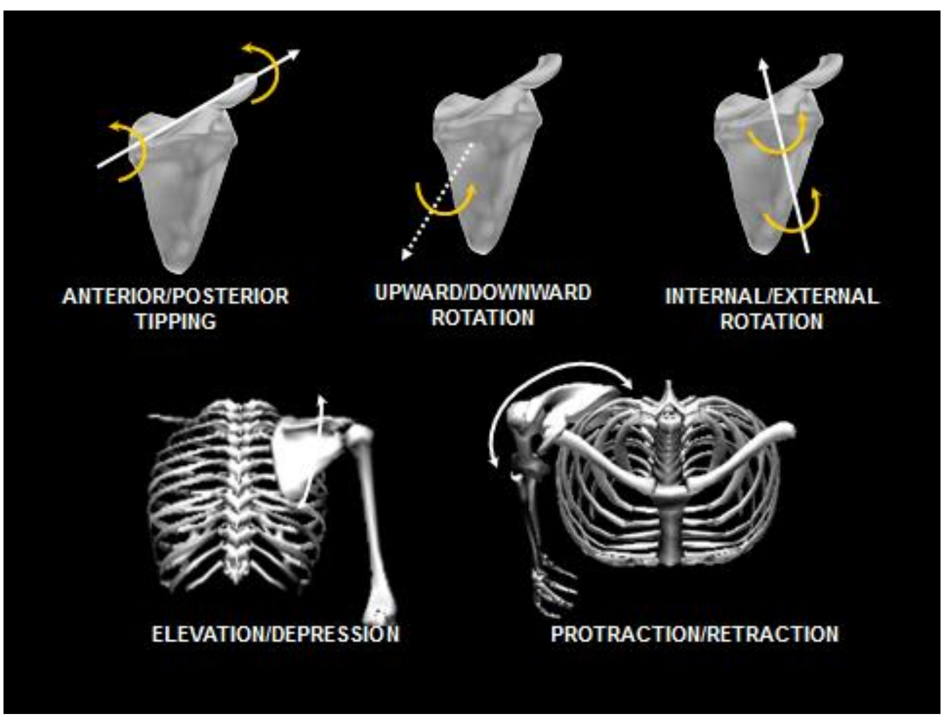

Figure 5 – Scapular orientation and position dependent variables.

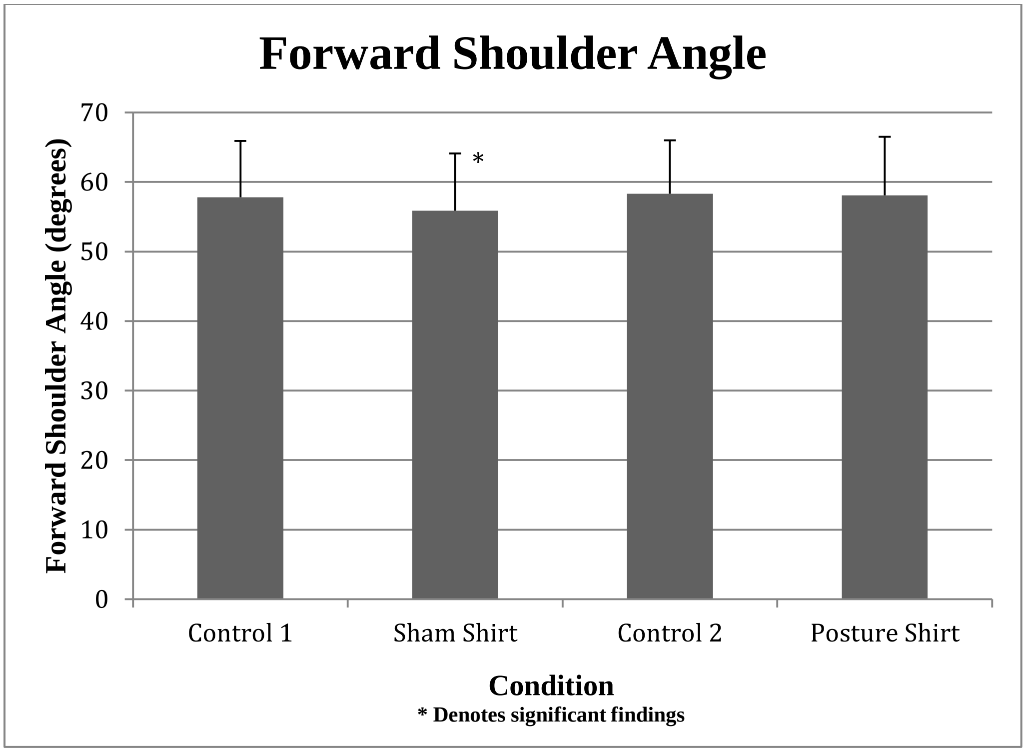

Figure 6 – Significant findings for forward shoulder angle

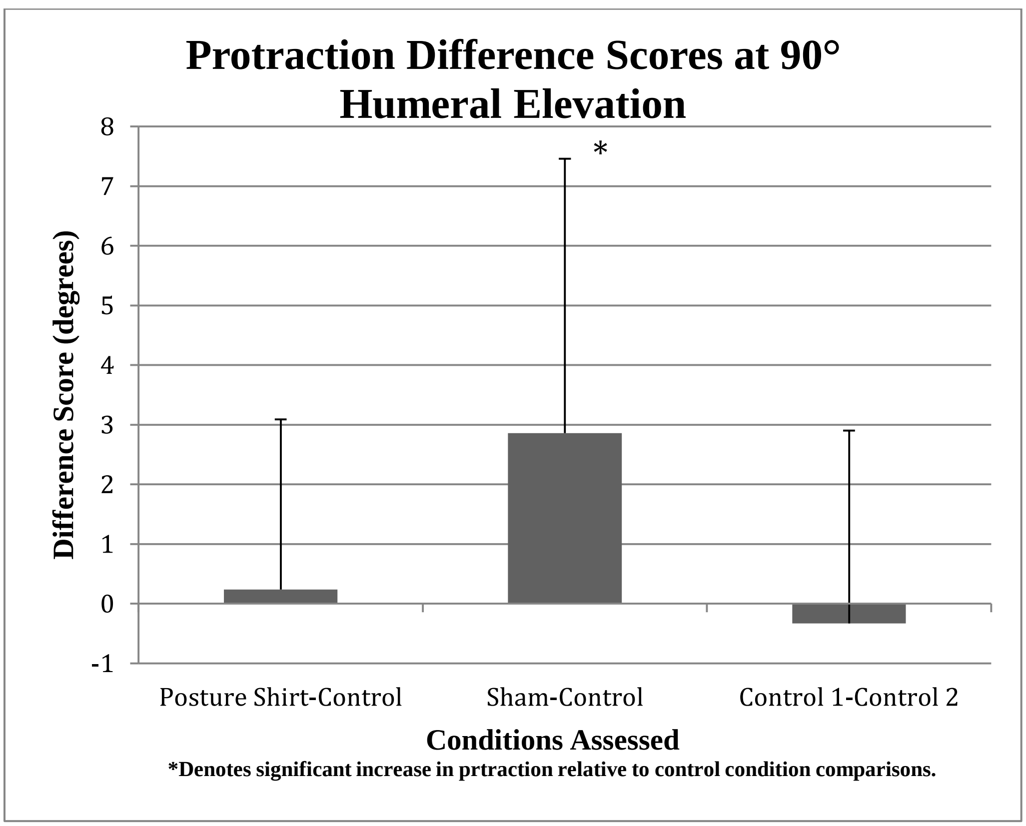

Figure 7 – Significant findings of scapular protraction at 90 degrees of elevation.

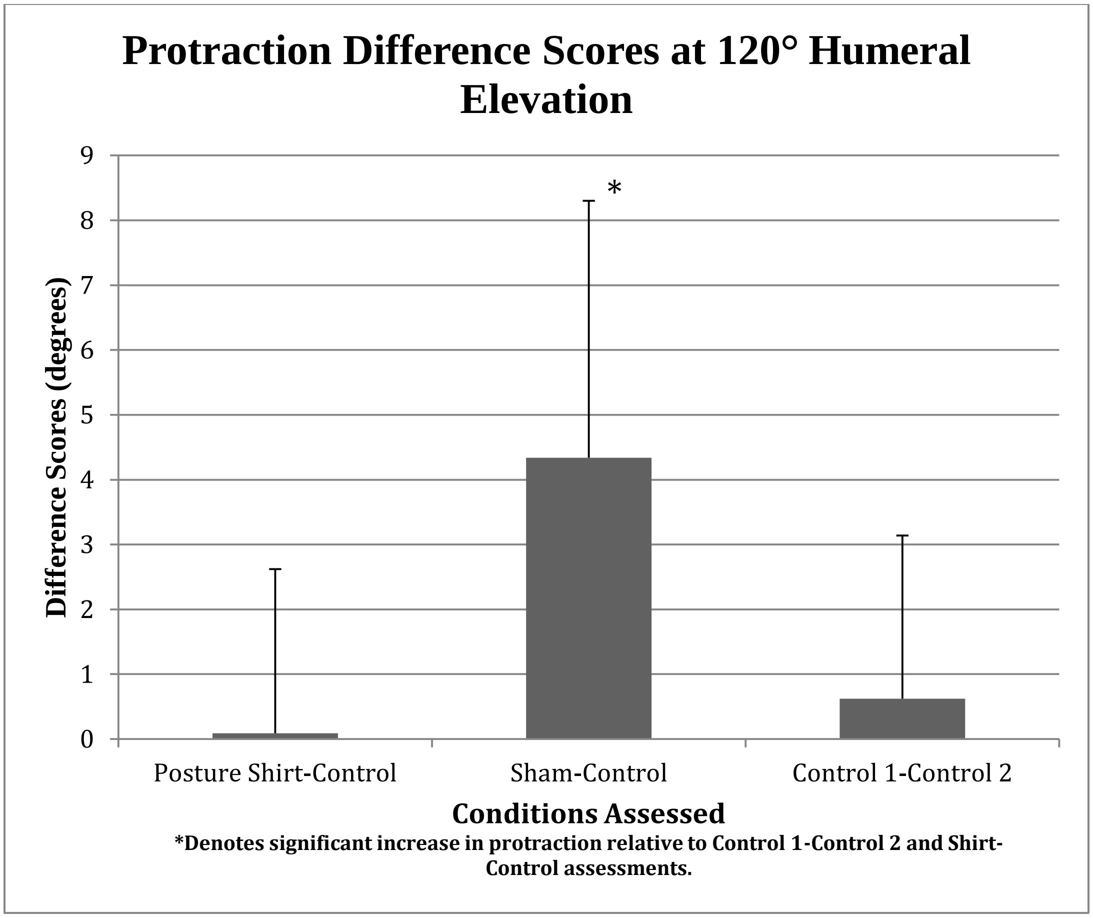

Figure 8 – Significant findings of scapular protraction at 120 degrees of elevation.

TABLES

Table 1: Posture Shirt Sizing Chart

Size	Chest (Men)	Blouse	Chest (Women)
X-Small	-	0-2	30-32”
Small	32-35”	4-6	32-34”
Medium	36-39”	8-10	34-36”
Large	40-43”	12-14	36-39”
X-Large	44-47”	14-18	39-42.5”
2X-Large	48-51”	18-20	42.5-46”
3X-Large	56-59”	-	-

Table 2: Digitized landmarks of the thorax, scapula, clavicle and humerus

Thorax	
C7	Spinous process of the 7^{th} cervical vertebra
T8	Spinous Process of the 8^{th} thoracic vertebra
IJ	Deepest point of Incisura Jugularis (suprasternal notch)
PX	Xiphoid process, most caudal point on the sternum
Scapula	
TS	Root of the spine of the scapula, the midpoint of the triangular surface on the medial border of the scapula in line with the scapular spine
AI	Inferior angle, most caudal point of the scapula
AA	Acromial angle, most laterodorsal point of the scapula
Clavicle	
SC	Most ventral point on the sternoclavicular joint
AC	Most dorsal point on the acromioclavicular joint
Humerus	
GH	Glenohumeral rotation center, estimated through motion recordings
EL	Most caudal point on the lateral epicondyle
EM	Most caudal point on the medial epicondyle

Table 3: Coordinate Systems of the Thorax $X_tY_tZ_t$	
O_t	The origin coincident with IJ.
Y_t	The line parallel to the line connecting the midpoint between PX and T8 and the midpoint between IJ and C7, pointing upward.
Z_t	The line perpendicular to the plane formed by IJ, C7, and the midpoint between PX and T8, pointing to the right.
X_t	The common line perpendicular to the Z_t- and Y_t-axis, pointing forwards.

Table 4: Coordinate System of the Scapula - $X_sY_sZ_s$	
O_s	The origin coincident with AA.
Z_s	The line connecting TS and AA, pointing to AA.
X_s	The line perpendicular to the plane formed by AI, AA, and TS, pointing forward. Note that because of the use of AA instead of AC, this plane is not the same as the visual plane of the scapula bone.
Y_s	The common line perpendicular to the X_s- and Z_s-axis, pointing upward.

Table 5: Coordinate System of the Clavicle – $X_cY_cZ_c$	
O_c	The origin coincident with SC.
Z_c	The line connecting SC and AC, pointing to AC.
X_c	The line perpendicular to Z_c and Y_t, pointing forward. Note that the X_c-axis is defined with respect to the vertical axis of the thorax because only two bony landmarks can be discerned at the clavicle.
Y_c	The common line perpendicular to the X_c- and Z_c-axis, pointing upward.

Table 6: Coordinate System of the Humerus - $X_hY_hZ_h$

O_h	The origin coincident with GH.
Y_h	The line connecting GH and the midpoint of EL and EM, pointing to GH.
X_h	The line perpendicular to the plane formed by EL, EM, and GH, pointing forward.
Z_h	The common line perpendicular to the Y_h- and Z_h-axis, pointing to the right.

Table 7: Intrasession and Intersession Reliability of Forward Shoulder Angle (FSA) Measurement (Myers and Jolly 2006)

Posture (°)	Intrasession ICC	Intrasession SEM	Intersession ICC	Intersession SEM
Forward Shoulder Angle	0.89	5°	0.72	7°

Table 8: Intrasession and Intertester Reliability and Precision of Electromagnetic Tracking of Scapular Kinematics (Myers and Jolly 2006)

Scapular Kinematics (°)	Intrasession ICC	Intrasession SEM	Intertester ICC	Intertester SEM
Internal/External Rotation	0.93-0.99	0.84-1.4°	0.75-0.97	2.1-4.5°
Anterior/Posterior Tipping	0.97-0.98	0.89-1.2°	0.83-0.91	2.3-3.4°
Upward/Downward Rotation	0.91-0.98	0.73-1.1°	0.62-0.83	1.9-4.3°
Protraction/Retraction	0.80-0.96	1.0-2.1°	0.71-0.92	1.4-2.3°
Elevation/Depression	0.85-0.98	0.71-1.6°	0.83-0.88	1.5-2.0°

Table 9: Participant demographic information

Number of Participants (Males/Females)	21(11/10)
Age (years)	20.8±1.7
Height (cm)	173.2±11.9
Mass (kg)	74.7±14.5

Table 10: Means and standard deviations (SD) of forward shoulder angle in degrees.

	Pre-Sham Control (1)	Sham	Pre-Shirt Control (2)	Posture Shirt
Forward Shoulder Angle (FSA)	57.8±8.1	55.8±8.2*	58.3±7.7	58.1±8.4

*Denotes significant decrease in FSA during sham condition relative to controls and posture shirt.

Table 11: Change score means and standard deviations (SD) for scapular kinematics at each level of humeral elevation in degrees.

	30° elevation	60° elevation	90° elevation	120° elevation
Internal Rotation				
Shirt minus Control	-1.11±3.65	0.24±3.43	1.93±3.89	2.67±4.94
Sham minus Control	-1.89±4.67	-0.74±4.78	0.33±4.92	1.33±6.76
Control 1 minus Control 2	0.95±3.81	1.29±3.94	1.57±3.89	1.33±4.92
Upward Rotation				
Shirt minus Control	-0.33±2.03	-0.22±1.91	-0.10±2.34	-1.08±3.64
Sham minus Control	-0.26±3.54	0.29±2.25	1.04±2.67	0.38±5.23
Control 1 minus Control 2	-0.19±2.52	0.14±2.08	0.33±1.98	0.81±2.25
Posterior Tipping				
Shirt minus Control	-2.00±2.70	-1.60±2.48	-0.20±2.65	1.81±5.14
Sham minus Control	-1.38±4.02	-0.93±4.53	-0.49±5.15	-0.68±6.68
Control 1 minus Control 2	-0.52±2.18	-0.10±2.43	0.62±3.43	0.19±3.74
Protraction				
Shirt minus Control	0.38±3.21	0.21±3.10	0.24±2.85	0.09±2.53
Sham minus Control	2.66±5.20	2.40±5.03	2.86±4.60*	4.34±3.96ǂ
Control 1 minus Control 2	-0.29±3.55	-0.43±3.66	-0.33±3.23	0.62±2.52
Elevation				
Shirt minus Control	-0.30±1.61	-0.55±1.41	-0.49±1.67	-1.18±1.91
Sham minus Control	-0.98±2.25	-1.05±2.14	-0.76±2.75	-1.39±3.74
Control 1 minus Control 2	-0.43±2.36	-0.57±1.91	-0.43±1.75	0.10±2.02

*denotes significant differences in change scores between the Sham minus Control and Control 1 minus Control 2 scores.

ǂdenotes significant differences in change scores between the Sham minus Control score and the Shirt minus Control and Control 1 minus Control 2 scores.

Table 12. Statistical analyses used for posture and kinematic assessments

Question	Description	Data Source	Comparison	Method
1	What is the acute effect of posture shirt use on forward shoulder angle (FSA) in college students with rounded shoulder posture.	Photographic posture measures taken under each condition.	Angular measurements of FSA under each condition.	One way ANOVA with one within factor (condition)
2	What is the effect of posture shirt use on scapular kinematics during an elevation task in the scapular plane?	Kinematic data taken from electromagnetic motion capture system.	Change scores of scapular kinematic variables between conditions.	Two way ANOVA with two within group factors (condition and angle)

REFERENCES

Agel, J., R. M. Palmieri-Smith, et al. (2007). "Descriptive epidemiology of collegiate women's volleyball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004." J Athl Train 42(2): 295-302.

Agel, J., J. Ransone, et al. (2007). "Descriptive epidemiology of collegiate men's wrestling injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004." J Athl Train 42(2): 303-310.

Allegrucci, M., S. L. Whitney, et al. (1994). "Clinical implications of secondary impingement of the shoulder in freestyle swimmers." J Orthop Sports Phys Ther 20(6): 307-318.

Apparel, E. (2012). "Gravity V-Neck Shirt - Neuro Bands." Retrieved 04/2012, 2012, from http://www.eblife.com/index.php.

Apparel, E. (2012). "S3 Spine and Scapula System." Retrieved 06/2012, 2012, from http://www.eblife.com/index.php.

Bak, K. and P. Fauno (1997). "Clinical findings in competitive swimmers with shoulder pain." Am J Sports Med 25(2): 254-260.

Beach, M. L., S. L. Whitney, et al. (1992). "Relationship of shoulder flexibility, strength, and endurance to shoulder pain in competitive swimmers." J Orthop Sports Phys Ther 16(6): 262-268.

Bigliani, L. U. and W. N. Levine (1997). "Subacromial impingement syndrome." J Bone Joint Surg Am 79(12): 1854-1868.

Boice, J. D., Jr. and J. H. Lubin (1997). "Occupational and environmental radiation and cancer." Cancer Causes Control 8(3): 309-322.

Borstad, J. D. (2006). "Resting position variables at the shoulder: evidence to support a posture-impairment association." Phys Ther 86(4): 549-557.

Bourne, D. A., A. M. Choo, et al. (2011). "The placement of skin surface markers for non-invasive measurement of scapular kinematics affects accuracy and reliability." Ann Biomed Eng 39(2): 777-785.

Brochard, S., M. Lempereur, et al. (2011). "Accuracy and reliability of three methods of recording scapular motion using reflective skin markers." Proc Inst Mech Eng H 225(1): 100-105.

Bron, C., J. Dommerholt, et al. (2011). "High prevalence of shoulder girdle muscles with myofascial trigger points in patients with shoulder pain." BMC Musculoskelet Disord 12: 139.

Brossmann, J., K. W. Preidler, et al. (1996). "Shoulder impingement syndrome: influence of shoulder position on rotator cuff impingement--an anatomic study." AJR Am J Roentgenol 167(6): 1511-1515.

Bruls, V. E., C. H. Bastiaenen, et al. (2013). "Non-traumatic arm, neck and shoulder complaints: prevalence, course and prognosis in a Dutch university population." BMC Musculoskelet Disord 14: 8.

Bullock, M. P., N. E. Foster, et al. (2005). "Shoulder impingement: the effect of sitting posture on shoulder pain and range of motion." Man Ther 10(1): 28-37.

Caldwell, C., S. Sahrmann, et al. (2007). "Use of a movement system impairment diagnosis for physical therapy in the management of a patient with shoulder pain." J Orthop Sports Phys Ther 37(9): 551-563.

Carman, D. L., R. H. Browne, et al. (1990). "Measurement of scoliosis and kyphosis radiographs. Intraobserver and interobserver variation." J Bone Joint Surg Am 72(3): 328-333.

Challis, R. E. and R. I. Kitney (1983). "The design of digital filters for biomedical signal processing. Part 3: The design of Butterworth and Chebychev filters." J Biomed Eng 5(2): 91-102.

Chen, Q., S. Bensamoun, et al. (2007). "Identification and quantification of myofascial taut bands with magnetic resonance elastography." Arch Phys Med Rehabil 88(12): 1658-1661.

Chu, Y., J. Akins, et al. (2012). "Validation of a video-based motion analysis technique in 3-D dynamic scapular kinematic measurements." J Biomech 45(14): 2462-2466.

Cole, A. K., W. E. Prentice, et al. (2008). The Spine and Scapula Stabilizing (S3) Brace Has an Effect on Posture and Muscle Activity in Overhead Athletes with Poor Posture. MA Master's Thesis, University of North Carolina at Chapel Hill.

Corso, G. (1995). "Impingement relief test: an adjunctive procedure to traditional assessment of shoulder impingement syndrome." J Orthop Sports Phys Ther 22(5): 183-192.

Dick, R., M. S. Ferrara, et al. (2007). "Descriptive epidemiology of collegiate men's football injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004." J Athl Train 42(2): 221-233.

Dick, R., W. A. Romani, et al. (2007). "Descriptive epidemiology of collegiate men's lacrosse injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004." J Athl Train 42(2): 255-261.

Dick, R., E. L. Sauers, et al. (2007). "Descriptive epidemiology of collegiate men's baseball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004." J Athl Train 42(2): 183-193.

Feleus, A., S. M. Bierma-Zeinstra, et al. (2008). "Management in non-traumatic arm, neck and shoulder complaints: differences between diagnostic groups." Eur Spine J 17(9): 1218-1229.

Ferrante, M. A. (2004). "Brachial plexopathies: classification, causes, and consequences." Muscle Nerve 30(5): 547-568.

Finley, M. A. and R. Y. Lee (2003). "Effect of sitting posture on 3-dimensional scapular kinematics measured by skin-mounted electromagnetic tracking sensors." Arch Phys Med Rehabil 84(4): 563-568.

Fleisig, G. S., S. W. Barrentine, et al. (1996). "Biomechanics of overhand throwing with implications for injuries." Sports Med 21(6): 421-437.

Ge, H. Y., C. Fernandez-de-las-Penas, et al. (2006). "Sympathetic facilitation of hyperalgesia evoked from myofascial tender and trigger points in patients with unilateral shoulder pain." Clin Neurophysiol 117(7): 1545-1550.

Gerwin, R. D., J. Dommerholt, et al. (2004). "An expansion of Simons' integrated hypothesis of trigger point formation." Curr Pain Headache Rep 8(6): 468-475.

Graichen, H., H. Bonel, et al. (1999). "Three-dimensional analysis of the width of the subacromial space in healthy subjects and patients with impingement syndrome." AJR Am J Roentgenol 172(4): 1081-1086.

Greenfield, B., P. A. Catlin, et al. (1995). "Posture in patients with shoulder overuse injuries and healthy individuals." J Orthop Sports Phys Ther 21(5): 287-295.

Griegel-Morris, P., K. Larson, et al. (1992). "Incidence of common postural abnormalities in the cervical, shoulder, and thoracic regions and their association with pain in two age groups of healthy subjects." Phys Ther 72(6): 425-431.

Hardy, D. C., J. B. Vogler, 3rd, et al. (1986). "The shoulder impingement syndrome: prevalence of radiographic findings and correlation with response to therapy." AJR Am J Roentgenol 147(3): 557-561.

Hawkins, R. J., G. W. Misamore, et al. (1985). "Surgery for full-thickness rotator-cuff tears." J Bone Joint Surg Am 67(9): 1349-1355.

**Hibberd, E., S. Oyama, et al. (2012) "Effect of a 6-Week Strengthening Program on Shoulder and Scapular Stabilizer Strength and Scapular Kinematics in Division I Collegiate Swimmers
" Journal of Sports Rehabilitation 21, 253-265.**

Huang, J. H. and E. L. Zager (2004). "Thoracic outlet syndrome." Neurosurgery 55(4): 897-902; discussion 902-893.

Inman, V. T., J. B. Saunders, et al. (1996). "Observations of the function of the shoulder joint. 1944." Clin Orthop Relat Res(330): 3-12.

Joshi, M., C. A. Thigpen, et al. (2011). "Shoulder external rotation fatigue and scapular muscle activation and kinematics in overhead athletes." J Athl Train 46(4): 349-357.

Kalra, N., A. L. Seitz, et al. (2010). "Effect of posture on acromiohumeral distance with arm elevation in subjects with and without rotator cuff disease using ultrasonography." J Orthop Sports Phys Ther 40(10): 633-640.

Karduna, A. R., P. W. McClure, et al. (2000). "Scapular kinematics: effects of altering the Euler angle sequence of rotations." J Biomech 33(9): 1063-1068.

Karduna, A. R., P. W. McClure, et al. (2001). "Dynamic measurements of three-dimensional scapular kinematics: a validation study." J Biomech Eng 123(2): 184-190.

Katz, J. N., B. C. Amick, et al. (2000). "Prevalence of upper extremity musculoskeletal disorders in college students." Am J Med 109(7): 586-588.

Kebaetse, M., P. McClure, et al. (1999). "Thoracic position effect on shoulder range of motion, strength, and three-dimensional scapular kinematics." Arch Phys Med Rehabil 80(8): 945-950.

Kibler, W. B., A. D. Sciascia, et al. (2008). "Electromyographic analysis of specific exercises for scapular control in early phases of shoulder rehabilitation." Am J Sports Med 36(9): 1789-1798.

Kluemper, M., T. Uhl, et al. (2006). "Effect of Stretching and Strengthening Shoulder Muscles on Forward Shoulder Posture in Competitive Swimmers." Journal of Sports Rehabilitation 15: 58-70.

Langford, M. L. (1994). "Poor posture subjects a worker's body to muscle imbalance, nerve compression." Occup Health Saf 63(9): 38-40, 42.

Laudner, K. G., M. T. Moline, et al. (2010). "The relationship between forward scapular posture and posterior shoulder tightness among baseball players." Am J Sports Med 38(10): 2106-2112.

Lewis, J. S., A. Green, et al. (2005). "Subacromial impingement syndrome: the role of posture and muscle imbalance." J Shoulder Elbow Surg 14(4): 385-392.

Lewis, J. S. and R. E. Valentine (2007). "The pectoralis minor length test: a study of the intra-rater reliability and diagnostic accuracy in subjects with and without shoulder symptoms." BMC Musculoskelet Disord 8: 64.

Lucas, K. R., P. A. Rich, et al. (2010). "Muscle activation patterns in the scapular positioning muscles during loaded scapular plane elevation: the effects of Latent Myofascial Trigger Points." Clin Biomech (Bristol, Avon) 25(8): 765-770.

Ludewig, P. M. and T. M. Cook (2000). "Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement." Phys Ther 80(3): 276-291.

Lukasiewicz, A. C., P. McClure, et al. (1999). "Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement." J Orthop Sports Phys Ther 29(10): 574-583; discussion 584-576.

Lynch, S. S., C. A. Thigpen, et al. (2010). "The effects of an exercise intervention on forward head and rounded shoulder postures in elite swimmers." Br J Sports Med 44(5): 376-381.

Marshall, S. W., K. L. Hamstra-Wright, et al. (2007). "Descriptive epidemiology of collegiate women's softball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004." J Athl Train 42(2): 286-294.

McClure, P., L. Michener, et al. (2006). "Shoulder Function and 3-Dimensional Scapular Kinematics in People With and Without Shoulder Impingement Syndrome." Phys Ther 86(8): 1075-1090.

McClure, P. W., L. A. Michener, et al. (2001). "Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo." J Shoulder Elbow Surg 10(3): 269-277.

McPartland, J. M. (2004). "Travell trigger points--molecular and osteopathic perspectives." J Am Osteopath Assoc 104(6): 244-249.

McQuade, K. J., J. Dawson, et al. (1998). "Scapulothoracic muscle fatigue associated with alterations in scapulohumeral rhythm kinematics during maximum resistive shoulder elevation." J Orthop Sports Phys Ther 28(2): 74-80.

Meskers, C. G., H. Fraterman, et al. (1999). "Calibration of the "Flock of Birds" electromagnetic tracking device and its application in shoulder motion studies." J Biomech 32(6): 629-633.

Myers, J., J. Jolly, et al. (2006). "Reliability and Precision of in Vivo Scapular Kinematic Measurements Using an Electromagnetic Tracking Device." J Sport Rehabil(15): 125-143.

Myers, J. B. and J. Jolly (2006). "Reliability and Precision of in Vivo Scapular Kinematic Measurements Using an Electromagnetic Tracking Device " Journal of Sports Rehabilitation 15(2).

Myers, J. B., K. G. Laudner, et al. (2005). "Scapular position and orientation in throwing athletes." Am J Sports Med 33(2): 263-271.

Neer, C. S., 2nd (1972). "Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report." J Bone Joint Surg Am 54(1): 41-50.

Neer, C. S., 2nd (1983). "Impingement lesions." Clin Orthop Relat Res(173): 70-77.

Neer, C. S., 2nd (2005). "Anterior acromioplasty for the chronic impingement syndrome in the shoulder. 1972." J Bone Joint Surg Am 87(6): 1399.

Ono, T., T. P. Bastrom, et al. (2012). "Defining 2 components of shoulder imbalance: clavicle tilt and trapezial prominence." Spine (Phila Pa 1976) 37(24): E1511-1516.

Oyama, S., J. B. Myers, et al. (2008). "Asymmetric resting scapular posture in healthy overhead athletes." J Athl Train 43(6): 565-570.

Paine, R. M. and M. Voight (1993). "The role of the scapula." J Orthop Sports Phys Ther 18(1): 386-391.

Peterson, D. E., K. R. Blankenship, et al. (1997). "Investigation of the validity and reliability of four objective techniques for measuring forward shoulder posture." J Orthop Sports Phys Ther 25(1): 34-42.

Powell, J. W. and K. D. Barber-Foss (1999). "Injury patterns in selected high school sports: a review of the 1995-1997 seasons." J Athl Train 34(3): 277-284.

Reddy, A. S., K. J. Mohr, et al. (2000). "Electromyographic analysis of the deltoid and rotator cuff muscles in persons with subacromial impingement." J Shoulder Elbow Surg 9(6): 519-523.

Roddey, T. S., S. L. Olson, et al. (2001). "The effect of pectoralis muscle stretching on the resting position of the scapula in persons with varying degrees of forward head/rounded shoulder posture." Journal of Manipulative Therapy 10: 124-128.

Sahrman, S. (2002). Diagnosiss and Treatment of Movement Impairment Syndromes. St. Louis, Mosby.

Schlossberg, E. B., S. Morrow, et al. (2004). "Upper extremity pain and computer use among engineering graduate students." Am J Ind Med 46(3): 297-303.

Simons, D. G. and J. Travell (1981). "Myofascial trigger points, a possible explanation." Pain 10(1): 106-109.

Tate, A. R., P. W. McClure, et al. (2008). "Effect of the Scapula Reposition Test on shoulder impingement symptoms and elevation strength in overhead athletes." J Orthop Sports Phys Ther 38(1): 4-11.

Thigpen, C. A., D. A. Padua, et al. (2010). "Head and shoulder posture affect scapular mechanics and muscle activity in overhead tasks." J Electromyogr Kinesiol 20(4): 701-709.

Tovin, B. J. (2006). "Prevention and Treatment of Swimmer's Shoulder." N Am J Sports Phys Ther 1(4): 166-175.

Urschel, H. C., Jr. (1972). "Management of the thoracic-outlet syndrome." N Engl J Med 286(21): 1140-1143.

van der Windt, D. A., B. W. Koes, et al. (1995). "Shoulder disorders in general practice: incidence, patient characteristics, and management." Ann Rheum Dis 54(12): 959-964.

Veeger, H. E. (2000). "The position of the rotation center of the glenohumeral joint." J Biomech 33(12): 1711-1715.

Wang, C. H., P. McClure, et al. (1999). "Stretching and strengthening exercises: their effect on three-dimensional scapular kinematics." Arch Phys Med Rehabil 80(8): 923-929.

Wilbourn, A. J. (1990). "The thoracic outlet syndrome is overdiagnosed." Arch Neurol 47(3): 328-330.

Wong, C. K., D. Coleman, et al. (2010). "The effects of manual treatment on rounded-shoulder posture, and associated muscle strength." J Body Mov Ther 14(4): 326-333.

Worland, R. L., D. Lee, et al. (2003). "Correlation of age, acromial morphology, and rotator cuff tear pathology diagnosed by ultrasound in asymptomatic patients." J South Orthop Assoc 12(1): 23-26.

Wu, G., F. C. van der Helm, et al. (2005). "ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand." J Biomech 38(5): 981-992.