THE INFLUENCE OF SUBACROMIAL PAIN ON SCAPULAR KINEMATICS, MUSCLE RECRUITMENT AND JOINT PROPRIOCEPTION

by

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DISSERTATION ABSTRACT

Lucas R. Ettinger

Doctor of Philosophy

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Title: The Influence of Subacromial Pain on Scapular Kinematics, Muscle Recruitment and Joint Proprioception

Subacromial impingement accounts for significant burdens on the economy and individual quality of life. The development and progression of this disorder is thought to be related to overuse; however, little is known regarding biomechanical factors such as scapular kinematics, shoulder muscle recruitment and joint proprioception with respect to this disorder. The high degree of variability between individuals on these biomechanical measures limits our ability to make inferences behind the development of shoulder impingement. Here, biomechanical factors associated with impingement are investigated using within-subjects designs in order to reduce this inherent variability. Using modern clinical techniques, this dissertation is applicable towards treatment of shoulder impingement as well as scientific understanding of motor control and function in the presence of pain.

This dissertation includes un-published co-authored material.

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CHAPTER I

INTRODUCTION

Subacromial impingement syndrome describes the mechanical entrapment of the rotator cuff, specifically the supraspinatus tendon, within the subacromial space [Neer, C. S., 1983]. The subacromial space is defined as the region between the superior aspect of the humerus and the inferior acromion process. The development of subacromial impingement syndrome may be related to repetitive and elevated motion of the arm [Soslowsky et al., 2002; Svendsen, S. et al., 2004]. For example, dental hygienists suffer a high incidence of shoulder disorders, including impingement syndrome [Akesson et al., 1999; Liss et al., 1995; Oberg T, 1993]. The high incidence of injury in this population may be due to repetitive job exposure [Marklin et al., 2005]. Previous work in our laboratory demonstrates that a single day of exposure to dental work results in significant changes in scapular mechanics in dental hygienists, which could potentially increase the risk for shoulder injury [Ettinger et al., 2011]. However, the mechanisms associated with these changes remain unknown. One of the most common differences between patients with impingement syndrome and healthy individuals is subacromial pain [Ben-Yishay et al., 1994; Blaine et al., 2005; Voloshin et al., 2005]. It is possible that pain influences scapular mechanics and could be related to the development of this disorder. Therefore, the goal of this dissertation is to examine the relationship between pain and shoulder biomechanics in various populations with and without shoulder pain.

Pain adaptation models

In patients with impingement syndrome, neuromotor and biomechanical adaptations are thought to be related to bursal pain [Hebert et al., 2002; Kendall et al., 1993]. Understanding the relationship between pain and neuromuscular control is vital to the treatment and rehabilitation of patients with painful shoulder disorders. However, mechanisms for adaptations to pain are not well understood for the shoulder. Currently, the two dominant mechanisms for pain adaptation stem from similar biological models of neurophysiologic adaptation [Kofler, 2003; Lund et al., 1991]. The first model describes neuromotor adaptations to pain that protect muscle when painful stimuli occur [Lund et al., 1991]. These protective mechanisms appear to decrease the activity of the painful muscle while simultaneously increasing antagonistic muscle activity, thus reducing range of motion and/or velocity of movement in the painful muscle [Lund et al., 1991]. The implications of this model suggest that peripheral pain is an evolutionary mechanism that overrides motor movements, thus protecting injured muscle. In the case of impingement, this model would suggest that rotator cuff muscle activity would be reduced in the presence of pain. A decrease in rotator cuff activity may initially protect the muscle from injury; however, several studies suggest that rotator cuff activity is essential for maintaining overall shoulder health [Alpert et al., 2000; Myers, J. et al., 2009; Oh et al., 2011]. An alternative mechanism for shoulder function in the presence of pain may be related to neuromotor adaptations, where muscle recruitment is based on the biological importance of the muscle relative to the task [Kofler, 2003; Kofler et al., 2001]. These competing mechanisms differ in that the biological importance of the motor movement may outweigh the individual importance of specific muscle's wellbeing. The

implications of the second model suggest that maintaining mobility may be more important than the individual health of an injured muscle. This behavior can be thought of as a form of altruism, where the needs of the many outweigh the needs of one individual muscle. If the second model were true for the shoulder, rotator cuff activity would not be reduced in order to preserve scapular and humeral mechanics. However, over time the rotator cuff tendon may degenerate due to chronic usage coupled with mechanical compression within the subacromial space. In rats, mechanical compression coupled with repetitive usage results in severe supraspinatus tendon breakdown [Soslowsky et al., 2002]. At present, it is unknown which mechanism is responsible for the neuromotor behavior of shoulder muscle control in patients with subacromial pain.

Several studies support the notion that during acute joint and muscle pain, muscle activity in the agonist group is attenuated and muscle activity in the antagonist muscle group is augmented during voluntary movement [Graven-Nielsen et al., 1997; Lund et al., 1991]. The muscular adaptations to pain observed in these studies may serve to reduce movement velocity, range of motion and muscle forces. In a study conducted by Kofler et al., [2003] Electromyography (EMG) from muscles of the hand, all under the same myotome, were measured during painful stimulation of the fingertips. Results from their study indicate that the muscles respond synergistically, where muscles that are more involved in grip were found to be more affected than non-synergist muscles as measured by the timing and magnitude of their EMG silent periods. The fact that the muscles shared the same myotome yet responded differently suggests that pain inhibition may be under selective control, where inhibition depends on biological importance of the muscle to the task.

Muscular adaptations to pain

In a study conducted by Diederichsen et al., [2009] hypertonic saline was injected subacromially into the bursa in healthy individuals. The injections resulted in diffuse anterior shoulder pain, which is similar to symptoms of impingement. The injection resulted in increased activation of the antagonist (latissamus dorsi) muscle during arm elevation. However, agonist muscle activation had a more complex change where some agonists increased and others decreased in activity. Of particular importance, the serratus anterior and the lower trapezius increased in activity following experimental bursal pain, but agonists such as the deltoid decreased in activity. Interestingly, the overall range of motion of the joint was preserved; however, the individual muscle contributions were altered by the presence of pain. From this particular study, it is unclear which model of pain adaptation best fits for the shoulder. In addition, this study represents the immediate changes in motor mechanics in response to experimental painful stimuli [Diederichsen, L. et al., 2009]. It is possible that chronic pain may result in different neuromotor adaptations than experimental muscle and/or joint pain.

There is much debate in the literature pertaining to the consequences of subacromial pain on rotator cuff muscle activity. In a study conducted by Ben-Yishay et al., [1994] improvements were found to external rotator muscle activation as a result of a local anesthetic injection to the subacromial bursa in patients with Stage 2 and 3 shoulder impingement. This finding provides evidence that the rotator cuff may experience neurologic inhibition as a result of pain, which is dis-inhibited by a local anesthetic.

However, that study included patients with partial and full thickness rotator cuff tears, which could have biased the results. In a study conducted by Park et al., [2008] a local anesthetic injection to the subacromial bursa resulted in no significant changes in strength of the shoulder for patients with Stage 2 impingement; however, patients with Stage 3, full thickness cuff tears, did have significant improvements in external rotator strength after injection. It should be noted that this study only measured strength, but did not measure muscle activity (EMG) or kinematics [Park et al., 2008]. Without studying the individual contributions of muscle activity to strength during a given task, it is impossible to rule out synergistic muscle activity or compensatory neuromotor adaptations. One other study has demonstrated that subacromial injections improved deltoid firing recorded using EMG in patients with subacromial impingement [Scibek et al., 2008]. However, this study was inconsistent in the criteria of patient inclusion, where patients with full thickness rotator cuff tears and partial tears were all included. Additionally, this study failed to incorporate a three dimensional kinematic analysis of scapular mechanics in concert with muscle activation (EMG).

Several studies have compared the muscle activation of patients with impingement versus healthy controls [Bandholm et al., 2006; Clisby et al., 2008; Cools et al., 2003; Diederichsen, L. P. et al., 2009; Ludewig P, 2000; Michaud et al., 1987; Myers, J. et al., 2009; Reddy et al., 2000; Scovazzo et al., 1991]. In each of these studies, electromyographic muscle activity was normalized by a Maximal Voluntary Isometric Contraction (MVIC). However, there is concern that the patient population may have difficulty performing or are unwilling to perform MVIC tests due to increased pain and symptoms during MVIC testing [Marras et al., 2001]. Therefore, as part of this proposed

dissertation study, the influence of pain on EMG normalization techniques will be investigated.

Measuring deltoid muscle activity may serve as a proxy for rotator cuff muscle activity in patients with subacromial impingement. In a study conducted by McCully et al., [2007] a suprascapular nerve block resulted in compensatory increase in deltoid activity once rotator cuff function was compromised. Similarly, cadaveric studies have demonstrated that removal of the rotator cuff places a greater reliance on the deltoid [Oh et al., 2011]. Patients with impingement may similarly experience increased deltoid muscle activity in compensation of a painful rotator cuff. However, changing the balance between rotator cuff and deltoid activity may have implications on shoulder health. A recent study conducted in our laboratory found that in the absence of a functional rotator cuff (suprascapular nerve block), the humeral head superiorly translates with respect to the glenoid cavity as measured by fluoroscopy [San Juan J, 2012]. Similar measurements have been made by Deutsch et al., [1996] who described patients with Stage 2 and 3 impingement syndrome as having increased superior humeral center of rotation translation. Superior humeral head migration has been implicated as decreasing the acromiohumeral distance and increasing the compressive forces under the acromion and may be related to rotator cuff degeneration [Neer, 1972; Soslowsky et al., 2002].

Kinematic adaptations to pain

Ultimately, the goal of muscle activation in the agonist group is to produce movement, therefore studies examining the influence of pain on muscle activity are incomplete without an analysis of resultant movement. Additionally, studies examining

motor movement without an analysis of muscle activity cannot explain the cause of the kinematic findings. To date, many studies have measured scapular kinematics between patients with impingement and healthy controls, but the results are quite variable [Endo et al., 2001; Hebert et al., 2002; Ludewig, P. M. et al., 2000; Lukasiewicz et al., 1999; McClure et al., 2006; Poppen NK, 1976; Su et al., 2004]. Several studies have identified that patients with shoulder impingement syndrome have more anterior tilting of the scapula than healthy controls during arm abduction and flexion [Endo et al., 2001; Ludewig, P. M. et al., 2000; Lukasiewicz et al., 1999]. These results indicate that impingement syndrome may be the result of negative scapular mechanics where tilting of the scapula would increase subacromial compression, thus resulting in increased symptoms [Ludewig, P. M. et al., 2000]. In a radiographic study conducted by Endo et al., [Endo et al., 2001] scapular upward rotation was found to increase the subacromial outlet, thus potentially creating more space for the rotator cuff tendon to glide un-impinged. McClure et al., [2006] found that patients with shoulder impingement had more scapular upward rotation and clavicular elevation during arm elevation than healthy controls. This finding suggests that kinematics of the scapula are compensating positively and are utilizing movement strategies to reduce the symptoms of subacromial impingement. The literature regarding kinematic differences between the patient population and healthy controls is therefore somewhat conflicting. In sum, kinematic studies examining the differences between the patient population and healthy controls are limited because they compare different individuals. The high level of variability between individuals could explain the corresponding variability in results between studies. To

reduce this kinematic variability between subjects, a repeated measures design is proposed for this dissertation.

Proprioceptive adaptations to pain

Proprioception is a known sensory mechanism that provides information about extremity position and movement direction. Proprioceptive stimulation has been shown to elicit changes in the primary motor cortex [Weiller et al., 1996]. Therefore, deficits in proprioception may influence muscle behavior and kinematic movement patterns [Schouten et al., 2008; Weiller et al., 1996]. It is possible that pain associated with impingement influences shoulder proprioception. Previous studies have shown that healthy individuals have increased joint proprioceptive acuity at arm elevations closer to 90 degrees [Suprak et al., 2006a]. However, in patients with subacromial impingement syndrome, joint proprioceptive acuity has been found to decrease at higher shoulder joint angles closer to 100 degrees [Anderson et al., 2011]. This finding may be related to pain, which is often experienced at greater arm angles [Neer, C. S., 1983].

Despite the numerous studies pertaining to impingement syndrome, few studies have investigated the influence of pain on shoulder biomechanics. The relationship between pain and scapular kinematics, shoulder muscle activation and proprioception remains unclear. Accordingly, the focus of this dissertation is to investigate the influence of pain on shoulder biomechanics and neurophysiologic control of the shoulder.

This dissertation includes previously published and un-published co-authored material. Co-authors and corresponding chapters of involvement are listed below. Laurel Kincl Ph.D., Chapter II. Matthew Shapiro M.D., Chapters III-VI. Jason Weiss, Chapter III. Andrew Karduna Ph.D., Chapters II-VI.

CHAPTER II

PROPRIOCEPTION IN DENTAL HYGIENISTS WITH AND WITHOUT PAIN

Co-authors include Dr. Laurel Kincl and Dr. Andrew Karduna for project conception.

INTRODUCTION

Joint proprioception is a specialized sensory modality encompassing both joint position sense (the ability to identify and reproduce the position of a limb in space) and kinesthesia (the ability to detect limb movement) [Lephart et al., 1997; Proske et al., 2009; Riemann et al., 2002a]. Deficits in proprioception may influence muscle behavior and kinematic movement patterns; however the contribution of proprioception to motor behavior is unknown and is likely joint specific [Lephart et al., 1997; Schouten et al., 2008]. In patients with shoulder instability, proprioceptive deficits are reported when compared to healthy controls [Lephart et al., 1994; Zuckerman et al., 2003] and have been found in patients with shoulder injuries [Machner et al., 2003; Zuckerman et al., 2003]. Proprioceptive training as a preventative treatment has been found to be effective at reducing the likelihood of ACL tears in some soccer players [Caraffa et al., 1996] and is often used in rehabilitation from injury [Lephart et al., 1997]. However, to date no study has identified if proprioceptive deficits are the cause or the result of injuries.

In a study conducted by Bjorkland et al., [2000] simulated repetitive work resulted in decreased shoulder proprioceptive acuity in male and female workers. Interestingly, female workers had greater proprioceptive deficits compared to their male counterparts [Bjorklund et al., 2000]. The authors attributed the reduction in

proprioceptive acuity as being related to occupational fatigue. Muscle fatigue, which is common for many manual laborers, [Christensen, 1986; Oberg et al., 1995; Westgaard et al., 2001] has consistently been shown to result in a degradation in proprioception for human joints, including the ankle, [Forestier et al., 2002] elbow, [Sharpe et al., 1993] knee, [Hiemstra et al., 2001] lumbar spine, [Taimela et al., 1999] and most importantly for this study, the shoulder. [Bjorklund et al., 2000; Carpenter et al., 1998; Lee et al., 2003; Myers et al., 1999; Pedersen et al., 1999; Voight et al., 1996] These fatigue-induced proprioceptive deficits of the shoulder may result in altered muscle coordination [Carpenter et al., 1998] with subsequent alterations in joint performance, such as changes in scapular kinematics, [Ettinger et al., 2012; McQuade et al., 1998; Tsai et al., 2003] glenohumeral translations, [Chen et al., 1999; Royer et al., 2004] as well as the coordinated movement of the entire upper extremity [Cote et al., 2005; Murray et al., 2001; Rodgers et al., 2003]. Although there is no direct evidence for a link between proprioceptive deficits and injuries, alterations in shoulder proprioception have been measured during simulated work, where the authors claim *"in real work environments, proprioceptive deficits brought on by fatigue may be an important initiating factor associated with the occurrence of work-related musculoskeletal disorders"* [Bjorklund et al., 2000]. Others concur, where a relationship between proprioceptive deficits and shoulder injuries are likely [Carpenter et al., 1998; Lephart et al., 1996; Pedersen et al., 1999; Tripp et al., 2004]. The current gap in our knowledge is that there are no reports of treatments that can be used to mitigate these deficits, although many authors have suggested that increasing resistance to fatigue would be a sound approach [Carpenter et al., 1998; Lee et al., 2003; Miura et al., 2004].

In jobs such as dental hygiene, dental hygienists have high exposure to elevated and repetitive arm positions during work [Ettinger et al., 2013]. In addition, dental hygienists with greater duration of work exposure have been reported to have changes associated with their scapular kinematics following a single workday, which may be associated with workday muscle fatigue [Ettinger et al., 2012]. Work with large exposures to elevated humeral positions have a strong association with shoulder pain and rotator cuff pathology [Svendsen, S. et al., 2004; Svendsen, S. W. et al., 2004]. In the profession of dental hygiene, workers have a high estimated prevalence (64%-85% of active hygienists) of work related shoulder pain [Akesson et al., 1999; Ylipaa et al., 2002]. It is unknown if dental hygienists have changes in their proprioceptive acuity during the workday. Furthermore, it is unknown if dental hygienists with shoulder pain have greater deficits in shoulder proprioceptive acuity than hygienists without shoulder pain.

It is the goal of this study to measure shoulder joint proprioception in dental hygienists before and after work, additionally both dental hygienists with and without shoulder pain were recruited for this study. It is hypothesized that shoulder joint proprioceptive errors will be greater in dental hygienists following the workday and deficits will be greater in dental hygienists with work related pain than in dental hygienists without work related pain.

METHODS

Forty-three female dental hygienists with a mean age of 43.5 ± 10.2 years participated in this study. Prior to testing, all dental hygienists signed an informed

consent form approved by the Institutional Review board. All data were collected within the place of employment of the dental hygienist before and after the workday. The average number of work hours was 9.25 (±2.2) hours.

Instrumentation

A UPenn pain score was assessed on the day of data collection. The UPenn pain scale consists of three question each on a ten point Likert scale with 0 being no pain and 10 being worst pain possible [Leggin BG, 1993]. The first question assesses pain at rest with the arm at by the side. The second question assesses pain during normal activities such as eating, dressing and bathing. The final question assesses pain during strenuous activities such as reaching, lifting, pushing, pulling and throwing. For the UPenn pain scale, 22 out of 43 dental hygienists reported some pain on the day of data collection. Of the dental hygienists with pain, the average UPenn pain score was 7.8 out of 30 (± 5.2). Groups based on pain were determined when a UPenn pain score equal to, or greater than one was reported (n=22).

On the day before the proprioceptive evaluation, the time to fatigue during an external rotator fatiguing protocol was performed. The dental hygienist sat in a side laying position on a treatment table with their dominant arm supported at the elbow on their hip, and with their elbow flexed to 90 degrees. From this position, the dental hygienist held a 2.3kg weight for as long as they could. The dental hygienist was instructed to hold this position as steady as possible; and when the arm deviated by more than a couple of degrees the task was terminated. The average elapsed endurance test

was 78 seconds (± 24 seconds) until fatigue. No hygienists complained of pain during the endurance test.

Kinematic data were collected with the Polhemus Fastrak magnetic tracking system (Colchester, VT). The unit consists of a transmitter, two receivers and a digitizer. The first receiver was placed on the sternum at the level of the manubrium, using double sided tape. The second sensor was placed on the humerus with an orthoplast device and elastic straps. A third sensor was placed on the scapula and was used for estimating the center of the humeral head. This sensor was removed prior to proprioceptive testing. Bony landmarks were digitized in order to establish anatomical coordinate systems for the thorax and humerus. Each coordinate system and rotational matrix corresponded to the standards proposed by the International Society of Biomechanics Committee [Wu et al., 2005]. The thoracic anatomical coordinate system was established from C7, T8, the sternal notch and the xiphoid process. The center of the humeral head and the medial and lateral humeral epicondyles were used to establish the humeral coordinate system. The center of the humeral head was determined within 5mm of the true center and was defined as the position that moves the least with respect using a least squares algorithm.

Subjects were fitted with a head mounted display (Z800, eMagine, Bellevue, WA) which allowed for presentation of target angles and kinematic output from the subject on a two-dimensional display during testing. The head mounted display inhibited extraneous visual cues (Figure 2.1).

Protocol

All testing was performed during two session (before and after work). Participants completed a standardized warm-up on the limb of interest prior to testing. The warm-up consisted of Codman's pendulum exercises (rotations and sagittal plane motion) using a 2.7 kg weight.

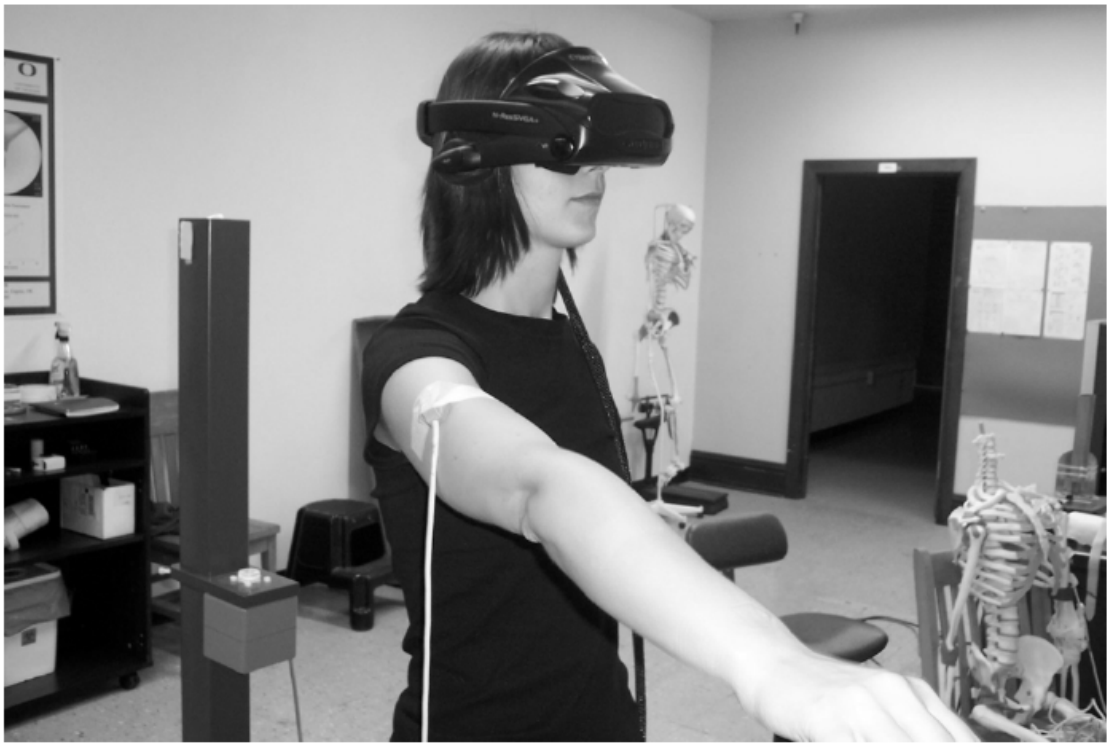

Figure 2.1. Active arm positioning-active repositioning paradigm where subjects are visually guided (2D goggle apparatus) to target locations for both plane and elevation.

Testing involved a five target testing paradigm, where each target was tested one time and the target order was randomized. The target positions were 70° of humeral elevation , and 40° of scapular plane, 75° of humeral elevation and 45° of scapular plane, 70° of humeral elevation and 35° of scapular plane, 75° of humeral elevation and 40° of

scapular plane, 65° of humeral elevation and 45° of scapular plane. Targets were chosen to represent the middle range of motion, where slight differences (± 5º) between targets were chosen to reduce learning effects. Additionally, based on previous work, we chose targets with no greater than (± 5º) in order to prevent the effects of angle on proprioceptive acuity [Suprak et al., 2006a]. To reduce fatigue due to testing, a five second rest interval occurred between each trial. The subject was presented with a countdown timer notifying them when the next trial would begin.

Subjects were directed to the target angles via custom made Labview software (National Instruments, Austin, TX). A grey screen contained black square box representing an area of ± 2° from the predetermined target position for scapular plane and humeral elevation and a single dynamic red ball provided feedback about the subject's arm position in real-time (Figure 2.2). At the beginning of each trial the subject's arm was relaxed at their side in neutral position. The subject was instructed to elevate their arm with an extended elbow with the thumb pointing upwards until the red ball fell inside the box. After the target position had been attained for one second, the display turned completely black and remained so for the rest of the trial. This removed any feedback about the subjects arm position. Subjects held the target position for three seconds and were instructed to use this time to memorize the location of their hand in space. A verbal cue prompted subjects to relax and return to the rest position. After another period of three seconds, subjects were prompted to return to the target position. The subject indicated when they had perceived to reach the target by pushing a wireless presenter remote (Libra P5, Ione, Fremont, CA) with their contralateral hand.

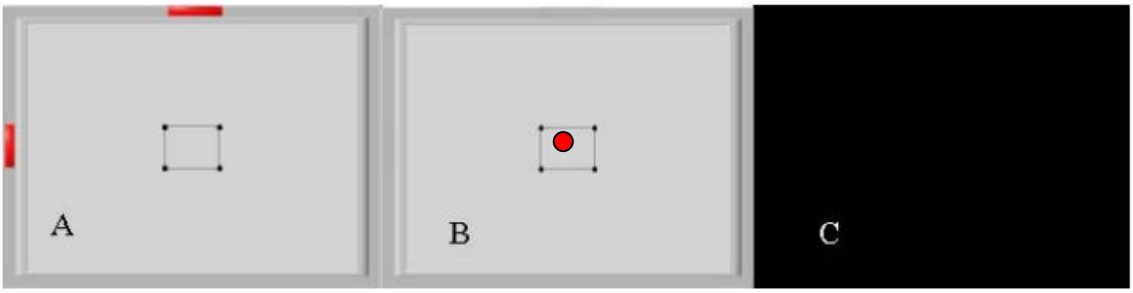

Figure 2.2. Visual guidance during joint position sense task. A) Directing subject's arm to target field. B) Subject has acquired target. C) Visual feedback when repositioning arm.

Data Analysis

Three-dimensional vectors were calculated for the positioned and repositioned arm positions using lines from the center of the humeral head through the midpoint of the elbow (midpoint between medial and lateral epicondyles) using techniques prevoiusly validated [Suprak et al., 2006a]. The magnitude of the angle between the positioned and repositioned arm vectors represents the joint position sense error (absolute vector error) and has been used in similar experiements [Suprak et al., 2006a, 2007]. Repositioning vector errors from the five trials were averaged and the mean repositioning error was used for subsequent analysis for pre and post-workday.

Statistical Analysis

Significance testing for repositioning error was performed using a two-way mixed effects ANOVA where workday condition (pre and post-workday) was the within-subject factor. Group based on pain was the between-subject factor and time to fatigue was run as a covariate. To determine differences in proprioceptive acuity between dental hygienists with and without shoulder disability, the mean repositioning errors pre and

post-workday were averaged. Repositioning errors for dental hygienists with reported pain from the UPenn pain scale (n = 22) with an average age of 42.3 ± 10 years and dental hygienists without pain (n = 21) with an average age of 46.2 ± 10 years were separated for group difference testing. For all statistical analysis, our significance level was set to $\alpha = 0.05$.

RESULTS

Pre workday proprioceptive errors (absolute errors) were 3.8º ± 3.0º and post workday errors were 3.7º ± 2.6º. Results of our ANOVA test indicate no significant interactions between time to fatigue (endurance) and group (pain) or proprioceptive errors by workday ($p = 0.73$, $p = 0.053$ respectively). There were no significant main effects of workday on proprioceptive acuity ($p=0.06$) (Figure 2.3); however, there was a significant between-subjects effect of pain on proprioceptive acuity ($p = 0.023$), where dental hygienists who reported pain had on average 1.3º more error than hygienists without pain (Figure 2.4).

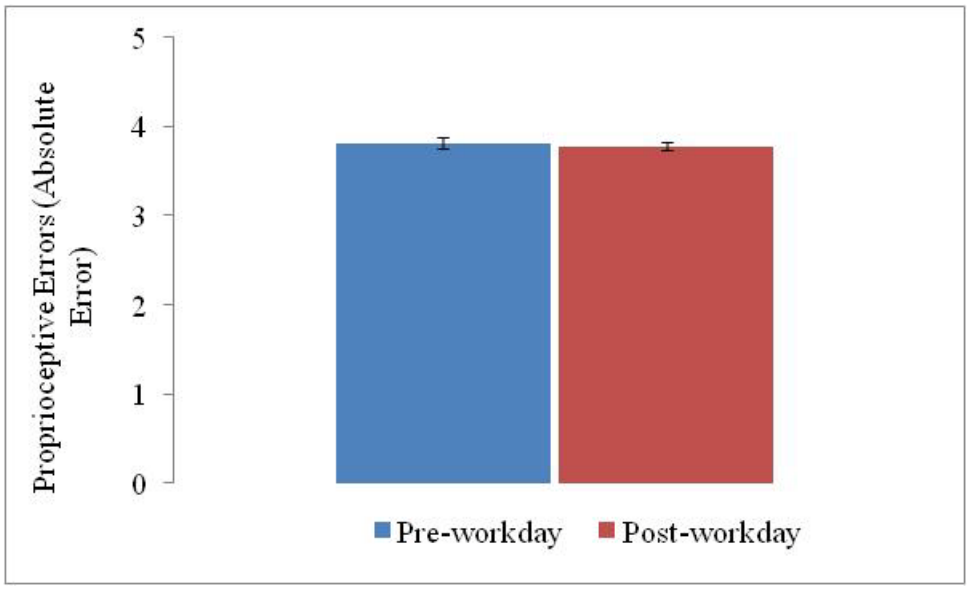

Figure 2.3. Absolue vector errors pre (blue) and post (red)-workday. Error bars represent standard errors.

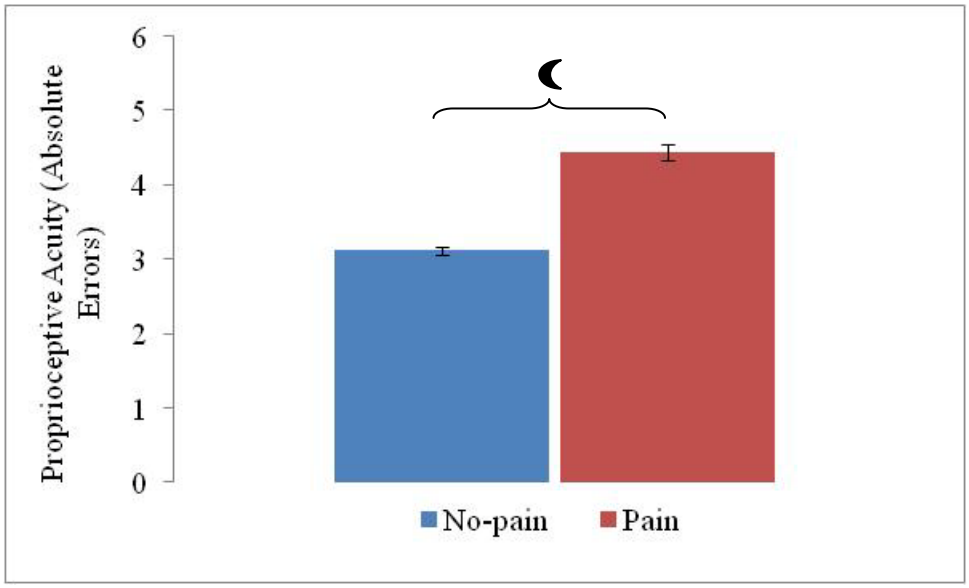

Figure 2.4. Absolute vector errors between dental hygienists with (red) and without (blue) shoulder pain. Proprioceptive errors were averaged by workday. Error bars represent standard errors. Significance where $p < 0.05$ is represented by ☾.

DISCUSSION

Previous studies indicate that exposure to repetitive work may lead to decreased proprioceptive acuity, especially in female workers [Bjorklund et al., 2000]. We have previously shown that dental hygienists are exposed to a high degree of repetitive motion during various work related tasks [Ettinger et al., 2013]. Results from the current study indicate that exposure to a single workday did not significantly influence joint position sense in dental hygienists (Figure 2.3). We hypothesized that dental hygienists would have a reduction in proprioceptive acuity as measured by greater errors in joint position sense post workday. Thus, we conclude that in general, exposure to a single day of dental work, does not impair joint position sense for dental hygienists. In an attempt to quantify the resistance to shoulder fatigue, we measured the time to fatigue during an external rotator fatiguing protocol. Despite the range in time to fatigue measured (34 - 142 seconds), we found no differences in terms of proprioceptive acuity by workday with respect to time to fatigue. This indicates that even in hygienists who are quick to fatigue, workday exposure had no influence on joint position sense. It is possible that our joint position sense task was not sensitive enough to measure changes in proprioceptive errors from a single day of work exposure. It is also possible that dental hygienists recovered from workday fatigue before data were collected post-workday.

On average differences of 1.3º (Figure 2.4) were found in shoulder proprioceptive acuity in dental hygienists with and without shoulder pain as reported on the UPenn pain scale questionnaire. Our results indicate that in the presence of shoulder pain, dental hygienists have greater proprioceptive errors than dental hygienists with no shoulder pain (Figure 2.4). It is possible that proprioceptive deficits are related to pain and shoulder

pathology within this population. However, it is unknown how the proprioceptive deficits are related to shoulder pain. In patients with subacromial impingement syndrome, greater proprioceptive deficits were found when compared to healthy controls [Anderson et al., 2011; Lephart et al., 1994; Machner et al., 2003]. Interestingly, proprioceptive errors increased in the patient population with increased arm elevation angle [Anderson et al., 2011]. The authors attributed this increase in proprioceptive errors with arm angle as being related to the greater sensations of shoulder pain experienced at higher arm elevation angles [Anderson et al., 2011]. Furthermore, proprioceptive errors have been found to be reduced following surgical intervention [Lephart et al., 1994; Machner, 2003]. In a study conducted by Haavik et al., [2011] patients with chronic neck pain were shown to have significantly greater absolute errors in their elbow when compared to the joint position sense of control subjects. Following cervical manipulation, patients with chronic neck pain showed significant reductions in elbow proprioceptive errors [Haavik et al., 2011]. Together these findings suggest that pain may influence proprioceptive acuity; furthermore, pain in general may negatively influence the interpretation of proprioceptive sensation.

Dental hygienists have a high incidence of shoulder pain (64%-85% of hygienists) [Akesson et al., 1999; Ylipaa et al., 2002]. Our results indicate that proprioceptive deficits are more likely to occur in dental hygienists who experience shoulder pain. It is unclear if the pathogenesis of proprioceptive deficits in the shoulder are related to pain. Future studies should investigate the influence of pain on proprioceptive acuity in order to disseminate the progression of shoulder disorders. Recent studies suggest that shoulder proprioceptive acuity increases with elevation angle [Suprak et al., 2006a].

Current work conducted in our laboratory suggests that the influence of elevation angle on increased proprioceptive acuity is true for the elbow as well as the shoulder [Hyler, 2013]. Individuals with shoulder pain often report worse pain at greater arm elevation angles [Lalumandier JA, 2001; Lentz et al., 2009; Scovazzo et al., 1991], which may be related to the increased external torque production [Descarreaux et al., 2005]. Dental hygienists with pain also report greater pain during arm elevation [Lalumandier JA, 2001]; however, our study did not address the influence of arm elevation (target) on proprioceptive acuity for the shoulder. In order to study the influence of pain on proprioception, future studies should incorporate increased elevation angles (targets) in order to address the influence of increased pain on proprioception. It is possible that pain disrupts the angular influence on proprioception in patients with shoulder dysfunction [Anderson et al., 2011].

Conclusions

Our study is the first to investigate proprioceptive differences within a real work environment before and after the workday. Furthermore, we are the first to investigate proprioceptive deficits in dental hygienists with and without pain. The lack of differences by exposure to a full workday could be due to the large variability in proprioceptive acuity between dental hygienists. We did detect small, but significant differences (1.3º) between groups of dental hygienists with shoulder pain. This finding may be related to the surfeit number of complaints of shoulder disorders and pain reported by dental hygienists.

PAIN AND BIOMECHANICAL CONSIDERATIONS

Our findings from Chapter II, indicate that pain may have an influence on proprioceptive acuity. Proprioceptive stimulation has been shown to be related to activation of the primary motor cortex in humans [Weiller et al., 1996]. Furthermore, experimental pain has been shown to inhibit the primary motor areas [Suppa et al., 2012]. In addition to the higher brain centers, pain has been shown to stimulate inhibitory interneurons at the spinal cord level in humans [Lund et al., 1991]. Therefore, it is possible that pain may influence motor output at the shoulder in individuals with painful shoulders. Previous work from our laboratory has indicated that dental hygienists have changes in scapular kinematics that could potentially increase their risk for shoulder injuries such as subacromial impingement syndrome [Ettinger et al., 2012]. The cause of these kinematic shifts in dental hygienists is unknown; however, it is possible that hygienists experienced greater fatigue and pain in the shoulder at the end of the workday when compared to the beginning of the workday. Due to the subjective nature of pain, wide variability is reported for shoulder pain scores between-patients [Ludewig P, 2000]. Experimentally induced pain studies use within-subject designs to reduce this inherent variability; however, results of these studies may not represent clinical pain [Diederichsen, L. et al., 2009]. Therefore, in chapter III we investigate the influence of removal of chronic pain on scapular kinematics in patients with subacromial impingement syndrome, using a within-subjects design.

CHAPTER III

SUBACROMIAL INJECTION LEADS TO FURTHER SCAPULAR DYSKINESIS

Co-authors include Dr. Matthew Shapiro for assistance in subject recruitment and Dr. Andrew Karduna for help with project conception.

INTRODUCTION

Shoulder pain is the third most common musculoskeletal disorder reported in the general population [Urwin et al., 1998]. In the United States the direct annual costs for treating shoulder pain totals approximately 7 billion dollars [Meislin et al., 2005]. Of these musculoskeletal complaints, the most common diagnosis of shoulder pain is subacromial impingement syndrome [Dorrestijn et al., 2011; van der Windt et al., 1995]. Subacromial impingement is characterized by a reduction of the acromiohumeral distance, resulting in mechanical compression of the supraspinatus tendon beneath the acromion process of the scapula and the superior aspect of the humeral head [Allmann et al., 1997; Neer, 1972; Neer, 1987; Saupe et al., 2006]. For shoulder complaints resulting in medical intervention, 22% of treatments involves anesthetic injections with corticosteroids [van der Windt et al., 1995].

A reduction in the acromiohumeral distance is thought to be a contributing factor towards rotator cuff degeneration, subacromial bursitis and pain [Flatow et al., 1994; Ludewig P, 2000; Saupe et al., 2006; Watson-Jones, 1976]. Kinematic factors such as superior humeral translations and scapular orientation may influence the acromiohumeral distance during elevation of the arm [Atalar et al., 2009; Bey et al., 2007; Deutsch et al.,

1996; Endo et al., 2001; Giphart et al., 2012]. Both an increase in scapular anterior tilting and a decrease in upward rotation may reduce the acromiohumeral distance during elevation of the arm, where anteior tilting of the scapula lowers the anterior acromion towards the head of the humerus and upward rotation elevates the lateral acromion away from the humerus [Endo et al., 2001; Flatow et al., 1994; Neer, C. S., 1983]. The acromiohumeral distance has been reported to be lowest when the arm is elevated between 60º [Bey et al., 2007] and 90º [Giphart et al., 2012], thus highlighting the importance of scapular orientation at mid to high range of humeral motion [Ludewig P, 2000].

Numerous studies have examined differences in scapular kinematics between patients with impingement versus healthy controls [Hebert et al., 2002; Lin et al., 2011; Ludewig, P. M. et al., 2000; Lukasiewicz et al., 1999; McClure et al., 2006; Timmons et al., 2012]. Although the kinematic findings from these studies are quite variable, the majority of these studies suggest that patients with impingement have more anterior scapular tilting than healthy controls during arm abduction and flexion and no differences in scapular external rotation when compared to healthy controls [Endo et al., 2001; Ludewig, P. M. et al., 2000; Lukasiewicz et al., 1999]. However, a recent meta-analysis indicates that from the literature (9 studies) no constant patterns in kinematics can be established between patients with impingement and controls [Timmons et al., 2012]. Due to the high between-subject variability for scapular kinematics, little is known regarding abnormal scapular motion and the impingement phenomenon. However, for populations other than impingement; such as wheelchair users, individuals with clinical shoulder pain have been reported to have greater upward rotation and anterior tilt of the scapula

[Nawoczenski et al., 2012]. This finding suggests that pain may be associated with abnormal scapular motion. Additionally, one case study found that patients with painful scapulothoracic tumors later developed subacromial impingement [Han et al., 2012]. This finding suggests that subacromial impingement may be secondary to scapular dyskenisia when pain is present [Han et al., 2012].

Local anesthetic injections in conjunction with corticosteroids are commonly administered to patients with shoulder impingement syndrome by orthopedic surgeons and general practitioners [Alvarez et al., 2005; Celik et al., 2009; Gruson et al., 2008]. Local anesthetics are used as a diagnostic tool, as well as a modality to temporarily decrease shoulder pain [Celik et al., 2009; Gruson et al., 2008]. Following subacromial anesthetic injections, patients have been reported to have increased humeral elevation [Alvarez et al., 2005; Celik et al., 2009; Gruson et al., 2008] and increased strength in arm abduction and external rotation [Ben-Yishay et al., 1994; Park et al., 2008]. However, in patients with rotator cuff tears, a reduction in pain following a subacromial injection resulted in decreased scapulothroacic motion and greater reliance on glenohumeral motion during arm elevation [Scibek et al., 2008]. A multitude of biomechanical differences have been reported for patients with cuff tears which include changes in supraspinatus tendon length [Farshad-Amacker et al., 2013], fatty infiltration of cuff muscles [Berhouet et al., 2009], changes to glenohumeral center of rotation [Deutsch et al., 1996] and altered glenohumeral kinematics [Yamaguchi et al., 2000]. Therefore, we suspect that patients with Stage 2 subacromial impingement, without rotator cuff tears, will respond favorably to an anesthetic subacromial injection. We hypothesize that the reduction of pain in patients with Stage 2 impingement will result in

decreased anterior tilt and increased upward rotation of the scapula during arm elevation. Further, we hypothesize that post treatment scapular kinematics will be similar to healthy controls.

METHODS

Twenty-one patients (13 males and 8 females) with stage 2 impingement syndrome and twenty-one healthy control subjects were recruited for this study. Mean ± SD demographic data for patients were age, 55.6 years ± 8.3 years; height, 174.1 cm ± 7.9 cm; and weight, 78.6 kg ± 13.4 kg. Mean and ± SD demographic data for control participants which were matched within 5 years of age to a patient of the same gender and arm dominance (19 right handed individuals) were age, 54.4 years ± 8.9 years; height, 172.9 cm ± 9.4 cm; weight, 77.8 kg ± 15.1 kg. For the patient population, our inclusion criterion required a positive sign for at least 3 of the following 5 tests: Hawkins-Kennedy, Neer, painful arc, empty can (Jobe) and/or painful external rotation resistance. Patients having had shoulder surgery on the symptomatic side, a positive Spurling test, traumatic shoulder dislocation or instability in the past 3 months, reproduction of shoulder pain with active or passive cervical range of motion, or signs of a rotator cuff tear (drop-arm test, lag signs, gross external rotation weakness assessed by a manual muscle test, or positive image findings) were excluded from this study. The experimental protocol was approved by the Institutional Review Board at the University of Oregon. Written and verbal instructions of testing procedures were provided, and written consent was obtained from each subject prior to testing.

Instrumentation

The Fastrak magnetic tracking device (Polhemus, Colchester, VT) was used for collecting 3-D *in-vivo* kinematics of the shoulder complex. The Polhemus unit consists of a transmitter, three receivers and a digitizer, all wired to a system electronics unit, which determines the relative orientation and position of the sensors in space. The transmitter serves as a global reference frame and was fixed to a rigid plastic base and oriented such that its coordinate axes aligned with the cardinal planes of the human body. The digitizer sensor was used to identify anatomical landmarks with respect to the global reference frame. After digitization, the arbitrary coordinate systems defined by the Polhemus were converted to anatomically appropriate coordinate systems based on the recommendations of the International Society of Biomechanics Committee for Standardization and Terminology (Wu et al., 2005).

Setup and Digitization

For digitization, participants were asked to stand in a neutral position with their arms relaxed by their sides. Three custom made "break-away" receivers were placed on different body segments of the symptomatic arm using double sided adhesive tape. The break-away sensors allowed the subject to be de-coupled from the polhemus unit without removing the sensors (Figure 3.1). The first receiver was placed on the thorax on the manubrium of the sternum at approximately the level of T3. The second receiver was positioned on the humerus by mounting it to an orthoplast device positioned on the proximal humerus with elastic straps. The final receiver was positioned over the scapula

after mounting it on a custom scapular tracking device machined from plastic (Karduna et al., 2001). This tracker was attached to the scapular spine and posterior-lateral acromion with Velcro. The transmitter was then positioned approximately 30 cm behind the participant and was elevated to the height of their scapula. Anatomical landmarks were then digitized using the Polhemus stylus. The thoracic landmarks were T8, xiphoid process, C7 and jugular notch. The scapula landmarks were the root of the scapular spine, inferior angle and posterior lateral boarder (acromial angle) of the scapula were digitized. The humeral landmarks were the medial and lateral epicondyles and the center of the humeral head. To calculate the center of the humeral head, the humerus is manipulated in small circular arcs within the mid-range of motion of the humerus. The center of the humeral head was defined by the point that moves the least with respect to the scapula through a least squares algorithm during humeral calibration (Karduna et al., 2001). Using the custom "break-away" sensors (Figure 3.1), no materials were removed during the protocol or for the treatment phase and only one calibration file was generated for the pre and post-injection measurements for the patient group.

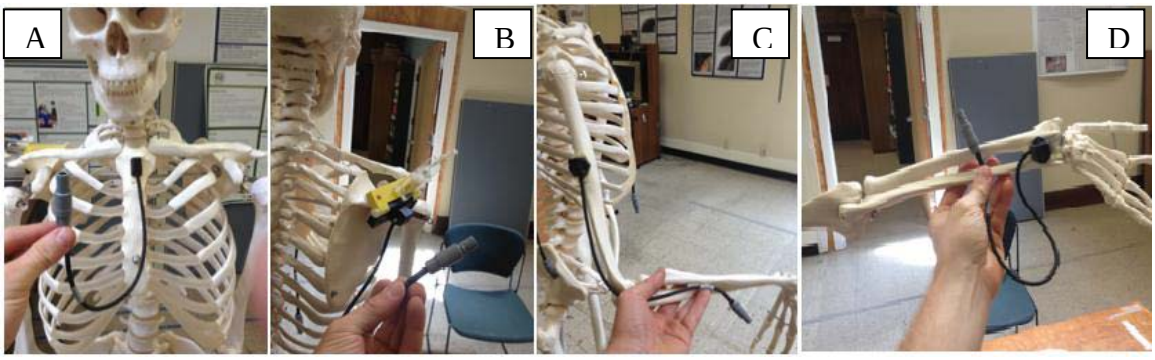

Figure 3.1. Experimental setup and "break-away" sensors de-coupled from Polhemus unit. A. Thoracic sensor, B. Scapular sensor, C. Humeral sensor, D. forearm sensor (Chapter VI only).

Experimental Procedure

Once the digitization and calibration were completed, participants completed three arm elevation trials. Each elevation trial consists of the patient raising their affected arm in the scapular plane (30 degrees from the frontal plane) and returning along the same path to a count of four in each direction. Trials were repeated when the participant's arm elevation deviated from the scapular plane (based on real time feedback provided to the investigator). Data were collected continuously at a rate of 40 Hz for the three trials, and then averaged for data analysis. Patients were asked to give their current shoulder pain level on an analog pain scale immediately after completing the shoulder elevation task.

Following the scapular kinematic evaluation, patients received two subacromial injections of (A) anesthetic (3 cc lidocaine with epinephrine) and (B) corticosteroid (6 cc 0.5% bupivacaine and 1 cc 40mg methylprednisolone acetate) as part of their normal treatment (Figure 3.2). Patients were then given a 15 minute adjustment period and were asked to move their arm in order to disperse the drug within the subacromial bursa. Following the adjustment period patients were asked to repeat their arm elevation task following the same procedure as before. Immediately following the post injection arm elevation task, patients were again asked to give their current shoulder pain level on an analog pain scale. Patients were blinded from their previous analog pain scale submission. For testing healthy subjects, the same kinematic evaluation was performed; however, no subacromial injections were given to the control group.

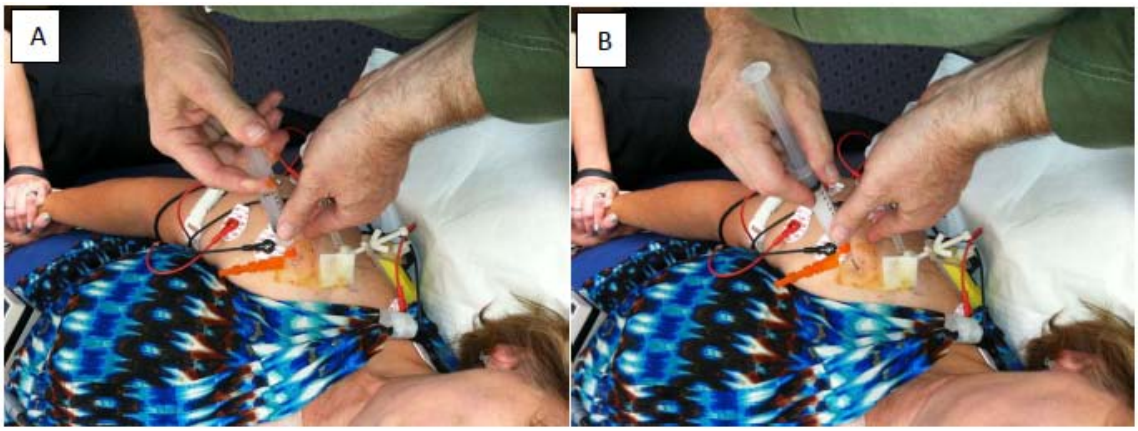

Figure 3.2. Anesthetic subacromial injection with epinephrine (A) and anesthetic injection with corticosteroid (B).

Statistical Analysis

To determine if there were differences in pain following treatment, a paired t-test was used between pre and post-injection VAS pain scores. To determine the influence of treatment on scapular kinematics, three 2-way repeated measures ANOVA were used. Each rotation of the scapula, upward and internal rotation and scapular tilt were treated as unique dependent variables. Humeral elevation angle at four increments, 30, 60, 90 and 120 degrees were treated as the first independent variable and condition (pre-injection, post-injection) was treated as the second independent variable. For significant interactions, pairwise comparisons were performed using Fisher's least significant difference test (LSD). To compare the effect of treatment with respect to healthy controls, three 2-way mixed effects ANOVAs were used. Humeral elevation angle at four increments was treated as the repeated measures independent variable and group (post-injection versus controls) was treated as the between-subjects factor. For significant interactions, pairwise comparisons were performed using the LSD. Due to the natural

influence of humeral elevation on scapular kinematics, we did not perform *post-hoc* testing for significant main effects of humeral elevation angle.

RESULTS

Following the anesthetic subacromial injection, patients reported a significant reduction in pain ($p < 0.001$), where patients on average had a 65% reduction in pain (Figure 3.3).

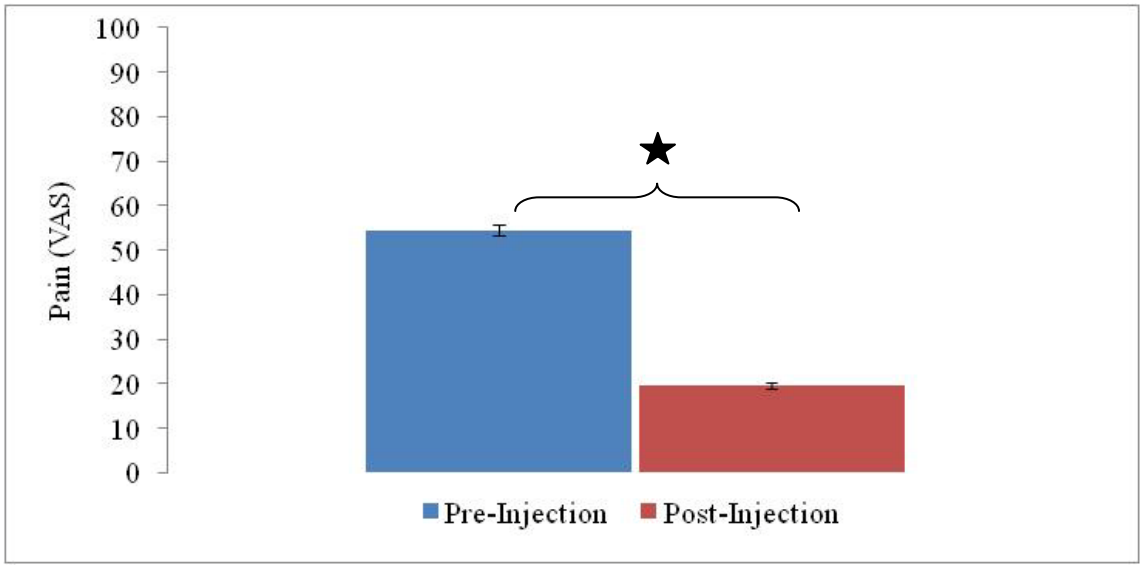

Figure 3.3. Visual analog scores pain pre and post-injection in patients with subacromial impingement. Significance where $p < 0.05$ is represented with ★.

For scapular tilt, there was a significant interaction between treatment and humeral elevation angle ($p = 0.032$). *Post-hoc* pairwise comparisons indicated that treatment had no significant influence on scapular tilt at 30º and 60º of humeral elevation ($p > 0.05$). However, significant differences were detected for 90º ($p = 0.04$) and 120º (p

= 0.007), with differences in anterior tiling of 2º and 3.5º, respectively. Comparing post-injection kinematics for patients with impingement versus healthy controls, a significant interaction between humeral elevation angle and group (controls versus impingement population) was detected (p = 0.006). *Post-hoc* pairwise comparisons indicate that no significant differences were pronounced between groups at 90º of humeral elevation (p > 0.05); however, significant differences were detected at 120º of humeral elevation, where the impingement group had on average 7.1º (±2.9º) greater anterior tilting than controls (p = 0.02) (Figure 3.4).

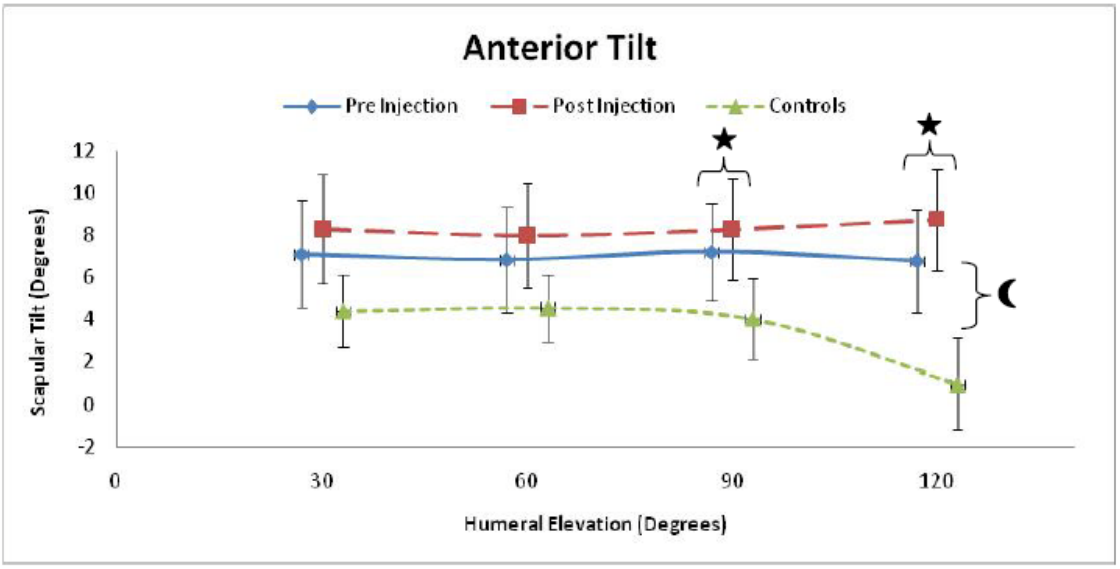

Figure 3.4. Anterior tilting angle (degrees) during arm elevation pre (blue, solid line) and post- (red, dashed line) injection versus healthy controls (greed, square dotted line). Significant differences for within subject comparisons are denoted with ★and significant differences for between subject comparisons are denoted with ☾.

For the influence of treatment and humeral elevation on scapular upward rotation, no significant interactions were detected (p = 0.93). No significant main effect was detected for treatment (p = 0.17). When comparing post-injection upward rotation to

control subjects, a significant interaction between humeral angle and group (controls versus impingement population) was detected ($p < 0.001$). *Post-hoc* pairwise comparisons indicate that no significant differences were pronounced between groups at 30º or at 120º ($p > 0.05$). However, at 60º of humeral elevation the impingement group had on average 5.1º (±1.9º) greater upward rotation than controls ($p = 0.013$). At 90º of humeral elevation the impingement group had on average 7.1º (1.8º) greater upward rotation than controls ($p = 0.001$) (Figure 3.5).

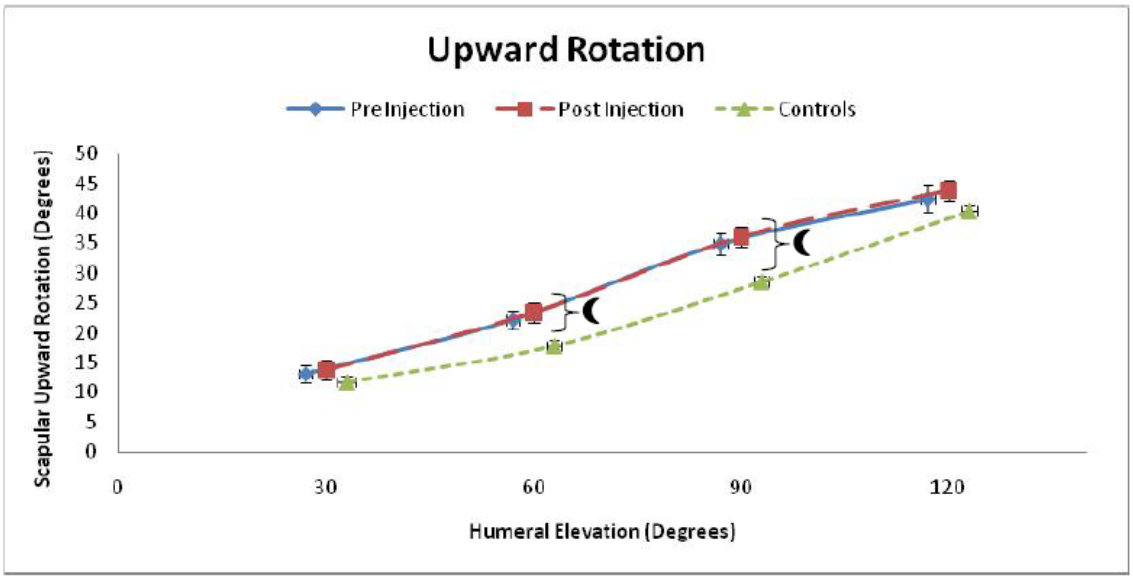

Figure 3.5. Upward rotation angle (degrees) during arm elevation pre (blue, solid line) and post-(red, dashed line) injection versus healthy controls (green, square dotted line). Significant differences for between subject comparisons are denoted with ☾.

For scapular internal rotation, no significant interactions between treatment and humeral elevation were detected ($p = 0.629$). No significant main effects of treatment ($p = 0.167$) or humeral elevation ($p = 0.977$) were detected. When compared to healthy controls, no significant interactions were detected ($p = 0.974$) (Figure 3.6).

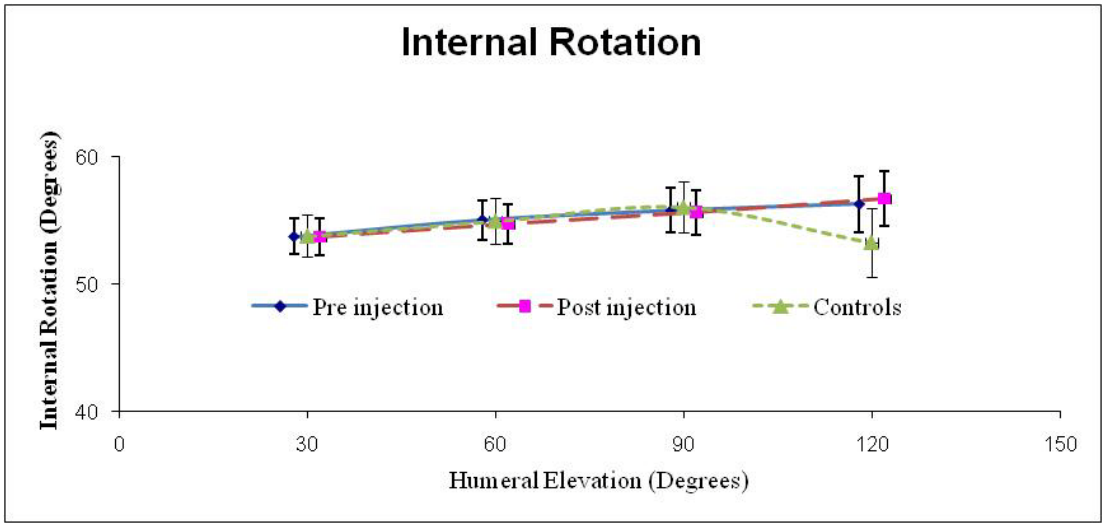

Figure 3.6. Internal rotation angle (degrees) during arm elevation pre (blue, solid line) and post-(red, dashed line) injection versus healthy controls (green, square dotted line).

DISCUSSION

We hypothesized that the reduction of pain in patients with Stage 2 impingement would result in decreased scapular anterior tilt and increased upward rotation and would result in no changes in scapular internal rotation during elevation of the arm. Additionally, we hypothesized that kinematics following the injection would be more representative of the kinematics of healthy control subjects. For anterior tilting, our results did not support the hypothesis. Following the injections, patients demonstrated a 2º increase in anterior tilting at 90º of humeral elevation and a 3.5º increase in anterior tilt at 120º degrees of elevation (Figure 3.4). When compared to healthy controls, patients post-injection had 7.1º greater anterior tilting at 120º degrees of arm elevation (Figure 3.4). For upward rotation, our results partially supported our hypothesis. No kinematic changes were detected following the injections; however, when compared to healthy

controls, patients post-injection, had 5.1º greater upward rotation at 60º and 7.1º greater upward rotation at 90º degrees of arm elevation (Figure 3.5). For scapular internal rotation, our hypothesis was supported, since no significant changes were noted following the subacromial injection, or when compared to healthy controls (Figure 3.6).

In studies examining differences in scapular kinematics versus healthy controls, most studies agree that patients with subacromial impingement have greater scapular anterior tilt than healthy control subjects [Endo et al., 2001; Hebert et al., 2002; Lin et al., 2011; Ludewig P, 2000; Lukasiewicz et al., 1999]. Our findings agree with the literature, especially at arm elevation angles of 90 and 120 degrees. Previous reports indicate that the acromiohumeral distance is minimized as the arm approaches greater arm elevation angles [Bey et al., 2007; Giphart et al., 2012]. In healthy individuals, scapular kinematics tend toward less anteriorly tilted scapular positions at greater elevation angles, presumably to provide a greater acromiohumeral clearance [Ludewig P, 2000]. Healthy control subjects in our study tended toward a less anteriorly tilted scapula at greater elevation angles, which agrees with the literature [Ludewig et al., 2009; van der Helm et al., 1995]. The anteior acromion is the predominant site of impingement, where acromial shape and orientation can greatly influence degeneration of subacromial tissues [Balke et al., 2013; Neer, 1972]. It has been postulated that the contact pressure beneath the acromion is associated with diffuse anterior shoulder pain [Balke et al., 2013; Neer, 1972; Saupe et al., 2006; Watson-Jones, 1976]. Following the reduction in pain using an anesthetic subacromial injection, our results indicate an increase in anterior scapular displacement, which may further reduce the acromiohumeral distance [Ludewig P, 2000]. Furthermore, the differences in scapular tilt following treatment were most prevalent at

greater arm elevation angles, thus potentially exacerbating the effects of a reduced acromiohumeral distance [Bey et al., 2007; Giphart et al., 2012; Soslowsky et al., 2002]. Our results indicate that subacromial pain may be related to scapular tilt, especially at greater humeral angles (Figure 3.3). However, it is possible that increased fluid in the subacromial bursa post injection had an influence on scapular tilt, perhaps due to increased subacromial pressure. Changes in scapular kinematics following the subacromial injection are likely to be due to changes in scapular muscle activation (Chapters IV and V).

For scapular upward rotation and patients with impingement syndrome, there is less agreement pertaining to trends in kinematics when compared to healthy controls. Several studies suggest that patients have decreased scapular upward rotation [Endo et al., 2001; Ludewig P, 2000], one demonstrated increased upward rotation [McClure et al., 2006], and several others found no differences [Hebert et al., 2002; Lukasiewicz et al., 1999]. Our findings suggest that when compared to healthy controls, patients demonstrate greater upward rotation, agreeing with one other study [McClure et al., 2006]. Our control participants demonstrated a linear increase in scapular upward rotation with arm elevation which is consistent with the literature [Inman et al., 1996; Ludewig et al., 2009; McClure et al., 2001; van der Helm et al., 1995]. Following the subacromial injection, we found no significant changes in upward rotation (Figure 3.4). This finding suggests that pain reduction via an anesthetic injection may not have an influence on scapular upward rotation in patients with subacromial impingement. In patients with rotator cuff tears, subacromial injections have been shown to decrease scapulothoracic motion and increase glenohumeral contribution towards arm elevation

[Scibek et al., 2008]. This may be related to an increase in humeral abduction strength following subacromial injections [Ben-Yishay et al., 1994; Park et al., 2008]. Our patients did not show evidence of rotator cuff tears, therefore differences in our results and Scibek et al., [2008] could be related to other factors such as; fatty infiltration of the cuff muscles [Berhouet et al., 2009], differences in cuff tendon lengths [Farshad-Amacker et al., 2013] and changes to the center of rotation of the glenohumeral joint due to superior translation of the humerus associated with rotator cuff tears [Deutsch et al., 1996].

Limitations

Our experimental design included a pre and post-treatment measurement for patients with subacromial impingement; however, due to practical reasons no treatment condition was given to healthy control subjects. Therefore, from our study, it is impossible to determine if the changes observed in scapular kinematics were due to changes in pain or some other influence of the subacromial anesthetic injection, such as increased fluid in the subacromial bursa. The subacromial injection added approximately 10cc of fluid into the subacromial bursa. The additional fluid within the subacromial bursa could potentially influence scapular kinematics by changing subacromial contact pressure. Future studies could use a placebo injection to investigate the influence of adding fluid to the subacromial bursa. Additionally, the size of the subacromial bursa could be taken into account with respect to scapular kinematics in patients with impingement.

Conclusions

An anesthetic subacromial injection successfully reduces pain in patients with impingement. However, the subacromial injection may temporarily further scapular abnormalities by increasing anterior tilt, specifically at arm elevations angles of 90º and 120º. Our findings suggest that pain may be important towards reducing scapular tilt, especially at higher arm elevation angles in patients with impingement.

SCAPULAR KINEMATICS AND MUSCULAR CONTROL

The kinematic shifts pre and post-injection investigated in chapter III represent changes in neuromuscular control of the shoulder joint. Previous studies have investigated neuromuscular control of the shoulder in patients with and without pain. Neuromuscular control for the shoulder is often measured using electromyography of shoulder and scapular muscles [Inman et al., 1996]. However, in order to make between-subject comparisons in terms of muscular output, electromyographic data are often normalized by Maximal Voluntary Isometric Contractions (MVIC). However, several studies have cautioned that the ability to produce MVIC may be reduced in the presence of pain. Therefore, in chapter IV we investigate the influence of pain on MVIC production in patients with impingement syndrome.

CHAPTER IV

EMG NORMALIZATION IS INFLUENCED BY SUBACROMIAL PAIN

Co-authors include Jason Weiss for assistance in data collection, Dr. Matthew Shapiro for subject recruitment and Dr. Andrew Karduna for help with project conception.

INTRODUCTION

Shoulder muscle activation has been measured using electromyography (EMG) since the early 1940's when Inman and Saunders first examined raw EMG signals from shoulder musculature [Inman et al., 1944]. Since that time, collection and analysis of EMG data have been standardized in order to make comparisons between individuals and between studies [Merletti, 1999]. Recently, normalized EMG was used to examine shoulder muscle activity in healthy subjects, as well as patients with subacromial impingement syndrome [Bandholm et al., 2006; Cools et al., 2003; Lin et al., 2011; Ludewig, P. M. et al., 2000; Moraes et al., 2008; Reddy et al., 2000]. Phadke et al., [2009] composed a comprehensive review of scapular muscular activation during arm elevation in patients with subacromial impingement syndrome versus healthy controls. From that review article, seven studies used similar methodological protocols which normalized EMG activity of scapular muscles to Maximal Voluntary Isometric Contractions (MVIC) for patients with subacromial impingement and healthy controls [Phadke et al., 2009]. From this review, discrepancies are reported between studies in terms of which scapular muscles have greater activation or lesser activation in the patient population versus healthy individuals.

Most studies agree that the upper trapezius activity is greater in patients with subacromial impingement than in healthy controls [Lin et al., 2011; Ludewig, P. M. et al., 2000; Peat et al., 1977]. However, for the lower trapezius Ludewig and Cook [2000] describe activity to be greater in patients with impingement than in controls; however, Cools et al., [2003] described patient activity of the lower trapezius to be lesser than controls. Three studies found no difference in activity of the lower trapezius in patients with impingement when compared to healthy controls [Bandholm et al., 2006; de Morais Faria et al., 2008; Finley et al., 2005]. For the serratus anterior muscle several authors suggest that patients have less activation with impingement versus healthy controls [Lin et al., 2011; Ludewig, P. M. et al., 2000; Peat et al., 1977], others suggest that there is no difference in activity for this population versus controls [Bandholm et al., 2006; de Morais Faria et al., 2008; Finley et al., 2005]. Several authors have described the deltoid muscles to have less activation in patients with impingement than in healthy controls [Clisby et al.; Michaud et al., 1987; Reddy et al., 2000]; however, Myers et al., [2009] found the deltoid to have greater activity in the patient population than in healthy controls. Differences between studies may be due to the severity of the impingement disorder, where some patients have greater disability due to their pain whereas others do not [Lentz et al., 2009]. Furthermore, patients may be avoiding activation of certain muscle such as the deltoids due pain inhibition [Ben-Yishay et al., 1994; Lentz et al., 2009], or compensatory strategies to avoid further damage of the supraspinatus tendon within the subacromial space during MVIC testing [Michaud et al., 1987].

In order to make meaningful EMG comparisons between individuals, standardization of electrode placement and normalization to a Maximal Voluntary

Isometric Contraction (MVIC) is recommended [Lehman et al., 1999]. Due to the standardization of the EMG normalization, muscle activity is often reported as a percentage of maximal activation and not in raw electrical activity as reported by Inman and Saunders [1996]. However, it has been cautioned that normalization to a MVIC in injured populations may be influenced by pain [Celik et al., 2011; Myers, J. B. et al., 2009]. If pain inhibits one's ability to maximally contract a muscle, the resultant MVIC might bias traditional normalization protocols.

Subacromial injections of local anesthetics have been shown to decrease shoulder pain in patients with subacromial impingement [Alvarez et al., 2005; Buchbinder et al., 2003; Celik et al., 2009]. Further, subacromial injections have been found to increase force production for the rotator cuff [Park et al., 2008], and increase arm abduction and flexion forces in patients with rotator cuff tears [Ben-Yishay et al., 1994; Cordasco et al., 2009]. In a study conducted by Brox et al., [1997] MVICs of several shoulder muscles were shown to be enhanced following a subacromial injection; however, the influence of this change on EMG normalization was not tested. It is the goal of this study to examine the influence of pain on shoulder muscle contractibility as measured by standardized MVIC procedures in patients with subacromial impingement syndrome. We hypothesize that through the use of an anesthetic subacromial injection, muscles involved in arm elevation (agonists) will have increased contractibility during MVIC. Further, we hypothesize that normalization to a MVIC in the presence of pain will result in an overestimation of the percent muscle activation during an arm elevation task.

METHODS

Fourteen patients with subacromial impingement participated in this study (55 ± 9 years). Inclusion criterion required a clinical diagnosis of impingement syndrome by one of our co-authors (MS), the clinical tests required a positive test of: Hawkins-Kennedy, Neer, painful arc, empty can (Jobe) and/or external rotation resistance. Exclusion criteria were: having had shoulder surgery on the symptomatic side, a positive Spurling test, traumatic shoulder dislocation or instability in the past 3 months, reproduction of shoulder pain with active or passive cervical range of motion, or signs of a rotator cuff tear (drop-arm test, lag signs, gross external rotation weakness assessed by a manual muscle test, or positive radiographic findings). The experimental protocol was approved by the Institutional Review Board at the University of Oregon. Written and verbal instructions of testing procedures were provided, and written consent was obtained from each patient prior to testing.

Instrumentation

A Myopac Jr. (Run Technologies, Mission Viejo CA) system was used to collect differential EMG activity from seven shoulder muscles (anterior, middle and posterior deltoids, upper and lower trapezius, latissamus dorsi and serratus anterior) on the affected side. A ground electrode was used on the contralateral clavicle to reduce signal noise. The system had a common mode rejection ratio of at least 90 dB, an amplifier input impedance of 10 MΩ and a band-pass filter (10-1000 Hz). After the data were sampled at 1200 Hz, it was run through a Root Mean Square (RMS) algorithm with a 50 ms window which served to rectify and low pass filter the data (rEMG). To calculate the MVIC, each

muscle was subjected to a 5 second isometric contraction (described in detail below). The amplitude of the contraction was determined by the RMS data over the middle 2 seconds of the muscle contraction.

Two surface electrodes were used for each muscle tested. Oval, pediatric (32 x 38 mm) ECG electrodes (Ag/AgCl) were selected for study due to their small appearance and low inter-muscular cross talk. Electrodes were placed with an inter-electrode distance of approximately 40 mm on the bellies of each muscle. Skin was cleaned prior to electrode placement using isopropyl alcohol preparation pads. Electrode placement for the deltoid muscles [Cram et al., 1998], upper trapezius [Cools et al., 2003], lower trapezius [Nieminen et al., 1993], serratus anterior [Ekstrom et al., 2004] and latissamus dorsi [Lehman et al., 2006] followed protocols described from the literature.

For collection of 3-D in-vivo kinematics of the shoulder complex during the arm elevation task, the Polhemus Fastrack (Colchester, VT) was used. The Polhemus unit consists of a transmitter, three receivers and a digitizer, all wired to a system electronics unit, which determines the relative orientation and position of the sensors in space. The transmitter served as a global reference frame and was fixed to a rigid plastic base and oriented such that its coordinate axes aligned with the cardinal planes of the human body. The digitizer sensor was used to identify anatomical landmarks with respect to the global reference frame. For digitization, participants stood with their arm in a neutral relaxed position. Custom “break-away” sensors (Figure 3.1) were attached to anatomical segments using double sided adhesive tape. The first receiver was placed on the thorax on the manubrium of the sternum at approximately the level of T3. The second receiver was positioned on the humerus by mounting it to an orthoplast device positioned on the

proximal humerus with elastic straps. The final receiver was positioned over the scapula after mounting it on a custom scapular tracking device machined from plastic [Karduna et al., 2001]. This tracker was attached to the scapular spine and posterior-lateral acromion with Velcro. The transmitter was then positioned approximately 30 cm behind the subject and was elevated to the height of their scapula using a non-metallic tripod. Anatomical landmarks were then digitized using the Polhemus stylus, for the thorax T8, xiphoid process, C7 and jugular notch. For the humeral matrix, the medial and lateral epicondyles were digitized and the center of the humeral head was calculated. To calculate the center of the humeral head, the humerus was manipulated in small circular arcs within the mid-range of motion of the humerus. The center of the humeral head was defined by the point that moves the least with respect to the scapula through a least squares algorithm during humeral calibration [Karduna et al., 2001]. After digitization, the arbitrary coordinate systems defined by the Polhemus were converted to anatomically appropriate coordinate systems based on the recommendations of the International Society of Biomechanics Committee for Standardization and Terminology [Wu et al., 2005].

Protocol

For the MVIC collection, each muscle was tested in a unique position using methods previously described. For the anterior deltoid, the patient performing resisted arm flexion with their affected arm placed in 90 degrees of humeral flexion, the elbow flexed 90 degrees and the forearm vertical [Maffet et al., 1997]. For the middle deltoid, the patient performed resisted abduction with the affected arm in 90 degrees of shoulder abduction, the elbow flexed 90 degrees and the forearm parallel to the floor [Alpert et al.,

2000]. Testing for the posterior deltoid involved resisted horizontal extension of the affected arm in 90 degrees of humeral abduction, elbow flexion of 90 degrees and the forearm parallel to the floor [Alpert et al., 2000]. For the upper trapezius the patient resisted abduction with the arm placed in 90 degrees of shoulder abduction, the elbow flexed 90 degrees and the forearm parallel to the floor, [Alpert et al., 2000]. For the lower trapezius the patient's arm was placed in 90 degrees of humeral elevation in the scapular plane and the elbow fixed at 90 degrees. From this position, the subject depressed and downwardly rotated the scapula against resistance applied manually by the investigator [Kendall et al., 1993]. During testing of the serratus anterior, many patients had trouble abducting their arm to 125° in the scapular plane. Therefore, when testing the serratus anterior the protocol was slightly modified from what was described in the literature [Ekstrom et al., 2004]. For serratus anterior, the patient's arm was abducted 90 degrees in the plane of the scapula, the patient performed resisted elevation with force applied to the humerus in the direction of adduction towards the lateral boarder of the scapula [Ekstrom et al., 2004]. The latissamus dorsi was tested with the subject performing maximal shoulder adduction against resistance with the humerus abducted 30 degrees (in the frontal plane) and internally rotated [Lehman et al., 2006]. All MVIC testing was performed before and after subacromial injection.

Before receiving the anesthetic injection, patients performed three arm elevations with their affected arm moving in the scapular plane (30 degrees anterior to the frontal plane) and returning along the same path to a count of four in both directions. Real-time feedback of the scapular plane of motion was observed digitally by the investigator. Trials were repeated when the patient's arm elevation deviated by more than 10 degrees

from the scapular plane. EMG and kinematic data were synchronized and collected continuously for the three elevation trials. Data from the three trials were averaged for subsequent data analysis. Patients were additionally asked to give their current shoulder pain level on a 0-100 visual analog pain scale (VAS) immediately following the shoulder elevation MVIC. Pre-treatment VAS was on average 56.1 (± 26.1). Post-treatment VAS was on average 21.3 (± 14.7).

Treatment Procedure

Following kinematic and MVIC evaluations, patients received a subacromial injection of anesthetic (6 cc 0.5% bupivacaine with epinephrine and 3 cc lidocaine with epinephrine) and corticosteroid (1 cc 40mg methylprednisolone acetate) as part of their recommended treatment. The procedure was completed by one of our co-authors (M.S) who is an orthopaedic surgeon. The injection was performed using an anterior approach where the needle was inserted into the subacromial space and the drugs were administered locally to the subacromial bursa. Patients were then given a 15 minute adjustment period after the injection and were asked to move their arm in order to disperse the drug within the subacromial bursa. Following the adjustment period, patients were asked to perform a new MVIC for each of the seven muscles tested using the same protocol as described above. No electrodes or sensors were moved during the injection.

To compare the MVIC normalization method, EMG activity during the arm elevation trial (pre injection) were normalized twice. The first method normalized EMG activity by the MVIC before the anesthetic injection, the second method normalized the

same EMG activity to a post-injection MVIC. A resting trial was subtracted from all EMG data.

$$\text{Method 1} = \frac{\text{rEMG } \textit{muscle} - \text{rEMG } \textit{rest (pre)}}{\text{rEMG } \textit{MVIC (pre)} - \text{rEMG } \textit{rest (pre)}} \times 100$$

$$\text{Method 2} = \frac{\text{rEMG } \textit{muscle} - \text{rEMG } \textit{rest (post)}}{\text{rEMG } \textit{MVIC (post)} - \text{rEMG } \textit{rest (post)}} \times 100$$

The rEMG *muscle (pre)* depicts the rectified EMG signal from each muscle during the arm elevation task pre-injection. The rEMG *rest (pre)* illustrates the resting rectified EMG data pre-injection. The rEMG *rest (post)* demonstrates the resting rectified EMG data post-injection. The rEMG *MVIC (pre)* is the MVIC for each muscle pre-injection. Finally, the rEMG *MVIC (post)* is the MVIC for each muscle post-injection.

To determine the influence of pain on MVIC, dependent samples t-tests were run. The MVIC (mV) was the quantitative dependent variable. The independent variable was treatment condition, pre and post-injection.

To determine the influence of MVIC on normalization technique during an arm elevation task, seven two-way repeated measure ANOVAs were used. The percent MVIC during an arm elevation task were the quantitative dependent variables. Injection (pre vs. post) was the categorical independent variable and humeral elevation angle with 3 levels (30, 60, 90 degrees of elevation) was the second independent variable. The significance level used was $\alpha = 0.05$ for all analyses. *Post hoc* t-tests using a Bonferroni correction were used whenever significant interactions or main effects were detected.

RESULTS

Results from the dependent samples t-tests indicated that following the subacromial injection, EMG (mV) for the MVIC tests were larger for the anterior, middle and posterior deltoid and the lower trapezius, $p < 0.05$. No significant differences were found for the latissamus dorsi, upper trapezius, or serratus anterior, $p > 0.05$ (Figure 4.1).

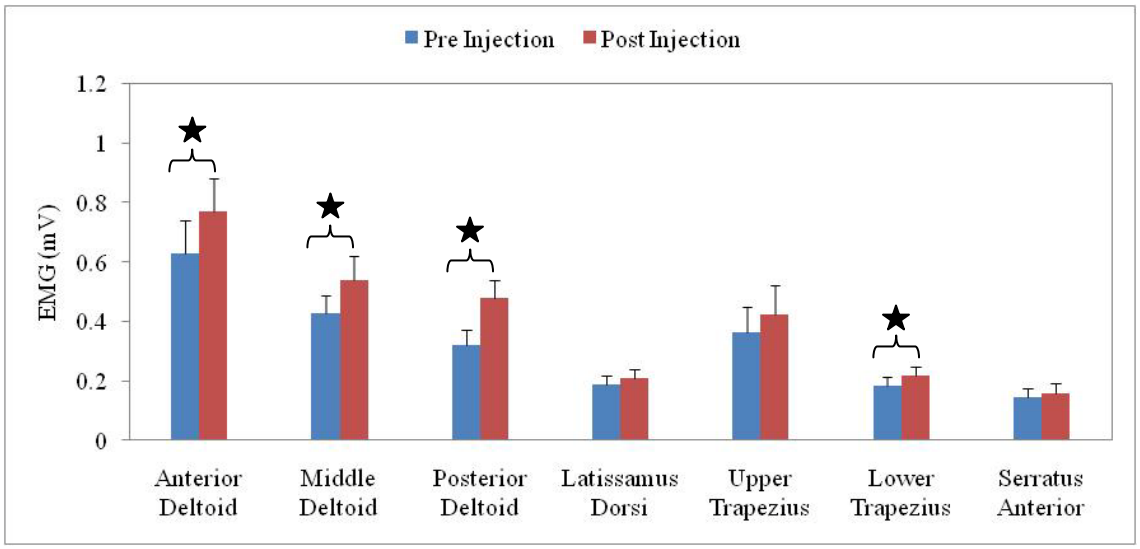

Figure 4.1. EMG (mV) before (red) and after (blue) injection in patients with impingement. Significance where $p < 0.05$ is represented by ★.

All results from the ANOVA tests are reported in Table 4.1. For all muscles tested, only the anterior deltoid had a significant interaction between humeral elevation and normalization condition (Figure 4.2). Follow up t-tests indicated that pre and post-injection MVIC normalization differences occurred at 60° of humeral elevation. For all other muscles no significant interactions were found ($p > 0.05$). For the effects of normalization condition, the anterior deltoid and the lower trapezius were the only muscles influenced, which resulted in overestimation of muscle activity ($p < 0.05$). With the exception of the upper trapezius, there was a significant effect of humeral elevation

for all muscles tested ($p < 0.05$). For comparisons between pre and post-treatment pain levels, the results of the dependent samples (paired samples) t-test revealed that pre-treatment pain level was significantly greater than post-treatment VAS ($p < 0.001$).

Table 4.1. 2-Way Repeated Measures ANOVA Tests by Muscle.

Muscle	*ANOVA factor*	*df*	*F-ratio*	*P-value*
Anterior Deltoid	Condition (Pre – Post Injection)	1	6.865	0.019*
	Humeral Elevation Angle	2	30.660	0.001*
	Condition x Elevation	2	3.868	0.044*
Middle Deltoid	Condition (Pre – Post Injection)	1	0.104	0.751
	Humeral Elevation Angle	2	14.239	0.001*
	Condition x Elevation	2	0.192	0.827
Posterior Deltoid	Condition (Pre – Post Injection)	1	3.799	0.069
	Humeral Elevation Angle	2	7.453	0.006 *
	Condition x Elevation	2	1.631	0.229
Latissamus Dorsi	Condition (Pre – Post Injection)	1	3.094	0.102
	Humeral Elevation Angle	2	7.295	0.008 *
	Condition x Elevation	2	1.051	0.380
Upper Trapezius	Condition (Pre – Post Injection)	1	2.475	0.140
	Humeral Elevation Angle	2	1.663	0.230
	Condition x Elevation	2	1.441	0.175
Lower Trapezius	Condition (Pre – Post Injection)	1	6.486	0.024 *
	Humeral Elevation Angle	2	9.380	0.004 *
	Condition x Elevation	2	0.565	0.583
Serratus Anterior	Condition (Pre – Post Injection)	1	0.557	0.469
	Humeral Elevation Angle	2	14.273	0.001 *
	Condition x Elevation	2	2.120	0.163

*Note. * indicates statistical significance where p < .05.*

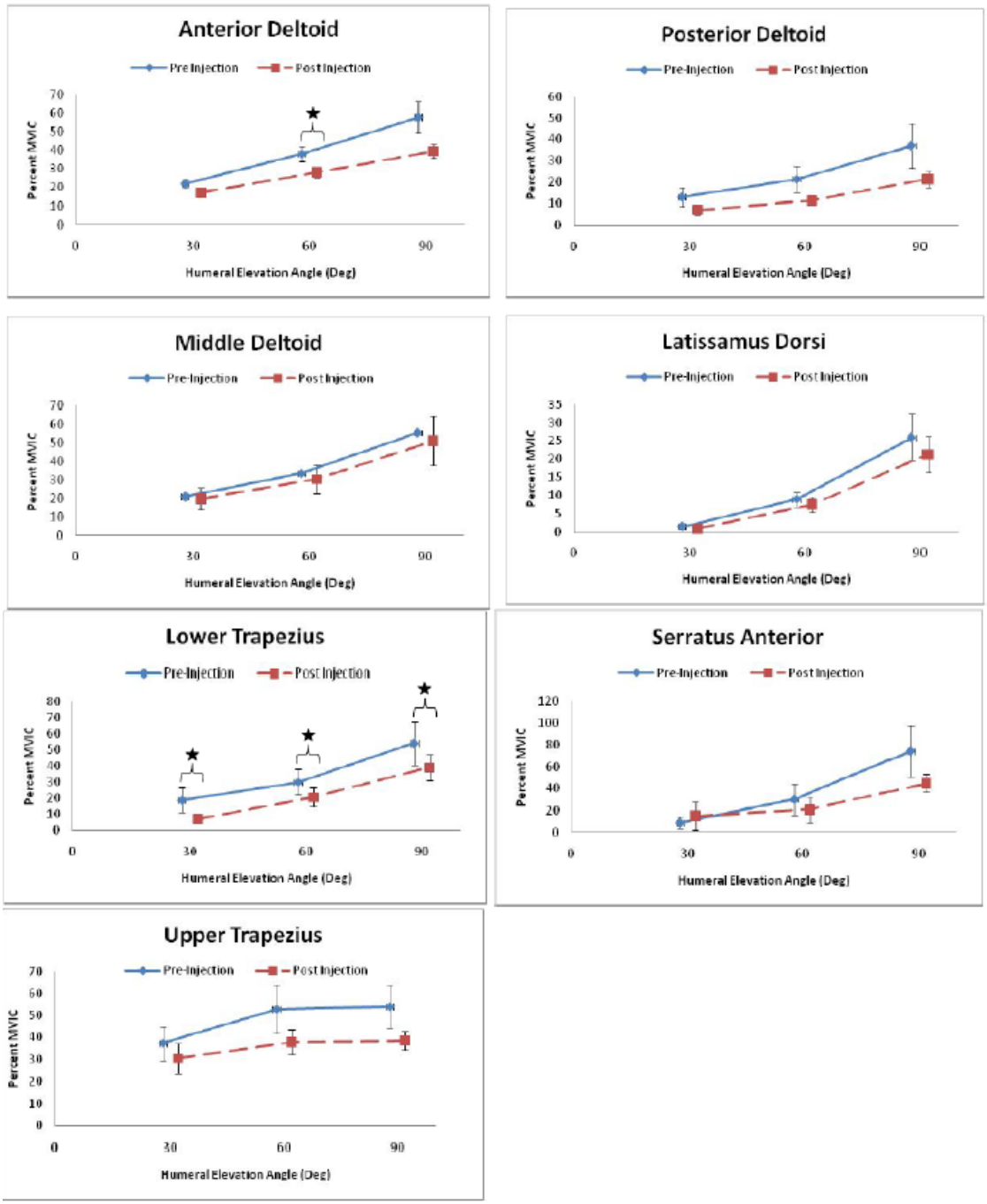

Figure 4.2. EMG (percent MVIC) normalized to before (red) and after (blue) injection in patients with impingement syndrome. Significance where $p < 0.05$ is represented by★.

DISCUSSION

From the present study, all patients experienced a reduction in subacromial pain due to an anesthetic subacromial injection. On average, patients experienced a 64% decrease in pain. For the anterior, middle and posterior deltoid and the lower trapezius muscles, we found that a reduction in subacromial pain significantly increased MVIC levels (Figure 4.1). However, pain reduction had no significant effect on MVIC for the latissamus dorsi, upper trapezius or the serratus anterior. Our results indicate that following a reduction in pain, the anterior deltoid MVIC was approximately 23% higher than before pain reduction, 25% higher for the middle deltoid, 50% higher for the posterior deltoid and 19% higher for the lower trapezius (Figure 4.1). Results from our normalization methods indicate that for both the anterior deltoid and the lower trapezius were significantly influenced by normalization to an MVIC after pain reduction. However, for the middle and the posterior deltoid, despite having significantly lower muscle activation pre-injection during the MVIC testing, there was no significant impact on the normalization of EMG data during an arm elevation task. The unpredictability of the influence of pain on normalization highlights the importance of MVIC testing during a pain free condition.

Submaximal contractions have been attributed to increased pain in patients with subacromial impingement [Bandholm et al., 2006]. Painful stimulation through group 3 and 4 afferents is associated with decreased muscle activation from agonist muscle groups [Lund et al., 1991]. This inhibition is believed to be regulated via inhibitory interneurons [Lund et al., 1991]. We hypothesized that following a subacromial injection, muscles involved in arm elevation (agonists) would have increased activation

during MVIC. Our results indicated that all three deltoid muscles (agonists) had greater MVICs post-injection thus supporting our hypothesis. Furthermore, we hypothesized that normalization to a MVIC in the presence of pain would result in an overestimation of the percent muscle activation during an arm elevation task. Our results indicated that only the anterior deltoid and the lower trapezius were significantly influenced by the normalization method (pre versus post-injection MVIC). Therefore, our second hypothesis is only partially supported.

It is possible that prior to the subacromial injection, muscle activation from the deltoids and the lower trapezius were inhibited resulting in decreased activation during the MVIC testing. During MVIC testing, all three deltoid muscles were significantly influenced by pain. Several studies have also suggested that the deltoid muscles have reduced activity in patients with subacromial impingement [Park et al., 2008; Reddy et al., 2000]. Ludewig et al., [2000] found that the upper and lower trapezius had more activation in patients with subacromial impingement versus healthy controls. However, our data indicate that the lower trapezius MVIC production is greater following a subacromial injection, suggesting that MVIC for the lower trapezius is influenced by pain. Further, this finding supports the necessity to normalize EMG data without pain. We found no change in upper trapezius activity following a subacromial injection. This finding supports evidence from the literature that upper trapezius may be compensating in patients with subacromial impingement and may not be inhibited by subacromial pain [Ludewig, P. M. et al., 2000]. Bandholm et al., [2006] found that patients with shoulder impingement had significantly greater latissimus dorsi activity than controls, supporting the pain adaptation model described by Lund et al., [1991]. We found that maximal

activation of the latissamus dorsi is unaffected by a subacromial injection, which did not support our hypothesis, nor did it support findings from the literature [Bandholm et al., 2006; Lund et al., 1991]. It is possible that patients did not alter their activity of the latissamus dorsi due to a lack of time to adapt a new movement strategy. Further, it is possible that activation of the latissamus dorsi was unaffected because patients still had mild pain following the injection.

With respect to normalization practices, our results indicate that percent activation (% MVIC) for the anterior deltoid and the lower trapezius were significantly overestimated when normalized to the painful MVIC condition (Table 4.1, Figure 4.2). This result suggests that previous reports may have over-estimated the contribution from these muscles [Bandholm et al., 2006; Lin et al., 2011; Ludewig, P. M. et al., 2000; Reddy et al., 2000]. In a study conducted by Myers et al., [2009] EMG were normalized by the mean activation of 10 arm elevation trial in patients with subacromial impingement. The author cautioned that normalization to a MVIC might be influenced by the impingement diagnosis. In a study conducted by Roy et al., [2009] EMG data from patients with subacromial impingement were normalized to a reference position which consisted of the mean EMG activity while holding the affected arm at a target location while holding a 1 kg weight. Other methods for EMG normalization for patients with subacromial impingement have been described [Lin et al., 2011]. Although these studies have taken measures to avoid the influence of pain on the normalization of EMG, the ability to compare and contrast between studies is obstructed by the differences in methodology. From several review articles on muscle activity in patients with impingement syndrome, the most commonly used normalization technique described in

the literature is with respect to a MVIC [Chester et al., 2010; Phadke et al., 2009]. Using similar methodologies for EMG normalization between studies aids researchers and clinicians to reach conclusions.

Limitations

This study does not address rotator cuff activity in patients with subacromial impingement. It is highly likely that pain has an influence on rotator cuff activity, specifically the supraspinatus as this muscle is most often affected by subacromial impingement [Michaud et al., 1987; Myers, J. et al., 2009; Neer, 1972; Reddy et al., 2000]. Indwelling electrodes are the most common method for accessing the rotator cuff muscular activity; however, due to patient and clinician time constraints our instrumentation was limited to surface electromyography.

Conclusions

Our study indicates that there is a problem with the current standard in EMG normalization with respect to a MVIC in patients with subacromial impingement. Due to this limitation, future researchers should be cautious when comparing muscle activation (EMG) between injured populations and healthy controls. Additionally, researchers should take advantage of reducing pain in the affected arm before making MVIC measurements.

MUSCLE RECRUITMENT AND PAIN

In the previous chapters we investigated the influence of subacromial pain on scapular kinematics and the ability to maximally contract shoulder muscles. The

kinematic shifts following removal of pain in chapter III, might represent a shift in neuromuscular control of shoulder and scapular stabilizing muscles. Previous studies comparing neuromuscular control between patients with shoulder pain and those without often normalized EMG data in the presence of pain. In chapter IV we explored the influence of normalization of EMG in the presence of pain. From this study we concluded that normalization to an MVIC in the presence of pain results in overestimation of the activation of a given muscle during an arm elevation task. We concluded that in order to make an accurate comparison between-individuals, normalization to an MVIC must be conducted without shoulder pain. In Chapter V we investigate the neuromuscular control of the shoulder joint in patients with subacromial impingement before and after removal of pain. Additionally, we use novel methodological approaches introduced in chapter IV, to normalize our EMG data

CHAPTER V

SHOULDER MUSCLE ACTIVITY IN PATIENTS WITH IMPINGEMENT BEFORE AND AFTER INJECTION

Co-authors include Dr. Matthew Shapiro for assistance in subject recruitment and Dr. Andrew Karduna for help with project conception.

INTRODUCTION

Activation of painful nociceptive receptors evokes neuromotor adaptations via inhibitory interneurons at the spinal cord level [Lund et al., 1991]. These mechanisms appear to decrease the activity of agonist muscles while simultaneously increasing antagonistic muscle activity, thus reducing the movement and/or velocity in the painful muscle. The implications of this model suggest that peripheral pain is an evolutionary mechanism that overrides motor movements, thus protecting the painful muscles from further injury. For the shoulder, experimentally induced subacromial pain results in a reduction of rotator cuff activation and strength [Diederichsen, L. et al., 2009; Stackhouse et al., 2012]. However, these findings may not be representative of clinical pain associated with shoulder injuries. In the case of subacromial impingement syndrome, peripheral pain may decrease agonist muscle activity, such as the rotator cuff during elevation of the arm. Several studies have documented that patients with subacromial impingement have reduced rotator cuff strength and isokinetic performance [Leroux et al., 1994; Reddy et al., 2000; Warner et al., 1990]. However, others report that patients

with impingement have greater rotator cuff activation when compared to healthy controls [Diederichsen, L. P. et al., 2009; Michaud et al., 1987].

For the rotator cuff, activation between 30º and 60º has been postulated to be rudimentary in maintaining the head of the humerus in an inferior position, where reductions in rotator cuff activity could result in superior humeral loading and increased subacromial contact pressure [Poppen et al., 1978]. Due to the importance of specific agonist muscle activity for maintaining shoulder health, neuromotor adaptations to pain may not be as simple as agonists being reduced and antagonists being increased. It is possible that muscles adapt to pain based on the their biological importance of the muscle relative to the task required [Kofler, 2003; Kofler et al., 2001]. This implies that in certain situations, the biological importance of the motor movement may outweigh the individual importance of specific muscle's wellbeing [Kofler, 2003; Kofler et al., 2001]. The implications of this second pain adaptation model suggest that maintaining mobility may be more important than the individual health of an injured muscle. Maintaining rotator cuff and scapular stabilizing musculature may be essential for maintaining overall shoulder health, but at the cost of further degeneration of the rotator cuff [Michaud et al., 1987; Soslowsky et al., 2002]. This model would oppose earlier pain adaptation models, which suggests an increase in antagonist and decrease in agonist activation in the presence of pain [Lund et al., 1991].

Suprascapular nerve block and cadaveric studies have shown that the deltoid muscles compensate during arm elevation when the supraspinatus is inhibited or torn [McCully et al., 2007; Oh et al., 2011]. This finding provides evidence that the deltoid can be used as a proxy for difficult to measure rotator cuff activation [Chester et al.,

2010], where greater deltoid activity may indicate reductions in rotator cuff activation [McCully et al., 2007; Oh et al., 2011]. However, there is disagreement in the literature pertaining to deltoid muscle activity in patients with impingement, where several studies suggest that patients have less deltoid activity during arm elevation than controls [Clisby et al., 2008; Michaud et al., 1987; Reddy et al., 2000], as opposed to data that suggest an increase in deltoid activity for these comparisons [Myers, J. et al., 2009]. In chapter IV we demonstrated that differences between studies could be methodological, where EMG activity is influenced by normalization in the presence of pain [Ettinger, 2013].

In addition to arm abductors, scapular stabilizers such as the serratus anterior and the trapezius muscle may have altered activity in patients with subacromial impingement. The serratus anterior and the lower trapezius, have been reported to have less activity in painful shoulders [Cools et al., 2003; Diederichsen, L. P. et al., 2009; Ludewig, P. M. et al., 2000; Peat et al., 1977; Scovazzo et al., 1991], although some studies have reported no significant differences in activity when compared to healthy controls [de Morais Faria et al., 2008; Finley et al., 2005]. Interestingly, experimentally induced pain resulted in heightened lower trapezius and activation of the serratus anterior [Diederichsen, L. et al., 2009]. While larger muscles such as the upper trapezius [Ludewig, P. M. et al., 2000; Peat et al., 1977] and the latissamus dorsi [Bandholm et al., 2006; Diederichsen, L. P. et al., 2009] appear to be compensating with more activity in painful shoulders versus healthy controls.

Local anesthetic injections to the subacromial space are commonly used to treat shoulder impingement syndrome and have been shown to significantly reduce shoulder pain [Alvarez et al., 2005; Ben-Yishay et al., 1994; Brox et al., 1997; Celik et al., 2009;

Yu et al., 2006]. Further, these injections have been shown to increase maximal internal and external rotation strength and arm abduction immediately following the injection [Ben-Yishay et al., 1994; Park et al., 2008]. This finding suggests that pain may be inhibiting muscles associated with arm abduction and rotation. Understanding the influence of clinical pain on shoulder muscle behavior in shoulder impingement may be important for rehabilitative strategies. To date, we are unaware of studies which have examined shoulder muscle activity during arm elevation in patients with subacromial impingement before and after injection of a local anesthetics. We hypothesize that a local anesthetic injection will result in increased activity of the deltoid, decreased activity of the upper trapezius and the latissamus dorsi and increased activity of the serratus anterior and the lower trapezius during elevation of the arm in patients with subacromial impingement syndrome.

METHODS

Twenty-one patients (13 males and 8 females) with impingement syndrome and twenty-one healthy control subjects were recruited for this study. Mean ± SD demographic data for patients were age, 55.6 years ± 8.3 years; height, 174.1 cm ± 7.9 cm; and weight, 78.6 kg ± 13.4 kg. Mean and ± SD demographic data for control participants which were matched within 5 years of age to a patient of the same gender and arm dominance (19 right handed individuals) were age, 54.4 years ± 8.9 years; height, 172.9 cm ± 9.4 cm; weight, 77.8 kg ± 15.1 kg. For the patient population, our inclusion criterion required a positive sign for at least 3 of the following 5 tests: Hawkins-Kennedy, Neer, painful arc, empty can (Jobe) and/or painful external rotation resistance. Patients having had shoulder surgery on the symptomatic side, a positive

Spurling test, traumatic shoulder dislocation or instability in the past 3 months, reproduction of shoulder pain with active or passive cervical range of motion, or signs of a rotator cuff tear (drop-arm test, lag signs, gross external rotation weakness assessed by a manual muscle test, or positive image findings) were excluded from this study. The experimental protocol was approved by the Institutional Review Board at the University of Oregon. Written and verbal instructions of testing procedures were provided, and written consent was obtained from each subject.

All EMG activity were normalized to a post-injection MVIC [Ettinger, 2013] . The MVIC for each muscle was performed post-injection during a 5 second contraction, where the amplitude of the contraction was determined by the RMS data over the peak activation during the middle 2 seconds of the muscle contraction. Each muscle's MVIC was determined in a unique testing position, with approximately 20 seconds of rest between testing of different muscles. More information on the specific MVIC testing procedures are reported in chapter IV.

In addition to MVIC testing, EMG activity was measured during an arm elevation task where patients were asked to complete three arm elevation trials. Each elevation trial consisted of the patient raising their affected arm in the scapular plane (30 degrees from the frontal plane) and returning along the same path to a count of four in each direction. Real-time feedback of the scapular plane was observed for each arm elevation trial. Trials were repeated when patient's arm elevation deviated from the scapular plane. All EMG data will was filtered between 10 – 1000 Hz before being passed through the analog to digital board.

Protocol

Each muscle, the anterior, middle and posterior deltoids, the upper and lower trapezius, the latissamus dorsi and the serratus anterior, were tested in a unique position as described from the literature and in greater detail in chapter IV.

The Fastrak magnetic tracking device (Polhemus, Colchester, VT) was used for collecting 3-D humeral and thoracic motion within the treatment room of patients receiving an anesthetic injection. The Polhemus unit consists of a transmitter, three receivers and a digitizer, all wired to a system electronics unit, which determines the relative orientation and position of the sensors in space (Figure 3.1). The transmitter serves as a global reference frame and was fixed to a rigid plastic base and oriented such that its coordinate axes aligned with the cardinal planes of the human body. The digitizer sensor was used to identify anatomical landmarks with respect to the global reference frame. After digitization, the arbitrary coordinate systems defined by the Polhemus was converted to anatomically appropriate coordinate systems based on the recommendations of the International Society of Biomechanics Committee for Standardization and Terminology [Wu et al., 2005].

Experimental Procedure

Once the digitization and calibration were completed, participants completed three arm elevation trials. Kinematic and EMG data were synchronized and collected continuously at a rate of 40 Hz and 1200 Hz respectively for the three trials, and then averaged for data analysis. Patients were asked to give their current shoulder pain level on an analog pain scale immediately after completing the shoulder elevation task.

Following the kinematic and EMG collection, patients received a subacromial injection of anesthetic (6 cc 0.5% bupivacaine with epinephrine and 3 cc lidocaine with epinephrine) and corticosteroid (1 cc 40mg methylprednisolone acetate) as part of their normal treatment. The procedure was completed by one of our co-authors (M.S) who is an orthopedic surgeon. Patients were then given a 15 minute adjustment period and were asked to move their arm in order to disperse the drug within the subacromial bursa. Following the adjustment period patients were asked to repeat their arm elevation task following the same procedure as before. No sensors were removed during the injection and the same calibration data was used when measuring kinematics post injection. Immediately following the post injection arm elevation task, patients were again asked to give their current shoulder pain level on an analog pain scale. Patients were blinded from their previous analog pain scale rating.

Statistical Analysis

To determine the differences in pain following treatment, paired t-tests were used between pre and post-injection VAS pain scores. To determine the influence of treatment on muscular activity, seven 2-way repeated measures ANOVA were used. Each muscle activation (percent MVIC) for the anterior, middle, posterior deltoid, latissamus dorsi, upper and lower trapezius and the serratus anteior were treated as unique dependent variables. Humeral elevation angle at four increments, 30, 60, 90 and 120 degrees were treated as the first independent variable and condition (pre-injection, post-injection) were treated as the second independent variable. For significant interactions, pairwise comparisons were performed using the least significant difference test (LSD). To compare the effect of treatment with respect to healthy controls, seven 2-way mixed

effects ANOVA's were used. Humeral elevation angle at four increments was treated as the repeated measures independent variable and group (post-injection impingement versus controls) was treated as the between-subjects factor. For significant interactions, pairwise comparisons were performed using the LSD.

RESULTS

All patients complained of pain during the clinical examination and during elevation of the arm. Following the subacromial injection, all patients reported a modest decrease in pain. A dependent samples t-test indicate a significant reduction in VAS pain scores before and after treatment ($p < 0.001$) where patients had an average reduction in pain of 65% (Figure 3.3).

Anterior Deltoid

No significant interaction was found between treatment and humeral elevation angle for anterior deltoid ($p = 0.209$). Significant main effects of treatment were found at all levels of elevation and a significant main effect of humeral elevation was detected where on average the pre-injection state of the deltoid required 31.5% of maximal activation during elevation and the post-injection state of the deltoid required 34.5% of maximal activation ($p = 0.017$ and $p = 0.001$, respectively). Comparing post-injection anterior deltoid activation for patients with impingement syndrome versus healthy controls, a significant interaction between humeral elevation angle and group (controls versus impingement population) was detected ($p=0.008$). *Post-hoc* pairwise comparisons indicate that significant differences were pronounced between groups at 90º of humeral

elevation (p = 0.019); where the impingement syndrome group had on average 11% greater anterior deltoid activation than controls (Figure 5.1).

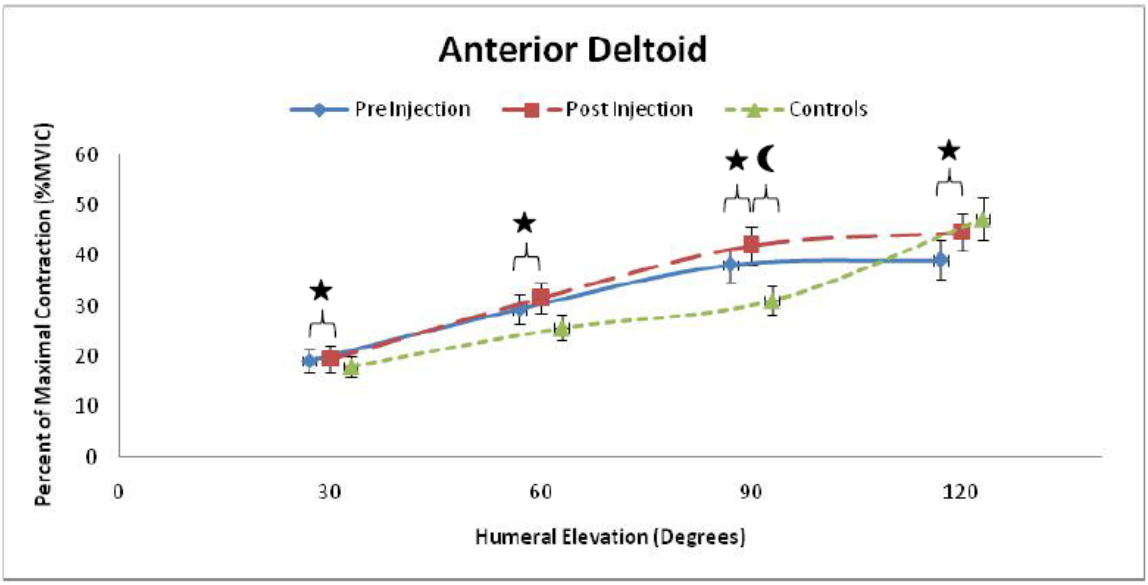

Figure 5.1. Activation of the anterior deltoid during arm elevation pre (blue, solid line) and post- (red, dashed line) anesthetic injection versus healthy controls (green, square dotted line). Significant differences for within-subject comparisons are denoted with ★ and significant differences for between-subject comparisons are denoted with ☾.

Middle Deltoid

A significant interaction was found between treatment and humeral elevation angle for middle deltoid (p=0.023). *Post-hoc* pairwise comparisons indicate that no significant differences occurred at 30º of elevation (p = 0.488); however following treatment, patients had on average 3.5% greater activation of the middle deltoid at 60º (p = 0.043), 4.9% greater activation at 90º (p = 0.05) and 7.3% greater activation at 120º (p = 0.014) of arm elevation. Comparing post-injection activation of the middle deltoid for patients with impingement syndrome versus healthy controls, a significant interaction between humeral elevation angle and group (controls versus impingement syndrome

population) was detected (p = 0.031). *Post-hoc* pairwise comparisons indicate that significant differences were pronounced between groups at 60º and 90º of humeral elevation (p = 0.05, p = 0.006 respectively); where the impingement syndrome group had on average 7.6% greater activation of the middle deltoid at 60º and 14.4% greater activation at 90º of arm elevation (Figure 5.2).

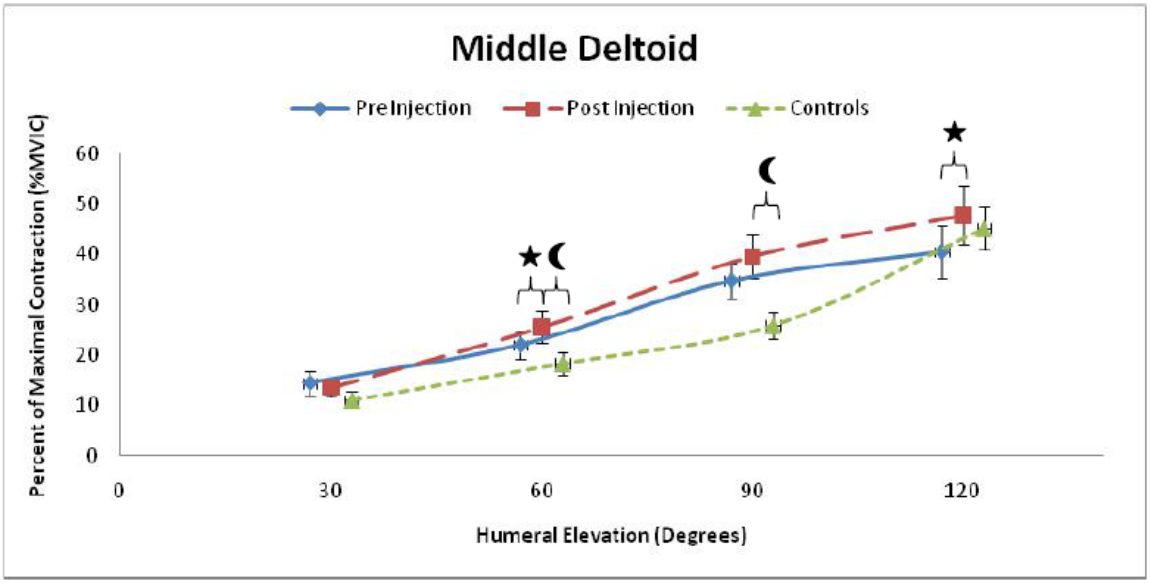

Figure 5.2. Activation of the middle deltoid during arm elevation pre (blue, solid line) and post- (red, dashed line) anesthetic injection versus healthy controls (green, square dotted line). Significant differences for within-subject comparisons are denoted with ★ and significant differences for between-subject comparisons are denoted with ☾.

Posterior Deltoid

No significant interactions were found between treatment and humeral elevation angle for the posterior deltoid (p = 0.107). No significant main effect of treatment was found (p =0 .052); however, a significant main effect of angle was found (p = 0.001). No

significant interactions (p = 0.246) or significant effects of group (p = 0.214) were detected between patients with impingement syndrome and healthy controls (Figure 5.3).

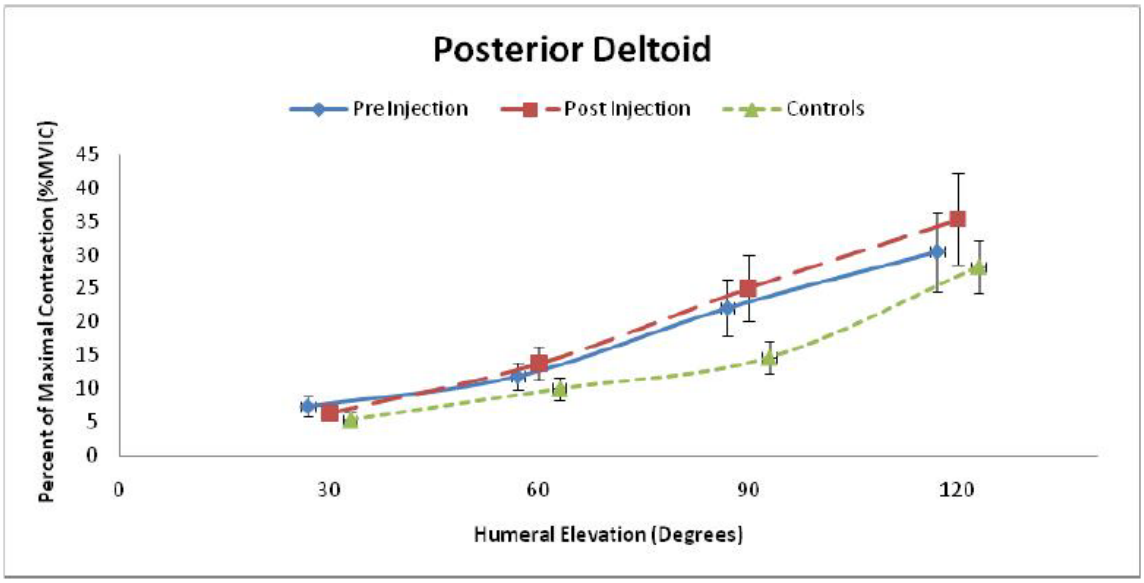

Figure 5.3. Activation of the posterior deltoid during arm elevation pre (blue, solid line) and post- (red, dashed line) anesthetic injection versus healthy controls (green, square dotted line).

Latissamus Dorsi

No significant interactions were found between treatment and humeral elevation angle for the latissamus dorsi (p = 0.980). No significant main effect of treatment were found (p = 0.091); however, a significant main effect of angle was found, where a linear increase in activation of the latissamus dorsi resulted with increased humeral elevation angle (p = 0.001). Comparing post-injection activation of the latissamus dorsi for patients with impingement syndrome versus healthy controls, a significant interaction between humeral elevation angle and group (controls versus impingement population) was detected (p = 0.028). *Post-hoc* pairwise comparisons indicate that significant differences were only pronounced between groups at 120º of humeral elevation (p =

0.041), where the control group had on average 13.0% greater activation of the latissamus dorsi at 120º than the impingement group post-injection (Figure 5.4).

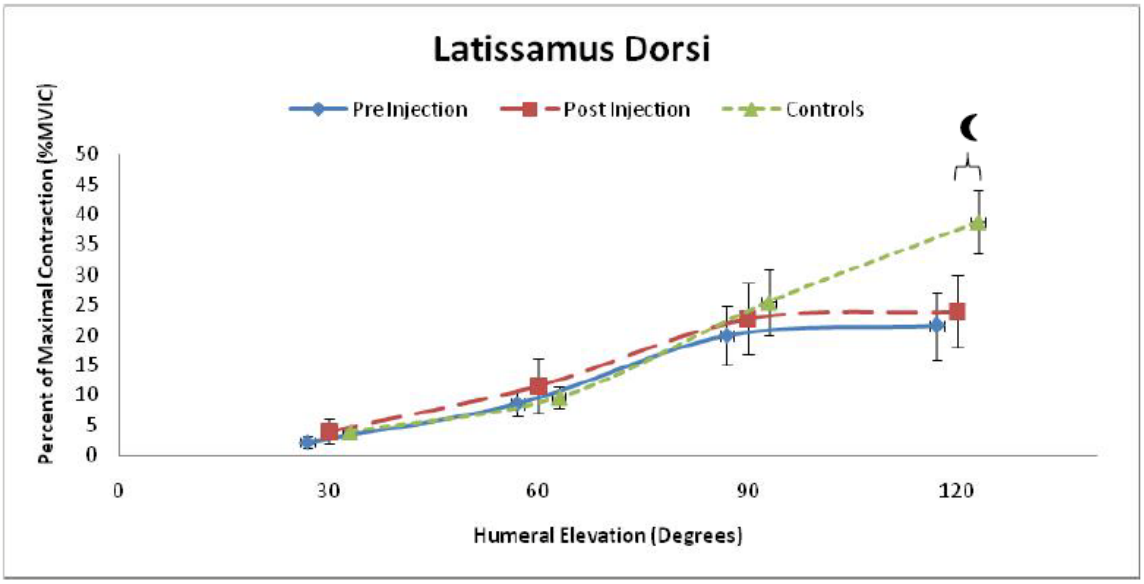

Figure 5.4. Activation of the latissamus dorsi during arm elevation pre (blue, solid line) and post-(red, dashed line) anesthetic injection versus healthy controls (green, square dotted line). Significant differences for between-subject comparisons are denoted with ☾

Upper Trapezius

A significant interaction was found between treatment and humeral elevation angle for the upper trapezius (p = 0.005). *Post-hoc* pairwise comparisons indicate that no significant differences occurred below 120º of elevation; however following treatment, patients had on average 14.5% greater activation of the upper trapezius at 120º of arm elevation. Comparing post-injection activation of the upper trapezius for patients with impingement syndrome versus healthy controls, a significant interaction between humeral elevation angle and group (controls versus impingement population) was detected (p = 0.041). *Post-hoc* pairwise comparisons indicate that significant differences were pronounced between groups at 30º, 60º, 90º but not 120º of humeral elevation (p = 0.019,

p = 0.001, p = 0.001, p = 0.280 respectively); where the impingement group had on average 8.9% greater activation of the upper trapezius at 30º, 15.9% greater activation at 60º, 19.5% greater activation at 90º of arm elevation (Figure 5.5).

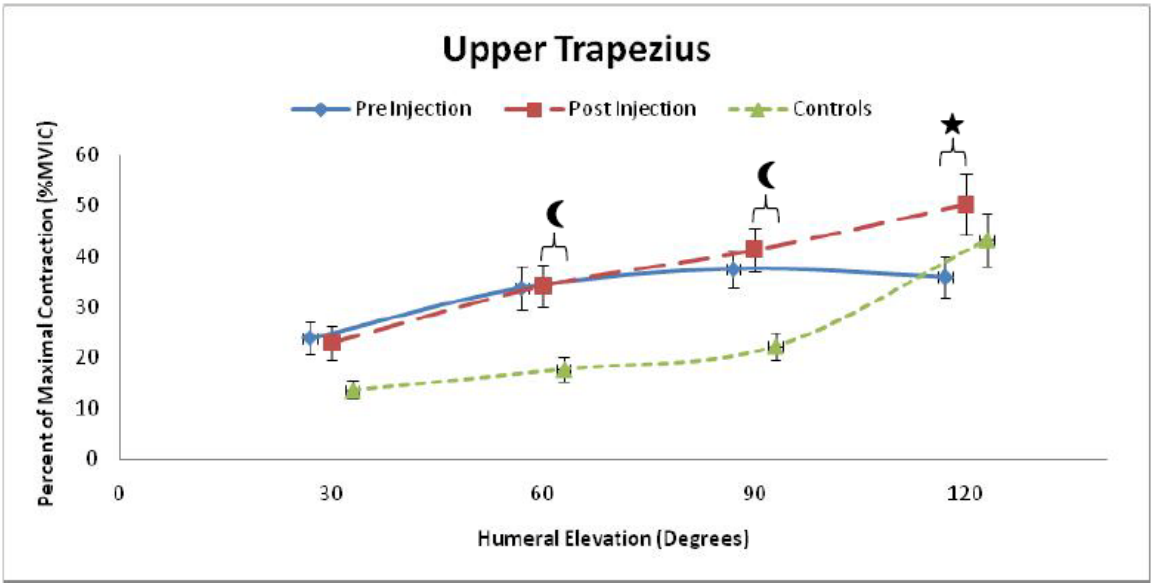

Figure 5.5 Activation of the upper trapezius during arm elevation pre (blue, solid line) and post- (red, dashed line) anesthetic injection versus healthy controls (green, square dotted line). Significant differences for within-subject comparisons are denoted with ★ and significant differences for between-subject comparisons are denoted with ☾.

Lower Trapezius

No significant interactions were found between treatment and humeral elevation angle for the lower trapezius (p = 0.651). No significant main effect of treatment was found (p = 0.100); however, a significant main effect of angle was found (p = 0.001). When comparing post-injection activation of the lower trapezius with respect to healthy controls, we detected a violation of sphericity, therefore for subsequent analysis Greenhouse-Geisser corrections were used. No significant interactions (p = 0.063) or significant effects of group (p = 0.831) were detected between patients with impingement

and healthy controls; however, a significant effect of angle was detected (p = 0.001) (Figure 5.6).

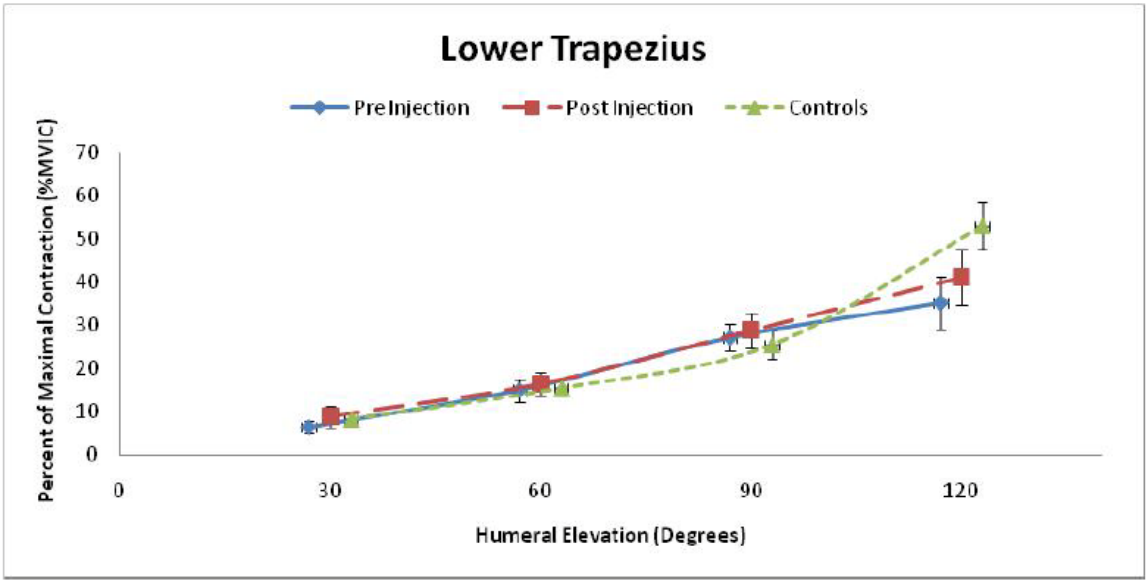

Figure 5.6. Activation of the lower trapezius during arm elevation pre (blue, solid line) and post-(red, dashed line) anesthetic injection versus healthy controls (green, square dotted line).

Serratus Anterior

No significant interactions were found between treatment and humeral elevation angle for the serratus anterior (p = 0.715). No significant main effect of treatment was found (p = 0.143); however, a significant main effect of angle was found (p = 0.001). When comparing post-injection activation of the serratus anterior to healthy controls no significant interactions (p = 0.278) or significant effects of group (p = 0.713) were detected between patients with impingement syndrome and healthy controls; however, a significant effect of angle was detected (p = 0.001) (Figure 5.7).

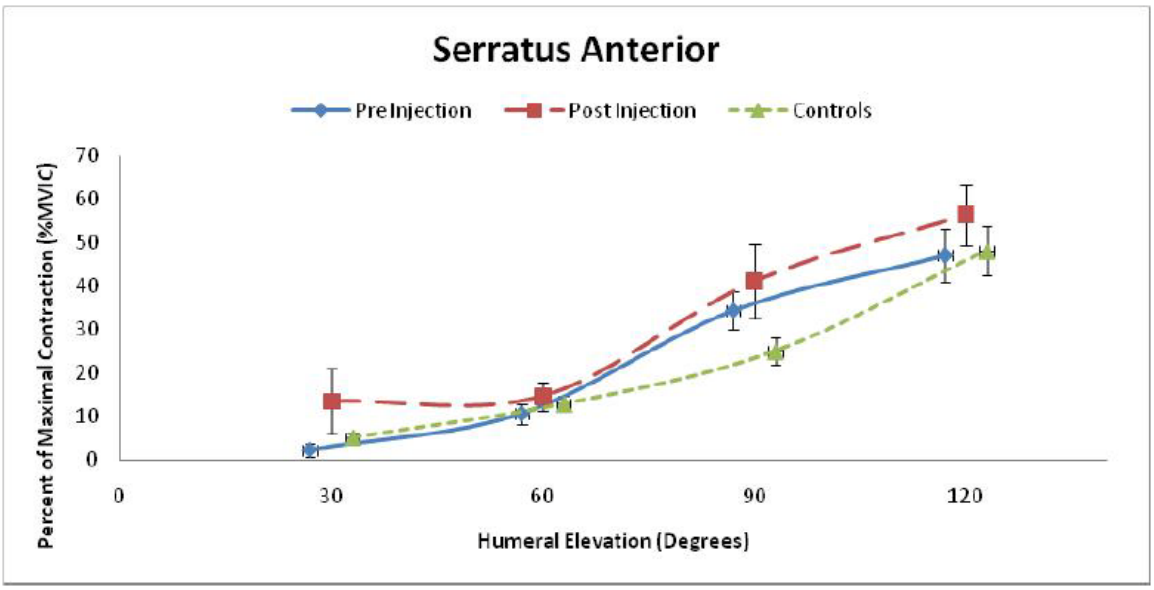

Figure 5.7. Activation of the serratus anterior during arm elevation pre (blue, solid line) and post-(red, dashed line) anesthetic injection versus healthy controls (green, square dotted line).

DISCUSSION

Our study is the first to examine scapular and humeral muscle activations during arm elevation in patients with subacromial impingement before and after reduction in pain via an anesthetic injection. We hypothesized that an anesthetic injection in patients with Stage 2 impingement syndrome would result in increased activity of the deltoid. Additionally, we hypothesized that the muscle activations for each muscle post-injection would be indistinguishable from muscle activations of healthy control subjects. For the deltoid muscles our hypothesis was partially supported. Following the anesthetic injection and during elevation of the arm, the anteior and middle heads of the deltoid increased. For the anterior deltoid, the magnitude of the increase in activation went from an average of 31.5% activation pre-injection to 34.5% activation post-injection for all humeral angles. For the middle deltoid, the increase in activity was observed only at 60º,

90º and 120º of elevation where the magnitude of the increased deltoid activity post-injection was greater at higher elevation angles (Figure 5.1 and 5.2). In general, our results indicate that the deltoid may be inhibited by pain as suggested by others [Clisby et al., 2008; Michaud et al., 1987]. Using the deltoid as a proxy for rotator cuff activation [McCully et al., 2007; Oh et al., 2011], our results suggests that in the presence of pain (pre-injection) the rotator cuff activation may be attenuated with respect to controls, which agrees with findings in the literature [Clisby et al., 2008; Michaud et al., 1987; Reddy et al., 2000]. However, contrary to our hypothesis, activation of the anterior and middle deltoid was greater post-injection when compared to healthy controls. This finding suggests that following treatment, rotator cuff activity may be further attenuated when compared to healthy controls [McCully et al., 2007; Oh et al., 2011]. Mismatches in deltoid and rotator cuff activation may be related to reductions in acromiohumeral distance [Alpert et al., 2000; Bandholm et al., 2006; Deutsch et al., 1996; Myers, J. et al., 2009; Poppen et al., 1978]. The trends for the posterior deltoid, although not significant, were similar to the anterior and middle heads of the deltoid (Figure 5.3), it is possible that we were underpowered to detect differences for this muscle.

In the presence of pain, antagonist muscles generally have heightened activation [Lund et al., 1991]. Activation of the latissamus dorsi during arm elevation reduces movement velocity and could potentially depress the head of the humerus in patients with impingement [Bandholm et al., 2006]. We hypothesized that activation of the latissamus dorsi would be greater in patients versus healthy controls and would be reduced following a subacromial anesthetic injection. However, our results do not support our hypothesis, as we found no influence of an anesthetic injection on percent activation of

the latissamus dorsi during elevation of the arm. Additionally, we found that at120º of humeral elevation, healthy control subjects had on average 13% (of maximum) greater activation of the latissamus dorsi than patients with impingement (Figure 5.4). Our findings are somewhat at odds with the literature, where others have demonstrated greater activation of the latissamus dorsi than controls between 40-55º of humeral elevation during an isokinetic force matching tasks [Bandholm et al., 2006]. It is possible that the latissamus dorsi is recruited differently during force matching tasks than in the unconstrained arm elevation paradigm implemented in our study. In a study conducted by Diederichsen et al., [2009] experimentally induced subacromial pain resulted in increased activation of the latissamus dorsi, which fits the pain adaptation model described by Lund et al., [1991] where antagonist muscles are augmented in the presence of pain. In the current study, patients had less antagonist muscle activation during arm elevation, which does not agree with the findings of others [Diederichsen, L. et al., 2009; Lund et al., 1991]. However, adaptations to clinical subacromial pain could be different than experimental pain based on the intensity of the nociceptive stimulus [Leis et al., 2000], the rate of adaptation to the stimulus [Kofler, 2003; Leis et al., 2000], the expectation of pain during arm elevation [Dube et al., 2011] and the degree of structural damage and substance P within the subacromial bursa [Gotoh et al., 1998].

Our results for the upper trapezius agree with previous reports that patients with impingement have greater activation of the upper trapezius when compared to healthy controls [de Morais Faria et al., 2008; Lin et al., 2005; Ludewig P, 2000; Peat et al., 1977]. We predicted a decrease in muscle activity following the anesthetic injection; however, our results indicate a 14.5% (of maximum) increase in activation as the arm

was elevated to 120º (Figure 5.5). Our results suggest that with a reduction in pain, activation of the upper trapezius increases. Our results support the findings from Diederichsen et al., [2009] where painful hypertonic saline injections resulted in decreased activation of the upper trapezius. Together, these findings suggest that the upper trapezius responds to changes in pain; however, the direction of these changes is not consistent with the adaptations observed between patients with subacromial impingement and healthy controls. Therefore an alternative mechanism other than pain might explain the heightened activation of the upper trapezius. Several ergonomic studies suggest that an overactive recruitment of the upper trapezius may be associated with shoulder injuries [Hanvold et al., 2013; Szeto et al., 2005]. Therefore, it is possible that overactive recruitment of the upper trapezius precedes the development of impingement syndrome.

We predicted that patients with impingement would have less activation of the lower trapezius and the serratus anterior when compared to healthy controls and would have increased activation following a local anesthetic injection. Contrary to our hypothesis, patients with impingement did not demonstrate reductions in activation when compared to controls. Additionally, we did not observe changes in muscle activation following the subacromial injection (Figure 5.6 and 5.7). The lower trapezius and the serratus anterior may have an influence on maintaining the acromiohumeral distance by posteriorly tilting the scapula and aiding the scapula in upward rotation [Ludewig P, 2000]. However, variable findings have been reported for activation of the lower trapezius and the serratus anterior, where some studies have found that patients with painful shoulders have less activation of the lower trapezius [Cools et al., 2003] and the

serratus anterior [Lin et al., 2011; Ludewig P, 2000; Peat et al., 1977] than in healthy shoulders, whereas others report no differences in activation of the lower trapezius and/or the serratus anterior [Bandholm et al., 2006; de Morais Faria et al., 2008; Finley et al., 2005]. We previously reported that the methodology in previous studies often relies on normalization to an MVIC which can be influenced by subacromial pain (chapter IV). Further, we have previously found that the lower trapezius was especially sensitive to the normalization method. Therefore, differences between our results and others, may be due to the methodological limitations of previous studies.

Limitations

We used deltoid function as a proxy for rotator cuff activation; however, indwelling electrodes are the most common method for accessing the rotator cuff muscular activity directly [Michaud et al., 1987; Reddy et al., 2000]. We opted away from using indwelling electrodes due to the time requirement in instrumentation, where all of our measurements were made in the clinic and needed to be performed in a timely manner. Another limitation in our experiment was that there was no randomization of the treatment protocol and the control group received no treatment.

Conclusions

We demonstrate altered shoulder muscle recruitment before and after pain reduction via an anesthetic injection. Our results suggest that pain influences shoulder muscle recruitment; however, simply reducing pain does not restore muscle recruitment patterns to healthy control levels. In most cases, our results show the opposite, where the

anesthetic injection resulted in further deviation from healthy control data in patients with impingement. These findings may represent an acute adaptation to a "pain free" shoulder. Future studies should examine the longitudinal influences of pain reduction on shoulder muscle function.

PAIN AND MOTOR CONTROL

In chapter II we investigated proprioceptive acuity in dental hygienists before and after the workday. We concluded that dental hygienists have similar acuity at the beginning and end of the workday; however, dental hygienists who complained of shoulder pain had greater proprioceptive deficits than dental hygienists without pain. These deficits noted in the pain group could be due to competitive integration of multiple sensory signals i.e. pain and proprioception. For afferent signals traveling to the brain, slower traveling pain signals can be competitively inhibited by faster traveling mechanoreceptive signals such as touch and vibration [Moayedi et al., 2013]. However, it is unknown if pain disrupts proprioceptive processing or signaling. The sixth chapter of this dissertation will investigate proprioceptive acuity during pain and after the removal of pain in patients with impingement. In addition, proprioception from adjacent joints will be investigated and compared with healthy controls.

CHAPTER VI

PROPRIOCEPTIVE ACUITY IN PATIENTS WITH IMPINGEMENT BEFORE AND AFTER INJECTION

Co-authors include Dr. Matthew Shapiro for assistance in subject recruitment and Dr. Andrew Karduna for help with project conception.

INTRODUCTION

Shoulder impingement syndrome is one of the most commonly reported musculoskeletal complaints, typically affecting adults between the ages of 45 - 65 years of age [van der Windt et al., 1995]. Patients with impingement typically present with loss of arm function and pain, which is intensified with elevation of the arm [Neer, C. S., 1983]. Other symptoms of impingement include altered scapular kinematics and scapular muscle recruitment during arm elevation [Lin et al., 2011; Ludewig, P. M. et al., 2000; Lukasiewicz et al., 1999; McClure et al., 2006; Michaud et al., 1987; Reddy et al., 2000]. Neuromuscular control of the shoulder joint is vital for maintaining shoulder stability and overall shoulder health [Lephart et al., 1994; Niessen et al., 2008; Riemann et al., 2002a, 2002b]. In monkeys, damage to the dorsal root reduces proprioceptive input to the somatosensory system, which results in movement disorders [Vierck, 1982]. It is possible that patients with shoulder impingement have proprioceptive deficits which influence muscle behavior and kinematic movement patterns for the shoulder [Anderson et al., 2011; Bandholm et al., 2006; Camargo et al., 2009; Haik et al., 2013; Machner, 2003; Maenhout et al., 2001].

Non-noxious mechanical stimuli and noxious stimuli activate mechanoreceptors and nociceptors respectively. Both afferent pathways are ultimately integrated by higher brain centers and can influence motor output where painful stimuli have been shown to inhibit the primary motor cortex [Valeriani et al., 1999] and proprioceptive stimuli influences motor cortical activity as well [Weiller et al., 1996]. Histological studies have indicated that a large concentration of noxious and non-noxious nerve endings terminate within the subacromial bursa, especially on the anterior side next to the coracoacromial ligament [Ide et al., 1996]. However, in patients with subacromial impingement, fewer sensory nerve endings were found in the coracoacromial ligament than in other healthy populations [Morisawa, 1998]. It is unknown what the contribution of these nerve endings in the subacromial bursa are with respect to shoulder proprioception. In a study conducted by Zuckerman et al., [1999] subacromial anesthetic injections had no influence on joint position sense or kinesthetic sense in healthy individuals, suggesting that sensory receptors in the subacromial bursa have minimal influence on proprioception

Six studies have investigated proprioception in patients with impingement syndrome. The modalities of proprioception accessed in patients with impingement syndrome vary from kinesthesia [Machner, 2003], to force steadiness [Bandholm et al., 2006; Camargo et al., 2009; Maenhout et al., 2001] and recently to joint position sense tasks [Anderson et al., 2011; Haik et al., 2013]. Differences between patients with impingement syndrome and controls have been reported for kinesthetic sense, where the detection of movement threshold was higher in the impingement syndrome group than controls and improved following acromion decompression surgery [Machner, 2003]. No differences were found between those with impingement syndrome and controls for joint

angle matching tasks in medial and lateral rotation [Haik et al., 2013], but were found in elevation tasks where higher elevation angles resulted in worse proprioceptive acuity in the impingement syndrome group [Anderson et al., 2011]. Patients have greater difficulty performing isokinetic and concentric abduction force steadiness tasks than controls [Bandholm et al., 2006; Maenhout et al., 2001] and consistently overshoot their target in external rotation [Maenhout et al., 2001]; but have no difficulty performing isometric abduction force steadiness tasks [Bandholm et al., 2006; Camargo et al., 2009]. Therefore, it is possible that not all modalities of proprioception are influenced the same for patients with impingement syndrome and may depend on humeral angle. Previous studies have found that joint position accuracy improves linearly from low to high arm angles, peaking at 90º of elevation in healthy individuals for the shoulder [Anderson et al., 2011; Hyler, 2013; Suprak et al., 2006b; Zuckerman et al., 1999] and similarly for the elbow [Hyler, 2013]. However for patients with impingement, the influence of joint angle on accuracy may be disrupted [Anderson et al., 2011]. It is possible that this disruption in accuracy is associated with pain, which is intensified by elevation of the arm.

Several studies compared proprioception of the symptomatic shoulder versus the contralateral asymptomatic shoulder [Anderson et al., 2011; Machner, 2003; Maenhout et al., 2001]. Maenhout et al., [2001] investigated precision and consistency between the symptomatic and asymptomatic sides and found greater errors in the symptomatic side versus healthy controls, suggesting a systemic proprioceptive deficit. Although not significant, asymptomatic arms tended to have greater errors than healthy controls and were less sensitive to the influence of angle during position sense tasks [Anderson et al.,

2011]. No comparisons were made to controls in the study by Machner et al., [2003] but Warner et al. [1996] reported similar proprioceptive errors after surgery compared to healthy controls. Anatomic factors, such as acromial morphology are associated with impingement and tend to be found bilaterally [Nicholson et al., 1996], while supraspinatus tendon girth tends to be greater in both symptomatic and asymptomatic shoulders versus healthy controls [Barisic et al., 2006]. Therefore, the asymptomatic arm may suffer from similar proprioceptive deficits as the control arm based on the anatomy and physiology of the joint. Hyler et al., [2013] recently demonstrated that adjacent joints demonstrate similar proprioceptive acuity and are both sensitive to angles with maximal sensitivity around 90º for both the shoulder and elbow. To assess if proprioceptive deficits are systemic, multiple joints should be investigated in patients with joint pathology.

To date, no study has investigated the influence of subacromial pain reduction on shoulder proprioception. Furthermore, no study has investigated proprioceptive acuity of peripheral pain reduction on adjacent joints. We hypothesize that joint position errors will be greater in magnitude for the patient population versus controls and accuracy will be less sensitive to changes in arm angle. However, following a reduction in pain, we hypothesize that the magnitude of errors will decrease and patients will have a linear response with decreasing errors with respect to arm angle. Further, we hypothesize that no differences in errors of magnitude or arm angle will be detected by group or condition (injection) for the elbow.

METHODS

Seventeen patients with stage 2 subacromial impingement and seventeen healthy control subjects were recruited for this study. Patients had an average age of 50.1 (± 10.6) years. Healthy controls participants had an average age of 52.2 (± 10.0) years. Control subjects were matched within 5 years of age to a patient of the same gender and arm dominance. For the patient population, inclusion criteria were a positive sign for at least 3 of the following 5 tests: Hawkins-Kennedy, Neer, painful arc, empty can (Jobe) and/or painful external rotation resistance [Michener et al., 2009]. Patients having had shoulder surgery on the symptomatic side, a positive Spurling test, traumatic shoulder dislocation or instability in the past 3 months, reproduction of shoulder pain with active or passive cervical range of motion, or signs of a rotator cuff tear (drop-arm test, lag signs, gross external rotation weakness assessed by a manual muscle test, or positive image findings) were excluded from this study. The experimental protocol was approved by the Institutional Review Board at the University of Oregon. Written and verbal instructions of testing procedures were provided, and written consent was obtained from each subject prior to testing. Following the orthopedic evaluation, patients were asked to indicate their worse shoulder pain level on a visual analog pain scale (VAS).

After the study protocol, patients received a subacromial injection of anesthetic (6 cc 0.5% bupivacaine with epinephrine and 3 cc lidocaine with epinephrine) and corticosteroid (1 cc 40mg methylprednisolone acetate) as part of their normal treatment. The procedure was completed by one of the co-authors (M.S) who is an orthopedic surgeon. Patients were then given a 15 minute adjustment period and were asked to move their arm in order to disperse the drug within the subacromial bursa. The diagnostic

special tests were repeated and patients were again asked to report their shoulder pain level during the clinical tests on a VAS. Patients were blinded from their previous VAS submission. Following the adjustment period, patients were asked to repeat the study protocol. No sensors were removed for the injection and the same calibration data was used from the previous study protocol.

Instrumentation

The Fastrak magnetic tracking device (Polhemus, Colchester, VT) was used for collecting 3-D *in-vivo* kinematics of the shoulder and forearm. The Polhemus unit consists of a transmitter, three custom "break-away" receivers and a digitizer, all wired to a system electronics unit, which determines the relative orientation and position of the sensors in space. The break-away receivers allowed for disconnection between the polhemus unit and the sensor without removing the sensor from the subject (Figure 3.1). The transmitter served as a global reference frame and was fixed to a rigid plastic base and oriented such that its coordinate axes aligned with the cardinal planes of the human body. The digitizer sensor was used to identify anatomical landmarks with respect to the global reference frame. After digitization, the arbitrary coordinate systems defined by the Polhemus was converted to anatomically appropriate coordinate systems. The anatomical coordinate system for the thorax was based on the recommendations of the International Society of Biomechanics Committee for Standardization and Terminology [Wu et al., 2005]. Using the scapular and forearm sensors, motion of the humerus and forearm were tracked following the protocols established by Lin et al., [2012].

Three “break-away” receivers were placed on anatomical segments for the duration of the study, and each receiver was detached from its cable during the treatment phase (Figure 3.1). The first receiver was placed on the sternum at the level of the manubrium, just inferior to the jugular notch. The receiver was taped into place using double sided adhesive tape, with an additional layer of tape on top of the receiver which helped secure the device to the skin. The second receiver was placed on the dorsum of the wrist using double sided tape and elastic sports tape. The third receiver was placed over the scapula after mounting it on a custom scapular tracking device machined from plastic (Karduna et al. 2001). This tracker was attached to the scapular spine and posterior-lateral acromion with Velcro (Figure 3.1). All kinematic data were represented using standard Euler angle sequences for plane, elevation and external rotation of the humerus, and flexion, supination and carrying angle for the elbow [Wu et al., 2005]. For the current study, only shoulder elevation and elbow flexion angles were used.

For digitization and testing, subjects sat on a stool to help stabilize their thoracic posture. After digitization, subjects were outfitted with a head mounted display (Z800, eMagine, Bellevue, WA) which allowed the subjects to see a virtual representation of their arm position, while preventing visual feedback from their hand or the outside environment (Figure 6.1). The predetermined target angles were 50°, 70°, and 90° for either elbow flexion or shoulder elevation in the sagittal plane. All targets were repeated four times and were presented in random order. The order of joint testing (shoulder and elbow) was randomized. To avoid fatigue, subjects were given a five second rest break between each trial. Practice trials were completed prior to testing until subjects indicated competency with the protocol. Subjects were guided to each target angle using a custom

LabView program (National Instruments, Austin, TX). The center of the head mounted display contained two fixed, parallel white lines that represented a ± 1° boundary with respect to the target. Subjects elevated their arm or flexed their elbow with their thumb pointed upwards and their arm in the sagittal plane, until a red line, which represented real-time feedback of their limb, appeared on the screen. Subjects placed the red line between the two fixed white lines, indicating target acquisition (Figure 6.1). Once in this position, subjects were instructed to "memorize the location of your hand in space" for three seconds. The virtual representation then disappeared and the subject was then instructed to "relax your arm by your side". After five seconds with their arm by their side, the computer program instructed the subject to "return your arm to the target position". After the subject returned to where they thought their arm had previously been, they indicated to the researcher by saying "here", the researcher then marked this position for later analysis.

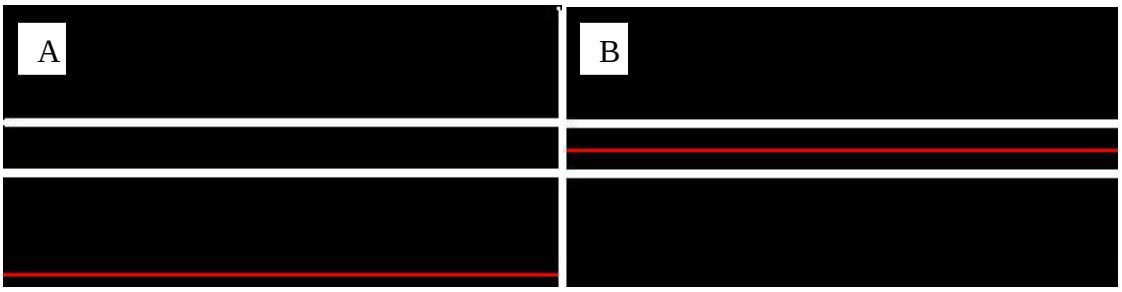

Figure 6.1. Virtual representation of the arm (red line) with respect to the target position (space between the white lines). Left figure (A), demonstrates the arm moving towards the target, and the right figure (B), represents the arm within the target field.

To evaluate accuracy and precision of the joint position sense task, the angular difference between the positioned and repositioned position (± 1º of target angle) was

calculated for each target. The constant error was calculated from the average of the angular deviations for each group of targets 50°, 70°, and 90° and represents the angular accuracy and directional bias [Schmidt, 1999]. The variable error (precision) was calculated from the standard deviation for the same group of targets and represents the individuals consistency during the angle matching task [Schmidt, 1999]. Constant and variable errors are used in concert to give a representation of overall joint position sense [Hyler, 2013].

Statistical Analysis

SPSS version 21.0 (IBM, Chicago IL) was used for statistical analysis. For differences in VAS pain scores, a dependent samples t-test was run on pre and post-injection pain scores.

Constant error (accuracy)

To test for linear influences of angle on constant errors, three separate one-way ANOVAs (pre, post-injection and controls) were run using *a priori* linear contrasts for both the shoulder and elbow. To test for the differences in magnitude of constant errors, we averaged data by target angle and performed dependent samples t-tests for the impingement group before and after injection and independent samples t-tests for differences between impingement groups with respect to controls for the shoulder and elbow.

Variable error (precision)

To test for consistency in target matching, we performed two-way repeated measures ANOVAs with variable error as the dependent variables for the shoulder and elbow. Target angle (50, 70 and 90 degrees) and condition (pre and post-injection) were the independent variables. Additionally, we performed two-way mixed effects ANOVAs to compare post-injection versus controls group for variable errors as the dependent variables for the shoulder and elbow. Target angle (50, 70 and 90 degrees) and group (post-injection versus controls) were the independent variables. For all statistical tests, alpha was set to 0.05. Pairwise comparisons were performed where significant interactions and main effects were found using the least significant difference (LSD) test.

RESULTS

VAS pain scores marked a significant ($p < 0.001$) 72% reduction in pain post-injection (Figure 6.2).

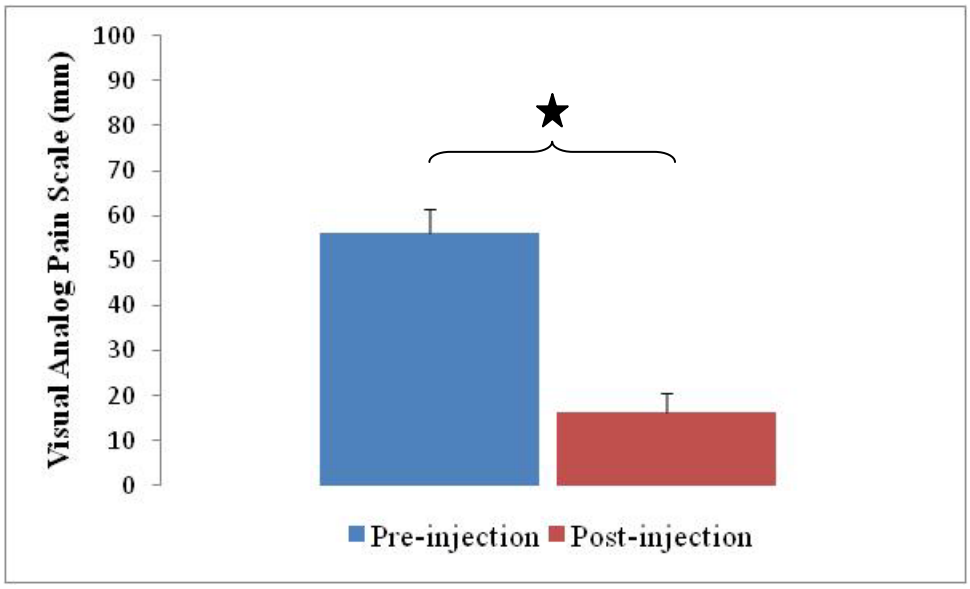

Figure 6.2. Visual analog pain scores (mm) pre and post-injection with standard errors. Significant differences are represented with ★.

We ran three (pre and post-injection and healthy controls) *a priori* one-way ANOVA tests with linear contrast for constant errors for the shoulder and elbow. For the shoulder, pre-injection linear contrasts were not significant ($p = 0.07$); however, the contrasts were significant for the elbow pre-injection ($p = 0.02$). Post-injection, no significance was found for the shoulder ($p = 0.128$); however, significance was detected for the elbow ($p < 0.001$). For controls, linear contrasts were significant for the shoulder ($p < 0.001$) and elbow ($p < 0.001$) (Figure 6.3 and 6.4).

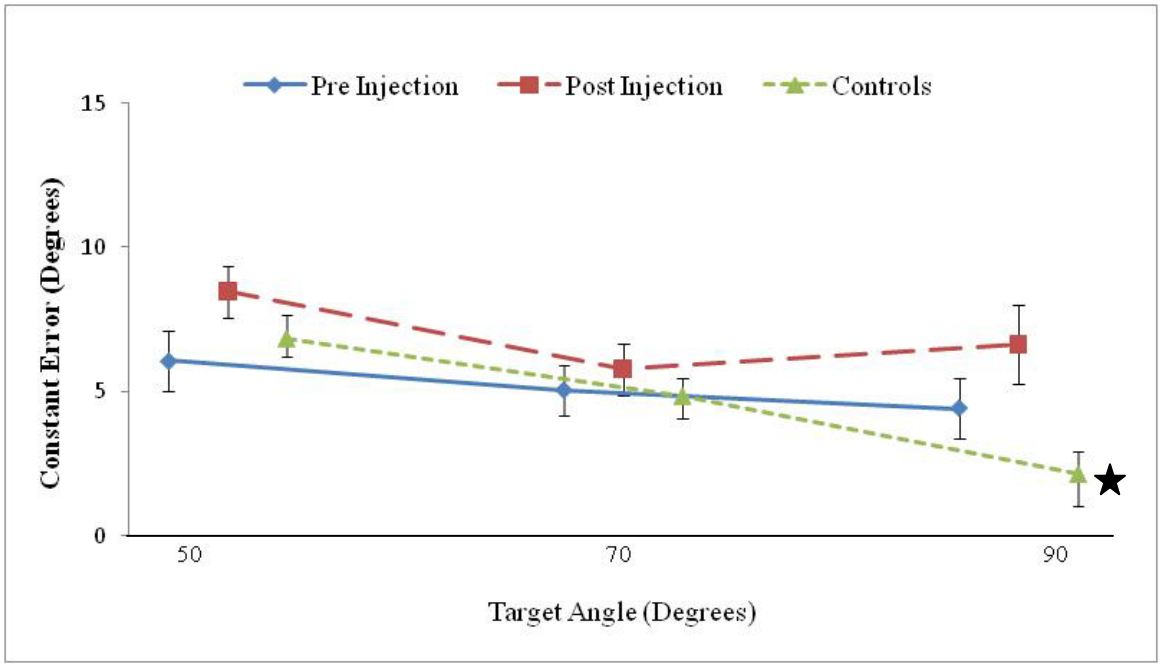

Figure 6.3. Linear contrasts for constant error for the shoulder (degrees) pre (blue, solid line) and post - (red, dashed line) injection and healthy controls (greed, square dotted line). Significance for linear contrasts tests is represented by ★.

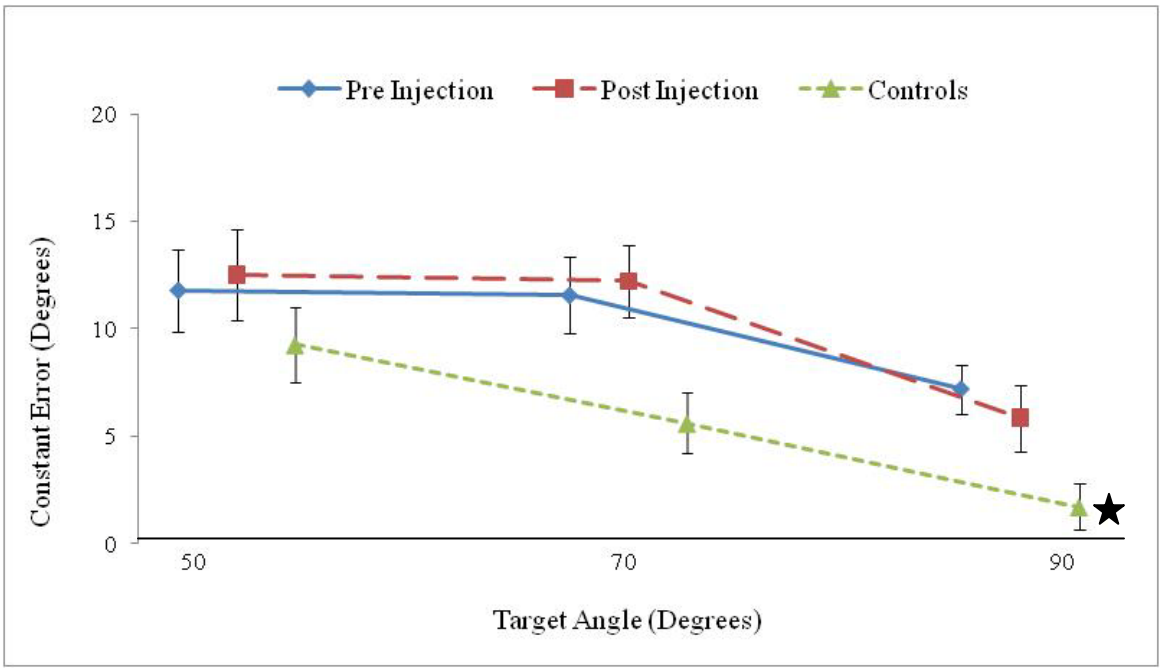

Figure 6.4. Linear contrasts for constant error for the elbow (degrees) pre (blue, solid line) and post- (red, dashed line) injection and healthy controls (greed, square dotted line). Significance for linear contrasts tests is represented by ★.

Results of our dependent samples t-test indicate that shoulder constant errors were on average 34% greater post-injection than pre-injection ($p = 0.042$); however, no changes were observed for the elbow ($p = 0.991$). Our independent samples t-tests indicate that pre-injection errors at the shoulder did not differ significantly from controls ($p = 0.510$); however, mean errors at the elbow were 46% greater for the patient population ($p = 0.018$). Independent samples t-tests for post-injection errors versus controls indicate that errors were 34% greater post-injection for the shoulder ($p = 0.038$) and were 46% greater post-injection for the elbow ($p = 0.031$) (Figure 6.5).

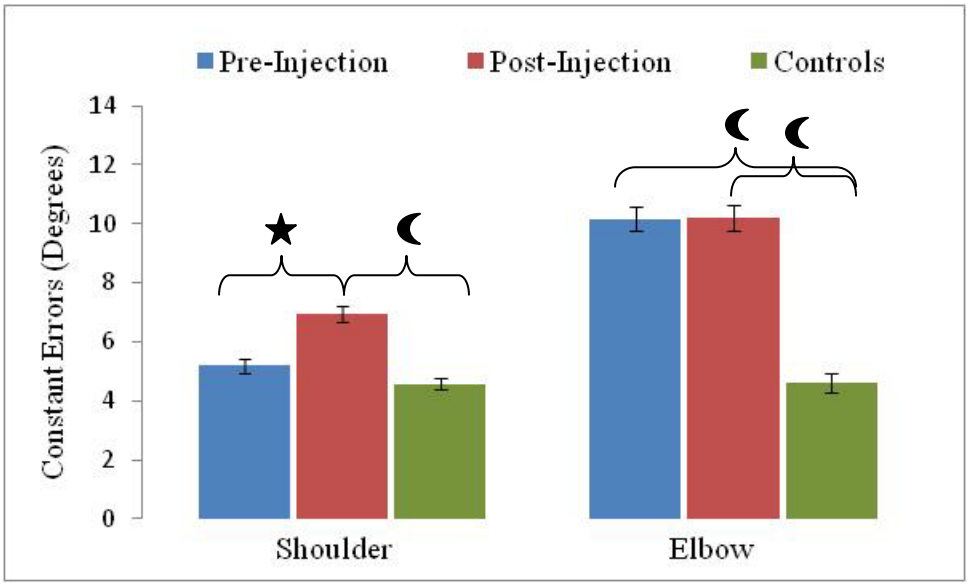

Figure 6.5. Magnitude of constant error (degrees) for the shoulder (left) and elbow (right), pre (blue) and post- (red) injection and healthy controls (green). Significance for paired samples is represented by ★. Significance for independent samples is represented by ☾.

For variable errors at the shoulder there was no significant interaction ($p = 0.211$) or main effects of injection ($p = 0.859$), nor was there any significant influence of target angle ($p = 0.724$). When compared to controls, post-injection variable errors were on average 62% greater for all angles ($p < 0.001$) (Figure 6.6). For variable errors at the elbow there were no significant interactions ($p = 0.276$) or main effects of injection ($p = 0.069$), nor were there any significant influences of target angle ($p = 0.106$). When compared to controls, post-injection variable errors were on average 80% greater for all angles ($p < 0.001$) (Figure 6.7).

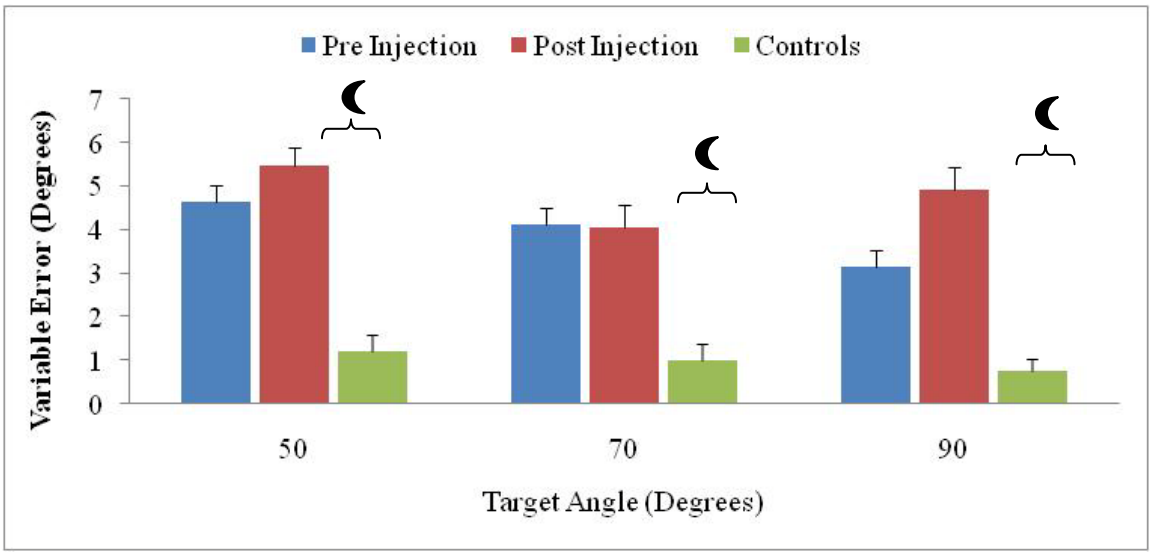

Figure 6.6. Variable error for the shoulder (degrees) pre (blue, solid line) and post- (red, dashed line) injection versus healthy controls (greed, square dotted line). Significant differences for between subject-comparisons are denoted with ☾.

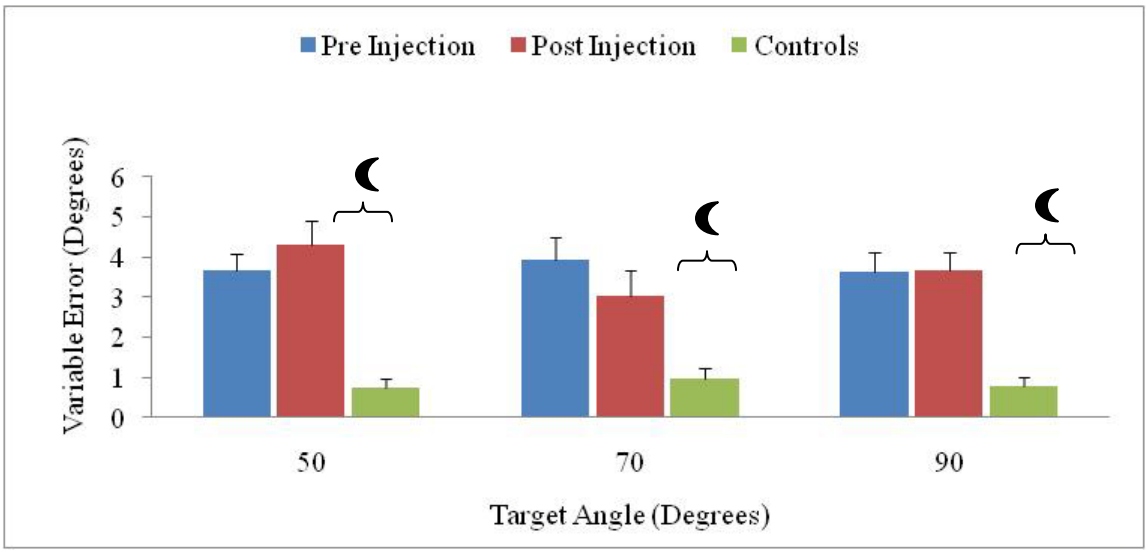

Figure 6.7. Variable error for the elbow (degrees) pre (blue, solid line) and post- (red, dashed line) injection versus healthy controls (greed, square dotted line). Significant differences for between-subject comparisons are denoted with ☾.

DISCUSSION

Our findings agree with the literature that for both the shoulder and elbow, healthy individuals demonstrate a decrease in constant errors with increased target elevation [Anderson et al., 2011; Hyler, 2013; Suprak et al., 2006b; Zuckerman et al., 1999]. We hypothesized that the linear relationship between target angle and accuracy would be disrupted in patients with subacromial impingement and would be restored following an anesthetic subacromial injection. Our results partially support our hypothesis, where pre-injection, patients did not display a linear decrease in constant errors with increased target elevation for the shoulder (Figure 6.3). However, following the subacromial injection the influence of angle on accuracy was not restored. This finding suggests that factors other than pain may influence the relationship between elevation angle and proprioceptive acuity for the shoulder in patients with impingement. Furthermore, patients with impingement may not be sensitive to the influence of angle on proprioception.

We additionally hypothesized that the magnitudes of the constant errors would be greater in the impingement group compared to controls and would be reduced following the anesthetic injection. Our results did not support our hypothesis, where patients were not different from controls pre-injection, and had greater overshooting errors post-injection (Figure 6.5). It is possible that patients were using pain to help guide their arm to the target positions and were unable to use this sensory modality once the subacromial bursa was anesthetized, thus resulting in poorer accuracy. Previous studies have shown that anesthetic injections to the subacromial bursa have no effect on proprioceptive acuity in non-pained individuals [Zuckerman et al., 1999]. We therefore find it unlikely that the

anesthetic injection had an influence on proprioception outside of pain reduction. In a study conducted by Hassen et al., [2002] joint position sense was measured before and after pain-reducing injections (anesthetic and placebo) in patients with chronic knee pain (osteoarthritis). Results from their study demonstrate that joint proprioceptive acuity is further diminished following anesthetic injection and is unchanged by placebo. This finding suggests that for the knee, when pain is reduced centrally, proprioceptive acuity is preserved and when pain is reduced peripherally, proprioceptive acuity is diminished. Patients with chronic pain may use afferent stimulation of intra-articular nociceptors to aid proprioceptive acuity during target matching tasks [Hassan et al., 2002]. Further, because neither injection condition (anesthetic or placebo) resulted in improved proprioceptive acuity, it is likely that factors other than pain are responsible for proprioceptive deficits at the knee. It remains unknown if pain helps or hinders proprioceptive acuity for the shoulder.

For accuracy at the elbow joint, we hypothesized that there would be no differences between patients with shoulder impingement versus healthy controls, nor would there be differences following the subacromial injection. Our results indicate that unlike the shoulder joint, patients demonstrated a linear increase in accuracy for the elbow as predicted (Figure 6.4). However, the magnitude of their differences were greater pre and post-injection and the magnitude of the differences were not influenced by the injection, where in either condition patients tended to overshoot the target when compared to controls (Figure 6.5). This finding suggests that adjacent joints have a disruption in proprioceptive acuity that is unrelated to the natural tendencies associated with angle. However, it is unknown whether or not these proprioceptive differences are

the result of the impingement or pre-date the impingement syndrome phenomenon. A possible explanation for the decrements in proprioceptive acuity at the elbow in patients with shoulder impingement could be related to disruptions in the processing of proprioceptive information centrally.

For constant and absolute errors, the linear influence of angle in healthy subjects has been repeated in multiple studies [Anderson et al., 2011; Hyler, 2013; Suprak et al., 2006b; Zuckerman et al., 1999]. However, this trend does not extend to variable errors (precision) [Anderson et al., 2011; Hyler, 2013; Zuckerman et al., 1999]. We hypothesized that variable errors in patients with impingement syndrome would be greater than controls but would improve following a subacromial injection. Results from our study partially support our hypothesis, where patients with impingement groups had greater variable error when repositioning their arm to targets than controls for both shoulder and elbow; however, following treatment, there were no significant changes in precision (Figures 6.6 and 6.7). This findings suggests that impingement syndrome is associated with a decrement in the ability to consistently determine where one's arm is located in space and may be independent from pain. It is possible that other symptoms associated with impingement such as rotator cuff deterioration, tendon thickening and changes to the subacromial bursa [Neer, C. S., 2nd, 1983] may influence the ability to consistently identify targets in space.

We manipulated the sensation of pain via a subacromial anesthetic injection, which resulted in increased proprioceptive errors. Hassan et al., [2002] demonstrated similar results after anesthetic injection to the knee in patients with osteoarthritis.

However, patients who underwent shoulder surgery have been reported to resolve proprioceptive deficits [Machner, 2003]. It is possible that patients have adapted to painful stimuli and have learned to use the nociceptive afferents towards performance and is acutely disrupted by the anesthetic injection. The manipulation of sensory information may result in periods of adjustment where changes in the processing of sensory information are exposure dependent [Fernandez-Ruiz et al., 1999]. In similar sensory systems, prism goggle studies are commonly used to examine the influence of visual manipulation on motor system adaptations and proprioception [Fernandez-Ruiz et al., 1999; Luaute et al., 2009; Redding et al., 2005]. Results from these studies indicate that manipulation of the visual field results in motor adaptations of the arm in space, which occur even after the prism goggles are removed (after-effect) [Fernandez-Ruiz et al., 1999; Luaute et al., 2009; Redding et al., 2005]. In this analogy, pain is similar to the prism goggles, and the removal of pain is analogous to the after-effects associated with the removal of the prism goggles. Therefore, it is possible that patients regain proprioceptive acuity once the after-effects of the injection subside. To determine the influence of an after-effect, studies should examine proprioceptive acuity in patients with impingement longitudinally after receiving subacromial injections.

Limitations

Only one modality of proprioception was included in this study and it is possible that other modalities such as force steadiness and kinesthetic sense would respond differently to an anesthetic subacromial injection. Further, we did not include a treatment condition for our control individuals. However, others have demonstrated that

subacromial injections resulted in no change in proprioceptive acuity for the shoulder [Zuckerman et al., 1999]. Due to the lack of randomization, which was constrained by our clinical design, it is possible that learning effects and familiarization to the protocols could impact the results post-injection. Further, it is possible that the magnitude of the differences were minimized post-injection due to a learning bias.

Conclusion

Proprioceptive errors in the shoulder increased following a subacromial injection. This finding may represent a change in the processing of proprioceptive signals in the absence of pain. The proprioceptive errors in the elbow were independent of pain and were higher than in control subjects. This finding may suggest that patients with subacromial impingement have systemically worse proprioceptive acuity, or may have disruptions in the processing of proprioceptive afferent stimuli.

CHAPTER VII

CONCLUSIONS

For dental hygienists there was no influence of workday exposure on shoulder proprioceptive errors. Additionally, no differences were detected by endurance on proprioception. Dental hygienists who reported pain, typically had greater proprioceptive errors than dental hygienists without pain; however, this effect was unrelated to workday exposure. These findings indicate that pain may influence the magnitude of proprioceptive errors in dental hygienists; however, workday exposure has little to no effect on proprioceptive errors in dental hygienists. When we investigated proprioception in injured populations our results indicate that patients with impingement have less sensitivity to angular position and tended to overshoot their targets with greater variability during angle matching tasks for the shoulder and elbow than controls. The disparities in proprioceptive acuity found in patients with impingement were not resolved following pain reduction, in-fact the magnitude of the errors increased post-treatment. These findings suggest that patients with impingement have decrements in either the signaling or processing of proprioceptive information and may use pain to reduce these inequalities. It is possible that dental hygienists who reported pain have underlying neuromechanical dysfunction that is related to proprioceptive deficits and deficits in motor control.

To investigate the influence of subacromial pain on motor control, we investigated scapular kinematics and muscle recruitment before and after pain reduction and compared these results to healthy controls. For scapular kinematics, we found that a

reduction in pain resulted in increased anterior tilting, but no changes in upward or internal rotation. However, when compared to healthy controls, patients had greater anterior tilting and upward rotation of the scapula. Our findings indicate that the removal of pain in patients with impingement results in further dyskinesis of the scapula. Patients could be using pain to limit scapular tilt and upward rotation and are unable to do so after an anesthetic injection. Further, we investigated the muscular activation in patients with impingement during the kinematic evaluation. However, due to limitations in EMG normalization, we first had to investigate the influence of pain on MVIC in the patient population. Our results indicated that 4 of the 7 shoulder muscles tested: were significantly impaired in the presence of pain. Additionally, normalizing EMG data to an MVIC in the presence of pain caused significant overestimation of anterior deltoid and lower trapezius muscles. These results indicated that subacromial pain can influence shoulder muscle activity, especially for the deltoid muscles and lower trapezius. Additionally, normalization to MVIC in the presence of pain can have unpredictable results. Using a novel MVIC normalization procedure we investigated EMG from 7 shoulder muscles during the kinematic evaluation. Our results indicated that following the reduction in pain, patients had increased anterior deltoid, middle deltoid and upper trapezius activity; further this trend extended to controls. Control subjects had greater activation of latissamus dorsi than the patient group post-injection. These findings may indicate that a reduction in subacromial pain could be associated with changes in shoulder muscle recruitment, primarily of the deltoid. This change in deltoid activity may lend evidence to rotator cuff function in patients without rotator cuff tears.

These studies lend evidence that pain may have an influence on motor control of the shoulder; however, many of the results from these studies indicate that pain may be beneficial in terms of reducing negatively-associated behaviors. In an analogy, pain may be similar to an alarm system, letting the body know that an insult to homeostasis may be present. Further, this alarm system appears to be integrated with other systems to compensate for the disruptions associated with the insult. However, when the ability for the alarm to be integrated with these other systems is removed (anesthetic injection), further disruption occurs. It is possible that pain alerts other systems into countering the negative behaviors associated with the insult, but when pain is removed, these alternative systems no longer compensate and the motor behavior goes in the direction of the insult.

Final Thoughts

Pain is an evolutionary adaptation and is probably important for the integration of multiple physiologic systems. Clinically, it is important to reduce pain in order to improve quality of life. However, it may be imperative to resolve the underlying insults that cause pain instead of targeting pain itself.

APPENDIX A

CONSENT FORM CHAPTER II

University of Oregon
Consent to Take Part In a Research Study
Project: Occupational Biomechanics in Dental Hygienists

You are invited to participate in a research study conducted by Andrew Karduna, PhD, from the department of Human Physiology at the University of Oregon. The purpose of this study is to investigate the effects of a typical workday on dental hygienists. We will be looking at shoulder motion and your ability to actively reposition your shoulder in a previously presented position. You were selected because you are a practicing dental hygienist. Non-invasive measurements will be made throughout the experiment. This study is funded by a grant from the Centers for Disease Control and Prevention.

If you decide to participate, you understand that the following things will be done to you once on the day prior to the experiment (lasting approximately one half hour):

- You will be asked to fill out several brief forms to provide basic information such as age, height and weight as well as your health and working conditions. Our funding agency also requires that we ask for information about your ethnicity and race. This information is optional.

- We will measure your shoulder endurance by positioned you on your side and asking you to hold up a five-pound weight in your hand for as long as you can.

- We will measure your shoulder tightness by positioning you on your back and measuring how far your arm can be passively moved.

One the day of the experiment, you will have the following things done to you twice – one session prior to your workday and one session immediately after your workday (lasting approximately one hour per session):

- Small sensors will be attached by straps or tape to your arm, upper back and shoulder and you will be asked to raise your arm overhead several times.

- You will be asked to wear a head-mounted display and actively position your shoulder in a specified target position, as viewed through these goggles. You will then be asked to attempt to replicate the presented position without the benefit of visual feedback. Several different target positions will be attempted.

- You will be asked to rate your level of shoulder fatigue on a scale of 6-20.

- Your shoulder strength will be measured by having you exert a maximal force.

One the day of the experiment, you will have the following things done to you during your entire workday:

- A small pager sized sensor will be attached to your arm with neoprene arm band. The sensor will be activated at the beginning of your workday and removed at the end of your workday. This sensor is approximately the same size and weight as an iPod nano and is not expected to interfere with your ability to perform your work.

There is no direct benefit to you by participating in this study. However, you understand that information gained in this study may help health care professionals better understand how to treat patients with occupational shoulder disorders. You will be paid $100 for your participation in this study. If you cannot complete the study, you will still be paid $30 for your time.

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

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

If you have any questions, please feel free to contact Dr Andrew Karduna, (541) 346-0438, Department of Human Physiology, University of Oregon, Eugene OR, 97403. If you have questions regarding your rights as a research subject, contact the Office for Protection of Human Subjects, University of Oregon, Eugene, OR 97403, (541) 346-2510. This Office oversees the review of the research to protect your rights and is not involved with this study. You have been offered a copy of this form to keep.

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

Print Name_____

Signature_____

Date_____

APPENDIX B

UPENN PAIN SCALE FORM CHAPTER II

Please circle the number closest to your current level of shoulder pain or satisfaction

1. Pain **at rest** with your arm by your side:

0 1 2 3 4 5 6 7 8 9 10

No Pain — Worst Pain Possible

2. Pain with **normal activities** (eating, dressing, bathing):

0 1 2 3 4 5 6 7 8 9 10

No Pain — Worst Pain Possible

3. Pain with **strenuous activities** (reaching, lifting, pushing, pulling, throwing):

0 1 2 3 4 5 6 7 8 9 10

No Pain — Worst Pain Possible

APPENDIX C

CONSENT FORM CHAPTERS III - VI

University of Oregon
Consent to Take Part in a Research Study
Project: Shoulder Impingement

You are invited to participate in a research study conducted by Andrew Karduna, PhD, from the department of Human Physiology at the University of Oregon. The purpose of this study is to investigate the differences in arm movements between left and rights sides of the body. Additionally, this study evaluates the direct effects of the treatment you received today by your doctor. You have been asked to participate either because you were diagnosed with a shoulder pathology and will receive an injection as part of the treatment determined by your doctor or you have no medical problems associated with your shoulder. This study is partially funding by the Centers for Disease Control and Prevention.

If you decide to participate, you understand that the following things will be done to you:

- You will be asked for some personal information such as your age and weight. Our funding agency also requires that we ask for information about your ethnicity and race. This information is optional.

- Small sensors will be attached by straps or tape to your arm, upper back and shoulder and you will be asked to raise your arm overhead several times, you will be asked to raise your arms overhead several times.

There is no direct benefit to you by participating in this study. However, you understand that information gained in this study may help health care professionals better understand how people use their arm during a typical day, as well the direct effects of the treatment you received on your shoulder. You will be paid $20 for your participation in this study.

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

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

If you have any questions, please feel free to contact Dr Andrew Karduna, (541) 346-0438, Department of Human Physiology, University of Oregon, Eugene OR, 97403. If you

have questions regarding your rights as a research subject, contact the Office for Protection of Human Subjects, University of Oregon, Eugene, OR 97403, (541) 346-2510. You have been offered a copy of this form to keep.

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

Print Name_____

Signature_____

Date_____

APPENDIX D

HIPPA RELEASE FORMS CHAPTERS III - VI

Shoulder Research Study

Your Slocum Center physician has identified you as a potential candidate for participation in a study being conducted by the Department of Human Physiology at the University of Oregon. This study examines arm motion for patients with shoulder pain. In order to participate in this study, you need to authorize Slocum Center to release elements of your Personal Health Information (PHI) so that researchers can determine if you fit the inclusion criteria for the study and to contact you regarding participation in the study. If you would like to be contacted for participation in this study, please complete this Authorization and return it to: Slocum Center for Orthopedic & Sports Medicine

Attention: Records Release

55 Coburg Road

Eugene, OR 97401

AUTHORIZATION FOR RELEASE OF PERSONAL HEALTH INFORMATION:

I hereby authorize the use or disclosure of my individually identifiable health information as described below. I understand that this authorization is voluntary, and that refusal to sign this authorization will not affect my ability to receive medical care. I understand that I may revoke this authorization at any time by presenting my written revocation to Slocum Center for Orthopedic and Sports Medicine, P.C. and that said revocation will not apply to information that has already been released in response to this authorization. By my signature below, I authorize Slocum Center for Orthopedic and Sports Medicine, to release to Researcher Andrew Karduna, PhD, Department of Human Physiology, University of Oregon, the following medical records:

My name, date of birth, and telephone number (see bottom of form)
Shoulder diagnosis
Results of imaging studies and chart notes for my shoulder injury

Dr. Karduna will use this information to contact me for the purpose of evaluating my participation in a research study of shoulder motion. Unless otherwise revoked, this authorization will expire one year from the date of its execution. I understand that Andrew Karduna, PhD (Principal Investigator) and the University of Oregon may not be bound by the Notice of Privacy Practices of Slocum Center for Orthopedic and Sports

Medicine, P.C., or federal privacy regulations. I understand that the researchers will only use or disclose my Personal Health Information for purposes approved by the Institutional Review Board at the University of Oregon or as required by law or regulations. The University of Oregon shall be solely responsible for protecting the privacy and security of my Personal Health Information as described in an Informed Consent Form I shall execute prior to enrollment in the study. The contact person at the University of Oregon is Dr. Andrew Karduna, Department of Human Physiology, University of Oregon, Eugene OR, 97403. By signing below, I understand and acknowledge the following:

- That I have read and understand this Authorization; and
- If I have any question about disclosure of my protected health information, I may contact Slocum Center's Privacy Officer, Kathy J. McBride.

Signature of patient: _____ Date:_____

Print Name: _____ Date of Birth: _____

Telephone Number: _____

APPENDIX E

VISUAL ANALOG PAIN SCALE CHAPTERS III - VI

How severe is your pain today? Place a vertical mark on the line below to indicate how bad you feel your pain is today.

No pain |_____| Very severe pain

REFERENCES CITED

Akesson, I., Johnsson, B., Rylander, L., Moritz, U., & Skerfving, S. Musculoskeletal disorders among female dental personnel - clinical examination and a 5-year follow-up study of symptoms Int Arch Occup Environ Health 1999*; 72*(6): 395-403

Allmann, K. H., Uhl, M., Gufler, H., Biebow, N., Hauer, M. P., Kotter, E., et al. Cine-MR imaging of the shoulder. Acta Radiol 1997*; 38*(6): 1043-1046.

Alpert, S. W., Pink, M. M., Jobe, F. W., McMahon, P. J., & Mathiyakom, W. Electromyographic analysis of deltoid and rotator cuff function under varying loads and speeds. J Shoulder Elbow Surg 2000*; 9*(1): 47-58.

Alvarez, C. M., Litchfield, R., Jackowski, D., Griffin, S., & Kirkley, A. A prospective, double-blind, randomized clinical trial comparing subacromial injection of betamethasone and xylocaine to xylocaine alone in chronic rotator cuff tendinosis. Am J Sports Med 2005*; 33*(2): 255-262.

Anderson, V. B., & Wee, E. Impaired joint proprioception at higher shoulder elevations in chronic rotator cuff pathology. Arch Phys Med Rehabil 2011*; 92*(7): 1146-1151.

Atalar, H., Yilmaz, C., Polat, O., Selek, H., Uras, I., & Yanik, B. Restricted scapular mobility during arm abduction: implications for impingement syndrome. Acta Orthop Belg 2009*; 75*(1): 19-24.

Balke, M., Schmidt, C., Dedy, N., Banerjee, M., Bouillon, B., & Liem, D. Correlation of acromial morphology with impingement syndrome and rotator cuff tears. Acta Orthop 2013.

Bandholm, T., Rasmussen, L., Aagaard, P., Jensen, B. R., & Diederichsen, L. Force steadiness, muscle activity, and maximal muscle strength in subjects with subacromial impingement syndrome. Muscle Nerve 2006*; 34*(5): 631-639.

Barisic, I., Ljutic, D., Jankovic, S., Vlak, T., Tomic, S., Kokic, S., et al. Relevant sonographic parameters of a painful shoulder in symptomatic dialyzed patients versus asymptomatic dialyzed and healthy volunteers. Coll Antropol 2006*; 30*(2): 313-318.

Ben-Yishay, A., Zuckerman, J. D., Gallagher, M., & Cuomo, F. Pain inhibition of shoulder strength in patients with impingement syndrome. Orthopedics 1994*; 17*(8): 685-688.

Berhouet, J., Collin, P., Benkalfate, T., Le Du, C., Duparc, F., Courage, O., et al. Massive rotator cuff tears in patients younger than 65 years. Epidemiology and characteristics. Orthop Traumatol Surg Res 2009*; 95*(4 Suppl 1): S13-18.

Bey, M. J., Brock, S. K., Beierwaltes, W. N., Zauel, R., Kolowich, P. A., & Lock, T. R. In vivo measurement of subacromial space width during shoulder elevation: technique and preliminary results in patients following unilateral rotator cuff repair. Clin Biomech (Bristol, Avon) 2007*; 22*(7): 767-773.

Bjorklund, M., Crenshaw, A. G., Djupsjobacka, M., & Johansson, H. Position sense acuity is diminished following repetitive low-intensity work to fatigue in a simulated occupational setting. Eur J Appl Physiol 2000*; 81*(5): 361-367.

Blaine, T. A., Kim, Y. S., Voloshin, I., Chen, D., Murakami, K., Chang, S. S., et al. The molecular pathophysiology of subacromial bursitis in rotator cuff disease. J Shoulder Elbow Surg 2005*; 14*(1 Suppl S): 84S-89S.

Brox, J. I., Roe, C., Saugen, E., & Vollestad, N. K. Isometric abduction muscle activation in patients with rotator tendinosis of the shoulder. Arch Phys Med Rehabil 1997*; 78*(11): 1260-1267.

Buchbinder, R., Green, S., & Youd, J. M. Corticosteroid injections for shoulder pain. Cochrane Database Syst Rev 2003*;* (1): CD004016.

Camargo, P. R., Avila, M. A., de Oliveira, A. B., Asso, N. A., Benze, B. G., & de Fatima Salvini, T. Shoulder abduction torque steadiness is preserved in subacromial impingement syndrome. Eur J Appl Physiol 2009*; 106*(3): 381-387.

Caraffa, A., Cerulli, G., Projetti, M., Aisa, G., & Rizzo, A. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. Knee Surg Sports Traumatol Arthrosc 1996*; 4*(1): 19-21.

Carpenter, J. E., Blasier, R. B., & Pellizzon, G. G. The effects of muscle fatigue on shoulder joint position sense. Am J Sports Med 1998*; 26*(2): 262-265.

Celik, D., Atalar, A. C., Guclu, A., & Demirhan, M. [The contribution of subacromial injection to the conservative treatment of impingement syndrome]. Acta Orthop Traumatol Turc 2009*; 43*(4): 331-335.

Celik, D., Sirmen, B., & Demirhan, M. The relationship of muscle strength and pain in subacromial impingement syndrome. Acta Orthop Traumatol Turc 2011*; 45*(2): 79-84.

Chen, S. K., Simonian, P. T., Wickiewicz, T. L., Otis, J. C., & Warren, R. F. Radiographic evaluation of glenohumeral kinematics: a muscle fatigue model. Journal of Shoulder and Elbow Surgery 1999*; 8*(1): 49-52.

Chester, R., Smith, T. O., Hooper, L., & Dixon, J. The impact of subacromial impingement syndrome on muscle activity patterns of the shoulder complex: a systematic review of electromyographic studies. BMC Musculoskelet Disord 2010*; 11* 45.

Christensen, H. Muscle activity and fatigue in the shoulder muscles of assembly-plant employees. Scand J Work Environ Health 1986*; 12*(6): 582-587.

Clisby, E. F., Bitter, N. L., Sandow, M. J., Jones, M. A., Magarey, M. E., & Jaberzadeh, S. Relative contributions of the infraspinatus and deltoid during external rotation in patients with symptomatic subacromial impingement. J Shoulder Elbow Surg 2008*; 17*(1 Suppl): 87S-92S.

Cools, A. M., Witvrouw, E. E., Declercq, G. A., Danneels, L. A., & Cambier, D. C. Scapular muscle recruitment patterns: trapezius muscle latency with and without impingement symptoms. Am J Sports Med 2003*; 31*(4): 542-549.

Cordasco, F. A., Chen, N. C., Backus, S. I., Kelly, B. T., Williams, R. J., 3rd, & Otis, J. C. Subacromial Injection Improves Deltoid Firing in Subjects with Large Rotator Cuff Tears. Hss J 2009.

Cote, J. N., Raymond, D., Mathieu, P. A., Feldman, A. G., & Levin, M. F. Differences in multi-joint kinematic patterns of repetitive hammering in healthy, fatigued and shoulder-injured individuals. Clin Biomech (Bristol, Avon) 2005*; 20*(6): 581-590.

Cram, J., & Kasman, G. Introduction to Surface Electromyography. Aspen Publishers, Inc 1998*; Gaithersburg* 408.

de Morais Faria, C. D., Teixeira-Salmela, L. F., de Paula Goulart, F. R., & de Souza Moraes, G. F. Scapular muscular activity with shoulder impingement syndrome during lowering of the arms. Clin J Sport Med 2008*; 18*(2): 130-136.

Descarreaux, M., Blouin, J. S., & Teasdale, N. Isometric force production parameters during normal and experimental low back pain conditions. BMC Musculoskelet Disord 2005*; 6* 6.

Deutsch, A., Altchek, D. W., Schwartz, E., Otis, J. C., & Warren, R. F. Radiologic measurement of superior displacement of the humeral head in the impingement syndrome. J Shoulder Elbow Surg 1996*; 5*(3): 186-193.

Diederichsen, L., Winther, A., Dyhre-Poulsen, P., Krogsgaard, M., & Norregaard, J. The influence of experimentally induced pain on shoulder muscle activity. Exp Brain Res 2009*; 194*(3): 329-337.

Diederichsen, L. P., Norregaard, J., Dyhre-Poulsen, P., Winther, A., Tufekovic, G., Bandholm, T., et al. The activity pattern of shoulder muscles in subjects with and without subacromial impingement. J Electromyogr Kinesiol 2009*; 19*(5): 789-799.

Dorrestijn, O., Greving, K., van der Veen, W. J., van der Meer, K., Diercks, R. L., Winters, J. C., et al. Patients with shoulder complaints in general practice: consumption of medical care. Rheumatology (Oxford) 2011*; 50*(2): 389-395.

Dube, J. A., & Mercier, C. Effect of pain and pain expectation on primary motor cortex excitability. Clin Neurophysiol 2011*; 122*(11): 2318-2323.

Ekstrom, R. A., Bifulco, K. M., Lopau, C. J., Andersen, C. F., & Gough, J. R. Comparing the function of the upper and lower parts of the serratus anterior muscle using surface electromyography. J Orthop Sports Phys Ther 2004*; 34*(5): 235-243.

Endo, K., Ikata, T., Katoh, S., & Takeda, Y. Radiographic assessment of scapular rotational tilt in chronic shoulder impingement syndrome. J Orthop Sci 2001*; 6*(1): 3-10.

Ettinger, L., Kincl, L., Johnson, P., Garfinkel, S., & Karduna, A. Workday Arm Elevation Exposure: A Comparison between two Professions. IIE Transactions on Occupational Ergonomics and Human Factors 2013.

Ettinger, L., McClure, P., Kincl, L., & Karduna, A. Exposure to a workday environment results in an increase in anterior tilting of the scapula in dental hygienists with greater employment experience. Clin Biomech (Bristol, Avon) 2011.

Ettinger, L., McClure, P., Kincl, L., & Karduna, A. Exposure to a workday environment results in an increase in anterior tilting of the scapula in dental hygienists with greater employment experience. Clin Biomech (Bristol, Avon) 2012*; 27*(4): 341-345.

Ettinger, L., Shapiro, M., Weiss, J., Karduna, A. EMG Normalization Is Influenced by Subacromial Pain. Electromyography and Kinesiology 2013*; In press*.

Farshad-Amacker, N. A., Buck, F. M., Farshad, M., Pfirrmann, C. W., & Gerber, C. Partial supraspinatus tears are associated with tendon lengthening. Knee Surg Sports Traumatol Arthrosc 2013.

Fernandez-Ruiz, J., & Diaz, R. Prism adaptation and aftereffect: specifying the properties of a procedural memory system. Learn Mem 1999*; 6*(1): 47-53.

Finley, M. A., McQuade, K. J., & Rodgers, M. M. Scapular kinematics during transfers in manual wheelchair users with and without shoulder impingement. Clin Biomech (Bristol, Avon) 2005*; 20*(1): 32-40.

Flatow, E. L., Soslowsky, L. J., Ticker, J. B., Pawluk, R. J., Hepler, M., Ark, J., et al. Excursion of the rotator cuff under the acromion. Patterns of subacromial contact. Am J Sports Med 1994*; 22*(6): 779-788.

Forestier, N., Teasdale, N., & Nougier, V. Alteration of the position sense at the ankle induced by muscular fatigue in humans. Med Sci Sports Exerc 2002*; 34*(1): 117-122.

Giphart, J. E., van der Meijden, O. A., & Millett, P. J. The effects of arm elevation on the 3-dimensional acromiohumeral distance: a biplane fluoroscopy study with normative data. J Shoulder Elbow Surg 2012*; 21*(11): 1593-1600.

Gotoh, M., Hamada, K., Yamakawa, H., Inoue, A., & Fukuda, H. Increased substance P in subacromial bursa and shoulder pain in rotator cuff diseases. J Orthop Res 1998*; 16*(5): 618-621.

Graven-Nielsen, T., Svensson, P., & Arendt-Nielsen, L. Effects of experimental muscle pain on muscle activity and co-ordination during static and dynamic motor function. Electroencephalogr Clin Neurophysiol 1997*; 105*(2): 156-164.

Gruson, K. I., Ruchelsman, D. E., & Zuckerman, J. D. Subacromial corticosteroid injections. J Shoulder Elbow Surg 2008*; 17*(1 Suppl): 118S-130S.

Haavik, H., & Murphy, B. Subclinical neck pain and the effects of cervical manipulation on elbow joint position sense. J Manipulative Physiol Ther 2011*; 34*(2): 88-97.

Haik, M. N., Camargo, P. R., Zanca, G. G., Alburquerque-Sendin, F., Salvini, T. F., & Mattiello-Rosa, S. M. Joint position sense is not altered during shoulder medial and lateral rotations in female assembly line workers with shoulder impingement syndrome. Physiother Theory Pract 2013*; 29*(1): 41-50.

Han, K. J., Cho, J. H., Han, S. H., Hyun, H. S., & Lee, D. H. Subacromial impingement syndrome secondary to scapulothoracic dyskinesia. Knee Surg Sports Traumatol Arthrosc 2012*; 20*(10): 1958-1960.

Hanvold, T. N., Waersted, M., Mengshoel, A. M., Bjertness, E., Stigum, H., Twisk, J., et al. The effect of work-related sustained trapezius muscle activity on the development of neck and shoulder pain among young adults. Scand J Work Environ Health 2013.

Hassan, B. S., Doherty, S. A., Mockett, S., & Doherty, M. Effect of pain reduction on postural sway, proprioception, and quadriceps strength in subjects with knee osteoarthritis. Ann Rheum Dis 2002*; 61*(5): 422-428.

Hebert, L. J., Moffet, H., McFadyen, B. J., & Dionne, C. E. Scapular behavior in shoulder impingement syndrome. Arch Phys Med Rehabil 2002*; 83*(1): 60-69.

Hiemstra, L. A., Lo, I. K., & Fowler, P. J. Effect of fatigue on knee proprioception: implications for dynamic stabilization. J Orthop Sports Phys Ther 2001*; 31*(10): 598-605.

Hyler, J., Karduna, K. . The shoulder and elbow joints and right and left sides demonstrate similar joint position sense. Motor Behavior 2013.

Ide, K., Shirai, Y., & Ito, H. Sensory nerve supply in the human subacromial bursa. J Shoulder Elbow Surg 1996*; 5*(5): 371-382.

Inman, V. T., Saunders, J. B., & Abbott, L. C. Observations of the function of the shoulder joint. 1944. Clin Orthop Relat Res 1944*;* (330): 3-12.

Inman, V. T., Saunders, J. B., & Abbott, L. C. Observations of the function of the shoulder joint. 1944. Clin Orthop Relat Res 1996*;* (330): 3-12.

Karduna, A. R., McClure, P. W., Michener, L. A., & Sennett, B. Dynamic measurements of three-dimensional scapular kinematics: a validation study. J Biomech Eng 2001*; 123*(2): 184-190.

Kendall, F., McCreary, E., Provance, P., Rodgers, M., & Romani, W. Muscles Testing and Function with Posture and Pain. Williams and Wilkins 1993*; Baltimore*(MD): 448.

Kofler, M. Functional organization of exteroceptive inhibition following nociceptive electrical fingertip stimulation in humans. Clin Neurophysiol 2003*; 114*(6): 973-980.

Kofler, M., Fuhr, P., Leis, A. A., Glocker, F. X., Kronenberg, M. F., Wissel, J., et al. Modulation of upper extremity motor evoked potentials by cutaneous afferents in humans. Clin Neurophysiol 2001*; 112*(6): 1053-1063.

Lalumandier JA, M. S., Parrott CB, Vendemia M. . Musculoskelitap pain: prevalence, prevention, and differences among dental office personel. . Gen Dent 2001*; 2* 160-166.

Lee, H. M., Liau, J. J., Cheng, C. K., Tan, C. M., & Shih, J. T. Evaluation of shoulder proprioception following muscle fatigue. Clin Biomech (Bristol, Avon) 2003*; 18*(9): 843-847.

Leggin BG, S. M., Neuman RM, Iannotti JP, WIlliams GR, Brennerman SK. . Reliability of a shoulder outcome scoring system. . American Journal of Sports Medicine 1993.

Lehman, G. J., MacMillan, B., MacIntyre, I., Chivers, M., & Fluter, M. Shoulder muscle EMG activity during push up variations on and off a Swiss ball. Dyn Med 2006*; 5* 7.

Lehman, G. J., & McGill, S. M. The importance of normalization in the interpretation of surface electromyography: a proof of principle. J Manipulative Physiol Ther 1999*; 22*(7): 444-446.

Leis, A. A., Stokic, D. S., Fuhr, P., Kofler, M., Kronenberg, M. F., Wissel, J., et al. Nociceptive fingertip stimulation inhibits synergistic motoneuron pools in the human upper limb. Neurology 2000*; 55*(9): 1305-1309.

Lentz, T. A., Barabas, J. A., Day, T., Bishop, M. D., & George, S. Z. The relationship of pain intensity, physical impairment, and pain-related fear to function in patients with shoulder pathology. J Orthop Sports Phys Ther 2009*; 39*(4): 270-277.

Lephart, S. M., & Henry, T. J. The physiological basis for open and closed kinetic chain rehabilitation for the upper extremity. Journal of Sport Rehabilitation 1996*; 5* 71-87.

Lephart, S. M., Pincivero, D. M., Giraldo, J. L., & Fu, F. H. The role of proprioception in the management and rehabilitation of athletic injuries. Am J Sports Med 1997*; 25*(1): 130-137.

Lephart, S. M., Warner, J. J., Borsa, P. A., & Fu, F. H. Proprioception of the shoulder joint in healthy, unstable, and surgically repaired shoulders. J Shoulder Elbow Surg 1994*; 3*(6): 371-380.

Leroux, J. L., Codine, P., Thomas, E., Pocholle, M., Mailhe, D., & Blotman, F. Isokinetic evaluation of rotational strength in normal shoulders and shoulders with impingement syndrome. Clin Orthop Relat Res 1994*;* (304): 108-115.

Lin, J. J., Hanten, W. P., Olson, S. L., Roddey, T. S., Soto-quijano, D. A., Lim, H. K., et al. Functional activity characteristics of individuals with shoulder dysfunctions. J Electromyogr Kinesiol 2005*; 15*(6): 576-586.

Lin, J. J., Hsieh, S. C., Cheng, W. C., Chen, W. C., & Lai, Y. Adaptive patterns of movement during arm elevation test in patients with shoulder impingement syndrome. J Orthop Res 2011*; 29*(5): 653-657.

Lin, Y. L., & Karduna, A. R. Sensors on the Humerus are not Necessary for an Accurate Assessment of Humeral Kinematics in Constrained Movements. J Appl Biomech 2012.

Liss, G. M., Jesin, E., Kusiak, R. A., & White, P. Musculoskeletal problems among Ontario dental hygienists. Am J Ind Med 1995*; 28*(4): 521-540.

Luaute, J., Schwartz, S., Rossetti, Y., Spiridon, M., Rode, G., Boisson, D., et al. Dynamic changes in brain activity during prism adaptation. J Neurosci 2009*; 29*(1): 169-178.

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

Ludewig P, L. P. Alterations in Shoulder Kinematics and Associated Muscle Activity in People With Symptoms of Shoulder Impingement. Physical Therapy 2000*; 80* 276-291.

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

Ludewig, P. M., & Reynolds, J. F. The association of scapular kinematics and glenohumeral joint pathologies. J Orthop Sports Phys Ther 2009*; 39*(2): 90-104.

Lukasiewicz, A. C., McClure, P., Michener, L., Pratt, N., & Sennett, B. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. J Orthop Sports Phys Ther 1999*; 29*(10): 574-583; discussion 584-586.

Lund, J. P., Donga, R., Widmer, C. G., & Stohler, C. S. The pain-adaptation model: a discussion of the relationship between chronic musculoskeletal pain and motor activity. Can J Physiol Pharmacol 1991*; 69*(5): 683-694.

Machner, A., Merk, H., Becker, R., Rohkohl, K., Wissel, H., & Pap, G. Kinesthetic sense of the shoulder in patients with impingement syndrome. Acta Orthop Scand 2003*; 74*(1): 85-88.

Machner, A., Merk, H., Becker, R., Rohkohl, K., Wissel, H., Pap, G. Kinesthetic sense of the shoulder in patients with impingement syndrome. Acta Orthopaedica Scandinavica 2003*; 74*(1): 85-88.

Maenhout, A. G., Palmans, T., De Muynck, M., De Wilde, L. F., & Cools, A. M. The impact of rotator cuff tendinopathy on proprioception, measuring force sensation. J Shoulder Elbow Surg 2001*; 21*(8): 1080-1086.

Maffet, M. W., Jobe, F. W., Pink, M. M., Brault, J., & Mathiyakom, W. Shoulder muscle firing patterns during the windmill softball pitch. Am J Sports Med 1997*; 25*(3): 369-374.

Marklin, R. W., & Cherney, K. Working postures of dentists and dental hygienists. J Calif Dent Assoc 2005*; 33*(2): 133-136.

Marras, W. S., & Davis, K. G. A non-MVC EMG normalization technique for the trunk musculature: Part 1. Method development. J Electromyogr Kinesiol 2001*; 11*(1): 1-9.

McClure, P. W., Michener, L. A., & Karduna, A. R. Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome. J Phys Ther 2006*; 86*(8): 1075-1090.

McClure, P. W., Michener, L. A., Sennett, B. J., & Karduna, A. R. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. J Shoulder Elbow Surg 2001*; 10*(3): 269-277.

McCully, S. P., Suprak, D. N., Kosek, P., & Karduna, A. R. Suprascapular nerve block results in a compensatory increase in deltoid muscle activity. J Biomech 2007*; 40*(8): 1839-1846.

McQuade, K. J., Dawson, J., & Smidt, G. L. Scapulothoracic muscle fatigue associated with alterations in scapulohumeral rhythm kinematics during maximum resistive shoulder elevation. Journal of Orthopaedic and Sports Physical Therapy 1998*; 28*(2): 74-80.

Meislin, R. J., Sperling, J. W., & Stitik, T. P. Persistent shoulder pain: epidemiology, pathophysiology, and diagnosis. Am J Orthop (Belle Mead NJ) 2005*; 34*(12 Suppl): 5-9.

Merletti, R. Standards for Reporting EMG data. Journal of Electromyography and Kinesiology 1999*; 9*(1): 3-4.

Michaud, M., Arsenault, A. B., Gravel, D., Tremblay, G., & Simard, T. G. Muscular compensatory mechanism in the presence of a tendinitis of the supraspinatus. Am J Phys Med 1987*; 66*(3): 109-120.

Michener, L. A., Walsworth, M. K., Doukas, W. C., & Murphy, K. P. Reliability and diagnostic accuracy of 5 physical examination tests and combination of tests for subacromial impingement. Arch Phys Med Rehabil 2009*; 90*(11): 1898-1903.

Miura, K., Ishibashi, Y., Tsuda, E., Okamura, Y., Otsuka, H., & Toh, S. The effect of local and general fatigue on knee proprioception. Arthroscopy 2004*; 20*(4): 414-418.

Moayedi, M., & Davis, K. D. Theories of pain: from specificity to gate control. J Neurophysiol 2013*; 109*(1): 5-12.

Moraes, G. F., Faria, C. D., & Teixeira-Salmela, L. F. Scapular muscle recruitment patterns and isokinetic strength ratios of the shoulder rotator muscles in individuals with and without impingement syndrome. J Shoulder Elbow Surg 2008*; 17*(1 Suppl): 48S-53S.

Morisawa, Y. Morphological study of mechanoreceptors on the coracoacromial ligament. J Orthop Sci 1998*; 3*(2): 102-110.

Murray, T. A., Cook, T. D., Werner, S. L., Schlegel, T. F., & Hawkins, R. J. The effects of extended play on professional baseball pitchers. Am J Sports Med 2001*; 29*(2): 137-142.

Myers, J., Guskiewicz, K., Schneider, R., & Prentice, W. Proprioception and neuromuscular control of the shoulder after muscle fatigue. Journal of Athletic Training 1999*; 34*(4): 362-367.

Myers, J., Hwang, J. H., Pasquale, M. R., Blackburn, J. T., & Lephart, S. M. Rotator cuff coactivation ratios in participants with subacromial impingement syndrome. J Sci Med Sport 2009*; 12*(6): 603-608.

Myers, J. B., Hwang, J. H., Pasquale, M. R., Blackburn, J. T., & Lephart, S. M. Rotator cuff coactivation ratios in participants with subacromial impingement syndrome. J Sci Med Sport 2009*; 12*(6): 603-608.

Nawoczenski, D. A., Riek, L. M., Greco, L., Staiti, K., & Ludewig, P. M. Effect of shoulder pain on shoulder kinematics during weight-bearing tasks in persons with spinal cord injury. Arch Phys Med Rehabil 2012*; 93*(8): 1421-1430.

Neer, C. Anterior Acromioplasty for the chronic impingement syndrome in the shoulder. Bone and Joint Surgery 1972*; 54* 41-50.

Neer, C. S. Impingement lesions. Clinical Orthopedics 1983*; 173* 70-77.

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

Neer, C. S., Poppen, N.k. [Abstract]. Orthpopedic Trans 1987*; 11* 23.

Nicholson, G. P., Goodman, D. A., Flatow, E. L., & Bigliani, L. U. The acromion: morphologic condition and age-related changes. A study of 420 scapulas. J Shoulder Elbow Surg 1996*; 5*(1): 1-11.

Nieminen, H., Takala, E. P., & Viikari-Juntura, E. Normalization of electromyogram in the neck-shoulder region. Eur J Appl Physiol Occup Physiol 1993*; 67*(3): 199-207.

Niessen, M. H., Veeger, D. H., Koppe, P. A., Konijnenbelt, M. H., van Dieen, J., & Janssen, T. W. Proprioception of the shoulder after stroke. Arch Phys Med Rehabil 2008*; 89*(2): 333-338.

Oberg, T., Karsznia, A., Sandsjo, L., & Kadefors, R. Work load, fatigue, and pause patterns in clinical dental hygiene. J Dent Hyg 1995*; 69*(5): 223-229.

Oberg T, O. U. Musculoskeletal complaints in dental hygiene: a survey study from sa Swedish county. Journal of Dental Hygiene 1993*; 5* 256-261.

Oh, J. H., Jun, B. J., McGarry, M. H., & Lee, T. Q. Does a critical rotator cuff tear Stage exist?: a biomechanical study of rotator cuff tear progression in human cadaver shoulders. J Bone Joint Surg Am 2011*; 93*(22): 2100-2109.

Park, J. Y., Lee, W. S., & Lee, S. T. The strength of the rotator cuff before and after subacromial injection of lidocaine. J Shoulder Elbow Surg 2008*; 17*(1 Suppl): 8S-11S.

Peat, M., & Grahame, R. E. Electromyographic analysis of soft tissue lesions affecting shoulder function. Am J Phys Med 1977*; 56*(5): 223-240.

Pedersen, J., Lonn, J., Hellstrom, F., Djupsjobacka, M., & Johansson, H. Localized muscle fatigue decreases the acuity of the movement sense in the human shoulder. Med Sci Sports Exerc 1999*; 31*(7): 1047-1052.

Phadke, V., Camargo, P., & Ludewig, P. Scapular and rotator cuff muscle activity during arm elevation: A review of normal function and alterations with shoulder impingement. Rev Bras Fisioter 2009*; 13*(1): 1-9.

Poppen, N. K., & Walker, P. S. Forces at the glenohumeral joint in abduction. Clin Orthop Relat Res 1978*;* (135): 165-170.

Poppen NK, W. P. J. Normal and abnormal motion of the shoulder. Bone Joint Surg Am 1976*; 58* 195-201.

Proske, U., & Gandevia, S. C. The kinaesthetic senses. J Physiol 2009*; 587*(Pt 17): 4139-4146.

Redding, G. M., Rossetti, Y., & Wallace, B. Applications of prism adaptation: a tutorial in theory and method. Neurosci Biobehav Rev 2005*; 29*(3): 431-444.

Reddy, A. S., Mohr, K. J., Pink, M. M., & Jobe, F. W. Electromyographic analysis of the deltoid and rotator cuff muscles in persons with subacromial impingement. J Shoulder Elbow Surg 2000*; 9*(6): 519-523.

Riemann, B. L., & Lephart, S. M. The sensorimotor system, part I: the physiologic basis of functional joint stability. J Athl Train 2002a*; 37*(1): 71-79.

Riemann, B. L., & Lephart, S. M. The Sensorimotor System, Part II: The Role of Proprioception in Motor Control and Functional Joint Stability. J Athl Train 2002b*; 37*(1): 80-84.

Rodgers, M. M., McQuade, K. J., Rasch, E. K., Keyser, R. E., & Finley, M. A. Upper-limb fatigue-related joint power shifts in experienced wheelchair users and nonwheelchair users. J Rehabil Res Dev 2003*; 40*(1): 27-37.

Roy, J. S., Moffet, H., McFadyen, B. J., & Lirette, R. Impact of movement training on upper limb motor strategies in persons with shoulder impingement syndrome. Sports Med Arthrosc Rehabil Ther Technol 2009*; 1*(1): 8.

Royer, P., Kane, E., Parks, K., Morrow, J., Moravec, R., Christie, D., et al. (2004). *Fluoroscopic assessment of the effects of rotator cuff fatigue on glenohumeral kinematics in shoulder impingement syndrome.* Paper presented at the The Annual Meeting of the American Society of Biomechanics, Portland, OR.

San Juan J, K. A. Superior Humeral Head Migration, A Floroscopic Study. Un Published Submission 2012.

Saupe, N., Pfirrmann, C. W., Schmid, M. R., Jost, B., Werner, C. M., & Zanetti, M. Association between rotator cuff abnormalities and reduced acromiohumeral distance. AJR Am J Roentgenol 2006*; 187*(2): 376-382.

Schmidt, R., Lee, TD. . (1999). *Methodology for studying motor performance. In: Motor control and learning : a behavioral emphasis*. Champaign, IL.: Human Kinetics.

Schouten, A. C., Mugge, W., & van der Helm, F. C. NMClab, a model to assess the contributions of muscle visco-elasticity and afferent feedback to joint dynamics. J Biomech 2008*; 41*(8): 1659-1667.

Scibek, J. S., Mell, A. G., Downie, B. K., Carpenter, J. E., & Hughes, R. E. Shoulder kinematics in patients with full-thickness rotator cuff tears after a subacromial injection. J Shoulder Elbow Surg 2008*; 17*(1): 172-181.

Scovazzo, M. L., Browne, A., Pink, M., Jobe, F. W., & Kerrigan, J. The painful shoulder during freestyle swimming. An electromyographic cinematographic analysis of twelve muscles. Am J Sports Med 1991*; 19*(6): 577-582.

Sharpe, M. H., & Miles, T. S. Position sense at the elbow after fatiguing contractions. Exp Brain Res 1993*; 94*(1): 179-182.

Soslowsky, L. J., Thomopoulos, S., Esmail, A., Flanagan, C. L., Iannotti, J. P., Williamson, J. D., 3rd, et al. Rotator cuff tendinosis in an animal model: role of extrinsic and overuse factors. Ann Biomed Eng 2002*; 30*(8): 1057-1063.

Stackhouse, S. K., Eisennagel, A., Eisennagel, J., Lenker, H., Sweitzer, B. A., & McClure, P. W. Experimental pain inhibits infraspinatus activation during isometric external rotation. J Shoulder Elbow Surg 2012.

Su, K. P., Johnson, M. P., Gracely, E. J., & Karduna, A. R. Scapular rotation in swimmers with and without impingement syndrome: practice effects. Med Sci Sports Exerc 2004*; 36*(7): 1117-1123.

Suppa, A., Biasiotta, A., Belvisi, D., Marsili, L., La Cesa, S., Truini, A., et al. Heat-Evoked Experimental Pain Induces Long-Term Potentiation-Like Plasticity in Human Primary Motor Cortex. Cereb Cortex 2012.

Suprak, D. N., Osternig, L. R., van Donkelaar, P., & Karduna, A. R. Shoulder joint position sense improves with elevation angle in a novel, unconstrained task. J Orthop Res 2006a*; 24*(3): 559-568.

Suprak, D. N., Osternig, L. R., van Donkelaar, P., & Karduna, A. R. Shoulder joint position sense improves with elevation angle in a novel, unconstrained task. J Orthop Res 2006b*; 24*(3): 559-568.

Suprak, D. N., Osternig, L. R., van Donkelaar, P., & Karduna, A. R. Shoulder joint position sense improves with external load. J Mot Behav 2007*; 39*(6): 517-525.

Svendsen, S., Bonde, J., Mathiassen, S. E., Stengaard-Pedersen, K., & Frich, L. H. Work related shoulder disorders: quantitative exposure-response relations with reference to arm posture. Occup Environ Med 2004*; 61*(10): 844-853.

Svendsen, S. W., Gelineck, J., Mathiassen, S. E., Bonde, J. P., Frich, L. H., Stengaard-Pedersen, K., et al. Work above shoulder level and degenerative alterations of the rotator cuff tendons: a magnetic resonance imaging study. Arthritis Rheum 2004*; 50*(10): 3314-3322.

Szeto, G. P., Straker, L. M., & O'Sullivan, P. B. A comparison of symptomatic and asymptomatic office workers performing monotonous keyboard work--1: neck and shoulder muscle recruitment patterns. Man Ther 2005*; 10*(4): 270-280.

Taimela, S., Kankaanpaa, M., & Luoto, S. The effect of lumbar fatigue on the ability to sense a change in lumbar position. A controlled study. Spine 1999*; 24*(13): 1322-1327.

Timmons, M. K., Thigpen, C. A., Seitz, A. L., Karduna, A. R., Arnold, B. L., & Michener, L. A. Scapular kinematics and subacromial-impingement syndrome: a meta-analysis. J Sport Rehabil 2012*; 21*(4): 354-370.

Tripp, B. L., Boswell, L., Gansneder, B. M., & Shultz, S. J. Functional Fatigue Decreases 3-Dimensional Multijoint Position Reproduction Acuity in the Overhead-Throwing Athlete. J Athl Train 2004*; 39*(4): 316-320.

Tsai, N. T., McClure, P. W., & Karduna, A. R. Effects of muscle fatigue on 3-dimensional scapular kinematics. Arch Phys Med Rehabil 2003*; 84*(7): 1000-1005.

Urwin, M., Symmons, D., Allison, T., Brammah, T., Busby, H., Roxby, M., et al. Estimating the burden of musculoskeletal disorders in the community: the comparative prevalence of symptoms at different anatomical sites, and the relation to social deprivation. Ann Rheum Dis 1998*; 57*(11): 649-655.

Valeriani, M., Restuccia, D., Di Lazzaro, V., Oliviero, A., Profice, P., Le Pera, D., et al. Inhibition of the human primary motor area by painful heat stimulation of the skin. Clin Neurophysiol 1999*; 110*(8): 1475-1480.

van der Helm, F. C., & Pronk, G. M. Three-dimensional recording and description of motions of the shoulder mechanism. J Biomech Eng 1995*; 117*(1): 27-40.

van der Windt, D. A., Koes, B. W., de Jong, B. A., & Bouter, L. M. Shoulder disorders in general practice: incidence, patient characteristics, and management. Ann Rheum Dis 1995*; 54*(12): 959-964.

Vierck, C. J., Jr. Comparison of the effects of dorsal rhizotomy or dorsal column transection on motor performance of monkeys. Exp Neurol 1982*; 75*(3): 566-575.

Voight, M. L., Hardin, J. A., Blackburn, T. A., Tippett, S., & Canner, G. C. The effects of muscle fatigue on and the relationship of arm dominance to shoulder proprioception. Journal of Orthopaedic and Sports Physical Therapy 1996*; 23*(6): 348-352.

Voloshin, I., Gelinas, J., Maloney, M. D., O'Keefe, R. J., Bigliani, L. U., & Blaine, T. A. Proinflammatory cytokines and metalloproteases are expressed in the subacromial bursa in patients with rotator cuff disease. Arthroscopy 2005*; 21*(9): 1076.

Warner, J. J., Lephart, S., & Fu, F. H. Role of proprioception in pathoetiology of shoulder instability. Clin Orthop Relat Res 1996*;* (330): 35-39.

Warner, J. J., Micheli, L. J., Arslanian, L. E., Kennedy, J., & Kennedy, R. Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. Am J Sports Med 1990*; 18*(4): 366-375.

Watson-Jones, R. (1976). *Fractures and Joint Injuries. Fifth edition.* (Vol. 2): London, Churchill Livingstone.

Weiller, C., Juptner, M., Fellows, S., Rijntjes, M., Leonhardt, G., Kiebel, S., et al. Brain representation of active and passive movements. Neuroimage 1996*; 4*(2): 105-110.

Westgaard, R. H., Vasseljen, O., & Holte, K. A. Trapezius muscle activity as a risk indicator for shoulder and neck pain in female service workers with low biomechanical exposure. Ergonomics 2001*; 44*(3): 339-353.

Wu, G., van der Helm, F. C., Veeger, H. E., Makhsous, M., Van Roy, P., Anglin, C., et al. 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 2005*; 38*(5): 981-992.

Yamaguchi, K., Sher, J. S., Andersen, W. K., Garretson, R., Uribe, J. W., Hechtman, K., et al. Glenohumeral motion in patients with rotator cuff tears: a comparison of asymptomatic and symptomatic shoulders. J Shoulder Elbow Surg 2000*; 9*(1): 6-11.

Ylipaa, V., Szuster, F., Spencer, J., Preber, H., Benko, S. S., & Arnetz, B. B. Health, mental well-being, and musculoskeletal disorders: a comparison between Swedish and Australian dental hygienist. J Dent Hyg 2002*; 76*(1): 47-58.

Yu, C. M., Chen, C. H., Liu, H. T., Dai, M. H., Wang, I. C., & Wang, K. C. Subacromial injections of corticosteroids and xylocaine for painful subacromial impingement syndrome. Chang Gung Med J 2006*; 29*(5): 474-479.

Zuckerman, J. D., Gallagher, M. A., Cuomo, F., & Rokito, A. The effect of instability and subsequent anterior shoulder repair on proprioceptive ability. J Shoulder Elbow Surg 2003*; 12*(2): 105-109.

Zuckerman, J. D., Gallagher, M. A., Lehman, C., Kraushaar, B. S., & Choueka, J. Normal shoulder proprioception and the effect of lidocaine injection. J Shoulder Elbow Surg 1999*; 8*(1): 11-16.