THE EFFECTS OF THORACIC SPINE MANIPULATION IN SUBJECTS WITH SIGNS OF SHOULDER IMPINGEMENT

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by
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ABSTRACT

THE EFFECTS OF THORACIC SPINE MANIPULATION IN SUBJECTS WITH SHOULDER IMPINGEMENT

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Doctor of Philosophy

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Doctoral Advisory Committee Chair:
Mary F. Barbe, PhD

Shoulder impingement is the most common cause of shoulder pain. It is often described as mechanical irritation of the tendons of the rotator cuff or long head of the biceps due to compression against either the structures of the subacromial arch or the glenoid and glenoid labrum. Various treatment options exist to address impingement, and recent studies suggest thoracic spine manipulation may be a useful option. The purpose of this study was to assess changes in range of motion (ROM), pain and shoulder function both immediately post- and 7 to 10 days after receiving thoracic spine manipulations. We also attempted to identify changes in scapular kinematics and shoulder muscle activity associated with thoracic spine manipulation in subjects with shoulder impingement.

Thirty subjects between the ages of 18 and 45 with signs of shoulder impingement participated in this repeated measures study. All subjects received both a mid-thoracic spine and a cervicothoracic junction manipulation. Changes in pain were assessed using an 11 point numeric pain rating scale. Subjects reported pain with performance of provocative testing (Jobes Empty Can, Hawkins-Kennedy and Neer's tests for impingement) as well as with performance of cervical rotation, thoracic spine flexion and extension and weighted humeral elevation. Shoulder elevation force production pre- and post- manipulation was assessed using hand-held dynamometry. Additionally, subjects completed the Penn Shoulder Score (PSS) and the Sports and Performing Arts Module of the Disabilities of the Arm, Shoulder and Hand (DASH) Questionnaire to assess shoulder pain and function 7 to 10 days post thoracic spine manipulation.

Electromagnetic sensors tracked three-dimensional scapular and clavicular kinematics as well as cervical, thoracic and humerothoracic ROM. Surface electromyography data were collected from the infraspinatus, serratus anterior, and the upper, middle and lower trapezius muscles with loaded humerothoracic elevation. A repeated measures analysis of variance (ANOVA) was used to compare scapular orientation and muscle activity at 30, 60, 90 ad 120 degrees of humerothoracic elevation before and after spinal manipulation.

Paired t – tests revealed significant decreases in pain [(Jobes 2.6 ± 1.1, Neer's 2.6 ± 1.3, Hawkins-Kennedy 2.8 ± 1.3; $p<0.001$ for all three tests) (weighted shoulder elevation 2.0 ± 1.5, $p<0.001$; cervical rotation 0.4 ± .9, $p=0.039$)] as well as improvements in shoulder function (Force production 5.5±3.1, PSS 7.7 ± 9.4 and DASH 16.4 ± 13.2; $p<0.001$ for each). No significant changes in any of the ROM assessments were observed. No changes in scapular or clavicular kinematics were observed, with the exception of small decrease in scapular upward rotation ($p = .04$). A small but significant increase in middle trapezius activity ($p = .03$) was detected; however, no other significant differences in muscle activity were observed following manipulation. Moreover, paired t-tests revealed no significant differences in muscle onset times after manipulation.

The findings of this study indicate that thoracic spine manipulation may be an effective intervention to treat pain associated with shoulder impingement; however, the improvements associated with thoracic spine manipulation are not likely explained by changes in scapular kinematics or shoulder muscle activity. Thoracic spine manipulation did not substantially alter scapular kinematics or motor control at the shoulder.

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I would like to extend my sincere thanks and gratitude for the patience and on-going mentorship and guidance of Dr. Philip McClure, who graciously gave me the opportunity to perform research in his laboratory, as well as Dr. Mary Barbe, my advisory committee chair, for the many years of guidance and support she provided throughout my Temple University experience. In addition, I would like to acknowledge Dr. Richard Lauer for his advice and expertise as a member of my advisory committee. I would also like to acknowledge both Dr. Laurita Hack and Dr. Katherine Shepard for their encouragement and mentorship throughout my time at Temple University. Finally I would like to thank my family and friends, especially Dr. Claire McGrath, as well as my colleagues at UMDNJ for their many years of much appreciated support and encouragement.

DEDICATION

This dissertation is dedicated to my mother, Patricia Muschlitz, whose strength and courage is an ongoing source of inspiration and without whom, I would not be the women I am today.

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LIST OF ABBREVIATIONS

NIOSH	National Institute for Occupational Safety and Health
sEMG	surface electromyography
RTC	rotator cuff
ANOVA	analysis of variance
CTR	cervico-thoracic ratio
ROM	range of motion
VAS	visual analog scale
fwEMG	fine wire electromyography
MVIC	maximal voluntary isometric contraction
NDI	Neck Disability Index
NPRS	numeric pain rating scale
GROC	Global Rating of Change
SPADI	Shoulder Pain and Disability Index
H-Reflex	Hoffman reflex
Hz	hertz
ms	millisecond
rpm	rotations per minute
DASH	Disability of the Arm Shoulder and Hand Questionnaire
PSS	Penn Shoulder Score
MCID	meaningful clinically important difference
IS	infraspinatus
SA	serratus anterior

UT	upper trapezius
MT	middle trapezius
LT	lower trapezius

CHAPTER 1

REVIEW OF THE LITERATUE

Introduction

The shoulder is the most mobile joint in the human body, although it sacrifices stability for multiple degrees of freedom and large ranges of motion. This mobility leaves the shoulder susceptible to injury and dysfunction. It has been reported that up to 24% of the population has experienced shoulder pain of some variety, and chronic shoulder pain is a common complaint among the sedentary as well as recreational and elite athletes[1]. Upper extremity athletes, such as pitchers[2-4] and swimmers[5, 6], are particularly susceptible to shoulder injuries. Hill found that 61% of collegiate pitchers and 51% of little league pitchers experienced shoulder pain that impaired their ability to participate in their sport [7]. According to one National Institute for Occupational Safety and Health (NIOSH) publication, shoulder injuries result in 12 missed worked days per year, third only to abdominal and wrist injuries[8].

Rotator cuff pathology, often due to impingement is one of the most common causes of shoulder pain and dysfunction[9-12]. Neer has broadly defined impingement as a mechanical compression injury of tissues in the subacromial space, also known as external impingement [13]. However, there are several other types of impingement as well. Internal impingement involves irritation of the underside of the rotator cuff by the glenoid and/or glenoid labrum and often occurs in overhead athletes[14, 15]. Posterior impingement refers to contact of the supra- and/or infraspinatus tendons with the posterior-superior glenoid labrum when the upper extremity is abducted and externally rotated[14, 16]. These various types of impingement may be caused by altered scapulothoracic or scapulohumeral kinematics[17-20], also known as scapular dyskinesis. Other causes include posterior capsule tightness[21, 22], faulty thoracic spine posture[23, 24], acromial arch pathology[25] and rotator cuff weakness. Impingement frequently leads to rotator cuff tendinopathy[26, 27].

Clinical signs of impingement include painful arc of motion between 70 and 120 degrees of abduction pain with palpation of the lateral or anterior subacromial region[28]. Individuals with impingement may also present with weakness of the serratus anterior and other shoulder girdle musculature along with positive findings with performance various special clinical tests, including Jobes empty can test, Hawkins-Kennedy test and Neer's test for shoulder impingement[29] .

A variety of treatment options have been proposed to treat shoulder impingement, including acromioplasty[30], posterior capsule stretch[21, 31], strengthening and neuromuscular re-education[32]. Recently, the use of joint mobilization, including spinal manipulation has been explored as a viable treatment option for shoulder pain associated with impingement[33-35].

Joint mobilization combined with traditional therapy, such as stretching and therapeutic exercise, may be superior to traditional therapy alone in treating patients with shoulder girdle dysfunction[33, 36, 37]. Winters et al found that in subjects with shoulder girdle dysfunction, spinal and rib mobilization was superior to traditional physiotherapy and corticosteroid injection in addressing shoulder pain and dysfunction [37]. Bergman et al found that subjects with shoulder pain and dysfunction who received thoracic and cervical spine mobilization in addition to traditional medical care demonstrated greater improvement as compared to those who received only traditional medical care[38]. In this study, tradition medical care consisted of oral analgesics, nonsteroidal anti-inflammatory medication, corticosteroid injection and therapeutic exercises[38]. Bang and Deyles found that the addition of joint mobilization techniques to strengthening, stretching and neuromotor re-education significantly improved strength, pain and function in subjects with rotator cuff pathology due to impingement [33]. Both Boyles and Strunce found that after thoracic spine and cervicothoracic junction manipulation, patients with shoulder impingement demonstrated significant decreases in self-reported disability and self-rated pain with various upper extremity activities[35,] . In addition to these findings, Strunce also found the spinal manipulation resulted in increased glenohumeral range of motion[35]. While evidence exists to support the use of spinal manipulation to treat shoulder impingement, the mechanisms by which these manipulations effectively alleviate symptoms at the shoulder are not well understood.

The conceptual framework for the hypothesized biomechanical and neuromotor effects of thoracic spine manipulation in individuals with shoulder impingement is shown in Figure 1. Elements in the square on the far left of the figure represent the factors contributing to shoulder impingement. The application of a thoracic spine manipulation results in biomechanical and neurophysiologic responses that ultimately impact pain and function in people with shoulder impingement. The bi-directional arrow between the biomechanical factors and neurophysiologic factors represents the proposed interaction between the two. The biomechanical effects of spinal manipulation, such as tissue stretch, may trigger a cascade of neurophysiologic responses. These neurophysiologic responses may, in turn result in additional biomechanical changes such as increased mobility due to pain modulation. Elements that were not assessed in this research study are shaded. The dotted lines connecting the thoracic spine manipulation box to shoulder impingement represent the theoretical impact that thoracic spine manipulation has in people with impingement. The dashed lines represent elements not assessed in this study but that are presumed to impact the outcomes associated with thoracic spine manipulation on people with shoulder impingement. Neurophysiologic changes mediated at the peripheral and supraspinal level are beyond the scope of this study; however, this framework acknowledges that these factors play a role in decreased pain and improved function.

The following review of the literature will explore the differences in scapular kinematics and motor control in people with or without shoulder pain related to shoulder impingement. The discussion of scapular kinematics will also explore the relationship between the thoracic spine and the scapula, known as the scapulothoracic mechanism[39]. Next, literature assessing the efficacy of thoracic spine manipulation to treat shoulder pain related to impingement will be reviewed. Finally, literature exploring the effects of spinal manipulation on biomechanics and neuromotor activity will be discussed.

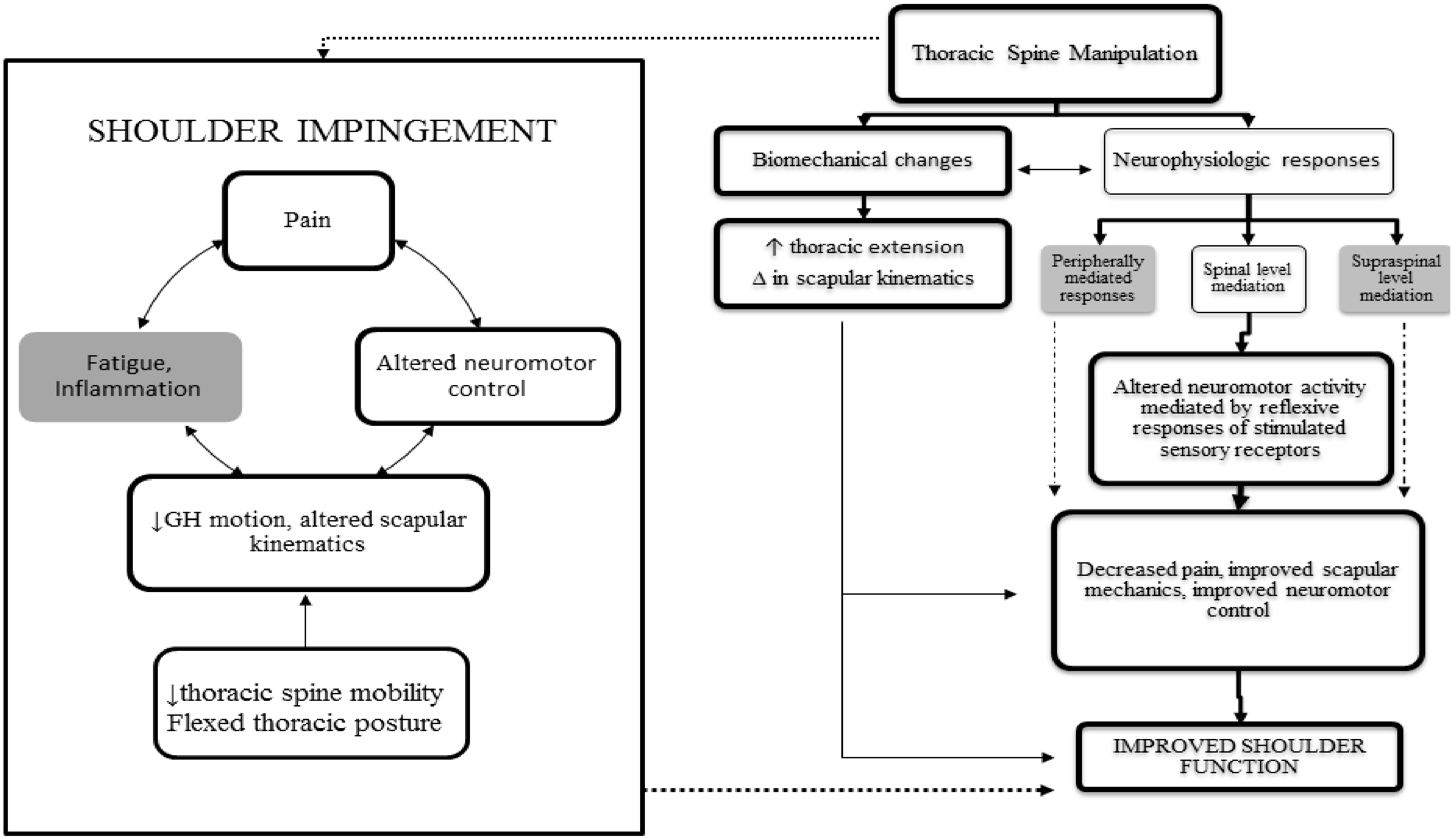


Figure 1. Theoretical framework: elements in the box on the far left of the figure represent the factors contributing to shoulder impingement. The application of a thoracic spine manipulation results in biomechanical and neurophysiologic responses that ultimately impact pain and function in people with shoulder impingement

Scapular Kinematics

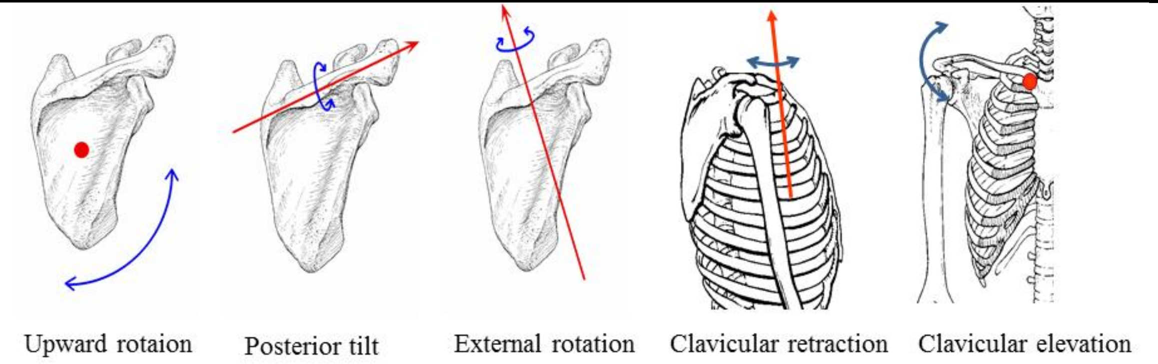
Inman et al[40] first described the contributions of the clavicle, scapula and humerus to normal shoulder motion in 1942. Since then, additional research has further elucidated the complex interactions of these segments along with the three-dimensional arthrokinematics and motor control necessary for proper upper extremity function[18-20, 27, 41-48]. An understanding of these biomechanical interactions is imperative to understand the underlying pathologic mechanics associated with shoulder impingement.

The four joints associated with shoulder motion include the sternoclavicular, acromioclavicular, glenohumeral, and scapulothoracic joints. The sternoclavicular joint is a saddle synovial joint that functions as a ball and socket joint. Motions occurring at the sternoclavicular joint allow the lateral end of the clavicle to be elevated, depressed, protracted and retracted as well as anteriorly and posteriorly rotated[49]. The acromioclavicular joint is a plane synovial joint located approximately two to three centimeters medial to the lateral most aspect of the acromion. The lateral end of the clavicle articulates with the acromion and is anchored to the scapula by several ligaments. The coracoclavicular ligament, consisting of the conoid and trapezoid ligaments, anchors the clavicle to the coracoid process of the scapula[49]. The conoid ligament primarily resists depression of the scapula[49] and produces posterior rotation of the clavicle when the clavicle is pulled by contraction of the upper trapezius[27]. The trapezoid ligament resists medial displacement of the scapula[49]. The glenohumeral joint is a ball-and-socket synovial joint that allows a wide range of movement including flexion/extension, abduction/adduction, medial/lateral rotation and circumduction and relies heavily on ligamentous structures and the muscles of the rotator cuff for stability[49]. The last joint, the scapulothoracic articulation, is not a true bony articulation. Instead, this articulation allows motion to occur between the fascial planes of the scapula and the wall of the thorax and is essential for normal function of the shoulder complex. Movement at the scapulothoracic articulation involves a complex coupling of motions at both the sternoclavicular and the acromioclavicular joints[43].

Normal shoulder elevation involves contributions from all four of these joints[43] and entails approximately 50 degrees of scapular upward rotation and approximately 20 – 25 degrees of posterior tilt[43, 48], along varying degrees of internal rotation[43, 48]. For example, at the sternoclavicular joint, the clavicle posteriorly rotates approximately 30 degrees[43, 50], retracts about 15-20 degrees[43] and elevates less than 10 degrees[48, 50] with full humeral elevation.

Scapular Kinematic Terminology

Scapular orientation is typically described in terms of rotations about three axes[48] and are illustrated in Figure 2. Upward and downward rotation occurs about an axis perpendicular to the plane of the scapula. Upward rotation is defined as lateral motion of the inferior angle while the glenoid fossa rotates superiorly. Internal and external rotation occurs about a vertical axis and serves to maintain scapular contact with the ribcage during elevation in both the frontal and sagittal planes. Internal rotation occurs when the lateral angle moves medially while external rotation occurs when the lateral angle move laterally. Scapular rotation about a medial-lateral axis produces scapular tipping or tilt. Anterior tilt occurs when the superior border moves anteriorly and the inferior angle moves posteriorly. Posterior tilt occurs when the superior border of the scapula moves posteriorly and the inferior angle move anteriorly. Superior-inferior translation refers to scapular motion relative to its resting position between the second and seventh ribs. The clavicle serves as a strut, fixed at the sternoclavicular and acromioclavicular joints. Therefore, clavicular motions of protraction/retraction and elevation/depression can be used to describe scapular positioning[48].



Upward rotaion Posterior tilt External rotation Clavicular retraction Clavicular elevation

Figure 2. Scapular and clavicular rotations modified with permission from McClure PW, Bialker J, Neff N, Williams G, Karduna AR. Shoulder function and 3-dimensional kinematics in people with shoulder impingement syndrome before and after 6-week exercise program, Physical Therapy, 2004:84(9): 832-48. This material is copyrighted and any further reproduction or distribution in prohibited.

Scapular Kinematic Variations

Variations in scapular kinematics that are associated with shoulder impingement have been well documented, although the results vary significantly across studies, perhaps due to differences in methodology, motions assessed and severity of symptoms between studies. The following analysis of the literature discusses current findings regarding scapula kinematics in people with shoulder pain and impingement. A summary of the findings regarding scapular kinematics in patients with shoulder impingement can be found in Table 1.

Table 1. Scapular kinematic findings

Authors	Impingement Group Findings	Assessment technique
Su	Decreased scapular upward rotation	Goniometry
Endo		Radiography
Ludewig		Electromagnetic tracking
Lin		Electromagnetic tracking
McClure	Increased scapular upward rotation	Electromagnetic tracking
Hebert		Optical tracking
Lukasiewicz	Decreased scapular posterior tilt (more anterior tilt)	Electromechanical digitization
Ludewig		Electromagnetic tracking
Borstad		Electromagnetic tracking
Lin		Electromagnetic tracking
McClure	Increased scapular posterior tilt (less anterior tilt)	Electromagnetic tracking
Laudner		Electromagnetic tracking
Hebert		Optical tracking
Endo		Radiography
Ludewig	Increased scapular internal rotation	Electromagnetic tracking
Borstad		Optical tracking
Hebert		
Lukasiewicz	Increased scapular upward translation	Electromechanical digitization
Lin		Electromagnetic tracking
Mell*		Electromagnetic tracking
Warner	Scapular winging	Moiré topography

*Subjects had rotator cuff tears

Several techniques have been employed to assess scapular kinematics in both healthy subjects and in those with shoulder pathology. These techniques include goniometry, Moiré topography, electromechanical digitization, electromagnetic tracking, optical tracking, radiography, and magnetic resonance imaging.

Goniometry

Su et al studied the effects of fatigue on scapular upward rotation in swimmers with and without shoulder impingement using goniometry [51]. Twenty swimmers with and 20 swimmers without clinical diagnosis of impingement were included in this pre-test/post-test study. Scapular upward rotation was measured at 45, 90 and 135 degrees of humeral elevation using goniometry pre and post a typical swim practice. Upper trapezius and serratus anterior strength was assessed using a hand-held dynamometer before and after practice. Both groups demonstrated decreased strength in the upper trapezius and serratus anterior after practice. They also observed that the impingement group demonstrated significantly less upward scapular rotation, especially at higher elevations, compared to the healthy group.

Moiré Topography

Warner et al applied a modified Moiré topographic analysis to assess three-dimensional scapulothoracic motion in subjects with and without shoulder instability or impingement syndrome [52]. Moiré topographic analysis involves the use of a pointed light source to cast shadows on a grid, behind which the patient is standing. It is purported that the variations in contour lines accurately depict scapulothoracic asymmetries. In this study, the control group consisted of 22 subjects being evaluated for lower extremity problems with no prior history of shoulder pain or dysfunction. The instability group consisted of 22 patients with anterior-inferior shoulder instability as determined by evidence of prior dislocation or intra-operative confirmation. The impingement group consisted of seven patients; diagnosis was determined by physical exam. During static assessment of scapulothoracic topography, all subjects held both arms elevated to 90 degrees in the frontal plane while holding a 4.5 kilogram weight. For assessment of scapulothoracic topography with dynamic activities, subjects lifted 4.5 kilogram weights simultaneously in both arms from 0 to 120 degrees of humeral elevation in the frontal plane.

Static testing indicated that 14% of the asymptomatic group, 32% of the instability group and 57% of the impingement group demonstrated scapulothoracic asymmetries. Dynamic testing revealed scapulothoracic asymmetries, and/or scapular winging in 18% of the asymptomatic subjects, 64% of the subjects with instability and in all seven subjects with shoulder impingement. This study demonstrated the importance of dynamic testing in revealing scapulothoracic abnormalities; however, no reliability data was provided for the custom Moiré apparatus.

Electromechanical Digitization

Van der Helm and Pronk first used three dimensional electromechanical digitization to assess scapulohumeral motion[53]. This technique requires digitization of bony landmarks to create local three-dimensional coordinates. Local coordinate data is then transformed into a global coordinate system to calculate rotational matrices of the previously palpated bony landmarks.

Lukasiewicz et al utilized electromechanical digitization in a two group, post-test design to compare scapular orientation between subjects with and without shoulder impingement [20]. The impingement group was comprised of 17 subjects with unilateral impingement. The comparison group was comprised of 20 subjects with asymptomatic shoulders. Scapular orientation was measured using the Metrecom, an electromechanical digitization system, during static humeral abduction in the scapular plane at 90 degrees and at maximal elevation. The impingement group demonstrated significantly less scapular posterior tilt at 90 degrees and maximal elevation compared to their asymptomatic side and those in the non-impaired group. No statistically significant differences were found for scapular upward rotation or internal rotation. However, there were significant differences in superior-inferior positioning of the scapular between the impingement and non-impaired groups. For example, the impingement group demonstrated greater superior translation at 90 degrees and at maximal elevation on both the symptomatic and asymptomatic sides as compared to the non-impaired group.

Electromagnetic Tracking

Ludewig and Cook also performed a two-group comparison with 50 subjects to analyze glenohumeral and scapulothoracic kinematics and associated muscle activity [18]. Groups were matched by occupational exposure to overhead activities and were separated into two groups: those with signs and symptoms of impingement and those without. Surface electromyography (sEMG) was used to collect data on the upper and lower trapezius and from the serratus anterior muscles. Kinematic data of the trunk, scapula, and humerus were collected at various degrees of humeral elevation in the scapular plane under three load conditions using an electromagnetic tracking system. Compared to the non-impingement group, the impingement group demonstrated decreased scapular upward rotation, increased anterior tilt and increased scapular internal rotation. The impingement group demonstrated a 9% decrease in serratus anterior muscle activity at all elevations and under all load conditions as compared to the non-impingement group (p =

0.05). Subjects with impingement also demonstrated 11% more upper trapezius activity in all phases and load combinations ($p = 0.05$). The lower trapezius demonstrated 13% increase in activity from 61- 90 degrees of elevation and 17% more activity from 91 – 120 degrees of humeral elevation ($p < 0.03$). These authors took great care to match upper extremity activity levels between the groups, making for stronger comparisons. Thus, the differences in scapular kinematics and muscle activity found between the groups, such as decreased scapular posterior tilt, could be causally related to impingement.

Lin et al used three-dimensional motion analysis and electromyography to assess scapular motion and shoulder muscle activity during functional tasks in subjects with and without shoulder dysfunction [54]. Shoulder dysfunction was non-specific, defined only as pain and limited range of motion without evidence of frank rotator cuff tear. Subjects performed a series of four functional tasks that were randomly ordered, including one hard, one routine, one medium and one easy task. The hard task was a weighted, overhead activity; the routine task was a shoulder height activity; the medium task involved sliding a box at desk top height; and the easy task involved reaching for a salt shaker at desk top height. Kinematic data was collected using the Polhemus FASTRAK. Electromyographic data was collected for the upper trapezius, lower serratus anterior, the latissimus dorsi, the anterior deltoid, the biceps brachii and the triceps muscles. They observed differences in peak scapular posterior tilt, upward rotation and upward translation between groups across the four functional tasks. Generally, the shoulder dysfunction group demonstrated less upward rotation and posterior tilt with increased superior translation than did the healthy subjects. The electromyographic analysis revealed differences in activity for the upper trapezius, serratus anterior and anterior deltoid between groups across all four functional tasks. Generally, the shoulder dysfunction group demonstrated increased upper trapezius and anterior deltoid activity and decreased serratus anterior activity. These findings agree with those of Ludewig and Cook[18] as well as those of Lukasiewicz et al[20]. However, the subjects in this study were not specifically diagnosed with impingement or rotator cuff tendonopathy, suggesting that perhaps the biomechanical abnormalities found in subjects with impingement are similar to those in people with general shoulder pain and dysfunction.

Mell et al also used electromagnetic tracking to study differences in scapular and glenohumeral rhythm between subjects with healthy shoulders, those with rotator cuff tendonopathy and those with actual rotator cuff tear [55]. Forty-two subjects were divided into 3 group based on their shoulder diagnosis. Full-thickness rotator cuff (RTC) tear diagnosis was confirmed via magnetic resonance imaging or ultrasonography. The MotionStar electromagnetic tracking system was used to assess scapular and glenohumeral kinematics during flexion and elevation in the scapular plane while subjects were seated in a modified wooden chair. Each reaching motion was performed three times. All ranges of humeral elevation were normalized to maximal humeral elevation and then divided into three phases based on the minimum and maximum values. Plots were then created for scapular elevation, tilt and protraction against non-normalized humeral elevation. Best fit lines were used to calculate shoulder rhythm for each of the three phases for each of the three repetitions of shoulder elevation in the sagittal and scapular planes. A one-way analysis of variance (ANOVA) was used to assess differences in slope between groups. While differences in shoulder rhythm slopes were found between the RTC tear group and both the tendonopathy and control groups, indicating increased scapular upward translation in the RTC cuff tear group, no other significant differences were detected with regards to scapular kinematics. This study used the anatomic coordinate system based on older works of van der Helm and Pronk[53]. Most current studies define their coordinate system based on the International Society of Biomechanics recommendations[56]. This is one possible explanation for the difference in findings of this study compared to that of many others.

In another study using electromagnetic tracking, Borstad and Ludewig assessed differences in scapular orientation during concentric elevation and eccentric lowering of the humerus in which 26 symptomatic subjects were compared 26 healthy subjects[42]. Three-dimensional orientation information for the thorax, scapula and humerus was collected during five repetitions of humeral elevation and lowering from 40 – 120 degrees in the scapular plane. The scapular plane elevation is typically defined as elevation in a plane 30 degrees[57] to 40 degrees[19] anterior to the frontal plane of motion. No difference in scapular elevation was found between groups during either the concentric or eccentric phase of the motion. However, they did find that the symptomatic group demonstrated increased scapular internal rotation at 120 degrees of elevation during the eccentric phase. The symptomatic group also demonstrated increased anterior tilt as compared to the asymptomatic group at higher elevations. Internal rotation during the eccentric phase at 100 degrees of elevation increased similarly for both groups. Their findings regarding scapular upward rotation agree with those of Ludwig[18] and Endo[58] in that a decrease in upward scapular rotation was observed in the symptomatic group.

Scapular positioning in throwers with shoulder impingement was assessed by Laudner et al[59]. Eleven male baseball throwers with internal impingement were matched with 11 baseball players without shoulder pain. Kinematic data was collected using the Flock of Birds electromagnetic tracking system integrated with Motion Monitor software. Maximal isometric load with elevation in the scapular plane was determined using the Biodex System 3 dynamometer. Participants held a load equivalent to 25% of their maximal load during humeral elevation trials. Participants then performed 10 repetitions of humeral elevation/depression in the scapular plane. A mixed-model ANOVA was used to determine differences between and within groups. No statistically significant differences were found between groups with regards to scapular internal/external rotation, upward/downward rotation, or sternoclavicular elevation. There were, however, differences in scapular tilt, at all levels of humeral elevation, between throwers with and without impingement. The throwers with impingement demonstrated greater posterior tilting of the scapula.

It should be noted that subjects in this study by Laudner et al[59] had internal impingement, also known as "thrower's" shoulder. Internal impingement specifically refers to impingement of the supraspinatus and possibly the infraspinatus between the posterior humeral head and the glenoid labrum. The mechanisms of internal impingement are slightly different than classic external impingement. Internal impingement is most often seen in overhead and involves irritation of the underside of the rotator cuff due to excessive contact with the glenoid labrum[14] as opposed to irritation of the superior side of the rotator cuff due to excessive contact with the coracoacromial arch as seen in classic external impingement[13]. Therefore, it is not surprising that some of the scapular kinematics noted in this study differ from those of other studies involving external or subacromial impingement. That said, the findings of this study agree with those of Endo[58] with regards to scapular posterior tilt, in which radiographic methods were used, although they differ from the findings of other studies in which electromagnetic tracking was used.

Lastly, McClure et al compared various physical factors between subjects with and without symptoms of shoulder impingement [19]. The factors assessed were 3-dimensional scapular kinematics, shoulder range of motion (ROM), muscle force and thoracic spine and shoulder resting posture. Each group consisted of 45 demographically matched subjects. The control group had no signs or symptoms of shoulder pain. The experimental group had been diagnosed with shoulder impingement. Scapular kinematics were quantified using the Polhemus 3SPACE FASTRAK electromagnetic tracking device. Shoulder range of motion in flexion, abduction, internal and external rotation was measured using a standard goniometer. Muscle force was measured using the “break test” method via a Nicolas hand-held dynamometer. They found that the impingement group demonstrated increased upward scapular rotation and clavicular elevation at 90 and 120 degrees of humeral flexion. They also demonstrated increased posterior tilt and clavicular retraction at 120 degrees of humeral elevation in the scapular plane and increased upward rotation at 90 degrees of humeral elevation in the scapular plane. The impingement group demonstrated decreased shoulder range of motion and decreased muscle force production compared to the control group.

Optical Tracking

Optical tracking uses cameras and either reflective or infrared-emitting markers to assess motion in three dimensions. The OPTOTRAK is a non-contact motion measurement system that tracks small infrared position sensors that are attached to a subject using multiple cameras. Hebert et al used the OPTOTRAK to assess three dimensional scapular positioning in 41 patients shoulder impingement at various degrees of humeral elevation [60]. They also calculated percent contribution of each scapular rotation to the total scapular range of motion in both shoulders of the subjects with shoulder impingement. Finally, they attempted to classify the shoulder impingement subjects into subgroups based on scapular tilting differences between the symptomatic and asymptomatic shoulders. It should be noted that these researchers used different nomenclature for scapular rotations than typically seen in literature in the United States. Hebert et al describes scapular anterior tilting and relative tilting of the scapula such that the acromion moves away from the greater tubercle and the inferior angle moves towards the rib cage. This is typically referred to as posterior tilt in US literature. Scapular external rotation is referred to as upward rotation of the inferior angle; this is traditionally referred to as upward rotation in literature in the United States. Scapular winging is referred to as posterior transverse rotation by Hebert et al[60].

Scapular rotations were assessed at rest, at 70, 90 and 110 degrees of elevation in the frontal and sagittal planes. Shoulder angle was monitored via goniometry. The authors created an index called the scapular total range of motion index, which assessed relative contributions of each of the three scapular rotations to total scapular motion. A Pearson product-moment correlation was used to quantify the relationship between each individual scapular rotation and total scapular range of motion. They found that in flexion, increasing arm elevation revealed increased anterior tilting (or posterior tilt in traditional nomenclature) and external rotation (upward rotation in traditional nomenclature) of the scapula. They also observed that the impinged shoulders demonstrated greater transverse rotation (internal rotation in traditional nomenclature). In contrast, no difference was noted between the different scapular rotation contributions to total scapular range of motion in abduction.

Radiographic Imaging

Endo et al performed a study using radiographic imaging to assess alterations in scapular tilt patterns in subjects with shoulder impingement using radiography [58]. Authors compared scapular rotation patterns between the affected and unaffected sides of subjects with impingement and between the dominant and non-dominant sides of normal subjects. Radiographic images were taken at 0, 45 and 90 degrees of shoulder abduction. They found that subjects with impingement demonstrated decreased upward scapular rotation and decreased anterior tilt as compared to the unaffected limb. Also of importance, no significant differences were found between normal volunteers and the unaffected side of subjects with impingement.

The technique employed in this study differed from previous studies discussed in which electromagnetic tracking was used to assess scapular kinematics. Despite the technical assessment differences, Endo's[58] findings were similar to those of Ludewig[18] with regards to upward rotation, although the direction of scapular tilting differed (decreased anterior tilt versus increased anterior tilt).

Magnetic Resonance Imaging

Graichen et al studied 20 subjects with varying degrees of rotator cuff tendonopathy [61] . Fourteen subjects had Neer's Grade I and II impingement with no evidence of rotator cuff tear. Six subjects had a supraspinatus tear of at least one centimeter in size. Scapular upward rotation was compared to 14 healthy controls using open magnetic resonance imaging. Scapular upward rotation was measured at 90 degrees of humeral elevation both with and without a 1 kilogram adduction force applied to the distal humerus. No significant between group differences were found in glenoid angulation with or without application of an adduction force. However the impingement group did present with more variability in glenoid angulation than did the control group.

There are several possibilities explaining why Graichen et al[61] did not find differences in scapular upward rotation between healthy subjects and those with impingement. One reason may be that the authors were assessing scapular positioning in a static posture. Warner et al[52] demonstrated that scapular asymmetries are better revealed dynamically versus statically. Even with the application of a 1 kilogram adduction force, the scapula may behave quite differently under dynamic conditions. Also reports of scapular upward rotation are variable between studies. The measurement techniques used with the magnetic resonance images may not have been sensitive enough to detect subtle differences in scapular angles.

It is clear from the above studies that both measurement techniques and findings associated with scapular kinematics are variable, particularly with regards to the findings associated with scapular upward rotation and tilt (Table 1). For example, McClure[19] and Hebert reported increased scapular upward rotation while others reported decreased upward rotation with humeral elevation in subjects with shoulder impingement [18, 20, 42, 54]. McClure[19], Endo[58] and Laudner[59] and Hebert all found increased posterior tilt with humeral elevation while Borstad[42], Ludewig[18] and Lin[54] found increased anterior tilt. Lin[62] and Lukasiewicz[20] both noted increased upward scapular translation in people with shoulder impingement. While the findings do vary, it is apparent that individuals with shoulder impingement do indeed demonstrate different scapular kinematics from their healthy counterparts. These variations may be the result of a faulty scapulothoracic mechanism along with altered neuromotor control, which some authors postulate may be responsible for shoulder pain and dysfunction associated with shoulder impingement[32, 63].

The Scapulothoracic Mechanism

Poppen and Walker[39] described the scapulothroacic mechanism as being vital to proper shoulder function. This mechanism refers to the interplay between the scapula and the thoracic cage and assists in movement of the arm into overhead positions. It requires a complex interaction of muscles to provide smooth and efficient scapulothoracic motion while maintaining stability of the humeral head in the glenoid socket[64,65]. The timing and function of the trapezius and serratus anterior force couple are believed to be essential in this action as they play an important role in scapular motion through midrange[44], which is often the painful for peope with shoulder impingement. A dysfunctional scapulothoracic mechanism may also be a result of abnormal resting posture of the scapula[66, 67], and altered kinematics of the glenohumeral, scapulothoracic, and acromioclavicular joints, which will affect how the muscles of the shoulder girdle perform[68]. It is therefore important to understand the scapular relationship to the thoracic spine with regards to shoulder function[69], especially when exploring the use of thoracic spine manipulation to treat shoulder impingement.

In a cross-sectional study done by Norlander and Nordgran[70], a cervico-thoracic ratio (CTR) method was used to assess the relationship between neck and shoulder pain and segmental spinal mobility in symptomatic subjects. Segmental mobility was measured using the CTR technique which assessed relative flexion range of motion based on a ratio of skin distraction between segments C7 to T5. The authors developed a classification of mobility yielding ordinary, hyper-, and hypo- segmental mobility and total relative flexion mobility. They used a stepwise regression to assess the relationship between segmental mobility, symptomology and neck-shoulder pain index scores. Hypomobility in segments C7-T1 and T1-T2 and hypermobility in segments T3-T4 were significant predictors of neck and shoulder pain. Hypomobility in segments C7-T1 and T1-T2 were also strong predictors of the prevalence of weakness in the hand and headache.

Unfortunately, the neck-shoulder pain index was based on one question asked of the subjects regarding the duration of their symptoms and was not validated. Five questions regarding clinical symptoms and four questions regarding mental stress were asked and answers were rated on a Likart scale. Neither of these questionnaires have been validated, weakening the impact of their findings.

Kebaetse[63] et al performed a repeated measures study to determine the effect of thoracic posture on shoulder range of motion, shoulder abduction force production and scapular kinematics. Thirty-four healthy subjects were recruited to participate in this study. Subjects were seated in a customized chair that provided adequate stabilization for proper measurement of all variables. The Metrecom Skeletal Analysis System was used to capture scapular position, shoulder range of motion data and thoracic spine posture. A Nicholas Hand-Held Dynomometer was used to measure shoulder force production with elevation in the scapular plane. Subjects demonstrated significantly more thoracic spine flexion, less shoulder range of motion and less force output in the slouched position versus the erect position. There was also more upward translation of the scapula in the slouched position, as well as less upward rotation and posterior tilt of the scapula from 90 degrees to maximal elevation. Additionally, in the slouched position, the scapular started in a laterally displaced position and moved medially. In the erect posture, the scapula moved laterally with elevation to 90 degrees and then returned to its start position between 90 degrees and maximal elevation. This study suggests that thoracic posture significantly impacts scapular behavior, as well as shoulder force production and range of motion.

Further indication of a relationship between thoracic spine position and shoulder range of motion is suggested in a study by Bullock et al[71]. Shoulder flexion range of motion and associated pain intensity were assessed using a repeated-measured design with 28 subjects. Range of motion was assessed in both slumped and erect postures using video analysis. Related pain intensity was assessed for both conditions using a visual analog scale (VAS). Subjects were screened using a battery of special tests to confirm diagnosis of impingement. Subjects sat on a plinth and were asked to complete three cycles of maximal shoulder elevation in each of the two postures: slumped and erect. Order of postures was randomly assigned. Shoulder elevation angles, associated pain intensity scores on VAS and posture were recorded for each trial and digital recording of the procedure was continuous. A repeated measures ANOVA was used to assess differences in ROM and pain intensity in relation to posture and measurement order. A statistically significant difference in ROM between the two postures (mean difference = 17.7, p = 0.001, 95% CI of 14.1 to 21.2) was found. They also observed a trend towards higher pain intensity scores in the slouched posture; however, no statically significant difference was found between positions (p= 0.18). Studies of the video camera and Peak Performance Technologies System have shown this method to be reliable and valid when filming static goniometers; however, this method has not been demonstrated reliable in motion studies. The authors attempted to address this by performing and intratester reliability study, and found their intratester reliability to be very high (ICC 2,1) at 0.99. Thus the findings of these studies[63, 71] indicate a relationship between thoracic spine position and shoulder range of motion does exist. It can be inferred that by improving thoracic spine extension ROM, shoulder ROM may be improved.

Theodoridis et al studied coupling patterns between the upper thoracic spine and arm elevation[72]. Twenty-five women with no history of shoulder or spine injuries were included in this study. Thoracic spine motion was assessed with the 3Space Tracker System (Polhemus Inc.) and upper extremity ROM was assessed by attaching a Myrin goniometer to the arm. Each subject was asked to maximally elevate the right arm in both the scapular and sagittal planes for three repetitions, while kinematic thoracic spine and shoulder ROM data were recorded. An ipsilateral coupling of right thoracic spine lateral rotation and flexion was observed with right arm elevation in both planes. This was coupled with thoracic extension in 23 of the 25 subjects with elevation in the sagittal plane and in 19 subjects with elevation in the scapular plane. The findings of this study suggest that assessment of thoracic spine motion must be considered when assessing upper extremity range of motion and function.

Fayad et al[73] considered the trunk to be an integral part of the kinematic chain for arm elevation as well. They measured trunk rotations coupled with arm elevation using the Polhemus FASTRAK in 30 healthy subjects and 13 subjects with frozen shoulders. They found that trunk extension was coupled with humeral elevation and trunk torsion was coupled with abduction. Subjects with frozen shoulders demonstrated decreased humeral elevation but increased trunk extension, suggesting trunk extension may be utilized to compensate for decreased glenohumeral range of motion. Thus the trunk appears to be part of the kinematic chain for arm elevation.

These studies[63, 71-74] indicate that thoracic spine positioning effects scapular kinematics and muscle force generation. Restrictions in segmental thoracic spine motion as well as postural deviations favoring a more flexed position could contribute to the decreased and painful range of motion often associated with shoulder impingement.

Thoracic spine mobilization may serve to normalize segmental mobility and enable more motion in thoracic spine extension, thereby facilitating increased shoulder ROM.

Motor Control of the Shoulder Complex

Maintenance of scapular position on the wall of the thorax is imperative for proper upper extremity function and is largely dependent on muscle activity[66]. Electromyographic studies quantifying muscle activity and assessing timing and coordination of scapular musculature have been done, and are important to elucidate the complex coordination of muscle activity needed for normal shoulder movement [64, 75]. Understanding normal motor control of the shoulder muscles allows for a better understanding of the pathologic mechanisms often associated with shoulder impingement. Below, a brief discussion of normal motor control will be followed by a review of the literature assessing the variations in neuromotor activity seen in individuals with shoulder pathologies such as impingement.

Functional Anatomy of Shoulder Musculature

The trapezius has its proximal attachments on the superior nuchal line, the external occipital protuberance and the spinous processes of C7 through T12 vertebrae. Its distal attachments are on the lateral third of the clavicle, and the acromion and spine of the scapula. The line of action of the distal clavicular attachment of the upper trapezius produces elevation and retraction of the clavicle[76]. Based on the knowledge of the complex coupling mechanisms at the scapulothoracic joint, excess activation of the upper trapezius could also result in scapular anterior tilting[27].

The middle trapezius has distal attachments to the scapular acromion[49, 76] and serves primarily to retract[49] and externally rotate the scapula[76]. The lower trapezius has direct attachments on the scapular spine with a line of action that suggests it plays a stabilizing role to counter the torque produced by other muscles such as the levator scapulae and serratus anterior[76].

The serratus anterior has distal attachments on the first eight ribs and a proximal attachment along the medial border of the scapula. It is a strong protractor of the scapula, especially with forward reaching. The inferior portion serves as a prime upward rotator of the scapula with humeral elevation[76]. It also serves to fix the scapula to the thoracic wall, countering the action of other extrinsic shoulder musculature. Impaired action of the serratus anterior results in scapular winging, a condition marked by the medial or inferior border being pulled away from the thoracic wall with humeral elevation[49]. Finally, the infraspinatus, the one rotator cuff muscle that will be assessed in this dissertation study, primarily serves to externally rotate the arm and hold the head of the humerus in the glenoid fossa[49].

Neuromotor Control of the Shoulder in Subjects with Impingement

Research suggests that people with shoulder pain and dysfunction demonstrate differences in muscle strength and altered motor control of key muscle groups[18, 19, 46 77]. However, as with scapular kinematics, current literature regarding neuromotor activity of the shoulder varies with regards to muscles and motions assessed, as well as severity of symptoms and subject demographics. The following review of the literature will compare and contrast these findings which are summarized in Table 2.

Table 2. Findings associated with electromyographic activity

Author	Findings associated with symptomatic shoulders	Electromyographic Technique
Ludewig	Decreased serratus anterior activity	sEMG
Lin		sEMG
Diederichsen		sEMG
Ludewig	Increased upper trapezius activity	sEMG
Szeto		sEMG
Lin		sEMG
Roy*	Decreased upper trapezius activity	sEMG
Reddy	Decreased rotator activity	fwEMG
Diederichsen		sEMG
Diederichsen	Increased supraspinatus and latissimus dorsi activity	sEMG
Reddy	Decreased deltoid activity	fwEMG
Cools	Increased latency of middle and lower trapezius	sEMG
Roy**		sEMG
Moraes***		sEMG
Hess	Increased latency of subscapularis muscle	fwEMG
McClure	Decreased force production of rotator cuff musculature	dynamometry

fwEMG = fine wire electromyography, sEMG = surface electromyography
*decreased upper trapezius activity noted in the pre-movement phase during frontal plane elevation
** found increased latency only in lower trapezius
***found increased and more variable latency time in upper, middle, and lower trapezius as well as in serratus anterior

Electromyography records the electrical activity evoked in muscle when it is activated by the nervous system during a contraction. The recording provides information about the timing of muscle activation and can be obtained using either indwelling wire or surface electrodes. Indwelling, fine wire electrodes are best suited for smaller, deep muscles[78] as well as for use in areas with significant amounts of subcutaneous adipose tissue[79]. Surface electrodes can be satisfactorily employed to provide a general representation of muscle activity[80].

Fine Wire Electromyographic Assessment

Reddy et al compared muscle activity between subjects with and without impingement during shoulder elevation [81]. All participants performed a maximal isometric contraction with the shoulder elevated to 20 degrees in the scapular plane. The torque produced was divided by the subject's arm length in order to normalize maximum force production. Subjects were then trained to elevate their arm with the elbow extended in the scapular plane at a speed of 100 degrees/second. Subjects performed two trails of elevation to 120 degrees while moving from internal to external humeral rotation. Fine wire EMG (fwEMG) was used to assess the activity of the middle deltoid and rotator cuff muscles. Electromyographic (EMG) activity was expressed as a percent of maximal voluntary isometric contraction (MVIC) and was compared to data from normal subjects in a separate study performed by two of the authors of this study. Subjects with impingement demonstrated decreased EMG activity in all muscle groups. The infraspinatus, subscapularis and middle deltoid demonstrated significantly less activity at 30 – 60 degrees of elevation. The findings of this study indicate a generalized decrease in activity of all rotator cuff muscles and of the deltoid in subjects with impingement. These findings should be interpreted with caution, however, because subjects with shoulder impingement had undergone arthroscopy in this study, although it was unclear how long after arthroscopy the testing was performed. It is therefore difficult to discern how pain and swelling associated with surgical intervention might have impacted the findings of this study. Additionally, data from subjects with shoulder impingement were compared to the data of healthy subjects from a previous study. This may have introduced differences due to different study personnel and environmental conditions.

Hess et al performed a study to compare the onset times of rotator cuff muscle activity between throwers with and without shoulder pain during a reaction time task[64]. Twenty male competitive baseball throwers were recruited to participate in this study. Twelve had complaints of shoulder pain while 11 others; matched for age, height, body mass, and level of activity; had no complaints of shoulder pain. All subjects underwent a physical examination to assess pain, range of motion, instability and signs of impingement. Fine-wire electrodes were inserted into the subscapularis, supraspinatus, and infraspinatus on the subjects' dominant side. An accelerometer was attached to their forearm. Subjects were seated with their arm positioned in 90 degrees of shoulder abduction and 90 degrees of elbow flexion with their palm resting flat on a plinth. They were instructed to rapidly externally rotate their shoulder the instant they visualized a light stimulus; 10 trials of this task were performed.

In this study, data were collected using AMLAB (AMLAB International Pty Ltd, Sydney Australia), a multi-channel data acquisition system that allows simultaneous collection, processing and display of fwEMG, torque and range of motion data. Timing of onset of EMG activity was analyzed in relation to the introduction of the light stimulus. They found that the subscapularis muscle onset occured significantly earlier in the control group as compared to the onset of the infra and supraspinatus muscles. There was also a significant difference in relative latency between groups for the subscapularis as compared to both infraspinatus and supraspinatus. In eight of the 11 control subjects, subscapularis was generally the first muscle activated. In eight of the 12 subjects with shoulder pain, it was generally the last muscles activated.

While the above study by Hess et al[77] lends support to the concept of altered motor control in painful shoulders, there were some limitations. Only the lower portion of the subscapularis was analyzed. Decker et al[82] indicated that different parts of the subscapularis have different functions. Based on the design of this study, we cannot determine how the upper part of the muscle was functioning. Additionally, all of the subjects in the painful group demonstrated positive signs of instability. Only two of the control subjects demonstrated signs of instability. It would be interesting to see what kind of relationship exists in the onset time of the subscapularis in subjects with instability compared to those without signs of instability.

Surface Electromyography (sEMG)

Cools et al performed a prospective cohort study using sEMG to assess timing differences in upper trapezius firing between 39 overhead athletes with shoulder impingement and 30 athletes without any history of shoulder injury [83]. Subjects were assessed for impingement via a battery of clinical special tests, while functional ability was assessed using the modified Rowe score, a self-reported, 100 point scale that assesses function, pain, stability and range of motion. Surface electromyography data was collected for the upper, middle and lower trapezius, as well as the middle deltoid using the Noraxon Myosystem 2000. Relative latency times for both the dominant and the non-dominant side for both groups were compared using an ANOVA. Significant differences between muscles (p=0.01) between groups (p=0.01) and between sides (p=0.05) were found. Post hoc analysis revealed longer latency times for the middle and lower trapezius on the injured side compared to the dominant side of the non-injured group. Both muscles also demonstrated longer latencies when compared the non-dominant side of injured and non-injured subjects.

The findings of Cools's study indicate that shoulder girdle muscle activation patterns may differ in subjects with shoulder impingement when reacting to an unexpected perturbation. However, it cannot be determined from this study if activation patterns differ with voluntary motions of the upper extremity. Furthermore, knowledge of the activation patterns of rotator cuff musculature and serratus anterior would also be helpful in understanding the pathomechanics of impingement.

Szeto et al[84] investigated muscle activity in the neck and shoulder during prolonged performance of computer keyboard tasks using surface electromyography. Forty-three female office workers were recruited for the study. Twenty-three had complaints of neck and shoulder discomfort, and twenty had no complaints of neck and shoulder pain in the past seven days and served as the control group. Surface EMG data were collected on bilateral cervical erector spinae, upper trapezii, lower trapezii and anterior deltoids. Subjects were seated at an adjustable work station and were allowed to adjust the station to meet their comfort. Each completed a standard typing task while EMG data was collected. Upon completion of the typing task, subjects rated their pain in each of the following regions: right and left neck, upper back, shoulder, elbow and wrist/hand. Differences in some muscle activity were seen between groups. The control group demonstrated more right cervical erector spinae activity, which increased over time. They also demonstrated symmetry of activity in bilateral upper trapezii muscles. The group with complaints of neck and shoulder pain demonstrated more right upper trapezius activity than the control group and reported significantly more pain upon completion of the typing task. Although this study lacked complete description of the typing task, it does lend support to the theory that individuals with painful shoulder may demonstrate different muscle firing patterns with activity than their pain-free counterparts.

Scapular muscle activation, latencies and rotator cuff performance between ten subjects with and ten subjects without impingement were compare in a study by Moraes et al[85] compared. Surface EMG data was collected for the upper trapezius, middle trapezius, lower trapezius, and serratus anterior muscles bilaterally during upper extremity elevation in the scapular plane. Latency was defined as the time between start signal and onset of muscle activity. Onset of activity was defined as the earliest time that EMG activity exceeded the sEMG silence line by two standard deviations and remained there for at least 50 ms. Recruitment patterns were determined through definition of onset times. The Biodex isokinetic dynamometer was used to assess rotator cuff performance with internal and external rotation bilaterally for each subject. Data was collected during the performance of eccentric contractions at speeds of 60 and 180 degrees per second while the subjects were in supine with the shoulder abducted to 90 degrees and the elbow flexed to 90 degrees. No differences in recruitment patterns between groups were found. The upper trapezius was recruited first, followed by the serratus anterior, middle trapezius, and then lower trapezius. In contrast, significant differences between groups were found with regards to latency ($p<0.001$), with the impingement group demonstrating longer latency times. The impingement group also demonstrated greater variability with latency times. Isokinetic performance of the rotator cuff muscles with internal and external rotation was similar in both groups.

Roy et al studied upper extremity motor strategies and kinematics during reaching tasks at various speeds[86]. Twenty healthy subjects and thirty-three subjects with impingement participated in this study. Surface EMG data was collected for the upper, middle and lower trapezius muscles, the latissimus dorsi, the serratus anterior, infraspinatus, and anterior and middle deltoid muscles. Subjects reached to a target located at 90 degrees of elevation. Reaching was performed both at a natural speed and at a higher rate of speed. Subjects with impingement demonstrated decreased upper trapezius activity in the pre-movement phase of activity and delayed onset of the lower trapezius. They also demonstrated increased trunk rotation and increased glenohumeral lateral rotation.

Diederichsen et al[87] compared EMG activity of shoulder musculature between subjects with and without shoulder impingement. Twenty-one subjects with shoulder impingement and twenty subjects without history of shoulder dysfunction were studied. Surface EMG was used to record activity of the serratus anterior, the anterior and middle deltoid, the upper and lower trapezius and the latissimus dorsi. Fine wire electrode was also used to record activity of the supra- and infraspinatus muscles. The experimental set-up consisted of a custom built shoulder machine designed to record limb motion and force during both shoulder abduction and external rotation. MVIC's were recorded and used to determine maximal torque output. Abduction and external rotation were performed using a load of 10% of the MVIC. EMG signals were normalized to the maximal EMG signal recorded during performance of the MIVC. Normalized EMG data was then calculated for the first six phases of each motion (0-15%, 16-30 %, 31-45%, 46-60%, 60 – 75%, 76-90% of full range of motion) The last 10% of motion was not analyzed due to direction reversal. Data from the symptomatic side was compared to the dominant side of control subjects; the asymptomatic side was compared to the non-dominant side of healthy subjects using a two-way ANOVA.

Diederichsen and colleagues found that with shoulder abduction, there was significantly more supraspinatus and latissimus dorsi activity in the symptomatic side of patients as compared to the dominant side of control subjects[87]. Participants with shoulder impingement demonstrated less serratus anterior activity. There was also a tendency towards more upper trapezius activity in participants with impingement although this was not significant at the 0.05 alpha level (p=0.09). With shoulder external rotation, the symptomatic sides demonstrated less infraspinatus and serratus activity compared to the dominant shoulder of the control subjects. The findings of this study agree with the findings of Ludewig[18], Lin[62], and Szeto[84].

While there is some degree of variation in motor control associated with shoulder dysfunction, some definitive trends do exist, particularly with respect to serratus anterior and upper trapezius activation and shoulder muscle force production. Diederichsen[87] Ludewig[18] and Lin[54] found subjects with shoulder impingement demonstrated decreased serratus activity with external rotation and abduction. Ludewig[18], Lin[54] and Szeto[84] also found an increase in upper trapezius and lower trapezius activity during humeral elevation in the impingement group. In contrast, findings regarding deltoid activity varied. Reddy[81] found a general decrease in deltoid activity, while Lin[54] noted an increase in anterior deltoid activity in subjects with shoulder impingement.

McClure[19] noted decreased strength with performance of humeral internal and external rotation as well as elevation in the scapular plane (40 degrees anterior to the frontal plane). In contrast, Moreas found no differences in internal and external humeral rotation strength between people with and without shoulder impingement. Reddy found a generalized decrease in all shoulder muscle activity in subjects with shoulder impingement; however, force output cannot be determined based on a quantification of EMG signal[81]. Cools found that subjects with impingement demonstrated both longer and more variable latency times in both the middle and lower trapezius[83], while Moraes found that subjects with impingement demonstrate longer and more variable latency times in the upper, middle and lower trapezius as well as in the serratus anterior muscles[85].

In summary, subjects with shoulder pain demonstrated increased upper trapezius activity and decreased serratus activity with decreased force production and some altered recruitment patterns in the symptomatic limb[77, 84]. The findings with regards to increased upper trapezius and decreased serratus activity are of particular significance.

Johnson et al suggested that due to the anatomic arrangement of the fibers of the upper trapezius, it is not well suited to upwardly rotate the scapula, but is more likely to produce elevation and retraction of the scapula [76]. Ludewig and Reynolds propose that increased upper trapezius activity may reduce scapular posterior tilt while decreased serratus anterior activity decreases scapular upward rotation[15]. Decreased posterior scapular tilting and upward rotation was detected in people with shoulder pathology in several of the previously reviewed kinematic studies[18, 20, 42, 51, 58, 62].

Joint Mobilization and Manipulation for the Treatment of Neck and Shoulder Pain

Maitland has defined joint mobilization as "an externally imposed, small amplitude passive motion that is intended to produce gliding or traction at a joint"[88]. Complete details of Maitland's classification system of joint mobilization are found in Table 3. Joint manipulation is often thought of as a particular type of joint mobilization and is typically defined as the application of a quick thrust maneuver to a joint[89]. The American Physical Therapy Association, in an attempt to uniformly define mobilization and manipulation, has outlined the following definition: mobilization/manipulation: a manual therapy technique comprising a continuum of skilled passive movement to the joints or related soft tissues (or both) that are applied at varying speeds and amplitudes, including a small amplitude/high velocity therapeutic movement[90].

Table 3. Maitland's Classification of Oscillatory Joint Mobilizations

Grade I	Small amplitude movement performed at the beginning of the range
Grade II	Large-amplitude movement performed within the range but not reaching the limit of the range
Grade III	Large amplitude movement performed up to the limit of the range
Grade IV	Small amplitude movement performed at the limit of the range
Grade V	High velocity thrust performed at the limit of the range – manipulation (non-oscillatory)

Historically, joint mobilizations and manipulations have been employed by various health care practitioners, including chiropractors, osteopaths and of course, physical therapists, each of whom has contributed to the knowledge base and philosophic principles for the use of such manual therapeutic techniques. Recent research has suggested that joint mobilization, including manipulation, combined with traditional therapy may be superior to traditional therapy alone in treating patients with shoulder pain[33-35, 37, 91]. Clinicians and researchers have found thoracic spine manipulation to be an effective treatment for neck and shoulder. Wainner et al describes this phenomenon by which impairments remote to the patient’s primary complaint may contribute to or be related to the patient’s chief complaint as regional interdependence and suggests that this phenomenon warrants careful examination of adjacent neuromusculoskeletal structures[92].

Cleland and colleagues have applied the concept of regional interdependence to study the effects of thoracic spine manipulation in patients with neck pain[25, 93]. In 2005, Cleland et al performed a randomized controlled study to assess the immediate effects of thoracic spine manipulation in people with neck pain[25]. Subjects were included if they presented with signs of mechanical neck pain near the cervicothoracic junction. All participants completed the Neck Disability Index (NDI) and reported their pain at rest using a visual analog scale. Subjects were randomly assigned to either a manipulation group or a control group that received a sham manipulation. Subjects in the manipulation group received thoracic spine manipulation treatment based on identified areas of restriction. The participants in the sham group were positioned as if they were going to receive manipulative therapy. However, upon exhalation, no high velocity thrust was performed. Five minutes after completion of the treatment, subjects reported their perceived pain levels on the visual analog scale. A significant and clinically meaningful difference in VAS scores was detected between groups after treatment ($p<.001$). There were no reports of adverse side effects other than mild soreness following the intervention. The results of this study suggest that spinal manipulation distal to site of pain may be a safe and effective intervention strategy. However, only immediate effects of thoracic spine manipulation on neck pain were assessed. Functional and biomechanical improvements were not measured.

In 2007, Cleland et al[93] compared two different types of joint mobilizations: thoracic spine thrust mobilization (manipulation) and thoracic spine non-thrust mobilization, for treating patients with complaints of mechanical neck pain. Thirty subjects were randomly assigned to each of the two treatment groups (thrust manipulation or the non-thrust thoracic spine mobilization). The non-thrust group received 30 seconds of posterior to anterior oscillatory joint mobilizations at T1, followed by the same mobilization procedure at T2 down to T6. These subjects were also instructed in a basic cervical mobility exercise program as part of a traditional physical therapy intervention. Subjects in the thrust mobilization group received manipulations targeting the upper and middle thoracic spine. They also received instructions in the same general cervical exercise program. All subjects were asked to attend a follow-up session 2 to 4 days after their initial treatment. Outcome measures included the Neck Disability Index, a numeric pain rating scale (NPRS) and the Global Rating of Change (GROC).

They found a statistically significant difference ($p = 0.001$) between the two groups for both pain and disability as determined by Neck Disability Scores. Subjects who received thrust manipulation experienced a greater 10% (95% CI = 15.3 - 14.7) improvement in Neck Disability Scores and a 2% (95% CI = 1.4 - 2.7) improvement in pain. These subjects also exhibited better GROC scores ($p< 0.01$) with a mean difference of 1.5 points (95% CI = 0.48 – 2.5). There was no significant difference in the number of side effects between groups. The results of this study indicate thrust mobilization may be effective in the short-term treatment of mechanical neck pain.

Returning to the concept of regional interdependence, in addition to the treatment of neck pain, thoracic spine mobilizations and manipulations have also been applied to the management of shoulder dysfunction, including impingement. Thoracic spine manipulation, combined with additional therapies was used to treat subjects with shoulder pain and dysfunction in several studies[33, 36, 37]. Winters et al performed a randomized, single blind study to compare the efficacyof traditional physical therapy, steroid injection and manipulation for treating patients with complaints of shoulder pain [37]. All 198 subjects underwent a physical examination. Based on the findings of this exam, subjects were assigned to either a synovial group or a shoulder girdle group. The synovial group consisted of subjects whose shoulder problems likely originated from within the subacromial space, the acromioclavicular joint, glenohumeral joint or any combination of these. The shoulder girdle group consisted of subjects who demonstrated decreased shoulder range of motion and whose dysfunction likely originated from the cervical or upper thoracic spine, or upper ribs. Subjects in the synovial group were randomly assigned to one of three treatments conditions: corticosteroid injection, physiotherapy or manipulation. Subjects in the shoulder group were randomly assigned to one of two treatment groups: physiotherapy or manipulation.

Subjects receiving corticosteroid injection received one to three injections to two or more of the previously mentioned regions immediately after random assignment and at one and two weeks later, as needed. Physiotherapy was administered twice a week to the treatment group. Sessions included “classic” exercise therapy, massage and physical agents. The manipulation group received manipulation and or mobilization of the cervical spine, upper thoracic spine, upper ribs, acromioclavicular joint and glenohumeral joint one time per week for up to six sessions, as needed.

Manipulation was more effective than physiotherapy ($p< 0.001$) for subjects in the shoulder girdle group. At five weeks, 70% of the manipulation group considered themselves cured compared to only 10% of the physiotherapy group. In the synovial group, the injection group improved most quickly followed by the manipulation group and then the physiotherapy group ($p<0.001$). At five weeks, 75% of the corticosteroid injection group felt they were cured compared to 40% of the spinal manipulation group and 20% of the physiotherapy group.

These results suggest that in subjects whose shoulder pain is related to shoulder girdle dysfunction, manipulation is an effective intervention. In contrast, for subjects with shoulder complaints that are likely caused by dysfunction in subacromial structures, injection is superior to manipulation and physiotherapy. It is unknown if subjects in the synovial group would have benefited from both corticosteroid injection and manipulation combined. Also, manipulation may be an effective option for those patients who do not wish to or cannot undergo corticosteroid injection.

Bergman et al performed a randomized, controlled trial with 150 patients with shoulder girdle dysfunction to determine the effectiveness of manipulation in addition to "usual care" for treating shoulder pain and dysfunction[36]. In this study "usual care" was administered by general practitioners and included information, advice and therapy. Therapy included oral anti-inflammatory medications, corticosteroid injections and physiotherapy consisting of therapeutic exercises, massage and physical agents. Manipulative therapy included both mobilizations and manipulations to decrease motion restrictions at cervical or upper thoracic spinal segments. Outcome measures of patient perceived recovery, shoulder pain, functional disability, and general health were recorded at baseline, 6 weeks and 12 weeks.

At 6 weeks after their initial session, participants demonstrated differences in outcomes favoring the manipulation group; however, these differences were not statistically significant. At 12 weeks more patients reported full recovery or very large improvement in the manipulation group as compared to the usual care group (difference =1.5 points [CI, 0.5-2.5 points] on an 11 point scale). They also demonstrated a significant improvement in shoulder pain as compared to the controls (difference=2.0 points [CI, 0.3 – 3.7] points on a 21 point scale). Thus findings for shoulder disability and general health favored manipulative therapy although not all of their comparisons were statistically significant. The findings of these above studies suggest that manipulative therapy may result in faster recovery in some patients with shoulder pain and dysfunction.

In another study assessing the efficacy of joint mobilization for treating shoulder dysfunction, Bang and Deyle compared two physical therapy interventions for the treatment of shoulder impingement[33]. One treatment consisted of a shoulder exercise program while the other consisted of shoulder exercise program combined with manual therapy to the upper quarter. Fifty-two subjects were randomly assigned to one of the two groups. Upon completion of a thorough upper quarter examination, subjects were instructed in a standardized exercise program that consisted of both strengthening and flexibility exercises. The manual therapy group also received various joint mobilization techniques specific to the findings of their initial upper quarter examination.

Both groups demonstrated improvements in function and pain reduction. The manual therapy group demonstrated significantly more improvement in function and decrease in pain as compared to the exercise group. Only the manual therapy group demonstrated significant strength improvements. This study agrees with the findings of Bergman et al[36] and Winters et al[37] in that joint mobilization and/or manipulation combined with exercise is superior to exercise alone in treating shoulder pain. However, based on the methodology of this study, it cannot be determined which manual techniques are superior when addressing shoulder pain, as they used techniques that were aimed at both the shoulder girdle and the axial skeleton.

The most compelling evidence for the use of thoracic spine manipulation to treat shoulder impingement comes from studies performed by Boyles et al[34] and Strunce et al[35]. Boyles et al performed a one group pre-test, post-test study examining the effects of thoracic spine manipulation on people with shoulder impingement[34]. Fifty-six subjects between the ages of 18 and 50 underwent a standard physical examination. Subjects rated their pain levels on the NPRS during the performance of the Neer's impingement test, Hawkins-Kennedy test for impingement, active shoulder abduction, resisted internal and external rotation and the Jobes Empty Can test. Pain and disability were measured using the Shoulder Pain and Disability Index (SPADI) and change in quality of life was measured on the Global Rating of Change Scale (GROC). Manipulations were then performed on the mid thoracic spine, cervicothoracic junction and in some cases, the ribs. Follow up, using the SPADI, GROC and NPRS, was performed 48 hours later. Significant differences were found on the NPRS for both the Neer's ($p = .001$) and Hawkins-Kennedy ($p < .001$) tests for impingement as well as resisted internal ($p = .008$) and external rotation ($p = .007$) and active abduction ($p = .001$). Significant differences in pre and post-test measures were also found on the SPADI ($p = .001$). Spinal manipulation demonstrated short-term improvements in pain with provocative testing. However, because follow-up was performed only at 48 hours post treatment, long-term effects of spinal manipulation remain unknown.

Strunce et al also performed a pre-test post-test design study investigating the immediate effects of thoracic spine and rib manipulation in people with shoulder pain [35]. Study participants underwent an upper quarter examination, including assessment of cervical and thoracic spine mobilization. Based on the findings of this examination, participants received a high-velocity thrust manipulation to the upper thoracic spine or ribs. Pain was measured using a 100mm visual analog scale pre- and post-manipulation(s) immediately following completion of active range of motion and provocative testing. Shoulder active range of motion and GROC scale were also assessed pre- and post- manipulation.

They found changes in pain and range of motion that were both statistically significant and clinically meaningful. All but one subject demonstrated at least minimal improvement on the GROC. Six subjects demonstrated moderate improvement and six subjects demonstrated a large improvement. No adverse side effects were reported and no subjects reported worsening of symptoms following the manipulations. This study further corroborates the findings of Boyles et al[34] with regards to decreases in shoulder pain following thoracic spine manipulation.

In conclusion, these studies lend support for the use of thoracic spine manipulation to treat patients with shoulder impingement; however in order to hypothesize how and why thoracic spine mobilization is beneficial for treatment of shoulder impingement, it is imperative to understand changes in the neuromuscular and

Table 4. Summary of findings associated with the use of joint mobilization and manipulation to treat neck and shoulder pain

Region Studied	Treatments assessed	Findings related to joint mobilization
Neck Pain		
Cleland et al, 2005	Thrust manipulation of thoracic spine vs sham manipulation	Thrust manipulation group demonstrated greater: ↓pain (VAS) ↓NDI
Cleland et al, 2007	Thrust manipulation to upper and lower thoracic spine vs sham manipulation	Thrust manipulation group demonstrated greater ↓ pain ↓ NDI ↑ GROC

Shoulder pain		
Winters et al	Traditional physiotherapy vs corticosteroid injection vs joint manipulation	For subjects whose shoulder pain was associated with shoulder girdle structures, those receiving joint manipulations demonstrated shorter duration of symptoms
Bergman et al, 2004	Traditional care (NSAIDS, corticosteroid injection and physiotherapy) vs cervical and thoracic spine mobilization and thrust manipulation	43% of treatment group compared to 21% of traditional care group reported full recovery
Shoulder Impingement		
Bang and Deyle,	Shoulder exercise alone vs shoulder exercise plus manual therapy , including joint mobilizations specific to upper quarter exam findings	Exercise plus manual therapy group demonstrated greater: ↓ pain ↑ function ↑ strength
Boyles et al, 2009	Mid thoracic spine and cervicothoracic junction thrust manipulation, plus rib mobilization when indicated	↓ pain (NPRS) ↓ SPADI
Strunce et al, 2010	Thrust manipulation to upper thoracic spine or ribs	↑ ROM ↑ GROC ↓ Pain (VAS)

VAS = visual analog scale, NDI = Neck Disability Index, GROC = Global Rating of Change, NPRS = numeric pain rating scale, SPADI = Shoulder Pain and Disability Index

skeletal system associated with spinal manipulation. A summary of the findings associated with the use of joint mobilization and manipulation to treat neck and shoulder pain can be found in Table 4.

Physiologic Responses to Spinal Manipulation

Numerous rationales for implementing joint mobilization and manipulation have been suggested and include the promotion increased joint extensibility and range of motion, muscle relaxation, and pain reduction to name just a few. While the physiologic effects of spinal manipulation have not been studied in great detail, Herzog proposed three primary mechanisms to explain the benefits associated with spinal manipulation [94]. He suggested the mechanisms were primarily biomechanical, neurophysiologic or neuromotor in nature (Table 5). The biomechanical theory proposed that the application of an external force, such as manual manipulation, induces movement of not only the targeted vertebrae but also adjacent segments[95-98], resulting in realignment of previously painful, mal-aligned vertebral structures, and thereby alleviating pain and restoring function. The neuromotor theory purported that spinal manipulation results in inhibition of spastic muscles, a reduction in pain, and changes in muscle activation and may be elicited by reflexive responses due to stimulation of various proprioceptors and mechanoreceptors, such as muscle spindles and/ or golgi tendon organs.[94, 99]. Finally, the neurophysiologic theory suggested that decreases in pain perception are due to alterations of neural or chemical mediators triggered by spinal manipulation[100, 101].

In an attempt to further clarify the physiologic effects of spinal manipulation, Bialosky proposed a conceptual modal describing an interaction of several mechanisms that occur as a result of spinal manipulation[102].

Table 5. Descriptions of earlier proposed mechanisms of action associated with spinal manipulation

Theoretical Mechanism of Action Associated with Spinal Manipulation	Description
Biomechanical	The application of an external manipulative force induces movement of not only the targeted spinal segment, but also adjacent segments, resulting in restoration of normal motion and realignment of previously painful, mal-aligned vertebral structures
Neuromotor	The application of an external manipulative force results in

	inhibition of spastic muscles, pain reduction and muscle activation, each elicted by reflexive responses due to stimulation of mechanoreceptors, muscle spindles, and/or golgi tendon organs
Neurophysiologic	The application of an external manipulative force results in neural or chemical modulation of pain perception

Both Herzog[94] and Bialosky[102] agree that spinal manipulation induces biomechanical changes to structures local to the site of force application. However, Bialosky suggests that all other responses to spinal manipulation are neurophysiologic in nature. He describes neurophysiologic mechanisms as chemical and neuromotor responses to biomechanical stimulus that likely originate from the periphery, the spinal cord, or through supraspinal modulation. Some evidence suggests that peripherally modulated responses to injury may be altered with the application of a mobilization force[103]. Spinal manipulation may also serve as a counter-irritant and facilitate pain modulation at the spinal cord level. Bialosky suggests that manipulation induced neuromotor responses, such as changes in motor neuron activity[104, 105] and altered electromyographic activity[106-108], occur due to reflexive responses at the spinal cord level, after the stimulation of various mechanoreceptors such as muscle spindles[102]. Finally, he suggests that spinal manipulation may influence specific supraspinal structures, which in turn modulate responses at the spinal cord level[101, 109]. A simplified version of Bialosky's[102] explanation of physiologic responses to joint manipulation is illustrated in Figure 3. The following section reviews the literature studying the proposed explanatory mechanisms underlying the beneficial effects of spinal manipulation, paying particular attention to biomechanical and neuromotor changes associated with spinal manipulation.

Biomechanical Responses Associated with Spinal Manipulation

Gal et al[98] studied the biomechanical effects of spinal manipulation by assessing the movements of vertebrae in two unembalmed human male cadavers. Posterior to anterior thrust manipulations were performed using a reinforced hypothenar contact. Thrust manipulation was applied to the right transverse processes of T10, T11 and T12 vertebrae. Force application was measured using a pressure pad at the site of application. Significant movement occurred between the target vertebrae and the adjacent segment, and thrust to T11 resulted in the adjacent vertebrae remaining in a slightly hyper-flexed position. These findings suggest that thrust manipulation may increase thoracic spine segmental extension.

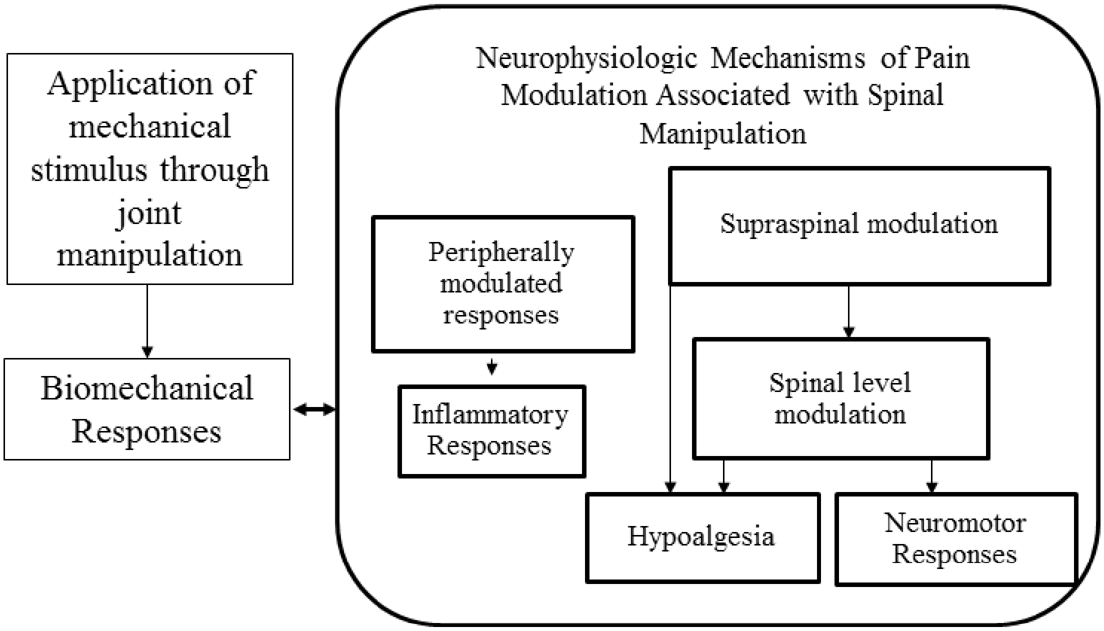


Figure 3. Proposed neurophysiologic effects of spinal manipulation. Modified with permission from Bialosky et al, 2009[102].

Neuromotor Responses to Spinal Manipulation

Neuromotor responses to spinal manipulation were studied by Herzog et al[107]. They examined reflex muscle responses elicited by spinal manipulation in 10 asymptomatic males who underwent a sequence of 11 small-amplitude, high-velocity spinal manipulations. Surface EMG data were recorded bilaterally for the splenius capitis at C4, the trapezius, posterior deltoid, latissimus dorsi, longissimus thoracis, quadratus lumborum and gluteus maximus muscles. A reflex response was defined as present if EMG activity increased at least three times above baseline levels within 500 milliseconds of the application of a manipulation.

Cervical spine treatments elicited an EMG response that occurred in most of the assessed muscles of the neck and back; however EMG responses in the arm or buttocks were highly variable. Spinal manipulation of the high and midsections of the thoracic spine resulted in 100% response rate in the five back muscles that were assessed. It also elicited a 50% response rate in the deltoids. However, response in the gluteal region was highly variable. Overall, this study demonstrated that lumbar spine manipulations resulted in a consistent response of the muscles of the back, although less consistently in the gluteal region. These findings could have implications for use of thoracic spine manipulation in the treatment of other areas such as the shoulder and neck.

In addition to Herzog's[107] findings, Keller and Colloca demonstrated increased electromyographic activity following spinal manipulation[110]. In this study, 20 patients with low back pain were assigned to the treatment group. These patients underwent chiropractic intervention involving spinal manipulation at multiple levels using a mechanical device. The sham group underwent the same assessment process but did not receive manipulation with the mechanical device. No significant differences in muscle activity were found between individual leads; however, a significant increase was found for the total lumbar EMG output between the two groups.

The effects of spinal manipulation on alpha motor neuron excitability were studied by Dishman et al[104]. In this study, spinal manipulation was applied and changes in Hoffman reflex (H-reflex) amplitude of both the tibial nerve and median nerve were calculated. The H-reflex can be used to assess modulation of monosynaptic reflex activity in the spinal cord and is an estimate of alpha motor neuron excitability[111] . Lumbar spine manipulation resulted in a 60 second long attenuation of the H-reflex of the right tibial nerve. Cervical spine manipulation did not result in changes in the tibial nerve reflex; however, it did significantly, albeit temporarily, attenuate the median nerve H-reflex. These findings indicate that spinal manipulation has at least a localized effect of temporarily attenuating motor neuron excitability.

Assessment of both Biomechanical and Neuromotor Responses to Spinal Manipulation

A few authors have assessed both biomechanical and neuromotor responses to spinal manipulation. Researchers in a study performed by Colloca et al had two primary objectives [96] . The first was to determine the effect of various force-duration profiles on lumbar vertebral movement. The second was to assess the effect of these varied force-duration profiles on EMG activity of the paraspinal muscles. It was hypothesized that variations in both force amplitude and pulse duration would alter lumber motion and EMG activity. In order to achieve these objectives, 10 Merino sheep were anesthetized to allow for the insertion of bone pins affixed with accelerometers to the spinous processes of L1 and L2. Fine wire EMG electrodes were inserted into bilateral multifidi between L3 and L4. Spinal manipulation was produced with a mechanical testing apparatus that cradled the L3 spinous process. A total of six pulses were applied to the L3 spinous process: three at 80 Newtons (N) of force with a pulse duration of 10, 100 or 200 ms; and three with a constant pulse duration of 100 ms at 20, 40 and 60 N of force.

They observed that increased force resulted in both increased posterior to anterior displacement and increased oscillations at L2 and L1. Pulse durations of 100 and 200 milliseconds (ms) resulted in increased L3 displacement as compared to the 10 ms pulse;

however, the 10 ms pulse resulted in greater oscillations at L2. In one sheep the 10 ms pulse duration elicited muscle inhibition. However overall, EMG amplitude increased with increased force magnitude. Thus, both Gal[98] and Colloca[106] found biomechanical changes associated with spinal manipulation local to the site of force application. Colloca's study also suggests local neuromotor changes in response to spinal manipulation[106].

Changes in spine kinematics and trunk muscles EMG responses to spinal manipulation were studied by Lehman and McGill[108, 112]. In their first case report, they assessed changes in spinal kinematics and EMG responses of the erector spinae and external oblique muscles in an elite golfer experiencing low back[112]. The patient received two spinal manipulations targeting the lumbar spine. Kinematics and EMG output were assessed pre- and post- manipulation in quiet stance, and during simple tasks (ie flexion/extension and lateral bending) as well as during a complex task (golf swing). They found no changes in range of motion during simple tasks after manipulation; however, the patient did demonstrate an increase in total range of motion during performance of the golf swing. They detected an overall decrease in EMG activity both during quite stance and during performance of the golf swing following manipulation. A second study done by Lehman and McGill included 14 subjects with low back pain and five control subjects[108]. In this study, all subjects participated in a dynamic activity pre- and post- spinal manipulation. Kinematics and EMG of seven of the participants with low back pain, along with the 5 healthy subjects were also assessed in quiet stance. Spine kinematics were assessed using the 3Space Isotrack. Surface EMG data of the rectus abdominis, external oblique and thoracic and lumber erector spinae muscles were collected bilaterally. Dynamic activities were performed prior to manipulation and included trunk flexion/extension, lateral bending and axial twisting. All subjects received a side posture rotary lumbar spine manipulation. The dynamic activities were then repeated immediately following the manipulation. Ten subjects, seven with low back pain and three control subjects, repeated the dynamic activities again 20 minutes after manipulation.

In this second study, Lehman and McGill then used an amplitude probability distribution function (APDF analysis) to determine the distribution of muscle activity levels[108]. While all subjects demonstrated changes in spinal range of motion, no consistent changes in kinematics were found. The data did, however, suggest that the greatest increases in sagittal plane motion occurred in those exhibiting the greatest level of pain and disability prior to receiving manipulation. Changes in sEMG muscle activity during performance of dynamic tasks were highly variable; therefore no trends in changes in motor activity could be determined. There was a general trend towards decreased muscle activity following manipulation in quiet stance with 16 of the 17 muscles tested demonstrating decreased signal activity. This particular study suggests that subjects with greater levels of pain and restricted ROM demonstrate more substantial biomechanical changes, while both studies suggest spinal manipulation may decrease EMG output, especially in patients experiencing pain.

Findings regarding neuromotor response to spinal manipulation are somewhat variable. Some of the reviewed studies indicate increased EMG activity following spinal manipulation[106, 107, 110] . In contrast, Lehman and McGill[108, 112] found decreased EMG activity of the erector spinae in quite stance post spinal manipulation. Their EMG findings with dynamic activities after spinal manipulation were highly variable. Dishman et al[104] found localized attenuation of alpha motor neuron excitability, which lasted for about 60 seconds. These study findings suggest that perhaps there is a brief period of "quiet" post manipulation followed by a period of increased muscle activity. This increase in EMG activity with performance of an MVIC as detected by Colloca et al[106] may be a result of decreased pain due to movement in previously painful motion segments or possibly due to other neurophysiologic processes. While it is appears some changes in EMG activity may occur following spinal manipulation, findings are somewhat variable and need to be further assessed to better determine how spinal manipulation might result in improvements in shoulder pain and dysfunction.

Additional Neurophysiologic Responses to Spinal Manipulation

In addition to the above discussed biomechanical and neuromotor responses, many studies have been performed to observe other neurophysiologic changes in pain sensitivity following spinal manipulation. While this dissertation study focuses primarily on biomechanical and neuromotor changes associated with spinal manipulation, other neurophysiologic mechanisms likely contribute to the reports of decreased pain immediately following spinal manipulation in people with shoulder impingement.

Terrett et al[113] assessed changes in cutaneous paraspinal pain tolerance after spinal manipulation. Fifty male undergraduate chiropractic students participated in the study. Localized painful segments were identified by running a stimulator that delivered a constant current of 110 volts at 60 Hz along either side of the vertebral column. Subjects verbally identified zones of increased pain intensity. These zones were marked with a grease pen and served as test sites. The stimulator was then set to zero and placed over the test site. Current was increased at a rate of 0.2mA per second. Subjects were instructed to indicate when they first felt a painful sensation. This amperage was considered their pain threshold. Intensity was increased until the patient reported maximal pain tolerance; this was identified as their tolerance level. Next the investigators performed posterior to anterior joint mobilizations from spinous process of T1 to T10 on the treatment group subjects. Subjects randomized to the control group received no further intervention. Subjects in the treatment group then underwent a thrust manipulation at the site of most resistance as identified with the posterior to anterior mobilizations. The threshold and tolerance procedures were repeated on each subject at 30 seconds, and 2, 5 and 10 minutes post treatment. The treatment group demonstrated significantly increased pain tolerance levels as compared to the controls suggesting that spinal manipulation altered pain sensitivity.

Bialosky, Bishop and George et al have also done several studies investigating the effects of spine manipulation on pain sensitivity [100, 114, 115]. In one such study, George et al, randomly assigned 60 healthy, asymptomatic subjects to one of three groups: stationary bike, lumbar extension group and spinal manipulation group [100]. The exercise intervention group rode a stationary bicycle for 5 minutes at 60-70 rotations per minute (rpm). Subjects in the lumbar extension group performed 3 sets of 15 repetitions of prone extension over the course of 5 minutes. Subjects in the spine manipulation group received four lumbosacral manipulations. Subjects underwent pain sensitivity testing prior to engaging in their respective interventions. Subjects then engaged in their respective interventions for 5 minutes. Thermal pain sensitivity testing was repeated five minutes after the intervention was completed. Spinal manipulation resulted in hypoalgesia in the lumbar areas but not the cervical regions. Hypoalgesia was greater for the spinal manipulation group as compared to the stationary bike group but there was no difference between the spine manipulation group and the lumbar extension group. The findings of this study suggest that spinal manipulation has an effect of inducing local hypoalgesia.

This work was expanded upon by Bialosky and Bishop[114] in their recent study that assessed pain sensitivity in both the upper and lower extremity following thoracic spine manipulation. Ninety healthy subjects were randomly assigned to either a thoracic spine manipulation treatment group or a cervical exercise group. Pain testing procedures were similar to those described above. Contrary to the above findings, thoracic spine manipulation not only induced local hypoalgesia in the upper extremity, but also induced reductions in pain sensitivity in the lower extremity.

In addition, some authors have studied the effects of spinal manipulation on centrally mediated responses[101, 109] . One such study was performed by Vernon et al[101]. They investigated the effects of spinal manipulation on endocrine responses by assessing changes in blood serum beta endorphin levels in twenty-seven male, first year chiropractic students. Beta endorphins are opioid neuropeptides thought to modulate stress responses[116]. The subjects were randomly assigned to one of three groups:

experimental, sham and control. The protocol consisted of 20 minutes of rest, the intervention and 40 minutes of post treatment testing. During the intervention period, both the experimental and sham group underwent a cervical spine assessment including testing of joint play, accessory motion and range of motion. Only the experimental group received a high-velocity low amplitude thrust. The control group simply rested during the intervention period. Heart rate, blood pressure, and self-reported anxiety measurements were taken at 20 and 5 minutes pre-intervention and at 5 and 20 minutes post-intervention. Blood samples were obtained via venapuncture at 15 and 5 minutes pre intervention and at 5, 15, and 20 minutes post intervention. None of the subjects in the sham or experimental group reported feeling pain as a result of the intervention. There were no significant differences between groups for heart rate, blood pressure or anxiety at any point. The experimental group demonstrated a small but significantly increased level of beta-endorphin 5 minutes post-intervention as compared to both the sham and the control group. Beta-endorphin levels tended to decreased over time in the sham and control group. After the spike in beta-endorphins at 5 minutes, levels also fell in the experimental group. The subjects in this study were healthy and none reported pain associated with the sham intervention or the spine manipulation. Anxiety levels were low and decreased as the procedure progressed. Thus, it could be concluded that it was the spinal manipulation that induced the increase in beta-endorphin levels.

The findings of the above studies indicate that spinal manipulation induces neurophysiologic responses, including changes in neuromotor activity, and changes in neurochemical mediators such as beta endorphin. Spinal manipulation also induces biomechanical changes both at the targeted segment as well as adjacent segments. The following dissertation research will attempt to elucidate what, if any biomechanical and neuromotor responses might contribute to the findings of decreased pain following spinal manipulation in people with impingement as described in Strunce[35] and Boyles[34]. Findings associated with physiologic responses to spinal manipulation are summarized in Table 6.

Table 6. Physiologic responses to spinal manipulation

Responses Studied	Purpose	Findings
Biomechanical		
Colloca et al 2005	Quantify vertebral movement and assess EMG responses following mechanically delivered spinal manipulation	Increased force application resulted in increased vertebral displacement and oscillations
Gal et al 1997	Assess vertebral movements following thrust manipulation in 2 cadavers	Movement occurred at both targeted vertebrae and adjacent vertebrae Targeted vertebrae remained in slight hyperextension following thrust manipulation
Lehman and McGill 1999	Assess changes in spine kinematics and EMG responses to lumbar spine thrust manipulation in 1 subject with LBP	No ROM differences were observed with performance of simple ROM tasks, Overall increase in ROM with performance of golf swing
Lehman and McGill 2001	Assess changes in spine kinematics and EMG responses to lumbar spine thrust manipulation in 14 subjects with LBP	No consistent changes in spine ROM; however subjects with the most pain demonstrated greatest ROM improvements
Neurophysiologic –Neuromotor		
Colloca, et al 2005	Quantify vertebral movement and assess EMG responses following mechanically delivered spinal manipulation	Overall increased EMG amplitude with performance of MVIC after spinal manipulation

Table 6 Continued

Dishman, et al 2002	Examining effects of spinal manipulation on motor neuron excitability using the H- Reflex	Attenuation of tibial nerve H-reflex with lumbar spine manipulation Attenuation of median nerve H-reflex, but not tibial nerve with cervical manipulation
Herzog, et al 1999	Assess reflexive muscle responses to 11 thrust manipulations in 10 asymptomatic men	Reflexive responses observed in back and gluteal muscles with lumbar spine manipulation Cervical spine manipulation yielded reflexive responses in muscles of neck and back, but not arms or buttocks
Keller and Colloca 2000	Study changes in EMG responses to mechanical spine manipulation at multiple spinal segments	Increase in total EMG output of lumbar musculature after spinal manipulation
Lehman and McGill 1999	Assess spine kinematics and EMG responses to lumbar spine thrust manipulation in 1 subject with LBP	No significant changes in EMG output following manipulation
Lehman and McGill 2001	Assess spine kinematics and EMG responses to lumbar spine thrust manipulation in 14 subjects with LBP	An overall decrease in EMG output in quiet stance following spine manipulation Changes in EMG output were highly variable with performance of dynamic tasks
Neurophysiologic -Additional responses		
George et al 2006	Study the effects of lumbar spine manipulation on thermal pain sensitivity	Hypoalgesia in lumbar regions but not in cervical regions
Terret 1984	Assess changes in cutaneous pain tolerance in 50 men	Increased pain tolerance
Vernon 1986	Examine changes in blood serum beta endorphin levels following spine manipulation	Increased blood serum beta endorphins after spinal manipulation

Gaps in the Literature

While evidence exists to support the use of spinal mobilization to treat shoulder impingement, the mechanisms by which spinal manipulation effectively alleviates symptoms at the shoulder are not well understood.

Researchers have described the relationship between segmental mobility and glenohumeral mechanics[70, 74, 117]. Biomechanical mechanisms could be implicated in subjects who demonstrated increased glenohumeral and/or thoracic spine ROM following thoracic spine mobilization. To date, only one study has assessed changes in glenohumeral ROM following thoracic spine manipulation[35]. None have assessed scapular kinematics or thoracic spine range of motion that may be associated with biomechanical changes following spinal manipulation.

Very little research assessing changes in shoulder muscle activity patterns following thoracic spinal manipulation in patients with shoulder pain has been performed. Herzog's study found changes in deltoid activation following mid and high thoracic manipulations; however, no other shoulder musculature was assessed. It is unclear, based on the existing literature, whether spinal manipulation affects the neuromotor activity of other shoulder musculature, such as the trapezius, serratus anterior or rotator cuff muscles.

Bialosky et al proposed that the phenomenon of regional interdependence may be a result of neurophysiologic effects induced by biomechanical changes that occur with the application of a mobilizing or manipulative force and suggests that further studies must be undertaken to assess these various mechanisms to better direct physical therapy interventions[118]. In accordance to the mission of the National Center for Complementary and Alternative Medicine (NCCAM)[119], this study explores the mechanisms by which spinal manipulation facilitates improvement in patients with shoulder impingement in an effort to contribute to the growing body of scientific evidence supporting the use spinal manipulation as a therapeutic intervention.

Study Objectives

The objectives and underlying aims of this dissertation were to:

I: Determine changes in pain, function and range of motion with cervical rotation and thoracic spine extension following thoracic spine manipulations

Ia. Determine changes in patient-rated pain and function immediately following and 7-10 days post thoracic spine manipulation. In 2 previously published studies[34, 35] changes in self-reported pain with provocative clinical tests were measured pre and post thoracic spine manipulation. These studies observed changes in pain immediately and 36 – 48 hours[35,34] post manipulation. We attempted to corroborate these findings by assessing pain with provocative tests as well as with performance of weighted humeral elevation. While some researchers have found immediate and short-term decreases in pain, none have studied patient pain and function longer than 48 hours after manipulation. In this dissertation study, subjects were asked to complete the Penn Shoulder Scale (Appendix A) and the Sports/Performing Arts Module of the Disability of the Arm Shoulder and Hand Questionnaire (Appendix A) prior to manipulation and again 7-10 days post manipulation.

Ib. Determine the effect of thoracic spine thrust manipulations on humero-thoracic, cervical and thoracic spine range of motion (ROM). Maximal cervical spine rotation, thoracic spine flexion and extension and humerothoracic active ROM were assessed using the Polhemus Liberty pre and post mid thoracic spine and cervicothoracic joint manipulations. Humerothoracic ROM changes after manipulation have been studied in one article[35]. In that study, ROM was measured via goniometry. We assessed changes in weighted humerothoracic ROM using an electromagnetic tracking system. In addition, we assessed changes in cervical and thoracic spine ROM following thoracic spine manipulation, which had not been studied previously.

II. Explore and clarify specifically which mechanisms correlate to the observation of decreased shoulder pain following thoracic spine manipulation in subjects with shoulder impingement.

IIa. Determine the effect of thoracic spine manipulation on humerothoracic range of motion and scapular kinematic patterns during shoulder elevation. Scapular upward rotation, posterior tilt, external rotation and clavicular elevation and protraction during humeral elevation were assessed using the Polhemus Liberty pre and post thoracic spine and cervicothoracic joint manipulation. This was the first study to examine the effects of spinal manipulation on scapular kinematics in subjects with shoulder impingement.

IIb. Determine the effect of thoracic spine manipulations on surface EMG (sEMG) activity of the upper (UT), middle (MT), and lower trapezius (LT), serratus anterior (SA) and infraspinatus (IS) muscles during humeral elevation**.** The onset and magnitude of surface EMG activity of these muscles were compared pre and post mid-thoracic and cervicothoracic junction joint manipulations. This was the first study to examine changes in EMG activity with active ROM activities following thoracic spine manipulation in subjects with signs of shoulder impingement.

CHAPTER 2

CHANGES IN STRENGTH, PAIN AND RANGE OF MOTION AFTER THORACIC SPINE MANIPULATION IN SUBJECTS WITH SIGNS OF SHOULDER IMPINGEMENT

Introduction

Rotator cuff pathology, often due to impingement, is one of the most common causes of shoulder pain and dysfunction[9, 10, 12, 120]. Neer[13] broadly defined subacromial impingement as a mechanical compression injury of the rotator cuff, specifically the supraspinatus tissues, under the acromion. This type of impingement is now more broadly defined as external impingement and includes the mechanical irritation of the rotator cuff tendons or long head of the biceps beneath any aspect of the coracoacromial arch, including the acromion, the coracoacromial ligament and/or the acromioclavicular joint itself[27]. Internal impingement involves irritation of the underside of the rotator cuff by the glenoid and/or glenoid labrum and often occurs in overhead athletes[14, 15]. These various types of impingement may be caused by altered scapulothoracic or scapulohumeral kinematics[17-20] posterior capsule tightness[21, 22], faulty posture[23, 24] acromial arch pathology[25, 121] or rotator cuff weakness, and frequently leads to rotator cuff tendinopathy[26, 27]. Clinical signs of impingement include painful arc of motion between 70 and 120 degrees of abduction[28] , and pain with palpation of the lateral or anterior subacromial region. A variety of treatment options including acromioplasty[30], posterior capsule stretch[21, 31], and strengthening and neuromuscular reeducation[32] as well the use of joint mobilization, including spinal manipulation have been explored as viable treatment options for shoulder pain associated with impingement[33-35].

Joint mobilization, combined with traditional therapy may be superior to traditional medical care[36, 37] (oral analgesics, non-steroidal anti-inflammatory medication and corticosteroid injection), or traditional physical therapy[33] (strengthening, stretching, and neuromuscular re-education) alone for treating patients with shoulder girdle dysfunction[33, 36, 37]. Winters et al found that in subjects with shoulder pain due to shoulder girdle dysfunction, spinal and rib mobilization was superior to traditional physiotherapy and corticosteroid injection in addressing shoulder pain[37]. Bergman et al found that subjects with shoulder pain and dysfunction who received thoracic and cervical mobilization in addition to traditional medical care demonstrated greater improvement as compared to those who received only traditional medical care[36]. The addition of joint mobilization techniques to a standard exercise program of strengthening and stretching exercises improved strength, pain and function in subjects with shoulder impingement in a study performed by Bang and Deyles[33] . Finally, Boyles[34] and Strunce[35] observed that subjects with shoulder impingement reported decreased pain and disability after receiving thoracic spine and cervicothoracic junction manipulation.

The purpose of this study was to determine changes in range of motion (ROM), patient-rated pain, and shoulder function both immediately following and 7 to 10 days after receiving thoracic spine manipulation. Previous studies have examined changes in patient- rated pain on both an 11 point numeric pain rating scale and a 100 point visual analog scale immediately and 36 – 48 hours post thoracic spine manipulation[34,35]. We attempted to corroborate these findings for comparison purposes. In addition, we further assessed shoulder pain and function 7 – 10 days after receiving manipulation using the

Penn Shoulder Score and the Sports and Performing Arts Module of the Disabilities of the Arm, Shoulder and Hand Questionnaire (DASH). Researchers have found immediate and short-term decreases in pain after thoracic spine manipulation but none have assessed pain and function beyond 48 hours after receiving the treatment. Changes in thoracic spine and cervical rotation range of motion (ROM) have not been reported to date. In this study, changes in cervical rotation and thoracic flexion and extension ROM will be assessed using an electromagnetic tracking system.

Methods

Overview

This study employed a repeated measures pre-test, post-test design to assess changes in pain, strength and ROM following thoracic spine manipulation. Pain was assessed during performance of the Jobes Empty Can test, Hawkins-Kennedy and Neer's test for shoulder impingement, as well as with performance of weighted humeral elevation in the frontal, sagittal and scapular planes. Force production was measured using a hand-held dynamometer and function was assessed using the Penn Shoulder Score (PSS) and the Sport/Performing Arts Module of the Disability of the Arm, Shoulder and Hand. Cervical and thoracic spine range of motion was assessed using the Polhemus, an electromagnetic motion tracking system. Two spinal manipulations were then performed. Pain, strength and range of motion were reassessed immediately after the manipulations were performed, and the Penn Shoulder Score and Sport/Performing Arts Module of the DASH were completed 7 – 10 days after receiving the manipulation.

Subjects

Thirty subjects, 16 male and 14 female (mean age 30.64 ± 7.92), with signs of shoulder impingement participated in this study. Subjects were recruited from Temple, LaSalle and Arcadia Universities, Penn Athletic Club, Vesper Boat Club, and Bachelors Barge Club as well as Master's swim clubs in the Philadelphia region and personal contacts. It should be noted that most participants in this study were not seeking medical attention for their shoulder pain. Subjects were screened for signs of shoulder impingement, and were included if they reported at least 3/10 on a numeric pain rating scale with performance of the Hawkins-Kennedy, Neer's or Jobe's empty can test for shoulder impingement. Subjects were excluded from the study if they have had previous surgical intervention on their shoulder, demonstrated signs of complete rotator cuff (RTC) tear as indicated by gross weakness of the RTC musculature or imaging studies confirming a full thickness tear, history of spinal trauma or surgery, signs of neurologic involvement including numbness or tingling in the upper quarter, degenerative bone disease, rheumatic disease, or allergies to adhesives. Post-menopausal women were excluded from the study so as to exclude subjects at risk for osteopenia or osteoporosis. All subjects signed an informed consent approved by the Institutional Review Boards of Temple University, Arcadia University and University of Medicine and Dentistry of New Jersey.

Instrumentation

Pain Assessment (immediately post manipulation)

Pain was assessed using an 11 point numeric pain rating scale (NPRS) during the performance of the Jobe's Empty Can, the Hawkins-Kennedy and Neer's tests for shoulder impingement as well as with the performance of loaded humeral elevation in the frontal, scapular and sagittal planes. The NPRS has been shown to be a valid and reliable tool for subjects with shoulder pain[122]; the meaningful clinically important difference (MCID) for the NPRS is 2 points[123].

Force Production Assessment (immediately post manipulation)

Shoulder elevation force production was measured using an ergoFET (Hogan Health Industries, West Jordan, Utah) handheld dynamometer. Peak force, measured in pounds, was assessed using a traditional "break test" with the arm in neutral rotation, elevated to 90 degrees in the scapular plane.

Range of Motion Assessment (immediately post manipulation)

Range of motion data was collected using the Polhemus Liberty (Colchester, VT), an electromagnetic motion monitoring system using four receivers and a digitizing probe. Receivers were placed on the head, scapula, thorax and humerus. A Velcro strap was placed around the subject's head and the sensor was attached to the posterior aspect of the occiput with Velcro. The thoracic sensor was placed on the sternum just below the jugular notch via double-sided tape. The lead wire was secured to the sternum with cloth tape to prevent rotation of the sensor due to skin movement with shoulder elevation. In addition to these sensor placements, a scapular and humeral sensor as well as electrodes for surface electromyographic (sEMG) data detection were also applied, as sEMG data were collected as part of another aspect of this study. The following bony landmarks were palpated and marked with a grease pencil: the spinous processes of C7, T2, T8, T12; the dorsal-most aspect of the acromioclavicular (AC) joint, the root of the spine of the scapula, the inferior angle of the scapular, the xyphoid process, jugular notch, and right coracoid process. The medial and lateral epicondyles were palpated through the sleeve and marked with a sticker. These points were used to digitize the upper quarter segments and to create anatomic reference frames as per a previously established protocol[45, 48] that was based on the recommendations of the International Society of Biomechanics[56].

Shoulder Pain and Function Assessment (7 to 10 days post manipulation)

Shoulder function was measured using the Penn Shoulder Score and the Sports/Performing Arts Module of the Disability of the Arm, Shoulder and Hand (DASH) Scales. The Penn Shoulder Score is a 100 point scale that assesses pain, function and satisfaction and is a valid and reliable outcome measure for people with shoulder disorders[124]. The Sports/Performing Arts Module of the DASH was selected because the items in this questionnaire address the activity limitations and participation restrictions constructs[125] of the World Health Organisation's International Classification of Functioning, Disability and Health (ICF) Model[126] and has been found to be a valid and reliable tool to measure various upper extremity disorders[127]. Subjects completed these questionnaires before receiving the thoracic spine manipulations and again 7 – 10 days after receiving the manipulations.

Experimental Procedures

Upon completion of the digitization process, subjects were seated in a wooden chair that was modified to allow unimpeded scapular and thoracic spine motion. A Velcro strap was placed around their hips and chair to minimize pelvic rotation during thoracic spine flexion and extension procedures (Figure 4), which will be described below.

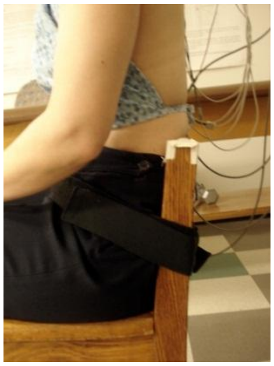


Figure 4. Subject seated modified wooden chair with pelvic strap

To assess muscle force, subjects were asked to place their affected limb in 90 degrees of humeral elevation in the scapular plane with the humerus in neutral rotation. Subjects were told to hold this position while the tester performed a “break test” using the handheld dynamometer. Resistance was applied and increased until the subject could no longer maintain their position against the force applied by the tester. The digital results screen of the dynamometer was covered during testing. The subject was informed of force production values upon request only after completion of all testing procedures.

Cervical rotation was assessed during performance of three repetitions of full available range of motion in each direction (right and left). Subjects were instructed to sit in a comfortable posture and turn their head as far to the right as possible. They were then instructed to slowly rotate as far as they could to the left, then back to the right; this was repeated three times. The thoracic sensor assessed motion relative to the global coordinate system while the cervical sensor was aligned to that of the thorax; therefore, cervical spine rotation was measured in relation to the thorax.

Thoracic spine flexion/extension was also assessed in the seated position. Subjects were instructed to maintain contact between their lumbar spine and the back of the wooden chair. They were then asked to sit in an exaggerated upright posture. When given the command to start, they were instructed to move from the upright posture into their end-range slumped posture while still maintaining contact between their lumbar spine and the back of the chair. Three repetitions of this motion were performed. To assess pain with humerothoracic elevation in the frontal sagittal and scapular planes, subjects were instructed to move through their full available elevation range of motion during a three second count as the tester counted aloud “one thousand one, one thousand two, one thousand three”. Subjects were allowed two practice elevations to ensure proper timing. The subjects performed elevation with a five pound hand-held weight if they weighed less than 150 pounds or a ten pound hand-held weight if they weigh more than 150 pounds. Subjects were asked to report any pain felt during the elevation trials using the NPRS.

Upon completion of the baseline activities, subjects received a thrust manipulation of the mid thoracic spine and at the cervicothoracic junction, similar to those reported in Boyles et al[34]. The mid thoracic spine thrust manipulation was performed at the apex of thoracic curve with the patient seated with his or her arms wrapped around their chest. The tester stood behind the subject, pressing her clavicular region against the area to be mobilized. The tester then wrapped her arms around the subject to clasp her hands together. The subject was then instructed to take a deep breath. As the subject exhaled, the tester compressed the subject's upper body while simultaneously lifting the subject slightly, pivoting on the tester's clavicular region. The tester than palpated the cervical vertebrae to find C7 and T1; this was identified as the cervicothoracic junction. The cervicothoracic manipulation was performed with the patient seated with his or her fingers interlocked posteriorly at the base of the cervical spine. The tester stood behind the subject and threaded her arms through the subject's so that her hands were on top of those of the subject. The subject was then gently reclined and asked to exhale. The tester provided a distractive thrust at the cervicothoracic junction (Figure 5). All subjects received the mid thoracic spine manipulation first, followed by the cervicothoracic junction manipulation. If a cavitation was detected with performance of the mid-thoracic spine manipulation, the tester proceeded to the cervicothoracic junction manipulation. If no cavitation, as determined by an audible pop, was detected by either the tester or the subject upon the first attempt of a manipulation, a second attempt was made before moving on to the next manipulation. No more than two attempts were made for each manipulation. Thoracic spine manipulation has been studied by several authors who reported nothing worse than mild side effects such as minimal, localized discomfort[35-37, 93, 128].

Figure 5. Thoracic spine manipulations. Mid-thoracic spine manipulation and cerivcothoracic spine manipulation

Care was taken during the manipulation procedures to not move any of the markers or electrodes. Upon completion of the manipulation procedures, subjects returned to the wooden chair placed directly in front of the transmitter and were retested on each of the previously described procedures with the exception of completion of the Penn Shoulder Score and the Sports/Performing Arts Module of the DASH. Subjects were given and self-addressed stamped envelope and a blank copy of the Penn Shoulder Score and the Sports/Performing Arts Module of the DASH to take home with them. They were then contacted by phone or email 7-10 days after the procedure asked to complete these questionnaires and return them to the tester. Subjects were provided with a blank, electronic copy of the questionnaires if they misplaced the copies given to them onsite.

Data Analysis

All data were assessed for skewness and kurtosis. Range of motion variables assessed were maximum cervical spine rotation, and thoracic spine flexion and extension prior to and immediately after manipulation. NPRS scores with provocative testing and humeral elevation as well as peak force with elevation in the scapular plane were also analyzed. Mean pre/post manipulation values were compared using two-tailed paired-samples t tests with alpha set to 0.05 for significance. Scores on the Penn Shoulder Score and the Sports/Performing Arts Module of the DASH were assessed prior to and 7-10 days after receiving the manipulations. One subject did not complete the Sports/Performing Arts Module of the DASH, therefore only data for only 29 Sports/Performing Arts Module of the DASH scores were analyzed. Changes in pre- and post-test scores were also assessed using a two-tailed, paired samples t-test.

A secondary analysis, instituted upon completion of the above described data analyses, using a 2 x 3 factoral ANOVA was performed to determine if changes in pain rating with cervical rotation, and weighted humeral elevation were dependent upon the detection of cavitation. Subjects were divided into three groups: cavitation with both manipulations, cavitation with one manipulation, or no cavitation detected.

Results

Pain Assessment (immediately post manipulation)

Significant improvements in pain were detected following thoracic spine manipulation with performance of the Jobes ($p < .001$), Neer's ($p < .001$) and Hawkins-Kennedy ($p < .001$) tests for impingement as well as with performance of cervical rotation (p =.039) loaded flexion (p < .001), scaption (p < .001) and abduction (p < .001). Scores for NPRS ratings are illustrated in Figure 6.

Shoulder Function Assessment (immediately post manipulation)

Force production with elevation in the scapular plane also improved (p < .001) following thoracic spine manipulation and is illustrated in Figure 7.

Shoulder Pain and Function (7 to 10 days post manipulation)

Scores on both the PSS (p > .001) and the Sports/Performing Arts Module of the DASH (p < .001) improved 7 – 10 days following thoracic SM. Changes on both of these scales are illustrated in Figure 8.

Range of Motion Testing (immediately post manipulation)

No significant differences in cervical rotation (p = .460) or thoracic spine ROM (p = .74) ROM were detected. A summary of pre-test/post-test comparisons can be found in Table 7.

Secondary Analysis

The secondary analysis indicated that decreases in pain with performance of cervical ROM and weighted humeral flexion, scaption and abduction were not dependent upon the detection of cavitation in either one, both or neither of the manipulations . A summary of the secondary analysis findings are found in Table 8.

Discussion

Subjects demonstrated decreased pain and increased force production immediately following spinal manipulation. Furthermore, they demonstrated improved shoulder function on the Penn Shoulder Score and the Sport/Performing Arts Module of the DASH 7 – 10 days after manipulation. However, no improvements in cervical or thoracic ROM from pre-test levels were observed.

Pain (immediately post manipulation)

The results of this study agree with the findings in both Strunce[35] and Boyles[34] regarding decreased pain with performance of both provocative testing as well as with active humeral and cervical range of motion immediately following thoracic spine manipulation. Furthermore, subjects also reported decreased pain 7 – 10 days after receiving the manipulation as reported on the Penn Shoulder Score. With cervical rotation testing, only three subjects reported pain of greater than 3/10 on the NPRS with pre-test assessments. While these subjects demonstrated similar decreases in pain compared to those of the rest of the subjects, (86.7% decrease in pain rating compared to 82% of the entire cohort), they demonstrated 4%, 8% and 21% increases in cervical rotation ROM compared to the 1% average increase for the entire group. This observation is similar to those of Lehman and McGill who found that subjects with the highest levels of pain demonstrated the greatest increases in range of motion[108.] One limitation of this study is that only 2 of the 30 subjects were seeking medical treatment for their shoulder pain suggesting that the subjects in this study were not severely impaired.

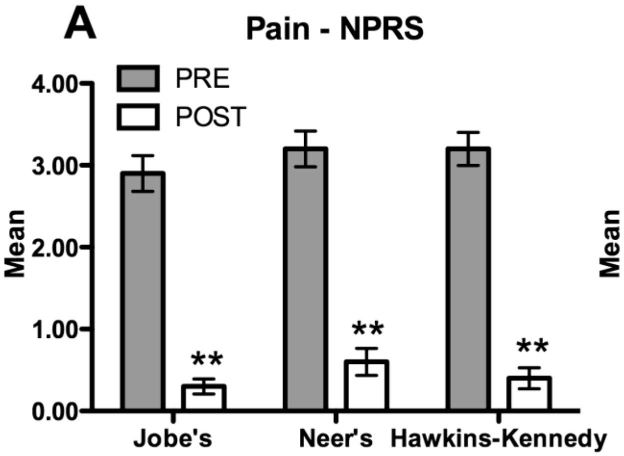


Figure 6. Changes in pain rating with A, provocative testing and B, range of motion pre- and post- manipulation

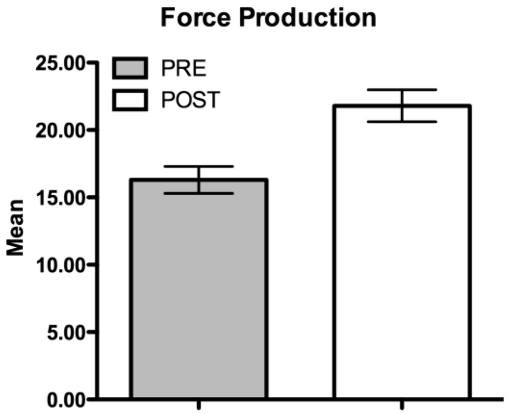


Figure 7. Changes in force production pre- and post- thoracic spine manipulation

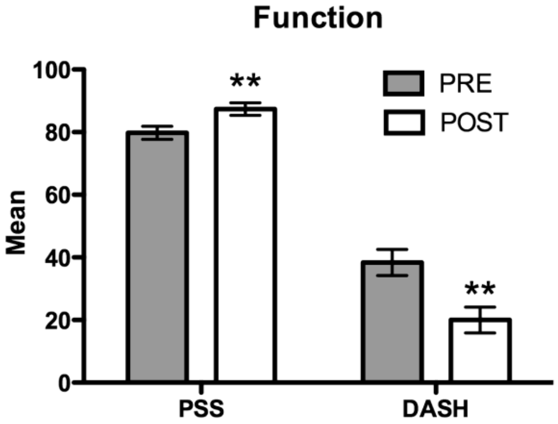


Figure 8. Changes in pre-test/post-test scores on Penn Shoulder Score and the Sports Module of the DASH

Shoulder Function (immediately post manipulation)

Shoulder elevation force production was assessed before and immediately after thoracic spine manipulation. The increase in force production observed in this study, may, in part, be associated with the findings of decreased pain. Research suggests that pain may alter temporospatial as well as quantitative elements of force production. Descarreaux et al assessed differences in force production parameters between subjects with and without low back and neck pain[130, 131]. In both studies, people with pain demonstrated increased time to peak force. Additionally, subjects with neck pain demonstrated greater peak force variability with performance of isometric contractions[131].

Table 7. Summary of statistics for all dependent variables

	Mean (sd) PRE	Mean (sd) POST	Mean difference (sd)	*p*	95% Confidence Interval	
Pain – NPRS[a]					Upper	Lower
Jobes	2.9 (1.2)	0.3 (0.5)	2.6 (1.2)	<.001	2.2	3.1
Neer's	3.2 (1.2)	0.6 (0.9)	2.6 (1.3)	<.001	2.1	3.0
Hawkins-Kennedy	3.2 (1.1)	.4 (0.7)	2.8 (1.3)	<.001	2.3	3.3
Cervical Rotation	0.5 (1.2)	0.1 (0.4)	0.4 (0.9)	0.039	0.02	0.7
Flexion	2.3 (1.7)	0.3 (0.6)	2.0 (0.3)	<.001	1.4	2.6
Scaption	1.2 (1.5)	0.1 (0.4)	1.2 (1.4)	<.001	0.6	1.7
Abduction	2.6 (1.7)	0.3 (0.8)	2.2 (1.5)	<.001	1.7	2.3
Force Production[a]						
Shoulder elevation	16.3 (5.5)	21.8 (6.5)	-5.5 (3.1)	<.001	-6.7	-4.3
Pain and Function[b]						
PSS	79.8 (11.4)	87.4 (10.9)	-7.6 (9.3)	<.001	-11.1	-4.1

Table 7 Continued

DASH	38.4 (22.9)	20.0 (22.7)	16.4 (16.2)	<.001	10.2	22.5
ROM[a]						
Thoracic flex/ext	47.4 (14.8)	45.7 (14.6)	1.8 (7.6)	.238	-1.3	4.9
Cervical rotation	117.9 (22.2)	119.4 (21.5)	-1.4 (10.0)	0.460	-5.5	2.6

[a]Assessed immediately after spinal manipulation, [b]Assessed 7 – 10 days post manipulation; NPRS = numeric pain rating scale, PSS = Penn Shoulder Score, DASH = Sports/Performing Arts Module of the Disability of the Arm, Shoulder and Hand Questionnaire

Table 8. Results of Secondary Analysis Assessing Differences in Pain Reduction Based on Detection of Cavitation.

Motion Assessed	Between Groups Analysis (cavitation with one, both or neither manipulation)	
	F	*p*
Cervical Rotation	0.04	.96
Humeral Flexion	0.09	.95
Humeral Scaption	0.05	.95
Humeral Abduction	.001	.99

In another study, Ylinen et al observed that increased pain was associated with decreased force production in women with chronic neck pain[132]. Research done by Vicenzino et al suggests that cervical joint mobilization is associated with both decreased pain and increased force production[109]. They observed that the application of high amplitude, oscillatory force (Maitland Grade III joint mobilization) at the C5-C6 segments resulted in significantly greater decreases in pain and increases in grip strength than did the placebo or control condition. While this dissertation study employed a different mobilization technique (Maitland Grade V, thrust manipulation), our findings agree with those of Vicenzino et al[109] in that joint mobilization (albeit different types) resulted in both decreased pain and increased strength.

To assess whether increased force production was associated with pain reduction, correlations between change in force production and change in pain with all provocative testing. No correlations were observed between change in force and change in pain with provocative testing was observed (Jobes R= .04, Neers R =.09, Hawkins-Kennedy R = -.09) (Figure 9). This finding makes sense given that most provocative maneuvers were done passively.

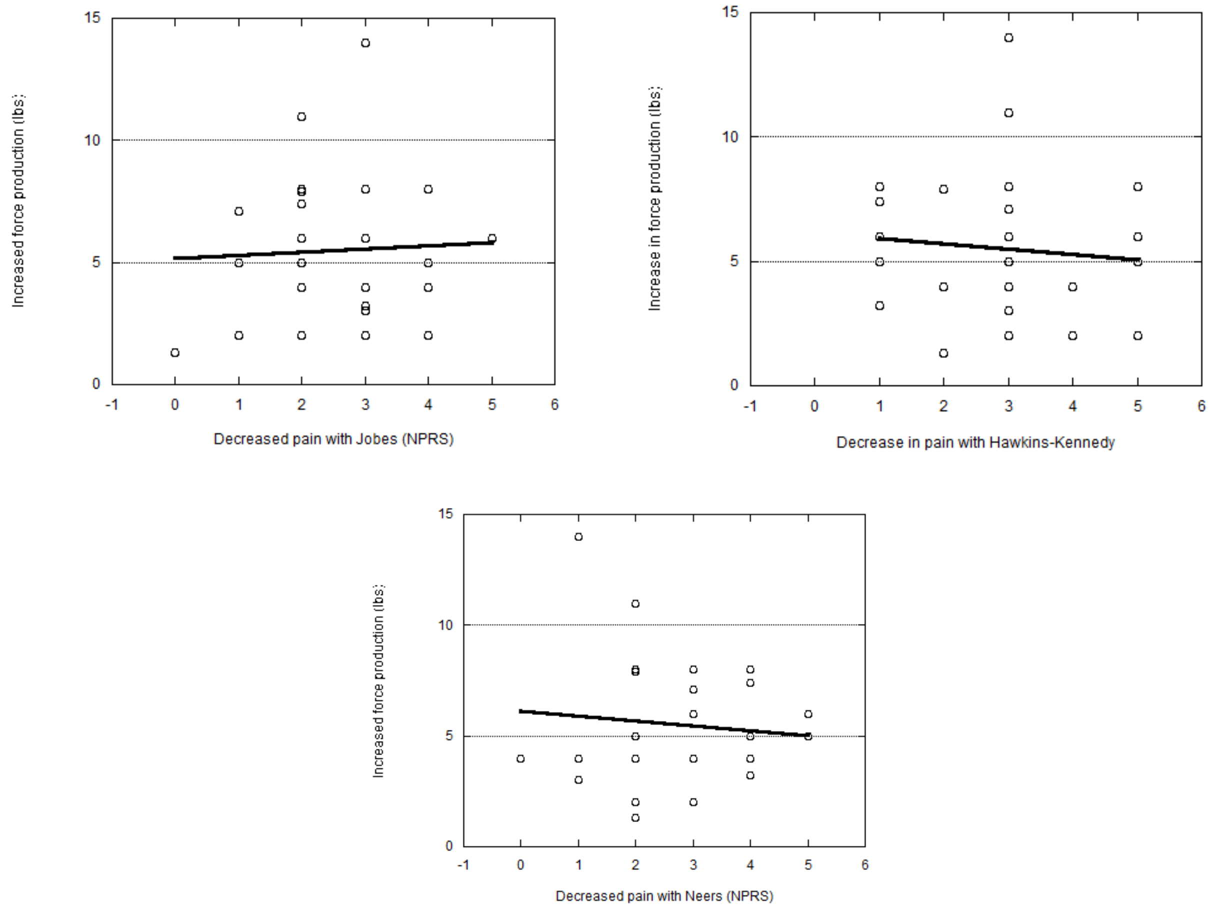


Figure 9. Correlation between force output and pain

In addition to pain, several studies have indicated that changes in thoracic spine posture and mobility may be associated with changes in force production[63, 70, 72-74, 117, 133, 134]. Norlander and Nordgran demonstrated that hypomobility between segments C7-T1 and T1-T2 was highly predictive of shoulder pain and hand weakness [70]. Kebaetse et al found that shoulder abduction force output increased with a more erect posture [63]. Improved segmental mobility or more erect resting posture after manipulation was not assessed in this study so it cannot be determined for certain if alterations in these factors influenced force production.

Shoulder pain and function (7 to 10 days post manipulation)

This study also assessed changes in pain and function 7 – 10 days after receiving manipulation using the PSS and DASH. These were completed immediately prior to, and 7– 10 days post manipulation to assess if thoracic spine manipulation is associated with changes lasting longer than the 36 – 48 hours previously assessed in the literature. While immediate decreases in pain are certainly important, the authors deemed changes in function and disability that persist for many days after the treatment as critical for assessing efficacy. Significant improvements were found on both the PSS and DASH 7 – 10 days after receiving the manipulation. Increased scores on the PSS represent improved function while decreased scores on the Sports/Performing Arts Module of the DASH indicate decreased shoulder disability. Changes on the PSS (mean difference = -7.7 ± 9.4; an 8% change) were less than that of the Sports/Performing Arts Module of the DASH (mean difference = 18.4 ± 16.2, a 48% change). This is likely due to a ceiling effect on the PSS, which is a basic functional measure. The subjects in this study were high functioning with nine elite athletes, three collegiate athletes and four highly competitive recreational athletes. The PSS was not sensitive enough to detect clinically meaningful changes in function in such a cohort**.** In contrast, the DASH assesses disability, which the World Health Organization defines disability as “an umbrella term covering impairments, activity limitations, and participation restrictions”[129]. Though participants were generally high functioning on the

PSS with regards to self-care and activities of daily living (mean pre-test score = 79.8 ± 11.5 out of 100), they clearly felt that their shoulder pain limited their ability to participate in tasks of great personal importance such as sport participation or job related tasks (mean Sports/Performing Arts Module DASH module (pre-test = 38.4±22.9 out of 100; post-test – 20.0 ± 22.7; 48% change). The Sports/Performing Arts Module of the DASH was more sensitive to changes in such areas as the subject self-selected sport, or activities that they felt were most impacted by their shoulder pain.

Thoracic and Cervical Spine ROM (immediately post manipulation)

Thoracic spine manipulation has been used to treat cervical spine dysfunction[25, 93, 135]. However, only one study to date observed changes cervical lateral flexion ROM in subjects with asymmetries following thoracic spine manipulation[136]. Nansel hypothesized that the application of a thoracic spine manipulation might induce movement of thoracic and cervical spine segments and therefore change cervical and thoracic spine ROM[136]. Such changes were not detected in this study. However, only four subjects reported any pain with cervical rotation and none reported pain with thoracic spine flexion and extension during pre-test assessments, suggesting that this cohort of subjects may not have had restrictions in segmental thoracic or cervical spine motion. Furthermore, the cervical sensor was aligned to that of the thorax; thus cervical ROM was assessed relative to the thorax. Sahrmann suggests that individuals move through the point of least resistance[137]. In this study, thoracic rotation was not restricted during cervical ROM testing. If thoracic restrictions were relieved with the application of thoracic manipulation, cervical rotation movement patterns may have changed without finding detectable changes in cervical range of motion alone. The findings of this study related to ROM are similar to those found in Lehman and McGill[108, 112]. They detected no changes in peak lumbar spine ROM following lumbar spine manipulation during the performance of uniplanar flexion and extension or during axial rotation in subjects with low back pain. However, they did find an increased in total ROM during the performance of a complex motor task (swinging of a golf club). This suggests that assessment of simple uniplanar tasks may not detect subtle changes in joint kinematics. Complex tasks require coupled joint motions and more complex coordination which may elucidate changes of overall ROM. Assessment of a more complex functional task following thoracic spinal manipulation was not performed in this study; this is thus one limitation of this study.

Secondary Analysis

The findings of the secondary analysis in this dissertation study assessing changes in pain based on whether or not cavitation was detected with performance of one, both or neither of the spinal manipulations showed there was no difference between these groups. These findings are similar to those of Sillevis and Cleland[138], Bialosky et al[139], Flynn et al[140] and Flynn et al[141]. Bialosky et al found that hypoalgesia following spinal manipulation was independent of detection of cavitation[139], while Flynn et al found that in subjects with low back pain receiving spinal manipulation, the odds of a successful outcome were not improved with detection of cavitation[140, 141].

There were several limitations to this study, including the lack of blinding, randomization and a control group. Several steps were taken to address the issue of blinding. During force production testing, the results screen was covered, and the subject was not informed of force production values until all testing was completed. Also, subjects did not know their scores on the pre-test Penn Shoulder Score or the Sports/Performing Arts Module of the DASH. Subjects were contacted 7-10 days after receiving the manipulation and asked to complete the post-test questionnaires but were not informed of their previous scores. Lastly, all range of motion measurements were obtained using the electromagnetic tracking device so the tester could not inadvertently influence ROM values. One additional limitation may have been the severity of subject symptomology. Most subjects were not seeking medical attention for their shoulder pain.

In summary, these findings suggest that thoracic spine manipulation is associated with decreased pain and improved function, both immediately after and 7 to 10 days post manipulation, in subjects with signs of shoulder impingement but not increased cervical rotation or thoracic spine flexion/extension range of motion. Decreases in pain were independent of detection of cavitation.

CHAPTER 3

BIOMECHANICAL AND NEUROMOTOR CHANGES AT THE SHOULDER FOLLOWING THORACIC SPINE MANIPULATION IN SUBJECTS WITH SIGNS OF SHOULDER IMPINGEMENT

Introduction

Research suggests that people with shoulder impingement present with biomechanical differences such as altered scapular kinematics[18-20, 51, 58-62] and neuromotor alterations such as variations in shoulder muscle activity[18, 19, 77, 81, 83-87] when compared to their pain free counterparts. Findings associated with altered scapular kinematics in people with shoulder impingement have been variable and include differences in scapular upward rotation, anterior/posterior tilt and internal/external rotation[18-20]. Common findings related to muscle activity include increased upper trapezius[18, 84] and decreased serratus anterior muscle activity[18, 87] in people with impingement. Furthermore, people with shoulder impingement often present with impairments at sites remote from the shoulder, including the cervical and thoracic spine[33, 34,70, 91, 134]. Cervicothoracic and thoracic spine manipulations have been used to treat shoulder pain and dysfunction associated with shoulder impingement and may result in improved outcomes[33-35, 37, 91], when compared to traditional therapeutic interventions, such as stretch and exercise, alone. While thoracic spine manipulation does appear to be beneficial in reducing shoulder pain and dysfunction, the mechanisms by which the manipulation induces changes are not well understood. Bialosky suggests that the introduction of a manipulative force results in biomechanical changes at the tissue level, such as joint capsule or muscle stretch, which stimulate various mechanoreceptors resulting in a variety of reflex responses[102]. These may include neuromotor responses, such as changes in motor neuron activity observed in Bulbulian and Dishman[104, 105] and altered electromyographic activity as observed in Colloca, Herzog and Lehman[106-108]. It has been suggested that further studies must be undertaken to assess the various physiologic responses to spinal manipulation to better direct physical therapy interventions[118] . The purpose of this study was to apply Bialosky's conceptual model of the effects of spinal manipulation to assess mechanisms by which thoracic spine manipulation facilitates improvement in patients with shoulder impingement by identifying changes in humerothoracic range of motion, scapular kinematics and muscle activity.

To date, only one study has assessed changes in glenohumeral ROM following thoracic spine manipulation[35]. None have assessed changes in scapular kinematics that may be associated with biomechanical changes induced by thoracic spinal manipulation. Furthermore, very little research assessing changes in shoulder muscle activity patterns following thoracic spine manipulation in patients with shoulder pain has been performed. Herzog found changes in deltoid activation following mid and high thoracic manipulations; however, no other shoulder musculature was assessed[107]. It is unclear, based on the existing literature, whether spinal manipulation affects the neuromotor activity of other shoulder musculature, such as the trapezius, serratus anterior or rotator cuff muscles.

Methods

Overview

This study employed a repeated measures, pre-test, post-test design. Pre-test measures included assessment of scapular kinematics during humerothoracic elevation in the sagittal plane using the Polhemus Fastrak. Humerothoracic elevation was also recorded at the same time.

Electromyographic activity of the upper, middle and lower trapezius as well as infraspinatus and serratus anterior muscles was assessed on the subjects' symptomatic side using surface electromyography (sEMG). Subjects then received a mid-thoracic and a cervicothoracic junction thrust manipulation. The above mentioned variables were then reassessed immediately after spinal manipulation.

Subjects

Thirty subjects, 16 male and 14 female (mean age 30.64 ± 7.92), with signs of shoulder impingement participated in this study. Subjects were recruited from Temple, LaSalle and Arcadia Universities, Penn Athletic Club, Vesper Boat Club, and Bachelors Barge Club as well as Master's swim clubs in the Philadelphia region and personal contacts. It should be noted that most participants in this study were not seeking medical attention for their shoulder pain. Subjects were screened for signs of rotator cuff pathology, and were included if they reported at least 3/10 on a numeric pain rating scale with performance of the Hawkins-Kennedy, Neer's or Jobe's empty can test for shoulder impingement. Subjects were excluded from the study if they have had previous surgical intervention on their shoulder, demonstrated signs of complete rotator cuff (RTC) pathology as indicated by gross weakness of the RTC musculature or imaging studies confirming a full thickness tear, history of spinal trauma or surgery, signs of neurologic involvement including numbness or tingling in the upper quarter, degenerative bone disease, rheumatic disease, or allergies to adhesives. Post-menopausal women were excluded from the study so as to exclude subjects at risk for osteopenia or osteoporosis. All subjects signed an informed consent approved by the Institutional Review Boards of Temple University, Arcadia University and University of Medicine and Dentistry of New Jersey.

Instrumentation

Kinematic Assessment

Scapular motion was measured using the Polhemus Liberty (Colchester, VT), an electromagnetic tracking device. The transmitter was leveled using a bubble level and oriented with the cardinal planes of the body. Receivers were placed on the head, scapula, sternum and humerus. A Velcro strap was placed around the subject's head and the sensor was attached to the posterior aspect of the occiput with Velcro. The scapular sensor was placed on the dorso-lateral aspect of the scapular spine via double-faced tape. It was reinforced with cloth tape to prevent sensor motion during humeral elevation trials. The sternal sensor was placed on the sternum at the jugular notch via double-sided tape. The lead wire was secured to the sternum with cloth tape to prevent rotation of the sensor due to skin movement with shoulder elevation. A neoprene sleeve was placed over the subject's arm and the humeral sensor was attached, via an elastic strap, to the distal humerus. The neoprene sleeve prevented sensor movement on the skin with humeral rotation.

The following bony landmarks were palpated and marked using a grease pencil: spinous processes of C7, T2, T8, T12; the dorsal-most aspect of the acromioclavicular joint, the root of the spine of the scapula, the inferior angle of the scapular, the xyphoid process, jugular notch, and right coracoid process. The medial and lateral epicondyles were palpated through the sleeve and marked with a sticker. These points were used to digitize the upper quarter segments and develop anatomic reference frames as described in a previously established protocol[48 45] and was based on the recommendations of the International Society of Biomechanics[56].

Electromyography

Surface EMG (sEMG) data was collected using the Noraxon Myosystem 1200 (Noraxan Inc, Scottsdale AZ). This unit provides a low pass filter at 400 Hz and a high pass filer at 20 HZ. Blue Sensor (AMBU, Glen Burnie, MD) 1.5 inch silver/silver chloride wet gel electrodes with a 1.5 inch inter-electrode distance were used to detect muscle activity. sEMG data was collected for the infraspinatus (IS), upper trapezius (UT), middle trapezius (MT), lower trapezius (LT) and serratus anterior (SA).

Experimental Procedure

The skin of areas for sEMG electrode placement was thoroughly cleansed and abraded with alcohol wipes. sEMG electrodes were placed as described in Ekstrom[142] for the UT, MT, LT and SA muscles, and Hintermeister[143] for the IS muscle. With the shoulder passively abducted to 90 degrees, the electrodes for the UT were placed parallel to the muscle fibers with one electrode supero-medial and one infero-lateral to a point two centimeters lateral to the midway point between C7 and the lateral aspect of the acromion. Electrodes for the MT were placed parallel to the muscle fibers, one medial and one lateral to a point located three centimeters lateral to the spinous process of T2. For placement of the LT electrodes, the shoulder was passively flexed to 90 degrees. Electrodes were placed obliquely, one superior and one inferior to a point five centimeters inferolateral from the root of the spine of the scapula. For the SA, the shoulder was passively abducted to 90 degrees. Electrodes were placed vertically along the mid-axillary line between ribs six and eight[142]. Electrodes for the IS muscles were placed in parallel, medial and lateral to a point 2.5 centimeters below the midpoint of the scapular spine[42]. The ground electrode was placed on the ulnar styloid process. A fully instrumented subject is illustrated in Figure 10.

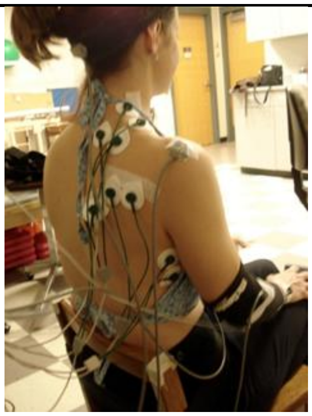


Figure 10. Fully instrumented subject showing placement of sensors and electrodes

Surface EMG data for reference contractions was collected for normalization of the sEMG signals. The reference contraction for the IS muscle was performed as described in Kelly[144]. The subject was seated in a modified wooden chair (Figure 7), that allowed for unobstructed thoracic and humeral ROM with the humerus aligned with the thorax and the elbow flexed to 90 degrees. The subject was asked to isometrically externally rotate the humerus. The tester provided resistance in the direction of internal rotation with one hand placed on the distal forearm and the other stabilizing the elbow to prevent shoulder abduction.

Reference contractions for the UT and SA were performed as described in Ekstrom[142]. The reference contraction for the UT was performed with the subject seated. The right shoulder was abducted to 90 degrees and the neck side-bent to the right. Simultaneous resistance to shoulder abduction and cervical side bending was provided by the tester. The reference contraction for SA was also collected with the subject seated with the shoulder elevated to 125 degrees in the scapular plane. Resistance was applied distal to the elbow and to the inferior angle of the scapula in an attempt to de-rotate the scapula. Reference contractions for the MT and LT were performed in the prone position as described by Kelly[144]. Resistance was applied to the horizontally abducted and externally rotated shoulder for testing of the MT. The arm was raised in line with the muscle fibers and downward resistance was applied to the arm for testing of the LT. Two trials of each muscle were performed; each contraction was held for five seconds with a brief rest between trials. Normalization reference values were calculated by finding the maximum amplitude of the root mean square (RMS) of the sEMG data and averaging the RMS of the 500 ms on either side of the peak value.

After reference contractions for each muscle were recorded, subjects were seated in a wooden chair place directly in front of the transmitter. Subjects were instructed in the performance of humerothoracic elevation, and were allowed two unweighted practice repetitions. Subjects were instructed to move through their full available elevation range of motion during a three second count as the tester counted aloud "one thousand one, one thousand two, one thousand three". Three repetitions of elevation were performed with a five pound hand-held weight if subjects weighed less than 150 pounds or a ten pound hand-held weight if they weighed more than 150 pounds.

Next, the subjects were directed to sit on a treatment plinth facing away from the tester. Thrust manipulations of the mid thoracic spine and the cervicothoracic junction, similar to those reported in Boyles et al[145] were employed. The mid thoracic spine manipulation was performed first, followed by the cervicothoracic junction manipulation. For the mid thoracic spine manipulation, the tester stood behind the subject, pressing her clavicular region against the area to be mobilized. The tester then wrapped her arms around the subject to clasp her hands together. The subject was then instructed to take a deep breath. As the subject exhaled, the tester compressed the subject's upper body while simultaneously lifting the subject slightly, pivoting on the tester's clavicular region. The tester than palpated the cerivical vertebrae to find C7 and T1; this was identified as the cervicothoracic junction. The cervicothoracic manipulation with the patient seated with his or her fingers interlocked posteriorly at the base of the cervical spine. The tester stood behind the subject and threaded her arms through the subject's so that her hands were on top of those of the subject. The subject was then gently reclined and asked to exhale. The tester provided a distractive thrust at the cervicothoracic junction. Manipulations are illustrated in Figure 11. If a cavitation was detected, the tester proceeded to the cervicothoracic junction manipulation. If no cavitation was heard or felt upon the first attempt of a manipulation, a second attempt was made before moving on to the next manipulation. No more than two attempts were made for each manipulation. Care was taken not to disrupt the placement of any of the electrodes or electromagnetic sensors. Immediately after the spinal manipulations, kinematic and sEMG data were collected again as described above.

Data Reduction

Kinematic Data

Raw scapular kinematic data was exported to an excel file and processed using a custom interpolation program written in Labview. This program interpolated the three elevation repetitions in 5 degree increments and then provided an average curve. Scapular and clavicular angles at 30, 60, 90 and 120 degrees of humerothoracic elevation were extracted for analysis.

Figure 11. Thoracic spine manipulations. **A**, Mid-thoracic spine manipulation; B, Cerivcothoracic spine manipulation

sEMG Data

Electromyographic data were collected and converted from analog to digital at a sampling rate of 1000 hz. Raw data were passed through a preselected low pass (400 hz) and high pass filter (20 hz), and were rectified using the root mean square (RMS) technique. This data was then exported to an excel file and processed in the custom interpolation program in Labview described above to provide RMS values corresponding to minimum, 30, 60, 90 and 120 degrees of glenohumeral elevation. These values were then normalized using the previously calculated normalization reference (point elevation values divided by reference value multiplied by 100) and expressed as a percentage of reference value. Muscle onset was defined a 2 standard deviations above resting values for greater than 50 milliseconds. Resting values were determined by averaging the initial 500 milliseconds of the reference contraction data. Relative time zero was defined as the first degree of humeral elevation in the positive direction achieved both pre- and post- test for each subject. This process allowed for determination of a relative onset time for each subject.

Data Analysis

A paired t-test was performed to compare humerothoracic elevation before and after receiving spinal manipulation. A two factor repeated measures analysis of variance (ANOVA) was performed to examine the effects of condition (pre and post thoracic spine manipulation) and glenohumeral elevation (30, 60, 90, and 120 degrees) for each of the five dependent kinematic variables. These included scapular upward rotation, external rotation and posterior tilt, as well as clavicular elevation and protraction. Humerothoracic elevation trials demonstrating signs of technical errors were excluded from the analysis. A two factor repeated measures ANOVA was also performed with condition and humerothoracic elevation as repeated factors for each of the five dependent sEMG variables which included RMS values for the infraspinatus, serratus anterior, upper trapezius, middle trapezius and lower trapezius muscles. Paired t-tests were also used to compare muscle onset times. Additionally, a secondary analysis was performed using a 2 x 2 factoral ANOVA, with range of motion pre- and post- manipulation as the repeated measures factor and change in pain as the between group factor, assessing whether changes in humeral elevation were related to change in pain ratings. Subjects were divided into 2 groups after analysis of pre- and post- manipulation data: those who reported a greater than a 2 point change in pain rating with humeral elevation and those that reported less than or equal to a 2 point change in pain post spinal manipulation. An alpha level of 0.05 was used to determine significance.

Results

Descriptive statistics for kinematic and electromyographic variables are found in Table 9 and 10 respectively.

Table 9. Descriptive statistics for scapular and clavicular angles (degrees)

Variable	Humerothoracic elevation (degrees)	Mean (SD) PRE	Mean (SD) POST
Scapular Upward Rotation	30	1.1 (8.2)	-.01 (11.2)
	60	12.2 (9.7)	11.2 (12.6)
	90	24.7 (10.1)	22.8 (11.7)
	120	31.1 (9.0)	29.4 (12.1)
Scapular External Rotation	30	-25.5 (7.2)	-28.1 (7.9)
	60	-28.2 (6.6)	-31.3 (6.9)
	90	-29.2 (5.8)	-26.2 (20.7)
	120	-25.5 (9.3)	-25.9 (7.8)
Scapular Posterior Tilt	30	-10.6 (8.1)	-8.4 (8.2)
	60	-7.2 (7.6)	-7.3 (8.9)
	90	-6.9 (8.4)	-6.4 (8.6)
	120	-0.8 (13.7)	0.4 (14.2)
Clavicular Elevation	30	6.9 (5.1)	4.6 (7.5)
	60	10.3 (5.6)	8.0 (7.8)
	90	13.5 (6.2)	11.7 (8.1)
	120	13.5 (6.5)	13.3 (8.9)
Clavicular Protraction	30	-16.1 (7.3)	-14.6 (8.9)
	60	-18.6 (7.7)	-16.8 (9.9)
	90	-24.1 (9.0)	-22.1 (10.9)
	120	-28.9 (6.2)	-26.4 (6.9)

Table 10. Descriptive statistics for electromyographic activity

Muscle	Degrees Humerothoracic Elevation	Mean RMS value (SD) PRE	Mean RMS value (SD) POST
Infraspinatus	30	22.4 (27.1)	25.1 (16.8)
	60	28.6 (18.3)	30.7 (27.5)
	90	28.4 (24.6)	33.2 (21.9)
	120	34.4 (25.3)	27.7 (24.7)
Serratus Anterior	30	33.4 (24.2)	45.1(36.6)
	60	52.2 (38.4)	73.0 (73.3)
	90	64.5 (56.9)	79.8 (65.3)
	120	71.4 (53.7)	75.4 (49.2)
Upper Trapezius	30	49.6 (28.5)	49.9 (46.7)
	60	68.3 (37.1)	90.5(60.5)
	90	87.3 (54.8)	99.5(78.9)
	120	90.1(49.3)	83.1(47.1)
Middle Trapezius	30	15.2 (9.5)	23.6 (17.2)
	60	20.9 (16.5)	25.4 (15.3)
	90	23.1 (7.3)	28.7 (18.4)
	120	21.4 (17.0)	29.9 (28.3)
Lower Trapezius	30	28.3 (19.1)	25.5 (23.8)
	60	33.1 (15.6)	47.2 (30.4)
	90	48.2 (19.4)	46.5(33.9)
	120	52.2 (36.4)	45.7 (29.1)

Analysis of variance was performed on all dependent variables. Because 12 of the 20 subjects' data did not include data for 120 degrees of elevation, an ANOVA was performed comparing pre and post manipulation at both 30, 60, 90, and 120 degrees of elevation as well as at just 30, 60, and 90 degrees of elevation. If significant differences were not found with either analysis, F values for the ANOVA containing 4 elements (30, 60, 90, 120 degrees of elevation) were reported. Results of the within group comparisons for kinematics are found in Table 11.

Table 11. Within group comparisons for kinematic data

Variable	Factor	*df*	F	*p*
Clavicular elevation	Condition	1,12	2.03	.18
	Condition x elevation	3,30	4.70	.01
Clavicular protraction	Condition	1,10	3.86	.08
	Condition x elevation	3,30	.11	.95
Scapular upward rotation (with 120º)	Condition	1,11	3.86	.08
	Condition x elevation	3,33	.11	.95
Scapular upward rotation (without 120º)	Condition	1,16	4.70	.05
	Condition x elevation	2,32	.06	.95
Sacpular External Rotation	Condition	1,10	0.14	.71
	Condition x elevation	3,30	.11	.95
Scapular posterior tilt	Condition	1,10	.05	.49
	Condition x elevation	3,30	.85	.48

Analysis of variance revealed a small, but significant decrease scapular upward rotation (3 elevation factors) with humerothoracic elevation following thoracic spine manipulation, $p = 0.05$. A significant interaction between condition and elevation was observed for clavicular elevation however post hoc t- tests revealed no significant difference in clavicular elevation at 30, 60, 90 or 120 degrees pre- and post- manipulation. No differences were observed following manipulation for scapular posterior tilt, scapular external rotation or clavicular protraction.

Scapular and clavicular angles are presented in Figure 12. No differences in humerothoracic elevation (p = .18) were observed.

Analysis of electromyographic data (Table 12) revealed a small but statistically significant increase middle trapezius activity (p=.03) following spinal manipulation; however, no differences were detected for the upper or lower trapezius muscles, or for the infraspinatus and serratus anterior muscles. Electromyography data are illustrated in Figure 13. In addition, no differences in onset times were detected for any of the muscles assessed (Table 13).

The secondary analyses detected no significant differences between groups (> 2 point changes and ≤ 2 point change) in humerothoracic flexion ROM before versus after spinal manipulation (See Table 14).

Table 12. Within Group Comparisons for Electromyographic Data

Muscle	Factor	*df*	F	*p*
Infraspinatus	Condition	1,11	.04	.85
	Condition x elevation	3,27	.77	.52
Serratus anterior	Condition	1,9	1.13	.32
	Condition x elevation	3,27	.22	.88
Upper trapezius	Condition	1,9	.96	.37
	Condition x elevation	3,27	1.85	.17
Middle trapezius (120)	Condition	1,9	3.34	.10
	Condition x elevation	3,27	.27	.84
Middle trapezius	Condition	1,15	35.73	.03
	Condition x elevation	2,30	.41	.67
Lower trapezius	Condition	1,9	.03	.87
	Condition x elevation	3,27	.88	.46

Table 13. Statistical Analysis of Muscle Onset Times

Muscle		95% Confidence Intervals		t	*df*	*p*
	Mean (*sd*)	Lower	Upper			
IS	.22 (.53)	-.10	.54	1.48	14	.16
UT	.22 (.76)	-.24	.68	1.05	14	.32
MT	.17 (1.30)	-.61	.95	.47	14	.64
LT	.06 (1.72)	-.98	1.10	.12	14	.90
SA	-.24(.65)	-.63	.16	-1.31	14	.21

Table 14. Assessment of Changes in Humerothoracic Flexion ROM compared to change in pain ratings Pre- and Post- Thoracic Spine Manipulation

	Between Groups Analysis	
	F	*p*
Changes in Humerothoracic ROM x Change in Pain	2.0	.171

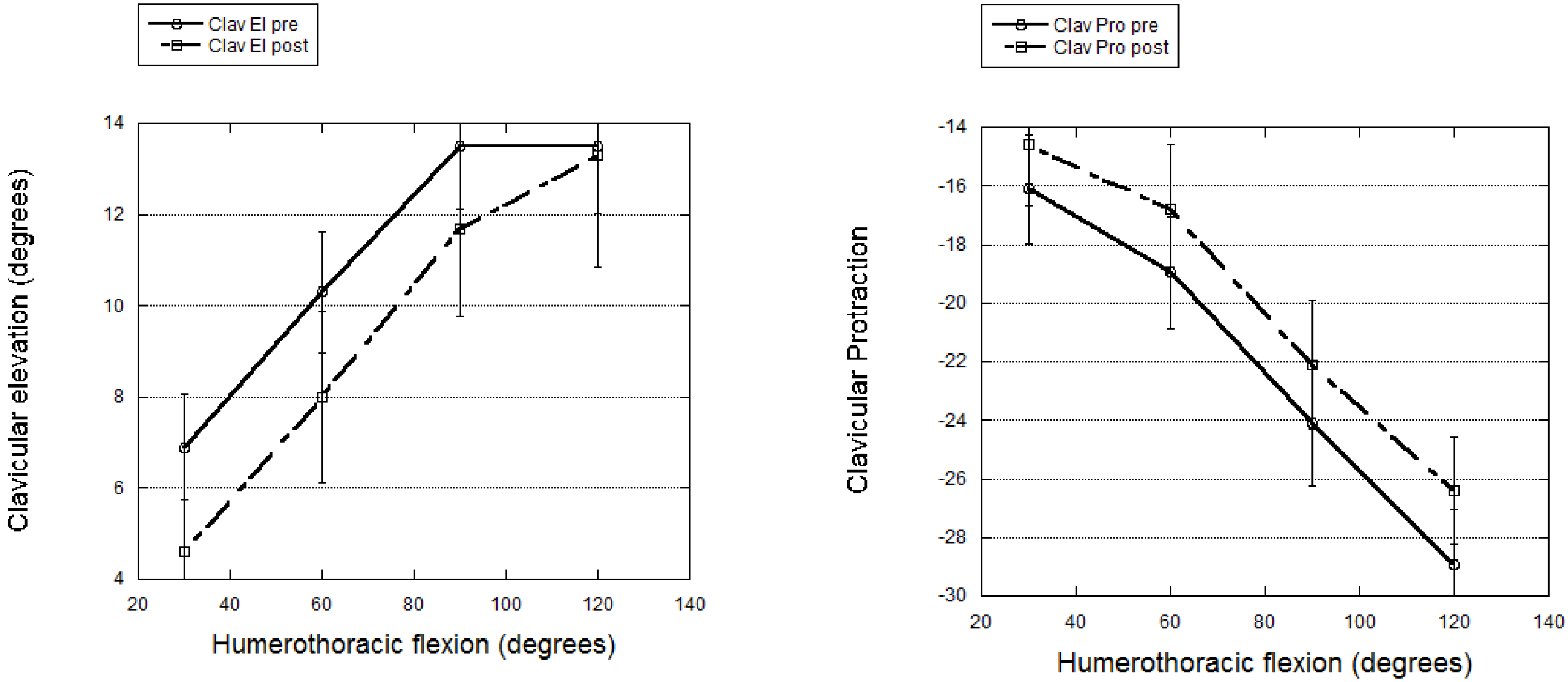


Figure 12. Scapular and clavicular angles pre and post thoracic spine manipulation

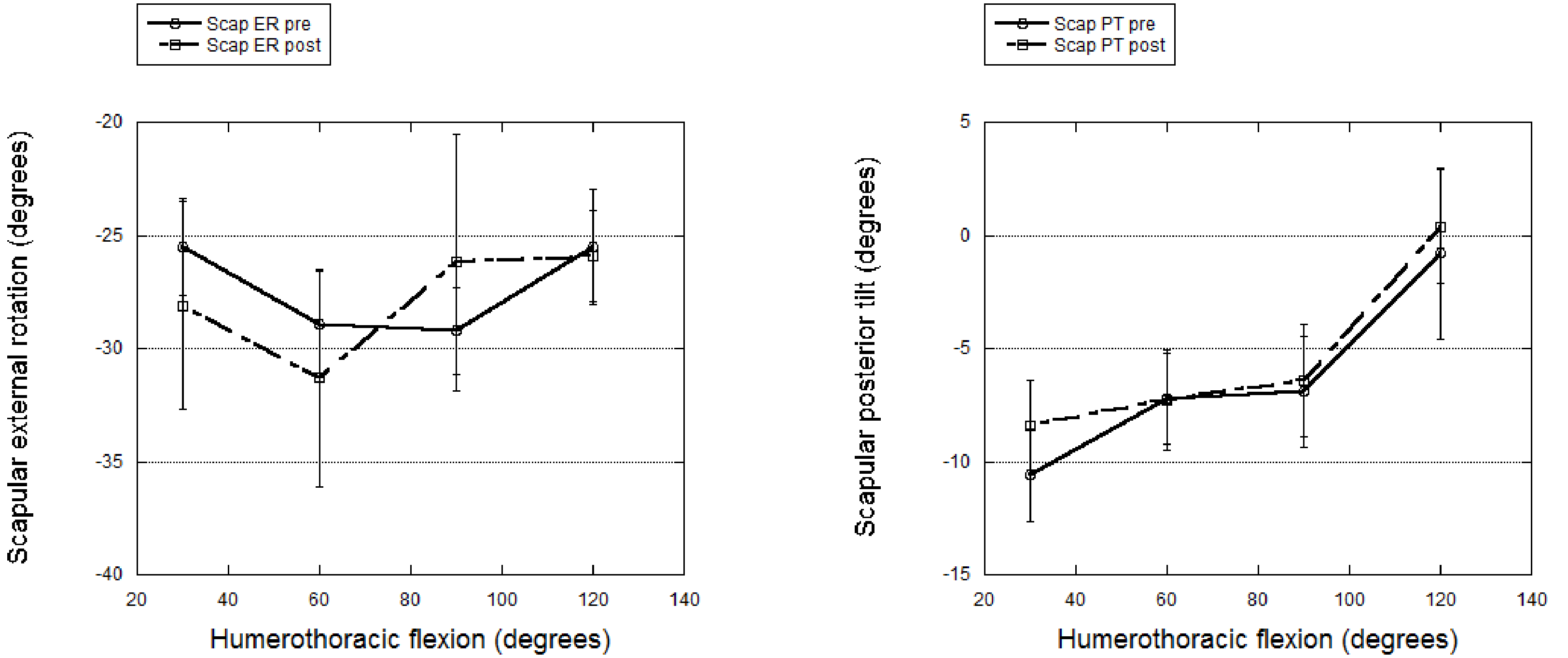


Figure 12. (Continued)

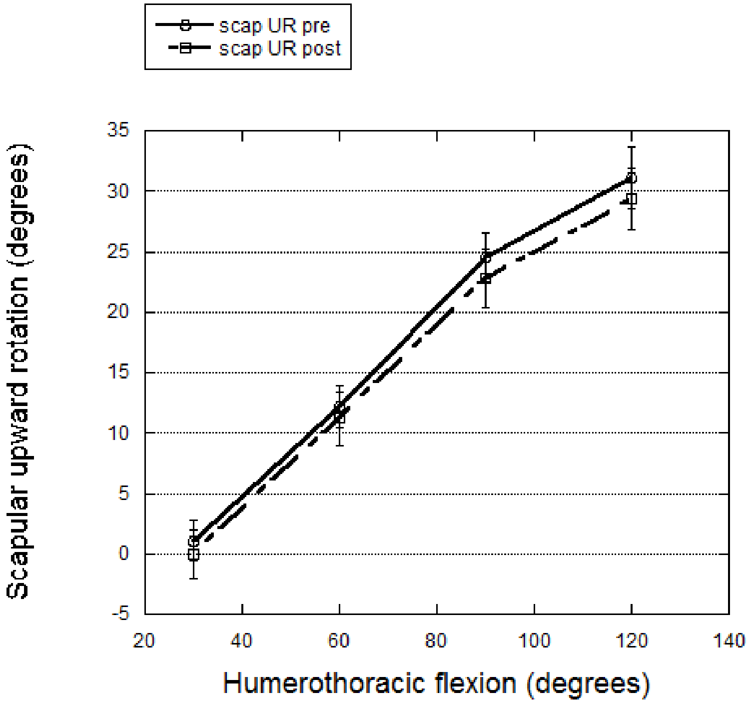


Figure 12. (Continued)

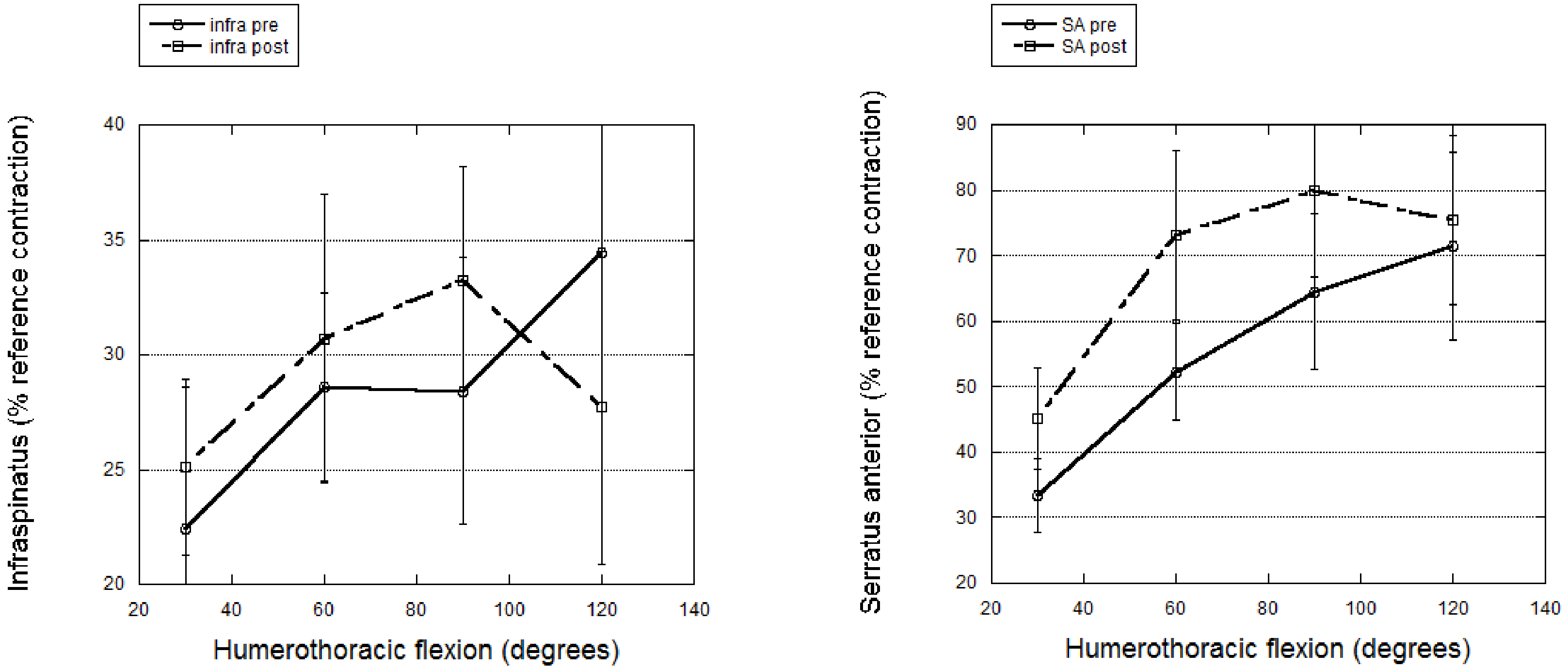


Figure 13. Electromyographic data pre- and post-thoracic spine manipulation at 30, 60, 90, and 120 degrees of humerothoracic elevation

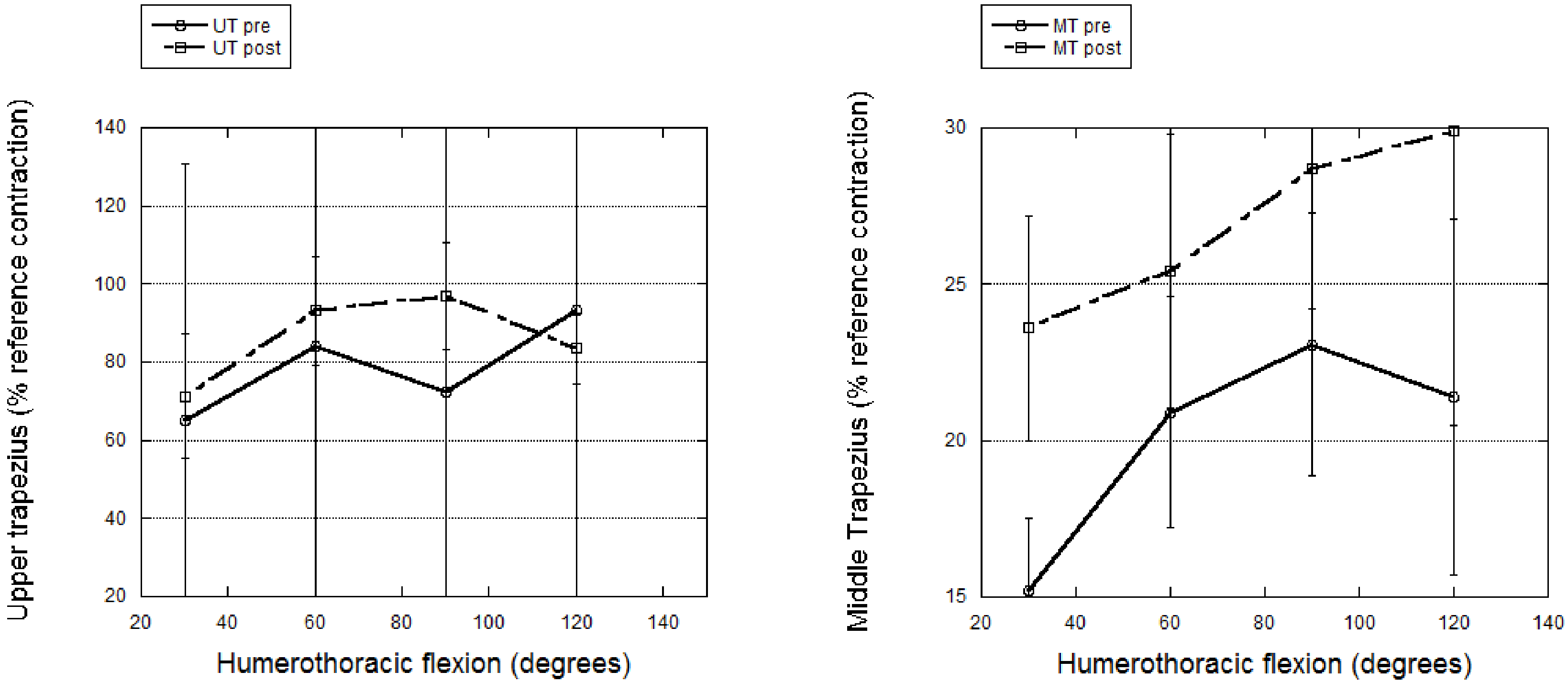


Figure 13. (Continued)

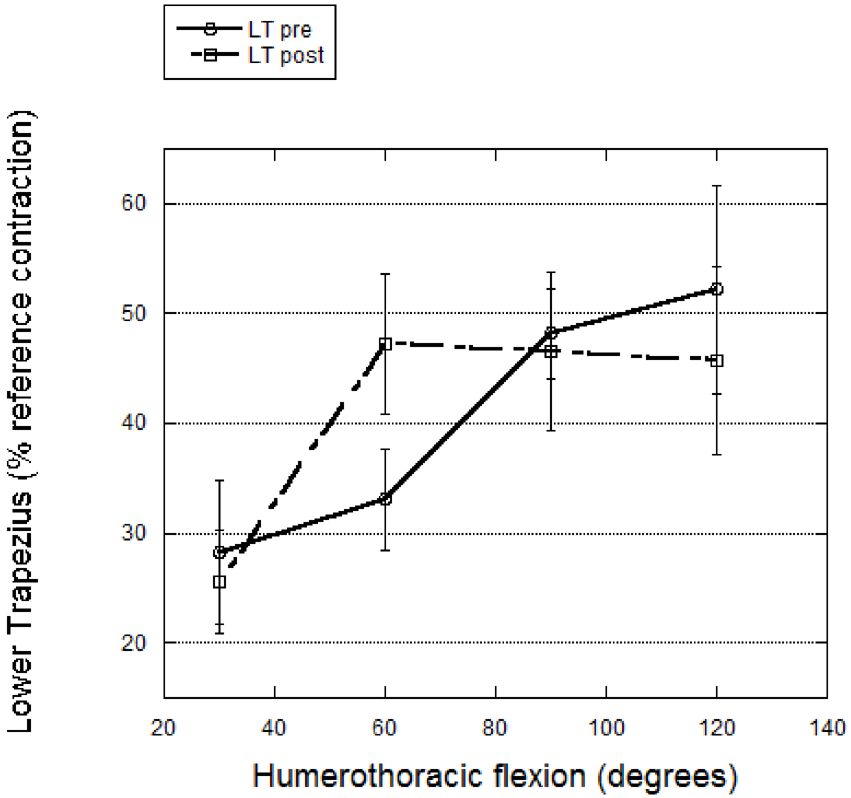


Figure 13. (Continued)

Discussion

Humerothoracic ROM

No changes in humerothoracic elevation were observed in this study. In contrast, Boyles[34] measured changes in glenohumeral elevation via goniometry and found that thoracic spine manipulation was associated with increased humeral elevation ROM. The conflicting findings between studies may, in part, be associated with the use of different measurement techniques as well as differences in elevation conditions. Boyles[34] used goniometry to assess glenohumeral range of motion, this study employed an electromagnetic tracking system to assess humerothoracic elevation. In addition, humeral elevation range of motion was assessed while holding a 5 or 10 pound weight in this study, whereas humeral elevation was performed unweighted in Boyles's study. Finally, with regards to subject population, only two subjects in this study were actively seeking medical attention for their shoulder pain. Nine subjects were elite athletes who reported their shoulder pain interfered with participation in their sport but did not wish to seek medical attention. Some of the subjects in Boyles's study were already seeking treatment for their shoulder pain and were referred to the study by their physical therapist.

Scapular Kinematics

This study demonstrated that thoracic spine manipulation may have induced minor changes in scapular upward rotation with weighted humeral elevation. No other changes in scapular kinematics were detected. Findings with regards to scapular upward rotation in people with impingement are highly variable. Lin[7] and Ludewig[2] found that subjects with impingement demonstrated less scapular upward rotation than did those without impingement. Conversely, McClure and Endo found subjects with impingement demonstrated more upward rotation[19, 58]. Furthermore, the effects of scapular rotations on subacromial clearance are not well understood. Karduna et al performed a study using cadavers to assess the effects of scapular orientation on contact forces in the subacromial space in eight fresh cadavers[146]. They found that increased scapular upward rotation resulted in decreased subacromial clearance, likely increasing compression forces on subacromial structures. Thus, decreased upward rotation may reduce compression of the subacromial structures. It this study, scapular upward rotation decreased by only a few degrees after manipulation. It is not likely that this small difference can fully explain the robust findings of decreased pain with elevation observed in Boyles[34] and Strunce [35] as well as in Chapter 2 of this dissertation study.

sEMG

This study observed a statistically significant, albeit small, increase in middle trapezius activity; however, no significant changes in electromyographic activity were detected in the upper and lower trapezius muscles or in the infraspinatus and serratus anterior muscles. According to Johnson et al[76], the primary role of the middle trapezius is that of stabilizing the scapula and resisting internal rotation of the scapula. Again, the increases in middle trapezius activity observed after manipulation in this study were small and while this increase in activity may have served to improved scapular stabilization, it is not likely that this finding fully explains the improved shoulder function observed in both Boyles[34] and Strunce[35] or the observation of increased force production reported in Chapter 2 of this dissertation study.

Most of the previous studies assessing changes in motor activity associated with spinal manipulation observed changes in reflex response[96, 104, 147] or resting electromyographic activity[110, 148]. The few prior studies[108, 112] that have used sEMG to detect changes in motor output with dynamic activity following spinal manipulation have assessed changes associated with lumbar spine manipulation. Lehman and McGill assessed changes in spine kinematics and electromyographic activity of the erector spinae muscles in a professional golfer following lumbar spine manipulation[112]. They found decreased electromyographic output both in quiet stance and during performance of a golf swing. They later performed a randomized, controlled study assessing the activity of the abdominal musculature as well as the thoracic and lumbar erector spinae muscles both in quiet stance and during dynamic activities[108]. In quiet stance, most muscles exhibited no change in EMG activity levels. Changes in muscle activity during performance of dynamic tasks pre and post manipulation were highly variable and no trends in muscle activity were able to be determined. Thus, the findings of this dissertation study associated with the upper trapezius, lower trapezius, serratus anterior and infraspinatus muscles agree with those of Lehman and McGill[108] in that no differences in muscle activity were detected after spinal manipulation, in this case, following thoracic spinal manipulation.

To date, the authors are not aware of any other findings assessing scapular kinematics or electromyographic activity following thoracic spine manipulation. One study has assessed pain perception following thoracic spine manipulation[149]. They observed hypoalgesia in both the upper and lower extremity following thoracic spine manipulation. In this dissertation study, subjects did report less pain with humeral elevation as well as with performance of provocative testing following thoracic spine manipulation (See Results in Chapter 2).

These findings support Bialosky's conceptual model explaining the mechanisms associated with spinal manipulation[102]. While the decrease in scapular upward rotation may, in part be associated with decreased compressive forces underneath the subacromial arch as observed by Karduna et al[146], it is not likely these findings alone explain the significant decreases in pain reported in previous studies [34, 35] and in Chapter 2 of this dissertation. Furthermore, only the middle trapezius muscle demonstrated increased activity following thoracic spine manipulation; the neuromotor responses of the other muscles assessed in this study did not change with manipulation. These findings suggest that other physiologic processes must be occurring concurrently to modulate pain. Bialosky has proposed, that joint manipulation induces biomechanical changes at the tissue level such as vertebral oscillations and zygapopheseal joint capsule stretch that, through sensory stimulation of various mechanoreceptors, induce a cascade of neurophysiologic responses, all of which may play a role in pain modulation[102]. Further studies assessing changes in pain perception at the neurophysiologic level combined with assessments of altered neuromotor control and segmental spine kinematics are needed to better understand how thoracic spine manipulation influences pain and function in people with signs of shoulder impingement.

CHAPTER 4

SUMMARY AND CONCLUSIONS

The intent of this research study was to contribute to the growing body of literature suggesting that thoracic spine manipulation may be an effective treatment option for people with shoulder pain associated with rotator cuff impingement. It applied a model exploring some of the proposed mechanisms explaining the effects of spinal manipulation to assess the effects of thoracic spine manipulation. The mechanisms by which thoracic spine manipulation alleviates pain and improves function needs to be explored to better develop comprehensive treatment plans for this patient population.

Pain and function assessment

This study assessed changes in shoulder pain and function both immediately following thoracic spine manipulation as well as 7 – 10 days after receiving the manipulations. Subjects reported their pain on an 11 point (0 – 10) numeric pain rating scale with the application of three provocative tests (Neer's, Hawkins–Kennedy, and Jobes Empty Can tests) as well as with performance of weighted humeral flexion, scaption and abduction. Subjects also rated their pain with the performance of cervical rotation and thoracic spine flexion and extension. Force output with the shoulder elevation to 90 degrees in the scapular plane with the humerus in neutral rotation was assessed using a hand-held dynamometer. Shoulder pain and function was further assessed 7 to 10 days post manipulation using the Penn Shoulder Score and the Sports/Performing Arts Module of the DASH. Upon completion of the manipulation procedures, subjects were again asked to rate their pain with provocative testing, and range of motion as described above. Force output was also assessed immediately after receiving the manipulations. Subjects were given a blank copy of both the Penn Shoulder Score and the Sports/Performing Arts Module of the DASH and asked to complete these questionnaires 7 – 10 days after receiving the manipulations.

ROM Assessment

All ROM assessments were performed with the subjects seated in a wooden chair, modified to allow unrestricted scapular motion. A pelvic strap was wrapped around their hips and the chair to minimize pelvic rotation. All ROM measurements were collected using an electromagnetic tracking system before and immediately after receiving the spinal manipulations.

Humerothoracic ROM was assessed during the performance of three repetitions of humeral elevation in sagittal plane while holding either a 5 or 10 pound weight. This was performed both before and after receiving the thoracic spine manipulations. Mean peak elevation was calculated by averaging the maximum elevation achieved in each of the three repetitions.

To assess cervical ROM, subjects were asked to turn their head as far to the right as possible. Subjects then performed three repetitions of right to left cervical rotation. Mean cervical rotation excursion was calculated by averaging the total range of motion for each repetition.

Thoracic flexion/extension ROM was assessed during the performance of three repetitions of moving from an exaggerated erect sitting posture into a slouched posture and then returning to the exaggerated upright posture. Subjects were instructed to maintain contact between their lumbar spine and the back of the chair through each of the repetitions.

Three-dimensional scapular kinematics assessment

Three-dimensional scapular kinematics were also assessed using an electromagnetic tracking system. Sensors were placed on the occiput, sternum, scapula and humerus. Digitization for development of anatomic coordinate was performed as described in McClure[48] and was based on the recommendations of the International Society of Biomechanics[56]. Scapular upward rotation, posterior tilt and external rotation, as well as clavicular elevation and protraction data were collected during the performance of humeral elevation in the sagittal plane. These data were exported to an excel file and processed in a custom interpolation program in Labview. Average scapular and clavicular rotations at 30 , 60, 90, and 120 degrees of humeral elevation were compared pre- and post- thoracic spine manipulation.

Shoulder muscle electromyographic activity assessment

Surface electromyography was used to detect changes in activity of the serratus anterior and infraspinatus muscles as well as the upper, middle, and lower trapezius muscles following thoracic spine manipulation. Reference contractions were performed for each muscle as described in Kelly[78] and Ekstrom[150] and Hintermeister[143] to allow for normalization of the sEMG data. Normalization reference values were calculated by finding the maximum amplitude of the root mean square (RMS) of the sEMG data and averaging the RMS of the 500 ms on either side of the peak value. Raw sEMG data were collected during the performance of weighted humeral elevation in the sagittal plane and processed using the root mean squares (RMS) technique. The RMS values were processed using the previously Labview program described previously. RMS values at 30, 60, 90 and 120 degrees of humeral elevation were than normalized as a percent of the previously calculated reference contraction values.

Pain and function: observed findings

The findings of this study agree with those of Boyles[34] and Strunce[35] with regards to decreased pain and improved function. We found that subjects reported decreased pain with the performance of provocative testing and weighted humeral elevation immediately after spinal manipulation. In addition, our study further assessed shoulder pain and function 7 – 10 days after receiving the thoracic spine manipulation. Specifically, subjects reported improved pain and function on the Penn Shoulder Score and improved ability to participate in sport or recreational tasks on the Sports/Performing Arts Module of the Disability of the Arm, Shoulder and Hand (DASH) questionnaire. The subjects in this study also demonstrated increased shoulder elevation force production immediately after receiving the thoracic spine manipulation. Based on the findings of Boyles[34], Strunce[35] and those of this dissertation study, it does appear that thoracic spine manipulation may be a beneficial addition to therapeutic intervention strategies for addressing the pain and dysfunction associated with shoulder impingement.

ROM: observed findings

Humerothoracic elevation ROM

No changes in humerothoracic elevation ROM were observed in this study. In contrast, Boyles[34] did observe increases in glenohumeral elevation following thoracic spine manipulation. The conflicting findings between studies may, in part, be associated with the use of different measurement techniques as well as differences elevation conditions. Boyles used goniometry to assess glenohumeral range of motion, this study employed an electromagnetic tracking system to assess humerothoracic elevation. In addition, humeral elevation range of motion was assessed while holding a 5 or 10 pound weight in this study elevation, whereas humeral elevation was performed unweighted in Boyles's study.

Cervical rotation ROM

No changes in cervical rotation were observed in this study. Only one study in the literature[136] has reported improved range of motion in people with neck pain follow thoracic spine manipulation. They found improvements in cervical lateral flexion in people with asymmetric range of motion. Only four subjects in this dissertation study reported pain with cervical rotation, all of whom reported less than 4/10 on the numeric pain rating scale. Cervical rotation motion was not painful and therefore not likely limited for most of the subjects in this study. Additionally, cervical rotation range of motion was measured in relation to the thoracic spine in this study. If thoracic spine manipulation improved segmental joint mobility, it is likely the increases in range of motion were gained through the thoracic spine, and possibly the lower cervical spine. Thoracic motion was not restrained while subjects performed cervical rotation.

Therefore, if gains in ROM were obtained through increased thoracic mobility, increased occipital excursion may not have been reflected in the motion data.

Thoracic spine flexion/extension ROM

Thoracic spine motion was assessed in relation to the global coordinate system. This allowed for detection of changes in range of motion excursion, but did not allow for detection of the changes in spine contour that might be demonstrated if thoracic spine segmental mobility improved after manipulation. Similar to the findings of Lehman and McGill[108], no changes in thoracic spine flexion/extension range of motion were observed in this study . Lehman and McGill found no changes in lumbar spine planar motion following a lumbar spine manipulation[108].

Three-dimensional scapular kinematics: observed findings

Scapular kinematic data were collected to assess biomechanical changes associated with thoracic spine manipulation in subjects with shoulder impingement. After receiving the thoracic spine manipulation, subjects demonstrated slightly less scapular upward rotation with humeral flexion. Kuduna et al found that in cadavers, increased scapular upward rotation resulted in decreased subacromial clearance, suggesting that decreased upward rotation may, in fact, decrease compressive forces on subacromial structures[146]. The subjects in this study reported decreased pain with both provocative testing and with weighted active range of motion after receiving the manipulations. However, it is not likely due to the small amount of decreased scapular upward rotation observed in this study. Furthermore, no other changes in scapular or clavicular motions were detected suggesting that other physiologic mechanisms are likely contributing to the findings of decreased pain and improved function following thoracic spine manipulation.

Shoulder muscle electromyographic activity: observed findings

Shoulder muscle electromyographic data were collected to assess changes in neuromotor control following thoracic spine manipulation. Small but significant increases in middle trapezius muscle activity during weighted humeral flexion were observed following spinal manipulation. The middle trapezius primarily serves to stabilize the scapula and limit scapular internal rotation[76]. In theory, it is possible that improved scapular stabilization resulting from small increases in middle trapezius, improved scapulothoracic stability, thereby contributing to findings of improved shoulder function, including increased force production following thoracic spine manipulation. However, the increases in middle trapezius activity were small and therefore do not likely explain the findings of decreased pain and increased shoulder function associated with thoracic spine manipulation.

No other significant findings associated with shoulder muscle electromyographic activity during performance of weighted humeral elevation were observed. These finding were similar to those of Lehman and McGill[108] who assessed lumbar spine and abdominal muscle activity before and after lumbar spine manipulation. They found that with performance of dynamic tasks, changes in muscle activity were highly variable with no significant differences for any muscles observed.

In summary, this repeated-measures study found that thoracic spine manipulation was associated with immediate decreases in pain and increased shoulder elevation force production in people with shoulder impingement. Thoracic spine manipulation was also associated with improved pain, function and activity participation 7 -10 days after receiving the intervention. The decreased scapular upward rotation observed after the intervention suggests that thoracic spine manipulation may induce small scapular kinematic changes at the shoulder complex. However, it is not likely that these changes in scapular kinematic changes account for the robust findings with regards to pain and function. Increased middle trapezius muscle activity was observed following thoracic spine manipulation; however, no additional changes in shoulder muscle activity were detected. Increased middle trapezius activity may have improved scapular stability; however, these small increases in middle trapezius do not likely account for all of the robust findings with regards to decreased pain, increased force production and improvement in other aspects of shoulder function.

Secondary analyses revealed that changes in pain were independent of whether or not cavitation (audible pop) was detected. Furthermore, subjects who experienced the greatest decreases in pain demonstrated did not demonstrate greater changes in humerothoracic elevation range of motion.

The findings of this study indicate that thoracic spine manipulation, regardless of detection of cavitation, may be an effective intervention to treat pain associated with shoulder impingement; however, the improvements associated with thoracic spine manipulation are not likely explained by changes in scapular kinematics or shoulder muscle activity. Thoracic spine manipulation did not substantially alter motor control at the shoulder or scapular kinematics. It is highly probable that other neurophysiologic processes, including mechanisms mediated at both the spinal and supraspinal levels, contribute to the significant reductions in pain and increases in function. Additional therapeutic and rehabilitative techniques such as postural and neuromuscular reeducation are likely necessary to aid in the complete restoration of normal shoulder function in people with impingement. Figure 14 illustrates the new theoretical framework, revised based on the findings of this study. The revised framework illustrates that thoracic spine manipulation induces local changes at the tissue level (i.e., vertebral oscillations, zygapophyseal joint capsule stretch) that trigger a cascade of neurophysiologic responses that ultimately modulate pain. Pain reduction, induced by spinal manipulation, may allow individuals experiencing shoulder pain due to impingement to better participate in other rehabilitative activities such as postural and neuromotor re-education. This combination of therapeutic activities, theoretically results in restoration of normal shoulder function.

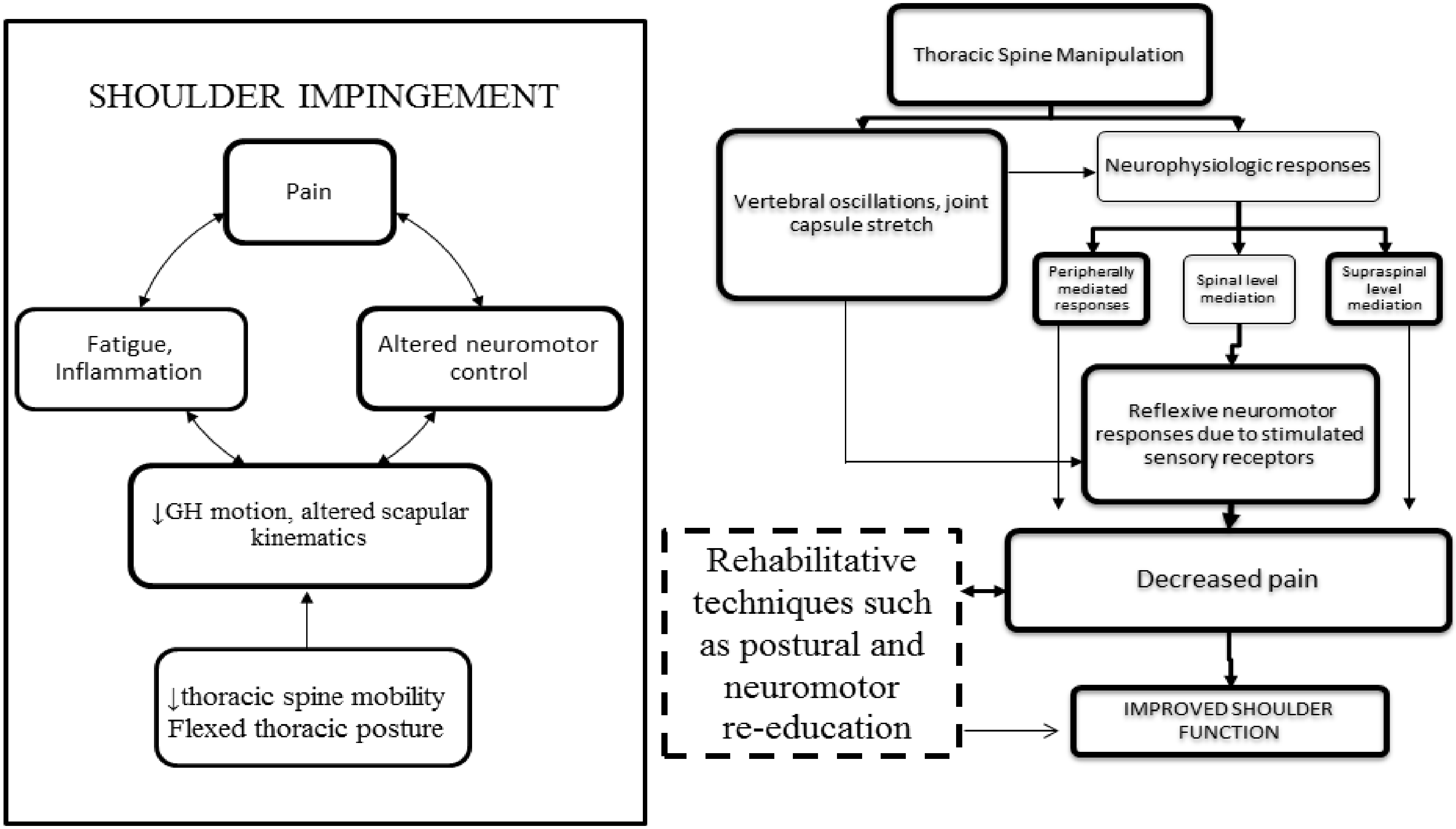


Figure 14. Revised theoretical framework

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APPENDIX A

The Penn Shoulder Score, Part 1: Pain and Satisfaction Subscales

Please circle the number closest to your level of pain or satisfaction	Official Use Only
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	_____ (10 - # circled)
Pain with normal activities (eating, dressing, bathing) 0 1 2 3 4 5 6 7 8 9 10 No pain … Worst pain possible	_____ (10 - # circled) Score 0 if not Applicable
Pain with strenuous activities (reaching, lifting, pushing, pulling) 0 1 2 3 4 5 6 7 8 9 10 No pain … Worst pain possible	_____ (10 - # circled) Score 0 if not Applicable
Pain Score	= ___ / 30
How satisfied are you with the current level of function of your shoulder? 0 1 2 3 4 5 6 7 8 9 10 No pain … Worst pain possible	_____ (10 - # circled)

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Penn Shoulder Score: Function Subscale

Please circle the number that best describes the level of difficulty you might have performing each activity					
	No difficulty	Some difficulty	Much difficulty	Can't do at all	Did not do before injury
1. Reach the small of your back to tuck your shirt in with your hand	3	2	1	0	X
2. Wash the middle of your back/neck bra	3	2	1	0	X
3. Perform necessary toileting activites	3	2	1	0	X
4. Wash the back of opposite shoulder	3	2	1	0	X
5. Comb hair	3	2	1	0	X
6. Place hand behind head with elbow held straight out to the side	3	2	1	0	X
7. Dress self (including put on coat and pull shirt off overhead)	3	2	1	0	X
8. Sleep on affected side	3	2	1	0	X
9. Open a door with affected arm	3	2	1	0	X
10. Carry a bag of groceries with affected arm	3	2	1	0	X
11. Carry a briefcase/ suitcase with affected arm	3	2	1	0	X
12. Place a soup can (1-2 lb) on a shelf at shoulder level w/o bending elbow	3	2	1	0	X
13. Place a one gallon container (8-10 lb) on a shelf at shoulder level w/o bending elbow	3	2	1	0	X
14. Reach a shelf above your head w/o bending your elbow	3	2	1	0	X
15. Place a soup can (1-2 lb) on a counter overhead w/o bending your elbow	3	2	1	0	X
16. Place a one gallon container (8-10 lb) on a shelf overhead w/o bending elbow	3	2	1	0	X
17. Perform a usual sports hobby	3	2	1	0	X
18. Perform household chores (cleaning, laundry, cooking)	3	2	1	0	X
19. Throw overhand/swim/overhead raquet sports. (circle all that apply to you)	3	2	1	0	X
20. Work full-time at your regular job	3	2	1	0	X
Scoring					
Total of colums = _______ (a)					
Number of Xs x 3 =______ (b), 60-____(b) = _____(c) (If no Xs are circled, function score = total # of columns)					

Function Score = (_______ ÷ _______) = _____ x 60 = (a) (c)	**Function Score = /60**

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DISABILITIES OF THE ARM, SHOULDER AND HAND

WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is:____________________________

p I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for your work?	1	2	3	4	5
2. doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. doing your work as well as you would like?	1	2	3	4	5
4. spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions relate to the impact of your arm, shoulder or hand problem on playing *your musical instrument or sport or both*.

If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you:_

○ I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.
An optional module score may not be calculated if there are any missing items.

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APPENDIX B

PROCEDURAL FLOWSHEET