THE ACCURACY OF THE PALPATION METER (PALM) FOR MEASURING SCAPULAR POSITION IN OVERHEAD ATHLETES.

M. Will Rondeau

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Approved by:
Advisor: William E. Prentice, PhD, ATC
Reader: Darin A. Padua, PhD, ATC
Reader: Shana E. Harrington, MPT
ABSTRACT

M. WILL RONDEAU: The Accuracy of the Palpation Meter (PALM) for Measuring Scapular Position in Overhead Athletes
(Under the direction of Dr. William E. Prentice)

The purpose of this study was to determine the validity, reliability and precision of the Palpation Meter while measuring scapular position in overhead athletes and to establish differences in scapular position with dominant shoulders versus non-dominant shoulders in overhead. A correlation analyses was used to determine if there was a relationship between laboratory and clinical measures of scapular position in twenty-nine Division I or recreational college-age overhead athletes. Intra Class Correlation and SEM values were used to determine the intratester reliability and precision of the Palpation Meter. Lastly, a paired t-test was used to determine the differences in scapular position at rest and 90° of abduction in dominant shoulder versus non-dominant. The Palpation Meter was found to be valid, reliable and precise when measuring scapular position at rest. The dominant scapular position of an overhead athlete was significant upwardly rotated, scapular upward/downward rotation, anterior/posterior tipping, and pectoralis minor length.
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Chapter I
Introduction

The glenohumeral joint, the most mobile joint in the human body, provides the greatest range of motion, though it is at the expense of joint stability. The balance between mobility and stability is tested in individuals performing repeated overhead activities in order to obtain optimal performance. Repeated overhead motions are believed to inflict extreme stress on both active and passive structures of the shoulder (Dillman, Fleisig, & Andrews, 1993). This stress is thought to contribute to the increased incidence of shoulder pain and injury in the aforementioned individuals (Grossman et al., 2005; Pradhan, Itoi, Hatakeyama, Urayama, & Sato, 2001). The resting position of the scapula is believed to be an important indicator of shoulder injury risk and rehabilitation. In this position, individuals performing overhead activities repeatedly may exhibit increased upward and internal rotation, anterior tilting, and/or protraction of the dominant scapula (in comparison to the non-dominant scapula) (Bastan, Wilk, Reinold, & Krenshaw, 2006; Myers, Laudner, Pasquale, Bradley, & Lephart, 2005b). Research has also demonstrated that baseball athletes may display deficits in glenohumeral internal rotation (GIRD), a significant increase in scapular internal and upward rotation, and retraction incurred in throwing with their dominant arms (Birkelo, Padua, Guskiewicz, & Karas, 2003; Downar & Sauers, 2005; Myers et al., 2005b). Scapular malposition may also predispose these athletes to posteriosuperior labral tears, supraspinatus tears, damage to anterior inferior capsular structures, and mechanical impingement (Burkhart, Morgan, & Kibler, 2003b; van der Hoeven & Kibler, 2006).
Individuals with shoulder impingement syndrome often display altered scapular positioning such as increased scapular downward rotation, protraction, anterior tilting, and internal rotation (Endo, Ikata, Katoh, & Takeda, 2001; Greenfield et al., 1995; Hebert, Moffet, McFadyen, & Dionne, 2002; Kibler & McMullen, 2003; Lukasiewicz, McClure, Michener, Pratt, & Sennett, 1999; Nijs, Roussel, Vermeulen, & Souvereyns, 2005; Su, Johnson, Gracely, & Karduna, 2004). These alterations in resting scapular position are thought to reduce the subacromial space which impinges both the supraspinatus and long head of the biceps tendons, as well as the subacromial bursa (Endo et al., 2001; McClure, Michener, & Karduna, 2006). The mechanical narrowing of the subacromial space compresses these structures, thus predisposing the shoulder to impingement syndrome (Endo et al., 2001; Karduna, Kerner, & Lazarus, 2005; Michener, McClure, & Karduna, 2003).

While evidence exists that counters the claim that scapular upward rotation reduces the subacromial space increased scapular upward rotation is, nonetheless, accepted as a healthy adaptation to overhead throwing (Karduna et al., 2005; Myers et al., 2005b).

Individuals who repeatedly throw or hit overhead have consistently exhibited a loss of glenohumeral internal rotation and an increased external rotation in his or her dominant arm compared to non-dominant arm (Borsa, Dover, Wilk, & Reinold, 2006; Crockett et al., 2002; Downar & Sauers, 2005; Ellenbecker, Roetert, Bailie, Davies, & Brown, 2002). This loss of internal rotation may cause tightening of posterior shoulder structures that may contribute to internal impingement (Myers, Laudner, Pasquale, Bradley, & Lephart, 2005a). Internal impingement occurs when the supraspinatus and infraspinatus are pinched between the posteriosuperior labrum and humeral head during the late cocking phase of throwing (Edelson & Teitz, 2000). Increased contact forces on the posteriosuperior labrum occurs as a
result of the overhead movement, and may lead to labral lesions (Edelson & Teitz, 2000; Halbrecht, Tirman, & Atkin, 1999). In addition, overhead athletes with internal impingement may also display increased scapular posterior tilting that results in reduced subacromial space (Laudner, Myers, Pasquale, Bradley, & LePhart, 2006). This is believed to explain why individuals performing repeated overhead activities are more susceptible to shoulder injuries.

Thus, assessment of scapular position is integral in the prevention and treatment of shoulder injuries such as impingement in those who repeatedly perform overhead activities. There are several clinical methods proposed to assess static scapular position (DiVeta, Walker, & Skibinski, 1990; Kibler, 1998; Lukasiewicz et al., 1999; Neiers & Worrell, 1993). These clinical methods are an attempt to capture static scapular position in three rotations and two translations (Lukasiewicz et al., 1999). These rotations and translations include retraction/protraction, elevation/depression, external/internal rotation, upward/downward rotation and anterior/posterior tipping. However, most clinical methods proposed to assess static scapular position have been shown to be unreliable and unspecific (Koslow, Prosser, Strony, Suchecki, & Mattingly, 2003; Neiers & Worrell, 1993).

The Palpation Meter (Performance Attainment Associates, St. Paul, MN) has been used to assess pelvic height and leg length discrepancies (Petrone et al., 2003) and was determined to be valid (ICC 2,3 = 0.90 for rater 1 and 0.92 for rater 2) with excellent intertester reliability (ICC3,3 = 0.97 and 0.98) and good intratester reliability (ICC2,3 = 0.88) (Petrone et al., 2003). The Palpation Meter may also be capable of capturing linear and angular measures of scapular position; however, we are not aware of any literature establishing the validity and reliability of the Palpation Meter for measuring scapular position.

Assessment of scapular position has been demonstrated as valid and reliable using
sophisticated motion analysis equipment (Barnett, Duncan, & Johnson, 1999; Karduna, McClure, Michener, & Sennett, 2001). Information from this equipment is valuable to the clinician, though it is highly impractical in the clinical setting. Therefore, there is a need to establish the validity, reliability, and precision of a method that will provide information regarding scapular position to the clinician. The Palpation Meter is well-suited to provide this information because it is both cost-efficient and user-friendly. Correlation of static scapular measures captured from the Palpation Meter and an electromagnetic tracking system can be performed to establish the criterion validity of the former. In addition, it is important to assess whether individuals who perform overhead movements repeatedly display altered scapular position in their dominant shoulder, in comparison to their non-dominant shoulder. Finally, establishing validity, reliability and precision provides the clinician with the ability to measure scapular position accurately in individuals who participate in overhead activities.

Statement of the Problem:

The purpose of this study was three-fold: First, to determine the validity of the Palpation Meter while measuring scapular position in collegiate Division I or recreational college-age overhead athletes. Second, to determine the reliability of the Palpation Meter. Finally, to analyze if there are side-to-side differences in scapular position with dominant shoulders versus non-dominant shoulders in overhead athletes.

Independent Variables

1) Dominant shoulder scapular measures

2) Non-dominant shoulder scapular measures
Dependent Variables

Glenohumeral joint at rest

1) Scapular upward/downward rotation
2) Scapular internal/external rotation
3) Scapular anterior/posterior tipping
4) Length of coracoid process to sternal notch
5) Resting pectoralis minor length
6) Mid-line of the spine to inferior angle of the scapula
7) Mid-line of the spine to the root of the scapula-the caliper was placed on the spinous process of T3 and the root of the scapula to measure protraction/retraction.
8) The root of the scapula to the angle of the acromion
9) Spinous process of T3 to the inferior angle of the acromion

Glenohumeral joint at 90° of abduction

1) Scapular upward/downward rotation
2) Scapular internal/external rotation
3) Scapular anterior/posterior tipping
4) Mid-line of the spine to inferior angle of the scapula
5) Mid-line of the spine to the root of the scapula-the caliper was placed on the spinous process of T3 and the root of the scapula to measure protraction/retraction.
6) The root of the scapula to the angle of the acromion
7) Spinous process of T3 to the inferior angle of the acromion
Research Questions
1) Is there a significant association between the Palpation Meter measures and laboratory measures?

2) Will there be a significant difference between those individuals performing repeated overhead activities measurements of scapular position in their dominant arm compared to their non-dominant arm?

3) Are the scapular measurements taken by the Palpation Meter reliable?

Null Hypothesis
H₀: There will not be significant differences found between clinical measures and laboratory measures.

H₀: There will not be a significant difference between overhead athletes’ measurements of scapular position in their dominant arm versus their non-dominant arm.

H₀: The Palpation Meter will not take reliable scapular measurements.

Research Hypothesis
Hₐ: There will be significant differences found between clinical measures and laboratory measures.

Hₐ: There will be a significant difference between overhead athletes’ measurements of scapular position in their dominant arm versus their non-dominant arm.

Hₐ: The Palpation Meter will provide reliable and precise scapular measurements.

Operational Definitions
1) **Overhead athletes** - those who actively participate in a sport that requires their dominant arm to be above shoulder height (90° of elevation) on a repetitive basis during throwing or striking activities such as tennis, softball, baseball and volleyball.

2) **Electromagnetic tracking system** - a six-degrees-of-freedom motion analysis system that uses receivers in an electromagnetic field to quantify scapular position in space.
3) **Palpation Meter (PALM)**- a clinical tool that combines a caliper and inclinometer into one unit and is able to be used while palpating specific landmarks.

4) **Clinical measures**- measures of scapular position with the Palpation Meter

5) **Dominant arm**- the arm an individual would use to throw or strike a ball for maximal distance or speed.

6) **Laboratory measures**- measures of scapular position with the Flock of Birds Motion Monitor System.

**Assumptions**

1) All subjects accurately and honestly answered the medical history questionnaire.

2) The instrumentation was calibrated accurately, as well as provided measurements and calculations precisely.

3) The athletes actively participated in a sport that requires their dominant arm to be above shoulder height on a repetitive basis during throwing or striking activities including tennis, softball, baseball and volleyball

**Delimitations**

1) Subjects were overhead athletes as defined as those individuals who actively participate in a sport that requires their dominant arm to be above shoulder height on a repetitive basis during throwing or striking activities which include tennis, volleyball, baseballs and softball.

2) Athletes were pain free with shoulder movements.

3) Athlete must not have participated in formal rehabilitation in the last 6 months.

**Limitations**

1) The swimming team was unable to be used due to their overwhelming participation in
other research studies.

**Significance of Study**

The Palpation meter provides a clinically applicable tool that may be able to assess scapular position. There are few clinical methods for assessing scapular position that are valid, reliable and efficient. Determining reliability and validity of the Palpation Meter would help a clinician in identifying athletes who may be at risk for injury and assess improvements in scapular position during rehabilitation. To determine if the PALM is sensitive to changes in scapular position, it is essential to further examine it in an overhead athletes’ dominant (throwing) and non-dominant (non-throwing) shoulders. This could add to the growing body of evidence supporting a change in scapular position and may provide clinicians with a better understanding of the adaptations that occur in the dominant shoulder.
Chapter II

Literature Review

The purpose of this literature review is to provide a comprehensive examination of the scapula and its importance concerning overhead athletics. Shoulder anatomy is crucial in the understanding of the position and movement of the scapula. In addition, assessing scapular position is important for the clinicians who treat overhead athletes, in that increased stresses and adaptations affect the shoulder due to repetitive sport specific movements. This literature review will conclude with a) the current techniques used to analyze scapular position and b) a discussion of the Palpation Meter as a valid and reliable clinical tool to linearly assess scapular position.

The shoulder is the most complex joint in the body, supported by three bones and four articulations (Inman, Saunders, & Abbott, 1996). The scapula, clavicle and humerus together form the sternoclavicular, acromioclavicular, scapulothoracic, and glenohumeral articulations. The scapula is a thin, flat triangular bone which is suspended against the posterolateral thorax. Originating from the scapula’s body are two processes: the acromion and coracoid. These allow for numerous muscle and ligamentous insertions, as well as form the coracoacromial arch, a superior barrier for humeral translation (Carmichael & Hart, 1985). The shape of the scapula provides for many precise muscle attachments, enabling it to move throughout all three cardinal planes. This unique anatomy is integral to its function (Carmichael & Hart, 1985).
The scapula has a variety of important functions pertaining to overhead activity: First, the scapula maintains an optimal muscle length for maximum strength output throughout a large range of motion (Hart and Carmichael 1985; Kibler 1998). In addition, the scapula permits the opening of the subacromial space, thus reducing impingement of the rotator cuff and subacromial bursa during humeral elevation (Kibler, 1998). Finally, and arguably the most important role of the scapula, is the establishing of the kinetic chain among the lower extremity, core, and humerus for overhead movements (Jobe and Pink 1993; Kibler 1998).

Like the scapula, the clavicle has several essential functions including acting as a rigid lever for muscular attachment, providing protection to vital blood vessels and nerves, and facilitating an increase in range of motion of the shoulder (Moseley, 1968). This semi-S shaped bone also acts as a strut, connecting the shoulder complex to the axial skeleton (Moore & Dalley, 2006; Moseley, 1968). The clavicle and sternum create the sternoclavicular joint, a plane synovial joint that allows movement of the clavicle, especially during glenohumeral elevation (Inman et al., 1996). The sternoclavicular joint is stabilized by the anterior, posterior sternoclavicular, costoclavicular, and interclavicular ligaments, as well as by the shape of the articular surfaces and the articular disc. This disc is located at the proximal end of the clavicle, dividing the joint into two sections (Culham & Peat, 1993; Moore & Dalley, 2006). Oppositely, the distal end of the clavicle articulates with the acromion process of the scapula to form the acromioclavicular joint. The acromioclavicular joint is made up of a wide acromioclavicular ligament and a wedge-like articular disc (Moore & Dalley, 2006). Most of the superior translation of the distal end of the clavicle is limited by two coracoclavicular ligaments: the conoid and trapezoid. This ligamentous
structure allows the clavicle to move intimately with the scapula in all three planes of scapulothoracic movement (Culham & Peat, 1993; Moore & Dalley, 2006). Elevation of the humerus for any overhead movements would not occur without the elongation and stretching of the sternoclavicular, acromioclavicular, and coracoclavicular ligaments (Inman et al., 1996).

The glenohumeral joint is a mobile, ball and socket joint formed by the articulation of the glenoid fossa and humeral head (Culham & Peat, 1993). Only about one-fourth of the large humeral head articulates with the glenoid fossa; hence, static and dynamic stability are incredibly important to the structural integrity of the shoulder (Carmichael & Hart, 1985). Static stabilization of the humeral head occurs through various mechanisms including the glenoid labrum, intraarticular pressure and glenohumeral ligaments. The glenoid labrum is a fibrocartilaginous ring that sits on the outside of the glenoid fossa, acts to increase surface area, and may increase stability by 10% (Halder, Kuhl, Zobitz, Larson, & An, 2001; Levine & Flatow, 2000). Furthermore, intraarticular pressure of the glenohumeral joint accounts for stability of the humeral head on the glenoid fossa (Kumar & Balasubramaniam, 1985).

Surrounding the entire joint is a loose fibrous joint capsule which is lined by a synovial membrane (Moore & Dalley, 2006). The coracohumeral and glenohumeral ligaments serve to externally reinforce the anterior aspect of the capsule (Carmichael & Hart, 1985). The coracohumeral ligament originates at the lateral edge of the coracoid process and inserts on the greater tuberosity, acting to check humeral external rotation and anterior translation. In addition, the superior, middle and inferior glenohumeral ligaments help to restrain anterior translation of the humeral head (Culham & Peat, 1993). During the throwing motion, it has been proposed that when the humerus is abducted and externally rotated, the inferior
glenohumeral ligament complex acts a hammock, supporting the humeral head inferiorly and anteriorly (Burkhart, Morgan, & Kibler, 2003a).

**Glenohumeral Musculature**

Although the static structures of the glenohumeral joint are integral to its function, the surrounding muscles may provide more dynamic stability for athletic movements. Dynamic stabilization of the humeral head occurs via four rotator cuff muscles consisting of the infraspinatus, supraspinatus, teres minor and subscapularis. The cuff muscles are positioned around the humeral head to provide compression throughout shoulder range of motion (Levine & Flatow, 2000). The rotator cuff acts dynamically and synchronically to abduct, depress, and rotate the humeral head about the glenoid cavity (Inman et al., 1996). In depressing and rotating the humeral head on the glenoid, the rotator cuff ensures maximal surface area articulation (Jobe & Pink, 1993).

The most superior rotator cuff muscle, the supraspinatus, originates in the supraspinatus fossa of the scapula and inserts into both the superior capsule and greater tubercle of the humerus. The supraspinatus acts to abduct the humerus during the first 15° of abduction, and perhaps more importantly, compresses the head superiorly with humeral elevation (Jobe & Pink, 1993; Moore & Dalley, 2006). The posterior rotator cuff muscles, consisting of the infraspinatus and teres minor originate on the scapula and insert into the greater tubercle of the humeral head joint capsule (Moore & Dalley, 2006). The infraspinatus and teres minor provide posterior stability as well as act to externally rotate the humerus and compress the humeral head. Anteriorly, the subscapularis originates from the subscapularis fossa and inserts on the lesser tubercle of the humerus. The subscapularis is the only rotator cuff muscle to internally rotate the humerus (Moore & Dalley, 2006). Although not part of the
rotator cuff muscles, the long head of the biceps brachii stabilizes the humeral head, preventing migration superiorly. It also acts to flex and horizontally adduct the humerus (Sakurai, Ozaki, Tomita, Nishimoto, & Tamai, 1998). Around fifty percent of the long head tendon originates on the supraglenoid tubercle where the second portion becomes a continuation of the labrum (Vangsness, Jorgenson, Watson, & Johnson, 1994). As a result of the attachment of the long head of the biceps tendon into the labrum, eccentric contraction of the muscle in movements like throwing, predisposes the athlete to superior labral anterior to posterior lesions (SLAP) (Mileski & Snyder, 1998).

Although the rotator cuff plays an integral role in the protection of the humerus, larger muscles of the shoulder function to accelerate the humerus in all overhead sport specific activities. These muscles include the deltoid, pectoralis major, latissimus dorsi, teres major, and coracobrachialis. The three heads of the deltoid originate on the scapula and clavicle insert into the deltoid tuberosity and act to extend, abduct, flex and help with internal and external rotation. The pectoralis major originates on the clavicle, lateral edge of the sternum, and costal cartilage of the sixth rib. The pectoralis major acts to adduct, internally rotate, and flex the humerus while simultaneously bringing the clavicle and scapula anteriorly. The latissimus dorsi originates from the thoracodorsal fascia, iliac crest, spinous processes of last six thoracic vertebrae and inserts at the intertubercular groove of the humerus. The latissimus dorsi acts to extend, adduct, and internally rotate the humerus. Similar in action, the teres major originates on the lateral border of the scapula and attaches on the medial border of the bicipital groove. Lastly, the coracobrachialis inserts on the lateral coracoid process and inserts on the medial humerus, acting to flex the humerus and anteriorly tip the scapula.
Together, the large and small muscles of the shoulder must work to simultaneously coordinate the movement and stability of the humerus (Jobe & Pink, 1993). A perfect example of this exists between the deltoid and supraspinatus, which both act to abduct the humerus. Although, their action is the same in the first 15° of abduction, thereafter the supraspinatus changes its role from abduction to compression of the humeral head. This is due to the opposing directions of force vectors between the supraspinatus and deltoid (Inman et al., 1996). Thus, if these two muscles are not activating in a coordinated fashion, injury to surrounding soft tissue structures may result. In addition, because many of these muscles originate from the scapula, careful scapular control is critical to maintaining these force couples (Paine & Voight, 1993).

Scapular musculature

Scapular control and stability is dependent upon the periscapular musculature because of the lack of bony articulations. One of the largest scapular stabilizers is the trapezius which is subdivided into three separate parts; upper, intermediate or middle and lower portions (Inman et al., 1996). The upper portion of the trapezius along with the levator scapulae acts as a passive suspensory support to stabilize and actively elevate the scapula (Paine & Voight, 1993). The upper trapezius is involved in a force couple to upwardly rotate the scapula (Inman et al., 1996; Paine & Voight, 1993). The middle portion of the trapezius inserts on the medial border of the scapula and acts to retract or adduct as well as fix the scapula during initial abduction (Inman et al., 1996). The lower trapezius inserts onto the medial inferior angle helps to "set" the scapula in initial glenohumeral movements. After initial glenohumeral elevation the lower trapezius works synergistically with the serratus anterior and upper trapezius to upwardly rotate the scapula (Bagg & Forrest, 1988).
Two muscles that act to upwardly rotate the scapula are the serratus anterior and rhomboid major and minor. The serratus anterior muscle inserts on the anterior medial border and inferior angle of the scapula and originates on the first eight ribs. The lower fibers of the serratus assist with the second half of the force couple to upwardly rotate the scapula. The upper fibers along with the middle trapezius and rhomboids activate to prevent "winging" of the scapula, technically known as internal rotation and anterior tipping (Paine & Voight, 1993). Internal rotation is more evident during a pushup position or when weight is carried in front of the body due to weakness of the serratus anterior, rhomboids and lower trapezius (Burkhart et al., 2003b; Paine & Voight, 1993). Inserting at the medial border and superior angle of the scapula are the rhomboid major and minor. Both act to retract and downwardly rotate the scapula. Anteriorly, the pectoralis minor originates at medial coracoid process of the scapula and inserts on ribs two through five. The pectoralis minor acts to anteriorly tilt, internally rotate, depress and protract the scapula. It is the only anterior muscle involved in scapulohumeral rhythm (Borstad & Ludewig, 2005). Muscles attaching to the scapula influence scapulohumeral rhythm.

Scapulohumeral rhythm

Inman et al. (1996) observed the scapula stabilize itself against the thoracic wall in the first 30 to 60° humeral abduction and flexion. Inman then describes scapular upward rotation and humeral abduction to be a 2:1 ratio between the humerus and scapula throughout flexion and abduction and many researchers agree with this observation (Hart & Carmichael, 1985; Kibler, 1998). Further research has shown that scapulohumeral rhythm might not be as simple as it was first described. Several researchers have found ratios of 2.25:1, 2.33:1, and even 1.25:1 scapulohumeral rhythm (Bagg & Forrest, 1988; Poppen &
Walker, 1976). In addition, it may be possible to organize scapulohumeral rhythm into three separate patterns each having a different ratio (Bagg & Forrest, 1988). The complexity of scapulohumeral rhythm may be a result of the three dimensional scapular motions.

**Scapular Motion**
Accessory motions of the scapula have also been shown to be an important part of shoulder movement. Scapular movements include internal/external rotation, anterior/posterior tipping, downward/upward rotation, and lastly elevation and depression (Ludewig, Cook, & Nawoczenski, 1996). During humeral elevation in the scapular plane, the scapula moves through upward rotation, posterior tipping, and external rotation in a very coordinated and progressive manner (Borsa, Timmons, & Sauers, 2003; Ludewig et al., 1996; Padua, Birkelo, Karas, Guskiewicz, & Thigpen, 2003). During the lowering phase of the humerus above $100^\circ$, the scapula moves into increased internal rotation and decreased anterior tipping. This may be due to scapular stabilizers activating in a slightly different pattern due to eccentric muscle contractions. Below $100^\circ$ of humeral elevation, however, scapulohumeral rhythm is identical to the concentric phase (Borstad & Ludewig, 2002).

**Scapular Position**
The normal static resting position of the scapula varies among the population and research. Scapular upward rotation is around 1-2° or essentially parallel to the spinous processes (Sobush et al., 1996). Internal rotation is measured at around 30-35°. Anterior tipping is measured at approximately 10° (Culham & Peat, 1993; Ludewig et al., 1996). The scapula is generally thought to sit at 30-45° anterior to the frontal plane which is referred to as the “scapular plane.” (Carmichael & Hart, 1985; Poppen & Walker, 1976). Due to the weight of the humerus, the glenoid fossa may be angled slightly superior (Carmichael &
Hart, 1985). Alterations in scapular position may be due to the extreme stresses placed on the shoulder during an overhead throwing movement.

**Overhead Athletes**

The overhead throwing motion combines large and small muscles accelerating and decelerating the humerus at an incredible speed in a short period of time (Altchek & Dines, 1995). According to Meister (2000), the throwing motion may be broken up into six distinct stages. Phase one is the preparation or the wind up, where as the athlete’s center of gravity is raising and little stress is place on the shoulder. Phase two consists of early cocking. The shoulder is moved into 90° of abduction and 15° of horizontal abduction. Phase three starts with planting of the front foot while the shoulder is in maximum external rotation, possibly up to 180°. Shoulder abduction should be around 100° and horizontal abduction, 15°. During phase four acceleration of the humerus occurs. The humerus can reach speeds up to 7000° per second. The humerus should stay in the scapular plane to prevent hyperangulation and decrease posterior labral friction from the humeral head (Burkhart et al., 2003b). Phase five begins with all muscle groups eccentrically contracting to slow down the humerus after the ball has been released from the hand. Maximum joint loads occur during this phase. Following through is the last phase which occurs as the body reestabishes equilibrium. The shoulder is internally rotated to 30°, of horizontal adduction and abduction is 100°. Shear forces are much less in this phase (Meister, 2000). It is obvious that these types of motions result in severe stress to the overhead athlete’s shoulder.

Due to these stresses on the shoulder, like those mentioned previously, adaptations occur to the glenohumeral joint in the overhead athlete. Bony changes may occur through increased retroversion of the humeral head in the dominant shoulder of an overhead athlete.
These osseous changes may take place at an early age to adapt to the stress placed on the shoulder and help to reduce injury (Crockett et al., 2002; Sabick, Kim, Torry, Keirns, & Hawkins, 2005). In addition to bony changes, general hypertrophy of the shoulder may be the first noticeable adaptation (Meister, 2000). It has also been proposed that the overhead athlete’s dominant shoulder may have a tight pectoralis minor, glenohumeral internal rotation deficits (GIRD) and increased external rotation (Burkhart et al., 2003b; Downar & Sauers, 2005; Myers et al., 2005a; Myers, Laudner, Pasquale, Bradley, & Lephart, 2006). Due to numerous muscular attachments, scapular position may also be affected by loads placed on the shoulder.

Several studies have proposed that healthy overhead athletes display an increased incidence of altered scapular position. Myers et al. (2005b) recently compared competitive baseball players to a control group and concluded that the throwing group had significantly increased scapular upward and internal rotation at rest and 0°, 30°, 60°, and 120° of humeral elevation. In addition, Bastan et al. (2006) looked at dominant shoulders versus non-dominant shoulders of professional baseball pitchers and found significant scapular position differences. At 0° of humeral elevation, the dominant shoulder was significantly more protraction and anteriorly tilted. At 90° of humeral elevation in the scapular plane, the dominant shoulder’s scapula was significantly more upwardly rotated. At 90° of abduction and full external rotation, the dominant shoulder’s scapula was significantly posteriorly tilted (Bastan et al., 2006). Lastly, at 90° of abduction and maximum internal rotation, the dominant shoulder’s scapula was significantly anteriorly tilted. Due to these alterations in the dominant shoulder’s scapular position, it has been proposed that overhead athletes may be more at risk for injury (Burkhart et al., 2003b).
Impingement

Injuries are incredibly common in overhead sports. This may be especially true for overhead athletes that display altered scapular position. A proposed relationship exists between altered scapular position and impingement syndrome (Greenfield et al., 1995; Hebert et al., 2002; Kibler & McMullen, 2003; Lukasiewicz et al., 1999; Nijs et al., 2005; Su et al., 2004). Impingement syndrome was first described by Dr. Charles Neer II in 1972 as the mechanical compression of tissues that lie in the subacromial space. The subacromial space is surrounded by the head of the humerus, anteroinferior acromion, coracoacromial ligament, and the acromial clavicular joint. As the space becomes smaller, structures like the supraspinatus tendon, subacromial bursa, shoulder joint capsule and long head of the biceps tendon become compacted and injured (Karduna et al., 2005; Michener et al., 2003).

Neer classified impingement syndrome into three categories, which were mainly identified using age. Jobe and Pink (1993) further classified impingement into 5 distinct groups. Jobe and Pink’s (1993) second group of impingement was originally named internal impingement by Walch et al. in 1992 and has been researched extensively (Burkhart et al., 2003a; Laudner, Myers et al., 2006; Myers et al., 2005a, , 2006; Walch, Boileau, Noel, & Donnell, 1992). Internal impingement occurs when the posterior aspect of the humeral head pinches the supraspinatus tendon and posterior superior labrum between the glenoid during the throwing position. Compressive and shear forces that occur during contact of the humeral head and posteriosuperior labrum is a normal physiological occurrence during shoulder external rotation and abduction but is increased with repetitive throwing (Burkhart et al., 2003a).

There is a strong correlation between mechanical impingement, internal impingement and altered scapular position (Burkhart et al., 2003b; Laudner, Myers et al., 2006). Subjects
with mechanical impingement syndrome display increased or decreased upward rotation, internal rotation and anterior tipping of the scapula (Greenfield et al., 1995; Lukasiewicz et al., 1999). It is unknown whether upward rotation is an adaptation to throwing and or impingement syndrome but both athletes have displayed this altered scapular position. Further testing has concluded that upward rotation of the scapula may actually decrease the subacromial space (Karduna et al., 2005). Most recently, Myers and Laudner (2006) have described glenohumeral and scapular adaptations in overhead athletes with internal impingement. Overhead athletes with internal impingement displayed glenohumeral deficits, posterior shoulder tightness, increased sternoclavicular elevation and increase posterior scapular tilt (Laudner, Myers et al., 2006; Myers et al., 2005a, , 2006).

Burkhart et. al. (2003b) theorized the SICK scapular syndrome (Scapular malposition, Inferior medial border prominence, coracoid pain and malposition, and dyskinesis of scapular movement) may contribute to SLAP lesions, posterosuperior labrum tears, supraspinatus impingement and anterior inferior capsular tightening. Burkhart et. al. (2003b) described three types of SICK scapula. Type I SICK scapula displays as inferior medial border prominence, type II consists of medial scapular border prominence and type III pattern shows superomedial border prominence. The first two patterns are generally associated with labral pathology whereas type III pattern is related to rotator cuff pathology and impingement (Burkhart et al., 2003b). The authors used empirical data from professional pitchers to determine adaptations that may occur after decades of throwing. These adaptations observed included a dropped dominant shoulder, tight pectoralis minor and short head of the biceps which may cause a lack of full glenohumeral flexion. Due to
these possible complications of altered scapular position it is vital to measure scapular position.

_Flock of Birds Motion Analysis_

Laboratory measures of scapular position are best performed by the MotionStar electromagnetic tracking system (Ascension Technology Corporation, Burlington VT) interfaced with MotionMonitor (Innovative Sports Training, Chicago, IL) acquisition software. The Flock of Birds Motion analysis system is a six degree of freedom electromagnetic tracking system that allows the researcher to quantify where the scapula, humerus, and thorax are in space. The Flock of Birds has been used in numerous studies looking at shoulder position and movement (Birkelo et al., 2003; Myers et al., 2005b; Thigpen, Gross, Karas, Garrett, & Yu, 2005). One study concluded that the Flock of Birds is a viable tool for measuring scapular kinematics (Meskers, Fraterman, van der Helm, Vermeulen, & Rozing, 1999). In addition, Karduna et. al. (2001) assessed the accuracy of skin-based three dimensional devices to measure scapular position by using bone pins placed along the spine of the scapula. The researchers concluded that skin-based three dimensional systems were accurate in the measures of scapular position (Karduna et al., 2001). Although the Flock of Birds Motion Monitor system is precise in measuring the scapula, it is expensive, time consuming and complicated to use. There is need to measure scapular position in the clinic. Currently there are several ways to clinically assess scapular position.

_Clinical Tests_

There are several different techniques clinicians use to assess scapular position. The most common is the Lateral Scapular Slide Test (LSST) which is performed by measuring the
inferior angle of the scapula to the closest spinous process at 0˚, 45˚ with the patient’s hands resting on their hips and 90˚ of shoulder elevation (Burkhart et al., 2003b; Kibler, 1998). Kibler asserts that the injured shoulder of an overhead athlete will have a difference of 1.5 cm scapular displacement difference than the non-injured side. (Kibler, 1998) Further research has found conflicting intertester reliability and poor specificity when using this method (Gibson, Goebel, Jordan, Kegerreis, & Worrell, 1995; Kibler, 1998; Koslow et al., 2003; Neiers & Worrell, 1993; Nijs et al., 2005; Odom, Taylor, Hurd, & Denegar, 2001; Watson, Balster, Finch, & Dalziel, 2005). Curtis and Roush (2006) determined the interater and intrarater reliability and precision of the LSST using a scoliometer in a shoulder pathology and non-pathology group. They concluded that the interater reliability for the LSST was high for the first two positions, (.78 to .92) but lower for position three (.70 to .82). The intrarater reliability for the first two positions was high (.87 to .96) but decreased with the third position (.75 to .77) using an ICC (2,2). In addition, Standard Error of the Mean (SEM) values were 3mm to 8.26mm and below the threshold of 1.5 cm. Due to the SEM values being less than Kibler’s 1.5 cm threshold, there may be an increased likelihood of error using the LSST (Curtis & Roush, 2006). Other similar and more reliable tests measuring lateral scapular displacement have been performed using the inferior angle of the acromion, through the spine of the scapula to the third thoracic vertebrae (DiVeta et al., 1990; Gibson et al., 1995; Neiers & Worrell, 1993; Nijs et al., 2005).

Diveta et. al (1990) devised one of the original clinical measures of scapular protraction by measuring total scapular distance. Total scapular distance was defined as the distance from the third vertebrae to the acromion angle. By using the third thoracic vertebrae and the acromion angle, the trouble of palpating the inferior angle is eliminated. Additionally,
Diveta measured the width of the scapula to normalize the scapular displacement for each subject (DiVeta et al., 1990). Diveta’s method of measuring scapular displacement has further been determined to have high reliability (ICC = .92 to .95) (Gibson et al., 1995). Normalization of the scapula, however, has been found to be less reliable (ICC = .34) (Neiers & Worrell, 1993).

The modified digital inclinometer has also been used to measure scapular position and unlike previous clinical measurements, the inclinometer was able to determine the angle of the scapula during upward rotation, however, this method was found to have poor intersession reliability (Borsa et al., 2003). Furthermore, a test using plurimeter-V gravity inclinometers successfully measured upward rotation with excellent intratester reliability (Bastan et al., 2006; Borsa et al., 2003; Downar & Sauers, 2005; Johnson, McClure, & Karduna, 2001).

The Lennie Test was also created to clinically measure scapular position using a caliper tool (Sobush et al., 1996). Twelve landmarks were first palpated and marked, while the distance from the midline of the spine to the superior angle, midline to the root of the spine, and midline to the inferior angle of the scapula was measured secondly with calipers and then placed against a ruler to determine the millimeters. Using these selected landmarks, protraction/retraction, depression/elevation and upward/downward rotation of the scapula could be obtained. In addition, the measurements in millimeters were compared to a radiograph to determine criterion validity for the Lennie Test. The test was found to be valid as well as intertester and intratester reliable. No significant differences were found between dominant shoulder and non-dominant shoulder in this all female non-athletic population (Sobush et al., 1996).
There are also several measures designed to quantify pectoralis minor tightness (Host, 1995). In addition, other methods have been created to measure forward shoulder posture and posterior scapular displacement using fabricated tools (Borstad, 2006; Host, 1995). Pectoralis minor tightness has also been implicated in altering scapular position (Borstad, 2006; Borstad & Ludewig, 2005). This altered scapular position is similar to scapular patterns observed with patients diagnosed with impingement syndrome (Greenfield et al., 1995; Lukasiewicz et al., 1999). Determining whether an overhead athlete is showing scapular patterns which may lead to impingement is of the utmost importance to preventing injury. Consequently, there is a need for a clinical tool that is able to linearly measure scapular position, pectoralis minor length and coracoid height that is specific, reliable and valid.

*Palpation Meter*

The Palpation Meter (Performance Attainment Associates, St. Paul, MN) may be able to accurately assess scapular position. With a combination of a caliper and an inclinometer, the Palpation meter is a versatile tool for any clinic. Originally the Palpation Meter was designed to measure pelvic heights and leg length discrepancies. Currently, however, there is no literature using the Palpation Meter to measure scapular position (Peterson et al., 1997; Plafcan, Turczany, Guenin, Kegerreis, & Worrell, 1997). To validate the Palpation Meter, Petrone et. al. (2003) took measurements of hip levels taken by the Palpation Meter and compared those to a radiograph and found excellent results (ICC=.9 and .92). In addition, the intrarater and interater reliability of the Palpation Meter was excellent (ICC=.97 and .88).
Prevention and treatment of shoulder injuries through assessment of scapular position is crucial to the clinician due to the proposed relationship between overhead athletes and altered scapular position. The Flock of Birds is a valid tool to measure scapular position but it is costly and not efficient. The importance of establishing the Palpation Meter as a valid and reliable tool to assess scapular position in overhead athletes would aid clinicians in preventing and treating injuries.
Chapter III
Methods

Subjects
Twenty-nine (15 male and 14 female) healthy individuals who regularly partook in overhead activities participated in this study. Overhead athletes included those participants who spent at least 45 minutes a day, three times a week practicing or playing with their dominant humerus above 90° in their respective sport. All subjects in the study currently participated in NCAA Division I and/or recreational club sports like volleyball, softball, baseball and tennis. Subjects were excluded if they were currently experiencing shoulder pain or have participated in formal rehabilitation in the last six months. Prior to participation, all subjects signed an informed consent form approved by the University of North Carolina –Chapel Hill Biomedical Institutional Review Board. Participants then completed a short medical history questionnaire to determine if they meet the study’s inclusion exclusion criteria (Appendix D). In the case that they answered “yes” to these questions, they were not eligible to participate in this study.

Instrumentation

Range of Motion
Shoulder range of motion was measured using a digital inclinometer. Measures included shoulder forward flexion, internal rotation, external rotation, abduction, and posterior capsule tightness.
Scapular Position

The Palpation Meter (Performance Attainment Associates, St. Paul Minnesota) was used to measure clinical scapular position. The Palpation meter is a tool that combines calipers with an analog inclinometer. Laboratory measures of scapular position were taken by the MotionStar electromagnetic tracking system (Ascension Technology Corporation, Burlington VT) interfaced with Motion Monitor (Innovative Sports Training, Chicago, IL) acquisition software. The laboratory assessment of scapular position was used as a criterion to validate the Palpation Meter’s clinical measurement. Electromagnetic tracking receivers were placed on landmarks including spinous process of C7, angle of the acromion process of the scapula, and the distal humerus. The Motion Monitor software uses data conveyed by electromagnetic receivers for the calculation of receiver position and orientation relative to an electromagnetic transmitter. The specific hardware used in this investigation consisted of an extended range direct current transmitter and four receivers.

Procedures

A convenience sample of 15 male and 14 female subjects were tested on the dependent variables of scapular upward/downward rotation, anterior/posterior tipping, internal/external rotation, mid-line of the spine to inferior angle of the scapula, mid-line of the spine to the root of the scapula, the root of the scapula to the angle of the acromion, spinous process of T3 to the inferior angle of the acromion, length of coracoid to the sternal notch and pectoralis minor length using a Palpation Meter and the electromagnetic tracking system.

Subjects reported to the Sports Medicine Research Lab for a one time testing session that lasted for approximately 75 minutes. Subjects wore athletic attire including a sports bra or tank top and a shirt that was removed so that the shoulder could be appropriately exposed
for preparation of measurements to be taken. Testers of the same sex as the subject were present during the testing sessions.

**Glenohumeral Range of Motion Measures**

Subjects underwent baseline glenohumeral (GH) range of motion measurements performed by the principal investigator (PI) using a digital inclinometer. Measures of GH flexion, internal rotation, external rotation, abduction and horizontal adduction were taken. The orders of the measurements were chosen using block randomization. Each measurement was taken three times and the average was used as the final value reported.

*Shoulder Flexion*

Subjects started in the standing position with his or her back against the wall. The shoulder was placed in a position of 0° abduction, adduction and rotation. The forearm was in a position of forearm neutral, with the palm facing the side of the body. The subject was then asked to actively flex his or her shoulder until he or she can no longer flex before initiating trunk extension. The subject held this position while the digital inclinometer was placed parallel to the long axis of the posterior humerus and displays the angle of flexion.

*Internal Rotation*

Subjects were positioned supine with knees flexed. The arm being tested was placed in 90° of shoulder abduction. The forearm was placed perpendicular to the testing table, in 90° of pronation, so that the palm is facing inferiorly toward the feet. The subject was actively moved into internal rotation, moving the palm towards the floor, until a firm end feel is felt or until the scapula begins to move from its stabilized position on the table. The subject held this position while the digital inclinometer was placed parallel to the long axis of the posterior forearm and displays the angle of internal rotation.
External Rotation

Subjects were positioned supine with knees flexed. The arm being tested was placed in 90° of shoulder abduction. The forearm was placed perpendicular to the testing table, in 90° of pronation, so that the palm is facing inferiorly toward the feet. The subject was actively moved into external rotation, moving the back of the hand toward the head, until a firm end feel is felt or until the scapula begins to move from its stabilized position on the table. The subject was held in this position while the digital inclinometer is placed parallel to the long axis of the anterior forearm and displays the angle of external rotation.

Abduction

Subjects were placed in the standing position with his or her opposite shoulder against the wall. The shoulder was placed in 0° of flexion and extension, with the shoulder in external rotation so that the palm is facing anteriorly. This external rotation is necessary for the greater tubercle of the head of the humerus to clear acromion process during abduction. The elbow was in extension to eliminate tension from the triceps brachii tendon. The subject was then asked to actively abduct the shoulder until a firm end feel is felt or when the humerus is stopped by the head. The subject was held in this position while the digital inclinometer was placed parallel to the long axis of the lateral humerus and displayed the angle of abduction.

Horizontal Adduction

To measure horizontal adduction, we implemented a method described by Laudner et al (Petrone et al., 2003). Subjects were placed supine with his or her knees bent and both shoulders flat on the table. The subject’s arm was placed in 90° of abduction, 0° of humeral rotation in the beginning position and 90° of elbow flexion. The tester grasped the forearm with one hand while with the other hand, the scapula was grasped by the lateral border and
stabilized against the table with a posteriorly directed force. The tester then passively moved
the shoulder into horizontal adduction with the forearm hand while still continuing to
stabilize the scapula and maintaining neutral humeral rotation. At the end of this range of
motion, a second tester placed the digital goniometer on the posterior humerus, lined up with
the ventral midline of the humerus. Full posterior capsule range of motion has been defined
as maximal humeral horizontal adduction or the initiation of scapular motion. The angle of
the humerus is considered the degrees of horizontal adduction.

**Palpation Meter**

Following range of motion measures, measurements of scapular position were taken
by placing the Palpation Meter's caliper tips on selected landmarks of the scapula. These
landmarks have been established by previous researchers to measure scapular
upward/downward rotation, protraction/retraction, anterior/posterior tipping, internal/external
tipping, elevation/depression, pectoralis minor length, and coracoid height. These landmarks
include the T3 spinous process, root of the scapular spine, acromion angle, medial border of
the scapula, spine of the scapula, coracoid process, sternal notch and 4th intercostal space.

**Palpation Meter Tasks**

Each subject randomly performed three tasks for each series of Palpation Meter
measurements on both their dominant and non-dominant arms while holding hand weights
standardized to 3% of their body weight. First, the subject was placed in a resting position of
0’ of flexion and abduction for 10 seconds while the series of measurements are taken.
Second, the subject held their shoulder in 90’ of abduction, resting for 15 seconds between
each measurement.
Palpation Meter Measurements

Subjects were asked to stand with their arms at their sides, face away from the researcher and given a verbal cue to relax. To reduce postural changes due to observation, this procedure was used to attempt to place the subject in their most natural postural position. Landmarks were first palpated and marked with a ball point pen. The mid-line of the spine was found by first marking C7-T1 and then palpating the PSIS to find mid-line of the spine. A flexible ruler was placed down the spine to use as a guide to mark the spine. To obtain scapular position, the selected landmarks were palpated again over the marked landmarks and then the tips of the calipers were placed directly on top of the chosen site. The inferior angle was defined as the point on the medial border of the scapula that first begins to travel laterally.

- Mid-line of the spine to inferior angle of the scapula - the caliper was placed on the spinous process of T7 and the inferior angle to measure protraction.
- Mid-line of the spine to the root of the scapula-the caliper was placed on the spinous process of T3 and the root of the scapula to measure protraction/retraction.
- The root of the scapula to the angle of the acromion – the caliper is placed on the root of the scapula and the inferior angle of the acromion to measure the width of the scapula
- Spinous process of T3 to the inferior angle of the acromion - the caliper was placed on the spinous process of T3 to the inferior angle of the acromion to measure scapular protraction/retraction.
- Coracoid process and the sternal notch - to measure protraction, coracoid height, and coracoid distance, the caliper was placed on the middle of the coracoid process and the sternal notch.
• Pectoralis minor length - calipers were placed on the medial coracoid process of the scapula and the fourth intercostal space at the sternum.

**Flock of Birds Motion Analysis**

A Flock of Birds® (Ascension Technologies, Inc., Burlington, VT) electromagnetic motion analysis system controlled by the Motion Monitor® (Innovative Sports Training, Inc. Chicago, IL) software was used to assess scapular position at a sampling rate of 50 Hz. Electromagnetic tracking receivers were placed on bony segments using double sided tape. A global reference system was set up using X, Y, and Z axes which corresponded with the three cardinal planes of the body. The Motion Monitor® system uses a stylus connected to a receiver to digitize bony landmarks so segment based local coordinates can be established for the humerus, scapula and thorax. Receivers were placed on the participants’ thorax over the spinous process of T3, and the involved shoulder over the broad flat surface of the scapular acromion and the posterior one third of the upper arm with the receiver over the area of least muscle mass to minimize potential receiver movement. The receivers were secured to the skin using double stick tape and pre-wrap which will be used to additionally secure the receiver over the posterior humerus. In order to assess the position of the shoulder, reconstruction of the bony landmarks will be performed following the recommendations by the International Society of Biomechanics-Shoulder Group Recommendations which has been used in previous studies (Laudner, Stanek, & Meister, 2006; Wu et al., 2005).

The following bony landmarks were digitized: the spinous processes of C7, T8, the distal point of the xiphoid process, suprasternal notch, medial and lateral epicondyle, the coracoid process, the inferior angle of the acromion, the root of the scapular spine, and the inferior angle of the scapula at the most inferior point of the scapula.
Once the subject was set up on the motion analysis system, he or she performed a trial for each arm while holding a hand weight standardized to 3% of their body weight. First, the subject stood in a resting position of 0° of flexion and abduction for five seconds while scapular motion was measured. Second, the subject held their shoulder in 90° of abduction for five seconds, resting for five seconds between each measurement.

**Data Reduction**

Three-dimensional coordinates of the digitized bony landmarks were calculated using the Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL). Segment reference frames were defined according to the recommendations set forth by the Shoulder Group of the International Society of Biomechanics (Wu et al., 2005). Humeral motions were calculated as the Euler angles of the humerus relative to the thorax reference frame in the following order of rotations: internal-external rotation about Y axis, elevation about the Z’ axis, and internal-external rotation about the Y” axis (An, Browne, Korinek, Tanaka, & Morrey, 1991). Scapular motions were calculated as the Euler angles of the scapula relative to the thorax reference frames in the following order of rotations: internal/external rotation about the Y axis, upward-downward rotation about the Z’ axis, and posterior-anterior tilting about the X” axis (Karduna, McClure, & Michener, 2000; Wu et al., 2005). Kinematic data were smoothed through a Butterworth a low pass digital-filter (4th order, recursive, zero phase lag) at an estimated optimum cutoff frequency of 3.5 Hz. The estimated optimum cutoff was determined after performing a spectral analysis for each kinematic variable. All humeral and scapular rotation spectral plots were similar.
Data Analysis

For the first research question, a correlation analysis was used to determine a relationship between the clinical (Palpation Meter instrument) measures and laboratory (electromagnetic motion analysis system) measures of scapula position. The dependent variables compared in the Pearson correlation were the mean of the lengths of mid-line of the spine to inferior angle of the scapula, mid-line of the spine to the root of the scapula, the root of the scapula to the angle of the acromion, spinous process of T3 to the inferior angle of the acromion, length of coracoid to the sternal notch and pectoralis minor length. The correlation coefficients were used to determine the criterion validity of scapular position measured using the Palpation Meter device. For the second question, the intratester reliability of the Palpation Meter was determined by an Intra Class Correlation coefficient. SEM values were used to determine the amount of error which occurred between the trials, otherwise known as precision. For the third research question (comparison of static scapula position between dominant and non-dominant shoulder), a paired t-test was used to compare scapular measurements from the electromagnetic tracking system between the dominant and non-dominant shoulder. The dependent variables for the second question were the means of the angles between the dominant shoulder and non-dominant shoulder. The standard error of measurement was used to determine the precision of the palpation meter. The alpha level of .05 was set a priori. Statistical analysis was performed with SPSS v13.00 (SPSS, Inc.; Chicago, IL).
<table>
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<td>DV: Scapular position measurements&lt;br&gt;IV: Palpation meter&lt;br&gt;IV: Flock of Birds</td>
<td>Pearson correlation coefficient analysis</td>
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<td>Will there be a significant difference between overhead athlete’s measurements of scapular position in their dominant arm compared to their non-dominant arm?</td>
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Chapter IV

Results

A total of twenty-nine subjects were utilized for this study. All twenty-nine subjects were students from the University of North Carolina at Chapel Hill who regularly participated in a sport that requires their dominant arm to be above shoulder height (90° of elevation) on a repetitive basis during throwing or striking activities (15 males, 14 females). There were 10 club volleyball players, 3 Division I varsity volleyball players, 4 recreational tennis players, 6 club softball players and 6 club baseball players.

Validity of the Palpation Meter

Means and standard deviations for scapular position measures from the Electromagnetic Tracking device and the Palpation Meter are listed in Table 1. Statistical analyses revealed a significant correlation between the Palpation Meter measurements of scapular position compared to the Electromagnetic Tracking Device measurements in resting position. Pearson R values for the shoulder at rest ranged from .594 to .837 for resting shoulder position for both dominant and non-dominant shoulders. Fewer significant relationships were revealed for scapular position measurements while the shoulder was in 90° of abduction. Pearson R values for the shoulder in this position ranged from .166 to .684 for both the dominant and non-dominant shoulder.
Reliability and precision of the Palpation Meter

Means and standard deviations are listed in Table 2. Intraclass correlation coefficients (2,k) revealed good intratester reliability between trials for resting position and shoulder abduction of scapular position measurements using the Palpation Meter. The ICC values for the shoulder in resting position ranged from .83 to .99. The ICC values for the shoulder in abducted position ranged from .86 to .94. The SEM values for the shoulder in resting position ranged from .20 to .70 cm. The SEM values for the shoulder in an abducted position ranged from .23 to .50 cm. The ICC and SEM values are located in Table 3. This indicates that the Palpation Meter provides a highly reliable method of assessing scapula position within day.

Dominant vs. non-dominant scapular position using the Electromagnetic Tracking Device

Means and standard deviations are located in Table 4. Statistical analyses revealed significant differences between dominant and non-dominant shoulders in 90° of abduction for scapular upward/downward rotation ($T_{1,28} = 8.936, p = <0.005$), anterior/posterior tipping ($T_{1,28} = 2.720, p = 0.009$), and pectoralis minor length ($T_{1,28} = -4.589, p = <0.05$). Statistical analyses revealed no significant differences between dominant and non-dominant scapular position in 90° of shoulder abduction for scapular internal/external rotation ($T_{1,28} = .444, p = 0.650$), and length of coracoid from sternal notch ($T_{1,28} = -1.724, p=0.085$). Statistical analyses revealed no significant differences with the shoulder in resting position for internal/external rotation ($T_{1,28} = -.058, p = 0.954$), upward/downward rotation ($T_{1,28} = -.167, p = 0.869$) and anterior/posterior tipping ($T_{1,28} = .103, p = 0.918$). A significant difference was found between pectoralis minor length ($T_{1,28} = -5.902, p = <0.005$) and length of
coracoid from sternal notch (T_{1,28} = 2.228, p = 0.034) between dominant and non-dominant shoulders in rest position.
Chapter V

Discussion

The primary purpose of this study was to determine the validity, reliability and precision of the Palpation Meter (Performance Attainment Associates, St. Paul, MN). Our results indicate that the Palpation Meter is able to accurately measure scapular position with little error when the shoulder is in a resting position in athletes who perform overhead activities repeatedly. The secondary purpose was to determine if differences in static scapular position exist between dominant and non-dominant shoulders of overhead athletes. Results indicated that only pectoralis minor length and length of the coracoid from the sternal notch significantly differed, as both were significantly shorter, in the dominant shoulder in resting position.

In static abduction, however, significant differences in scapular positioning existed. The overhead athletes’ dominant scapula displayed increased upward rotation, anterior tipping, and decreased lengths from the coracoid to the sternal notch and pectoralis minor. These results supported the Palpation Meter as a clinical tool in measuring differences in scapular position concerning overhead athletes. This method may play a helpful role in preventing and reducing shoulder injuries.

Validity, reliability and precision of the Palpation Meter

Assessment of static scapular position is an important part of a shoulder evaluation for sports medicine clinicians. Currently, there are many methods developed to clinically measure scapular position (DiVeta et al., 1990; Johnson et al., 2001; Kibler, 1998; Plafcan et
al., 1997; Sobush et al., 1996; Watson et al., 2005). This study attempted to validate the Palpation Meter, a clinical tool that measures scapular position, in using a combination of previously published clinical methods (Bastan et al., 2006; DiVeta et al., 1990; Kibler, 1998). We chose to use Diveta and Kibler’s linearly measurements of protraction due to their popularity and the ability to straightforwardly learn the methods (DiVeta et al., 1990; Kibler, 1998). Establishment of criterion validity occurred through the correlation of the Palpation Meter and the electromagnetic motion analysis system’s measurements. No study had previously used the electromagnetic motion analysis system as a “gold standard” to compare clinical measurements methods. The Flock of Birds has been used in numerous studies looking at shoulder position and movement (Birkelo et al., 2003; Myers et al., 2005b; Thigpen et al., 2005). One study concluded that the Flock of Birds is a viable tool for measuring scapular kinematics (Meskers et al., 1999). In addition, Karduna et. al. (2001) assessed the accuracy of skin-based three dimensional devices to measure scapular position by using bone pins placed along the spine of the scapula. Thus, the Flock of Birds electromagnetic tracking system is a viable tool to be used as the “gold standard.”

Based on the results of this study, in a resting position, the Palpation Meter is a valid tool for measuring scapular position. No previous research has validated the Palpation Meter for measuring scapular position. Other studies have shown linear distance measurements of scapular position, and may be reliable while using a flexible tape measure or string (Curtis & Roush, 2006; DiVeta et al., 1990). Upon further examination, studies have conversely found poor reliability, specificity and validity with some of these methods (Gibson et al., 1995; Koslow et al., 2003; Odom et al., 2001). This study revealed the Palpation Meter to have moderate-to-excellent intratester reliability when measuring scapular position in a resting
position at 90° of abduction. SEM values for the Palpation Meter were small, resulting in the ability to take extremely precise measurements (SEM = .20 - .70 cm). Research on the Palpation Meter has only been conducted on pelvic heights (Petrone et al., 2003). Petrone et al. (2003) determined that the Palpation Meter was valid (ICC 2,3 = 0.90 for rater 1 and 0.92 for rater 2) with excellent intertester reliability (ICC 3,3 = 0.97 and 0.98) and good intratester reliability (ICC 2,3 = 0.88) when measuring pelvic height. The Palpation Meter was chosen to measure scapular position due to its usability for a clinician.

In this study, the measurements were recorded from the Palpation Meter by an assistant, effectively blinding the primary tester. In past studies, a string was used to measure linear distance (Kibler, 1998). Although this blinded the tester, there was a possibility of the string stretching and therefore creating yet another potential degree of error. Similar studies have used linear measurements of scapular position to objectify scapular position. Sobush et. al. used a scoliometer with a method termed the “Lennie test” to measure scapular position in young, healthy females. The test was found to have moderate-to-good reliability (ICC=.64-.86), and was validated using radiographs.

Many of linear scapular measurements are based off of the Lateral Scapular Slide Test (LSST), a common method designed by Kibler to objectify clinical measurements for scapular position (Kibler, 1998). Kibler measured the inferior angle of the closest spinous process of the spine with a string with the shoulder in three positions: resting, hands on his or her hips, and 90 degrees of abduction with full internal rotation (Petrone et al., 2003). This method in past studies has shown conflicting accounts of reliability (Curtis & Roush, 2006; Koslow et al., 2003; Odom et al., 2001). In this study, the static shoulder positions measured occurred during rest and 90° of shoulder abduction.
As in past studies, palpating and defining the inferior angle of the scapula proved to be difficult (Gibson et al., 1995; Koslow et al., 2003). This was especially true in subjects with increased adipose tissue or musculature. The inferior angle was defined as the first lateral movement of the medial border on the scapula. The root of the spine and the acromial angle were used to measure scapular position linearly. Diveta et. al. (1990) were the first to establish these landmarks as a measurement of total scapular distance (TSD) from the spine. They achieved this by using a string to measure from the third thoracic spinous process to the root of the spine, and then to the acromial angle. Less error occurred during palpation due to the prominent characteristics of these landmarks (ICC = .94 and ICC = .80) (DiVeta et al., 1990; Neiers & Worrell, 1993). However, in the abducted position, both the inferior angle and the root of the spine were difficult to locate, perhaps due to the increased muscle activation of the serratus anterior during abduction as the scapula upwardly rotates. In this study, the Palpation Meter was less valid during the abducted position (R-values = .17-.65) compared to the resting position (R-values = .60-.84). Additionally, Curtis et. al. (2006) observed a reduction in Pearson Correlation values in the third position of the Lateral Scapular Slide Test in the abducted position (R-values =.78-.92) compared to the resting position (R-values = .91-.92). Therefore, according to this study and previous research, measuring scapular position with the shoulder abducted may not be possible due to the nature of the landmarks used and the variability of the measures (Curtis & Roush, 2006).

No current research exists examining the length of the pectoralis minor in overhead athletes while in a static standing position. A shortened pectoralis minor has been implicated in altering scapular kinematics. This appears to have similar patterns of scapular movement to those affected by impingement syndrome (Borstad & Ludewig, 2005; Hebert et al., 2002;
Lukasiewicz et al., 1999). Therefore, overhead athletes with a shortened pectoralis minor may be more susceptible to impingement syndrome. This results in the need for measurement of the pectoralis minor in overhead athletes to prevent injury. In this study, the measurement was performed by using the medial coracoid process and the fourth intercostal space. To our knowledge, these landmarks have not been used in previous studies to measure linear scapular position. Since the use of these landmarks has been validated and found reliable in this study, future use by clinicians appears promising.

**Dominant vs. non-dominant scapular position in overhead athletes using the electromagnetic tracking device**

Little research has been published observing the static scapular position of the dominant shoulder in overhead athletes compared to his or her non-dominant shoulder. No differences in the resting scapular position of the dominant shoulder versus non-dominant shoulder were observed in this study. Pectoralis minor length, however, was shorter by 2 cm in the resting position of the dominant shoulder. Further changes were seen when the athlete was asked to hold 3% of his or her body weight in 90° of shoulder abduction. In the dominant shoulder, upward rotation was increased by more than 14°, anterior tipping increased by 6°, and pectoralis minor length decreased by 1 cm. This is similar to results from published studies comparing dominant scapular position to non-dominant scapular position (Bastan et al., 2006; Myers et al., 2005b).

Bastan et al. (2006) performed a comparable study using calipers and a digital inclinometer to analyze dominant shoulders versus non-dominant shoulders of professional baseball pitchers. At 0° of humeral elevation, the dominant shoulder was significantly more protracted and anteriorly tilted. At 90° of humeral elevation in the scapular plane, the
dominant shoulder scapula was significantly more upwardly rotated but only by 2 degrees. At 90° of abduction and full external rotation, the dominant shoulder scapula was significantly posteriorly tilted (Bastan et al., 2006). Lastly, at 90° of abduction and maximal internal rotation, the dominant shoulder scapula was significantly anteriorly tilted. In addition, Myers et al. (2005b) found increased upward rotation by 8 degrees and internal rotation differences between the dominant shoulder of a throwing group versus a non-throwing group. Significant differences were found at 0°, 30°, 60°, and 120° of humeral elevation in the scapular plane. Downar and Sauers (2005) also observed increased upward rotation by 4 degrees in the dominant shoulder compared to the non-dominant shoulder at 90° of elevation. Increased upward rotation is believed to be a chronic adaptation that occurs in overhead athletes in order to protect structures in the subacromial space (Kibler, 1998; Michener et al., 2003; Myers et al., 2005b). As concluded by previous research, this study demonstrates that adaptations occur in the dominant shoulder of overhead athletes.

In each of these studies, the differences in degrees of upward rotation were much smaller than our findings. This may be due to the fact that in our study the subject was instructed to hold 3% of their body weight up at 90° of abduction while similar studies used no weight. Utilizing the weight may be more clinically applicable however, due to external forces that occur in sport specific movements for instance, throwing or hitting. Additionally, the clinician may be able to distinguish subtle changes in upward rotation in the dominant shoulder compared to the non-dominant shoulder by adding the weight.

**Clinical Relevance**

The use of the Palpation Meter while measuring static scapular position is highly feasible in sports medicine clinics. Although, only differences in scapular position were seen during
90° of abduction with the electromagnetic motion analysis system, the Palpation Meter was still found to be reliable, precise and valid when measuring scapular position at rest. The Palpation Meter was also shown to be valid and reliable while measuring pelvic levels. Thus, due to its ease of use and cost efficiency in comparison to an electromagnetic motion analysis system or other similar device, the Palpation Meter may be utilized by the clinician to gain easy, reliable, and objective measures of scapular position.

Limitations

The primary author of this study was a graduate student who had little experience using the Palpation Meter. Additionally, the author had modest clinical knowledge using the linear scapular measurements. A pilot test was performed prior to the study to familiarize the author with the Palpation Meter and linear scapular measurements. However, this study indicated that comparable experience is needed to reliably measure scapular position with the Palpation Meter in a resting position. In addition, a previous study assessing scapular position using similar methods showed measurements from surface landmarks by inexperienced testers as reliable (ICC=.64-.84) (Sobush et al., 1996).

Another limitation to this study was measuring scapular position in resting and 90° of abduction positions instead of during the performance of a functional task. Although this would be ideal, measuring dynamic scapular positions while throwing or hitting overhead (even with the electromagnetic magnetic tracking system) would be nearly be impossible due to the speed generated from the shoulder. Thus, the objective of the study was to determine a simple way to measure scapular position with a relatively inexpensive tool.
Future Research

Future research might look at using a digital inclinometer on the Palpation Meter to measure the angle of scapular position. Unfortunately, the Palpation Meter’s inclinometer only measures up to 30°, and scapular upward rotation angles were as high as 50° in this study. Using a digital inclinometer to measure scapular upward rotation has already been validated by a previous study (Johnson et al., 2001). Consequently, if the Palpation Meter was rebuilt or modified with a digital inclinometer, scapular angular measurements along with linear distance measurements may be easily obtained. Additionally, this study looked at intratester reliability during the same testing session, whereas future studies could look at the reliability of the Palpation Meter over several days and between testers. Lastly, only healthy, college-aged overhead athletes were tested. In the future, the Palpation Meter should be validated for use on a symptomatic population in order to confirm if changes in scapular position could be detected.

Conclusion

This study was the first to determine the validity, reliability, and precision of the Palpation Meter while measuring static scapular position in overhead athletes. The Palpation Meter was determined to be valid using criterion validity against the electromagnetic motion analysis system while the shoulder was in a resting position. The Palpation Meter may not be valid when measuring scapular position in 90° of abduction. Reliability of the Palpation Meter was determined as a good-to-excellent when the shoulder was at rest and at 90° of abduction. SEM values did not reach more than one centimeter for any of the measurements. Therefore, according to this study, clinicians can assume that there are scapular position differences between the dominant and non-dominant shoulder if the difference is greater than plus or minus one centimeter. The Palpation Meter is recommended as a clinical tool to
measure static scapular position in a resting shoulder position for college-aged overhead athletes.

In addition, this study found significant differences between the dominant and non-dominant shoulder scapular position during static abduction when holding 3% of subjects’ weight. Only the lengths of the pectoralis minor and coracoid from the sternal notch were significantly different in the dominant shoulder. According to these findings and previous research, it is arguably safe to conclude that adaptations occur to the dominant shoulder of overhead athletes.
Table 1. R-values and P-values for the Relationship between the Flock of Birds Motion Analyses System and the Palpation Meter for the Shoulder in Resting Position

<table>
<thead>
<tr>
<th></th>
<th>Dominant</th>
<th>Non-dominant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r-value</td>
<td>p-value</td>
</tr>
<tr>
<td>T3 to Root of Scapular Spine</td>
<td>0.594</td>
<td>0.001*</td>
</tr>
<tr>
<td>T8 to Inferior Angle of Scapula</td>
<td>0.755</td>
<td>&lt;0.005*</td>
</tr>
<tr>
<td>T3 to Acromion Angle</td>
<td>0.753</td>
<td>&lt;0.005*</td>
</tr>
<tr>
<td>Root of Scapular Spine to Acromion Angle</td>
<td>0.619</td>
<td>&lt;0.005*</td>
</tr>
<tr>
<td>Coracoid Length</td>
<td>0.673</td>
<td>&lt;0.005*</td>
</tr>
<tr>
<td>Pectoralis Minor Length</td>
<td>0.695</td>
<td>&lt;0.005*</td>
</tr>
</tbody>
</table>

*Indicates a significant relationship (p<=.05)
Table 2. R-values and P-values for the Relationship between the Flock of Birds Motion Analyses System and the Palpation Meter for the Shoulder Positioned at 90° of Abduction

<table>
<thead>
<tr>
<th></th>
<th>Dominant</th>
<th></th>
<th>Non-dominant</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r-value</td>
<td>p-value</td>
<td>r-value</td>
<td>p-value</td>
</tr>
<tr>
<td>T3 to Root of Scapular Spine</td>
<td>0.419</td>
<td>0.024*</td>
<td>0.166</td>
<td>0.390</td>
</tr>
<tr>
<td>T8 to Inferior Angle of Scapula</td>
<td>0.326</td>
<td>0.085</td>
<td>0.349</td>
<td>0.640</td>
</tr>
<tr>
<td>T3 to Acromion Angle</td>
<td>0.648</td>
<td>&lt;0.005*</td>
<td>0.463</td>
<td>0.012*</td>
</tr>
</tbody>
</table>

*Indicates a significant relationship (p=<.05)
Table 3. ICC (2,k) and SEM values for Reliability of the Palpation Meter in the Resting Position

<table>
<thead>
<tr>
<th>Distance</th>
<th>Dominant Arm</th>
<th>Non-Dominant Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC</td>
<td>SEM (cm)</td>
</tr>
<tr>
<td>T3 to Root of Scapular Spine</td>
<td>0.98</td>
<td>0.20</td>
</tr>
<tr>
<td>T8 to Inferior Angle of Scapula</td>
<td>0.96</td>
<td>0.30</td>
</tr>
<tr>
<td>T3 to Acromion Angle</td>
<td>0.97</td>
<td>0.29</td>
</tr>
<tr>
<td>Root of Scapular Spine to Acromion Angle</td>
<td>0.93</td>
<td>0.35</td>
</tr>
<tr>
<td>Coracoid Length</td>
<td>0.96</td>
<td>0.28</td>
</tr>
<tr>
<td>Pectoralis Minor Length</td>
<td>0.98</td>
<td>0.32</td>
</tr>
</tbody>
</table>
Table 4. ICC (2,k) and SEM values for Reliability of the Palpation Meter in 90° of Abduction

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Dominant Arm</th>
<th>Non-Dominant Arm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC</td>
<td>SEM (cm)</td>
</tr>
<tr>
<td>T3 to Root of Scapular Spine</td>
<td>0.93</td>
<td>0.23</td>
</tr>
<tr>
<td>T8 to Inferior Angle of Scapula</td>
<td>0.86</td>
<td>0.50</td>
</tr>
<tr>
<td>T3 to Acromion Angle</td>
<td>0.94</td>
<td>0.38</td>
</tr>
</tbody>
</table>
Appendix B

Figures
Figure 1. Scapular Position measured by the Flock of Birds Motion Analysis System in the Resting Position

*Indicates a significant relationship (p=<.05)
Figure 2. Scapular Position measured by the Flock of Birds Motion Analysis System in the 90° of Abduction Position

*Indicates a significant relationship (p=<.05)
Figure 3. Coracoid length and Pectoralis Minor Length measured by the Flock of Birds Motion Analysis System in the Resting Position

*Indicates a significant relationship (p=<.05)
Figure 4. Coracoid length and Pectoralis Minor Length measured by the Flock of Birds Motion Analysis System in the Abducted Position

*Indicates a significant relationship (p=<.05)
Figure 5. Mid-line of the Spine to the Root of the Spine of the Scapula.
Figure 6. Mid-line of the Spine to Inferior Angle of the Scapula
Figure 7. Mid-line of the Spine to the Acromial Angle of the Scapula
Figure 8. Scapular width: Root of the Spine to the Acromial Angle of the Scapula
Figure 9. Length from the Sternal Notch to the Coracoid Process
Figure 10. Pectoralis Minor Length: Coracoid Process of the Scapula to the Fourth Intercostal Space
Appendix C

Informed Consent Form
University of North Carolina-Chapel Hill Consent to Participate in a Research Study
Adult Subjects Biomedical Form

IRB Study #_____________________
Consent Form Version Date:______________
Title of Study: Comparison of Scapula Resting Position Using Different Assessment Instruments Before and After a Myofascial Release Intervention

Principal Investigator: Michelle M. McLeod, BA, ATC, LAT; M. Will Rondeau LAT, ATC, CSCS
UNC-Chapel Hill Department: Exercise and Sport Science
UNC-Chapel Hill Phone number: 919-962-2067
Email Address: mcleodm@email.unc.edu, rondeau@email.unc.edu
Co-Investigators: Shana Harrington, MPT; Darin Padua, PhD, ATC; Steve Leigh
Faculty Advisor: William E. Prentice, PhD, ATC, PT
Funding Source:

Study Contact telephone number: 919-962-2067
Study Contact email: mcleodm@email.unc.edu, rondeau@email.unc.edu

What are some general things you should know about research studies?
You are being asked to take part in a research study. To join the study is voluntary.
You may refuse to join, or you may withdraw your consent to be in the study, for any reason.

Research studies are designed to obtain new knowledge that may help other people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Deciding not to be in the study or leaving the study before it is done will not affect your relationship with the researcher, your health care provider, or the University of North Carolina-Chapel Hill. If you are a patient with an illness, you do not have to be in the research study in order to receive health care.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?
Position of the shoulder blade is believed to be an important factor that influences the risk of shoulder injury in people who regularly perform overhead activities (e.g. overhead throwing, swinging a tennis racquet, striking a volleyball, etc…). Thus, it is important to establish valid and reliable measures of shoulder blade position that can be easily performed in a clinical setting. It is also important to identify effective treatments for changing shoulder
blade position since individuals suffering from shoulder pain have been shown to display altered shoulder blade positioning when compared to healthy individuals. Therefore, the purpose of this study is to determine the reliability and validity of a novel clinical instrument (Palpation Meter device) to measure resting position of the shoulder blade in people who regularly perform overhead activities. We also will examine the effects of a myofascial release on resting shoulder blade position.

You are being asked to be in the study because you actively participate in repetitive overhead activities (throwing and striking) at least 3 times per week for a minimum of 45 minutes each session. It is believed that individuals participating in repetitive overhead activities are at greatest risk for exhibiting altered shoulder blade position and shoulder tightness which could possibly result in shoulder injury.

**Are there any reasons you should not be in this study?**

You should not be in this study if you currently experience shoulder pain, have undergone formal shoulder rehabilitation in the previous six (6) months, or are currently following a rehabilitation protocol that includes a myofascial release intervention (laying on a piece of foam or a small ball over areas of muscle tightness and tenderness) in the upper extremity.

**How many people will take part in this study?**

If you decide to be in this study, you will be one of approximately 30 people in this research study.

**How long will your part in this study last?**

If you participate in this study, you will spend approximately 90 minutes during one testing session. There is not a follow up session required.

**What will happen if you take part in the study?**

During the course of this study, the following will occur:

You will complete a short medical history questionnaire to determine if you have existing shoulder pain, have undergone formal rehabilitation in the previous six (6) months, or currently participate in a rehabilitation program that incorporates a myofascial release intervention. In the case that you answer “yes” to these questions, you will not be eligible to participate in this study. The purpose of the study and all procedures will be explained. Then you will have the opportunity to ask any questions. You may choose to not participate in the study at any time.

You will be randomly assigned into an intervention or a control group by drawing a stick from a cup with “intervention” or “control” showing your assignment. You will undergo baseline shoulder range of motion measurements performed by the principle investigator (PI) using a digital inclinometer. Measures of shoulder flexion, internal rotation, external rotation, abduction and posterior capsule tightness will be taken. Your shoulder blade position will be measured using the Palpation Meter and an electromagnetic motion analysis system. The Palpation Meter device is a clinical instrument that combines calipers and an inclinometer into one tool, and may be suitable for assessing shoulder blade position.
During the assessment of shoulder blade position, you will be asked to stand with your arms by your side, and points on your back, shoulder blade, and arm will be identified using a felt tip marker to assist in the measuring of shoulder blade position. Sensors from the electromagnetic motion analysis system will be attached at the base of your neck, the tip of your shoulder, and the end of your arm. Shoulder blade position will be measured with the Palpation Meter and electromagnetic motion analysis system of your dominant arm (arm used to throw or strike an object) and non-dominant arm (non-throwing or non-striking arm) in three different arm positions while holding a dumbbell in your hand that weighs 3% of your total body weight. The three different arm positions include: 1) arms by your side, 2) arms raised to 90-degrees away from the side of your body, and 3) arms raised to 90-degrees in front of your body. You will be asked to hold each arm position for approximately 5 -seconds while your shoulder blade position is measured.

If you are assigned to the intervention group, you will be instructed on how to perform the self myofascial release intervention using a foam roller over the shoulder musculature. A myofascial release treatment using a foam roll involves the individual using a large, firm roll of foam placed underneath the area where tightness or trigger points are felt. The individual then places the body part that is tight on top of the roller and rolls over and around the area, and may maintain a steady position where the majority of the discomfort is felt. This exercise is typically performed for one to two minutes over a single area. Prior to performing the intervention, you will watch a video showing proper technique, and will also receive verbal cues from the tester during each intervention. Each intervention technique will last for approximately two (2) minutes for a total of approximately six (6) minutes. Immediately following the final intervention, you will be re-measured for shoulder flexion, internal and external rotation, abduction and posterior capsule tightness with the digital inclinometer, as well as resting shoulder blade position using the Palpation Meter and electromagnetic motion analysis system.

If you are assigned to the control group, you will rest comfortably in a sitting position approximately 6 minutes and be re-measured for shoulder flexion, internal and external rotation, abduction and posterior capsule tightness with the digital inclinometer as well as resting shoulder blade position using the Palpation Meter and electromagnetic motion analysis system. This is to control for the intervention and possible gains in range of motion resulting from initial measurement.

During testing, male subjects will be required to take off their shirt; and female subjects will be in a tank top and wearing a sport bra. This is to allow exposure of your shoulder blade and arm for strength testing and sensor/electrode placement. An individual who is the same sex as the participant will be present at all times during testing.

**What are the possible benefits from being in this study?**
Research is designed to benefit society by gaining new knowledge. Results from this study may potentially show the effectiveness of a commonly used rehabilitation tool in the clinical setting. This will allow the clinical population to more appropriately prevent and treat injuries encountered on a day to day basis. The benefits to you from being in this study include measurement of your shoulder blade position to determine if it is altered, and the
possible relief of tightness and restored function of your dominant arm.

**What are the possible risks or discomforts involved with being in this study?**
If you are assigned to the intervention group, there is risk for common discomfort that may be experience during and following the intervention task. The discomfort typically subsides shortly following the completion of the intervention task. In addition, there may be uncommon or previously unknown risks that might occur. You should report any problems to the researchers.

**What if we learn about new findings or information during the study?**
You will be given any new information gained during the course of the study that might affect your willingness to continue your participation.

**How will your privacy be protected?**
No subjects will be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

A copy of this consent form will go in to your medical record. This will allow the doctors caring for you to know what study medications or tests you may be receiving as a part of the study and know how to take care of you if you have other health problems or needs during the study.

**What will happen if you are injured by this research?**
All research involves a risk of injury. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you seek medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

**What if you want to stop before your part in the study is complete?**
You can withdraw from this study at any time, without penalty. The investigators also have the right to stop your participation at any time. This could be because you have had an unexpected reaction, or have failed to follow instructions, or because the entire study has been stopped.

**Will you receive anything for being in this study?**
You will not receive anything for taking part in this study.

**Will it cost you anything to be in this study?**
No cost will be required of the participants of this study.

**What if you are a UNC student?**
You may choose not to be in the study or to stop being in the study before it is over or at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research. You may choose not to participate or withdrawal from the study at any time or for any reason without jeopardizing your relationship with your coach, athletic trainer, or physician and without being penalized in any way. There will be no benefit or consequence to your standing on your athletic team in any way.

**What if you have questions about this study?**
You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

**What if you have questions about your rights as a research subject?**
All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

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**Subject’s Agreement:**

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

_________________________________________   _________________
Signature of Research Subject     Date

_________________________________________
Printed Name of Research Subject

_________________________________________  _________________
Signature of Person Obtaining Consent   Date

_________________________________________
Printed Name of Person Obtaining Consent
Appendix D

Subject Information
Subject Information Form

Subject Number: ________

Circle One: Right handed  Left handed  (Which hand do you throw with?)

Age: _______  Height: ________  Weight: _________

Sport: ______________

Experience:

Last time competed in an overhead sport: ________________ (Month/Year)

Medical History:

Are you currently being treated for any shoulder problems?  Yes  No
Do you currently have any pain when you lift your arm overhead?  Yes  No
Have you been to rehabilitation for your shoulder injury in the past 6 months?  Yes  No
Appendix E

Data Collection Form
# Palm Data Collection Sheet

## Subject #__________

<table>
<thead>
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<th>Dominant Shoulder: Rest</th>
<th>Trial 1 cm</th>
<th>Trial 2 cm</th>
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<td>Non-dominant Shoulder: 90° Abd</td>
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Appendix F:

Manuscript

The accuracy of the palpation meter (palm) for measuring scapular position in overhead athletes.

Abstract

The purpose of this study was to determine the validity, reliability and precision of the Palpation Meter while measuring scapular position in overhead athletes and to establish differences in scapular position with dominant shoulders versus non-dominant shoulders in overhead. A correlation analyses was used to determine if there was a relationship between laboratory and clinical measures of scapular position in twenty-nine Division I or recreational college-age overhead athletes. Intra Class Correlation and SEM values were used to determine the intratester reliability and precision of the Palpation Meter. Lastly, a paired t-test was used to determine the differences in scapular position at rest and 90° of abduction in dominant shoulder versus non-dominant. The Palpation Meter was found to be valid, reliable and precise when measuring scapular position at rest. The dominant scapular position of an overhead athlete was significant upwards rotated, scapular upward/downward rotation, anterior/posterior tipping, and pectoralis minor length.

Introduction

The glenohumeral joint, the most mobile joint in the human body, provides the greatest range of motion, though it is at the expense of joint stability. The balance between mobility and stability is tested in individuals performing repeated overhead activities in order to obtain optimal performance. Repeated overhead motions are believed to inflict extreme stress on
both active and passive structures of the shoulder.\textsuperscript{1} This stress is thought to contribute to the increased incidence of shoulder pain and injury in the aforementioned individuals.\textsuperscript{2, 3} The resting position of the scapula is believed to be an important indicator of shoulder injury risk and rehabilitation. In this position, individuals performing overhead activities repeatedly may exhibit increased upward and internal rotation, anterior tilting, and/or protraction of the dominant scapula (in comparison to the non-dominant scapula).\textsuperscript{4, 5} Research has also demonstrated that baseball athletes may display deficits in glenohumeral internal rotation (GIRD), a significant increase in scapular internal and upward rotation, and retraction incurred in throwing with their dominant arms.\textsuperscript{4, 6, 7} Scapular malposition may also predispose these athletes to posteriosuperior labral tears, supraspinatus tears, damage to anterior inferior capsular structures, and mechanical impingement.\textsuperscript{8, 9}

Individuals with shoulder impingement syndrome often display altered scapular positioning such as increased scapular downward rotation, protraction, anterior tilting, and internal rotation.\textsuperscript{10-16} These alterations in resting scapular position are thought to reduce the subacromial space which impinges both the supraspinatus and long head of the biceps tendons, as well as the subacromial bursa.\textsuperscript{16, 17} The mechanical narrowing of the subacromial space compresses these structures, thus predisposing the shoulder to impingement syndrome.\textsuperscript{16, 18, 19} While evidence exists that counters the claim that scapular upward rotation reduces the subacromial space increased scapular upward rotation is, nonetheless, accepted as a healthy adaptation to overhead throwing.\textsuperscript{4, 18}

Individuals who repeatedly throw or hit overhead have consistently exhibited a loss of glenohumeral internal rotation and an increased external rotation in his or her dominant arm compared to non-dominant arm.\textsuperscript{7, 20-22} This loss of internal rotation may cause tightening of
posterior shoulder structures that may contribute to internal impingement.\textsuperscript{23} Internal impingement occurs when the supraspinatus and infraspinatus are pinched between the posteriosuperior labrum and humeral head during the late cocking phase of throwing.\textsuperscript{24} Increased contact forces on the posterosuperior labrum occurs as a result of the overhead movement, and may lead to labral lesions.\textsuperscript{24, 25} In addition, overhead athletes with internal impingement may also display increased scapular posterior tilting that results in reduced subacromial space.\textsuperscript{26} This is believed to explain why individuals performing repeated overhead activities are more susceptible to shoulder injuries.

Thus, assessment of scapular position is integral in the prevention and treatment of shoulder injuries such as impingement in those who repeatedly perform overhead activities. There are several clinical methods proposed to assess static scapular position.\textsuperscript{11, 27-29} These clinical methods are an attempt to capture static scapular position in three rotations and two translations.\textsuperscript{11} These rotations and translations include retraction/protration, elevation/depression, external/internal rotation, upward/downward rotation and anterior/posterior tipping. However, most clinical methods proposed to assess static scapular position have been shown to be unreliable and unspecific.\textsuperscript{28, 30}

The Palpation Meter (Performance Attainment Associates, St. Paul, MN) has been used to assess pelvic height and leg length discrepancies and was determined to be valid (ICC 2,3 = 0.90 for rater 1 and 0.92 for rater 2) with excellent intertester reliability (ICC3,3 = 0.97 and 0.98) and good intratester reliability (ICC2,3 = 0.88).\textsuperscript{31} The Palpation Meter may also be capable of capturing linear and angular measures of scapular position; however, we are not aware of any literature establishing the validity and reliability of the Palpation Meter for measuring scapular position.
Assessment of scapular position has been demonstrated as valid and reliable using sophisticated motion analysis equipment.\textsuperscript{32,33} Information from this equipment is valuable to the clinician, though it is highly impractical in the clinical setting. Therefore, there is a need to establish the validity, reliability, and precision of a method that will provide information regarding scapular position to the clinician. The Palpation Meter is well-suited to provide this information because it is both cost-efficient and user-friendly. Correlation of static scapular measures captured from the Palpation Meter and an electromagnetic tracking system can be performed to establish the criterion validity of the former. In addition, it is important to assess whether individuals who perform overhead movements repeatedly display altered scapular position in their dominant shoulder, in comparison to their non-dominant shoulder. Finally, establishing validity, reliability and precision provides the clinician with the ability to measure scapular position accurately in individuals who participate in overhead activities.

**Statement of the Problem:**

The purpose of this study was three-fold: First, to determine the validity of the Palpation Meter while measuring scapular position in collegiate Division I or recreational college-age overhead athletes. Second, to determine the reliability of the Palpation Meter. Finally, to analyze if there are side-to-side differences in scapular position with dominant shoulders versus non-dominant shoulders in overhead athletes.

**Methods**

**Subjects**

Twenty-nine (15 male and 14 female) healthy individuals who regularly partook in overhead activities participated in this study. Overhead athletes included those participants who spent at least 45 minutes a day, three times a week practicing or playing with their
dominant humerus above 90° in their respective sport. All subjects in the study currently participated in NCAA Division I and/or recreational club sports like volleyball, softball, baseball and tennis. Subjects were excluded if they were currently experiencing shoulder pain or have participated in formal rehabilitation in the last six months. Prior to participation, all subjects signed an informed consent form approved by the University of North Carolina–Chapel Hill Biomedical Institutional Review Board. Participants then completed a short medical history questionnaire to determine if they meet the study’s inclusion exclusion criteria (Appendix D). In the case that they answered “yes” to these questions, they were not eligible to participate in this study.

Instrumentation

Scapular Position

The Palpation Meter (Performance Attainment Associates, St. Paul Minnesota) was used to measure clinical scapular position. The Palpation meter is a tool that combines calipers with an analog inclinometer. Laboratory measures of scapular position were taken by the MotionStar electromagnetic tracking system (Ascension Technology Corporation, Burlington VT) interfaced with Motion Monitor (Innovative Sports Training, Chicago, IL) acquisition software. The laboratory assessment of scapular position was used as a criterion to validate the Palpation Meter’s clinical measurement. Electromagnetic tracking receivers were placed on landmarks including spinous process of C7, angle of the acromion process of the scapula, and the distal humerus. The Motion Monitor software uses data conveyed by electromagnetic receivers for the calculation of receiver position and orientation relative to an electromagnetic transmitter. The specific hardware used in this investigation consisted of an extended range direct current transmitter and four receivers.
Procedures
A convenience sample of 15 male and 14 female subjects were tested on the dependent variables of scapular upward/downward rotation, anterior/posterior tipping, internal/external rotation, mid-line of the spine to inferior angle of the scapula, mid-line of the spine to the root of the scapula, the root of the scapula to the angle of the acromion, spinous process of T3 to the inferior angle of the acromion, length of coracoid to the sternal notch and pectoralis minor length using a Palpation Meter and the electromagnetic tracking system.

Subjects reported to the Sports Medicine Research Lab for a one time testing session that lasted for approximately 75 minutes. Subjects wore athletic attire including a sports bra or tank top and a shirt that was removed so that the shoulder could be appropriately exposed for preparation of measurements to be taken. Testers of the same sex as the subject were present during the testing sessions.

Palpation Meter
Following range of motion measures, measurements of scapular position were taken by placing the Palpation Meter’s caliper tips on selected landmarks of the scapula. These landmarks have been established by previous researchers to measure scapular upward/downward rotation, protraction/retraction, anterior/posterior tipping, internal/external tipping, elevation/depression, pectoralis minor length, and coracoid height. These landmarks include the T3 spinous process, root of the scapular spine, acromion angle, medial border of the scapula, spine of the scapula, coracoid process, sternal notch and 4th intercostal space.

Palpation Meter Tasks
Each subject randomly performed three tasks for each series of Palpation Meter measurements on both their dominant and non-dominant arms while holding hand weights
standardized to 3% of their body weight. First, the subject was placed in a resting position of 0° of flexion and abduction for 10 seconds while the series of measurements are taken. Second, the subject held their shoulder in 90° of abduction, resting for 15 seconds between each measurement.

_Palpation Meter Measurements_

Subjects were asked to stand with their arms at their sides, face away from the researcher and given a verbal cue to relax. To reduce postural changes due to observation, this procedure was used to attempt to place the subject in their most natural postural position. Landmarks were first palpated and marked with a ball point pen. The mid-line of the spine was found by first marking C7-T1 and then palpating the PSIS to find mid-line of the spine. A flexible ruler was placed down the spine to use as a guide to mark the spine. To obtain scapular position, the selected landmarks were palpated again over the marked landmarks and then the tips of the calipers were placed directly on top of the chosen site. The inferior angle was defined as the point on the medial border of the scapula that first begins to travel laterally.

- Mid-line of the spine to inferior angle of the scapula - the caliper was placed on the spinous process of T7 and the inferior angle to measure protraction.
- Mid-line of the spine to the root of the scapula-the caliper was placed on the spinous process of T3 and the root of the scapula to measure protraction/retraction.
- The root of the scapula to the angle of the acromion – the caliper is placed on the root of the scapula and the inferior angle of the acromion to measure the width of the scapula
- Spinous process of T3 to the inferior angle of the acromion - the caliper was placed on the spinous process of T3 to the inferior angle of the acromion to measure scapular protraction/retraction.
- Coracoid process and the sternal notch - to measure protraction, coracoid height, and coracoid distance, the caliper was placed on the middle of the coracoid process and the sternal notch.
- Pectoralis minor length - calipers were placed on the medial coracoid process of the scapula and the fourth intercostal space at the sternum.

**Flock of Birds Motion Analysis**

A Flock of Birds® (Ascension Technologies, Inc., Burlington, VT) electromagnetic motion analysis system controlled by the Motion Monitor® (Innovative Sports Training, Inc. Chicago, IL) software was used to assess scapular position at a sampling rate of 50 Hz. Electromagnetic tracking receivers were placed on bony segments using double sided tape. A global reference system was set up using X, Y, and Z axes which corresponded with the three cardinal planes of the body. The Motion Monitor® system uses a stylus connected to a receiver to digitize bony landmarks so segment based local coordinates can be established for the humerus, scapula and thorax. Receivers were placed on the participants’ thorax over the spinous process of T3, and the involved shoulder over the broad flat surface of the scapular acromion and the posterior one third of the upper arm with the receiver over the area of least muscle mass to minimize potential receiver movement. The receivers were secured to the skin using double stick tape and pre-wrap which will be used to additionally secure the receiver over the posterior humerus. In order to assess the position of the shoulder, reconstruction of the bony landmarks will be performed following the recommendations by
the International Society of Biomechanics-Shoulder Group Recommendations which has been used in previous studies.\textsuperscript{34, 35}

The following bony landmarks were digitized: the spinous processes of C7, T8, the distal point of the xiphoid process, suprasternal notch, medial and lateral epicondyle, the coracoid process, the inferior angle of the acromion, the root of the scapular spine, and the inferior angle of the scapula at the most inferior point of the scapula.

Once the subject was set up on the motion analysis system, he or she performed a trial for each arm while holding a hand weight standardized to 3\% of their body weight. First, the subject stood in a resting position of 0° of flexion and abduction for five seconds while scapular motion was measured. Second, the subject held their shoulder in 90° of abduction for five seconds, resting for five seconds between each measurement.

**Data Reduction**

Three-dimensional coordinates of the digitized bony landmarks were calculated using the Motion Monitor\textsuperscript{\textregistered} software (Innovative Sports Training, Inc. Chicago, IL). Segment reference frames were defined according to the recommendations set forth by the Shoulder Group of the International Society of Biomechanics.\textsuperscript{35} Humeral motions were calculated as the Euler angles of the humerus relative to the thorax reference frame in the following order of rotations: internal-external rotation about Y axis, elevation about the Z’ axis, and internal-external rotation about the Y’’ axis.\textsuperscript{36} Scapular motions were calculated as the Euler angles of the scapula relative to the thorax reference frames in the following order of rotations: internal/external rotation about the Y axis, upward-downward rotation about the Z’ axis, and posterior-anterior tilting about the X’’ axis.\textsuperscript{35, 37} Kinematic data were smoothed through a Butterworth a low pass digital-filter (4th order, recursive, zero phase lag) at an
estimated optimum cutoff frequency of 3.5 Hz. The estimated optimum cutoff was determined after performing a spectral analysis for each kinematic variable. All humeral and scapular rotation spectral plots were similar.

**Data Analysis**

For the first research question, a correlation analysis was used to determine a relationship between the clinical (Palpation Meter instrument) measures and laboratory (electromagnetic motion analysis system) measures of scapula position. The dependent variables compared in the Pearson correlation were the mean of the lengths of mid-line of the spine to inferior angle of the scapula, mid-line of the spine to the root of the scapula, the root of the scapula to the angle of the acromion, spinous process of T3 to the inferior angle of the acromion, length of coracoid to the sternal notch and pectoralis minor length. The correlation coefficients were used to determine the criterion validity of scapular position measured using the Palpation Meter device. For the second question, the intratester reliability of the Palpation Meter was determined by an Intra Class Correlation coefficient. SEM values were used to determine the amount of error which occurred between the trials, otherwise known as precision. For the third research question (comparison of static scapula position between dominant and non-dominant shoulder), a paired t-test was used to compare scapular measurements from the electromagnetic tracking system between the dominant and non-dominant shoulder. The dependent variables for the second question were the means of the angles between the dominant shoulder and non-dominant shoulder. The standard error of measurement was used to determine the precision of the palpation meter. The alpha level of .05 was set a priori. Statistical analysis was performed with SPSS v13.00 (SPSS, Inc.; Chicago, IL).
Results

A total of twenty-nine subjects were utilized for this study. All twenty-nine subjects were students from the University of North Carolina at Chapel Hill who regularly participated in a sport that requires their dominant arm to be above shoulder height (90° of elevation) on a repetitive basis during throwing or striking activities (15 males, 14 females). There were 10 club volleyball players, 3 Division I varsity volleyball players, 4 recreational tennis players, 6 club softball players and 6 club baseball players.

Validity of the Palpation Meter

Means and standard deviations for scapular position measures from the Electromagnetic Tracking device and the Palpation Meter are listed in Table 1. Statistical analyses revealed a significant correlation between the Palpation Meter measurements of scapular position compared to the Electromagnetic Tracking Device measurements in resting position. Pearson R values for the shoulder at rest ranged from .594 to .837 for resting shoulder position for both dominant and non-dominant shoulders. Fewer significant relationships were revealed for scapular position measurements while the shoulder was in 90° of abduction. Pearson R values for the shoulder in this position ranged from .166 to .684 for both the dominant and non-dominant shoulder.

Reliability and precision of the Palpation Meter

Means and standard deviations are listed in Table 2. Intraclass correlation coefficients (2,k) revealed good intratester reliability between trials for resting position and shoulder abduction of scapular position measurements using the Palpation Meter. The ICC values for the shoulder in resting position ranged from .83 to .99. The ICC values for the shoulder in
abducted position ranged from .86 to .94. The SEM values for the shoulder in resting position ranged from .20 to .70 cm. The SEM values for the shoulder in an abducted position ranged from .23 to .50 cm. The ICC and SEM values are located in Table 3. This indicates that the Palpation Meter provides a highly reliable method of assessing scapula position within day.

**Dominant vs. non-dominant scapular position using the Electromagnetic Tracking device**
Means and standard deviations are located in Table 4. Statistical analyses revealed significant differences between dominant and non-dominant shoulders in 90° of abduction for scapular upward/downward rotation ($T_{1,28} = 8.936, p = <0.005$), anterior/posterior tipping ($T_{1,28} = 2.720, p = 0.009$), and pectoralis minor length ($T_{1,28} = -4.589, p = <0.05$). Statistical analyses revealed no significant differences between dominant and non-dominant scapular position in 90° of shoulder abduction for scapular internal/external rotation ($T_{1,28} = .444, p = 0.650$), and length of coracoid from sternal notch ($T_{1,28} = -1.724, p = 0.085$). Statistical analyses revealed no significant differences with the shoulder in resting position for internal/external rotation ($T_{1,28} = -.058, p = 0.954$), upward/downward rotation ($T_{1,28} = -.167, p = 0.869$) and anterior/posterior tipping ($T_{1,28} = .103, p = 0.918$). A significant difference was found between pectoralis minor length ($T_{1,28} = -5.902, p = <0.005$) and length of coracoid from sternal notch ($T_{1,28} = 2.228, p = 0.034$) between dominant and non-dominant shoulders in rest position.
Discussion

The primary purpose of this study was to determine the validity, reliability and precision of the Palpation Meter (Performance Attainment Associates, St. Paul, MN). Our results indicate that the Palpation Meter is able to accurately measure scapular position with little error when the shoulder is in a resting position in athletes who perform overhead activities repeatedly. The secondary purpose was to determine if differences in static scapular position exist between dominant and non-dominant shoulders of overhead athletes. Results indicated that only pectoralis minor length and length of the coracoid from the sternal notch significantly differed, as both were significantly shorter, in the dominant shoulder in resting position.

In static abduction, however, significant differences in scapular positioning existed. The overhead athletes’ dominant scapula displayed increased upward rotation, anterior tipping, and decreased lengths from the coracoid to the sternal notch and pectoralis minor. These results supported the Palpation Meter as a clinical tool in measuring differences in scapular position concerning overhead athletes. This method may play a helpful role in preventing and reducing shoulder injuries.

Validity, reliability and precision of the Palpation Meter

Assessment of static scapular position is an important part of a shoulder evaluation for sports medicine clinicians. Currently, there are many methods developed to clinically measure scapular position.27, 29, 38-41 This study attempted to validate the Palpation Meter, a clinical tool that measures scapular position, in using a combination of previously published clinical methods.5, 27, 29 We chose to use Diveta and Kibler’s linearly measurements of protraction due to their popularity and the ability to straightforwardly learn the methods.27, 29
Establishment of criterion validity occurred through the correlation of the Palpation Meter and the electromagnetic motion analysis system’s measurements. No study had previously used the electromagnetic motion analysis system as a “gold standard” to compare clinical measurements methods. The Flock of Birds has been used in numerous studies looking at shoulder position and movement.\textsuperscript{4, 6, 42} One study concluded that the Flock of Birds is a viable tool for measuring scapular kinematics.\textsuperscript{43} In addition, Karduna et. al. assessed the accuracy of skin-based three dimensional devices to measure scapular position by using bone pins placed along the spine of the scapula.\textsuperscript{32} Thus, the Flock of Birds electromagnetic tracking system is a viable tool to be used as the “gold standard.”

Based on the results of this study, in a resting position, the Palpation Meter is a valid tool for measuring scapular position. No previous research has validated the Palpation Meter for measuring scapular position. Other studies have shown linear distance measurements of scapular position, and may be reliable while using a flexible tape measure or string.\textsuperscript{27, 44} Upon further examination, studies have conversely found poor reliability, specificity and validity with some of these methods.\textsuperscript{30, 45, 46} This study revealed the Palpation Meter to have moderate-to-excellent intratester reliability when measuring scapular position in a resting position at 90° of abduction. SEM values for the Palpation Meter were small, resulting in the ability to take extremely precise measurements (SEM = .20 - .70 cm). Research on the Palpation Meter has only been conducted on pelvic heights.\textsuperscript{31} Petrone et al. determined that the Palpation Meter was valid (ICC 2,3 = 0.90 for rater 1 and 0.92 for rater 2) with excellent intertester reliability (ICC 3,3 = 0.97 and 0.98) and good intratester reliability (ICC 2,3 = 0.88) when measuring pelvic height.\textsuperscript{31} The Palpation Meter was chosen to measure scapular position due to its usability for a clinician.
In this study, the measurements were recorded from the Palpation Meter by an assistant, effectively blinding the primary tester. In past studies, a string was used to measure linear distance. Although this blinded the tester, there was a possibility of the string stretching and therefore creating yet another potential degree of error. Similar studies have used linear measurements of scapular position to objectify scapular position. Sobush et. al. used a scoliometer with a method termed the “Lennie test” to measure scapular position in young, healthy females. The test was found to have moderate-to-good reliability (ICC=.64-.86), and was validated using radiographs.

Many of linear scapular measurements are based off of the Lateral Scapular Slide Test (LSST), a common method designed by Kibler to objectify clinical measurements for scapular position. Kibler measured the inferior angle of the closest spinous process of the spine with a string with the shoulder in three positions: resting, hands on his or her hips, and 90 degrees of abduction with full internal rotation. This method in past studies has shown conflicting accounts of reliability. In this study, the static shoulder positions measured occurred during rest and 90° of shoulder abduction.

As in past studies, palpating and defining the inferior angle of the scapula proved to be difficult. This was especially true in subjects with increased adipose tissue or musculature. The inferior angle was defined as the first lateral movement of the medial border on the scapula. The root of the spine and the acromial angle were used to measure scapular position linearly. Diveta et. al. were the first to establish these landmarks as a measurement of total scapular distance (TSD) from the spine. They achieved this by using a string to measure from the third thoracic spinous process to the root of the spine, and then to the acromial angle. Less error occurred during palpation due to the prominent characteristics
of these landmarks (ICC = .94 and ICC = .80).\textsuperscript{27,28} However, in the abducted position, both the inferior angle and the root of the spine were difficult to locate, perhaps due to the increased muscle activation of the serratus anterior during abduction as the scapula upwardly rotates. In this study, the Palpation Meter was less valid during the abducted position (R-values = .17-.65) compared to the resting position (R-values = .60-.84). Additionally, Curtis et al.\textsuperscript{44} observed a reduction in Pearson Correlation values in the third position of the Lateral Scapular Slide Test in the abducted position (R-values = .78-.92) compared to the resting position (R-values = .91-.92). Therefore, according to this study and previous research, measuring scapular position with the shoulder abducted may not be possible due to the nature of the landmarks used and the variability of the measures.\textsuperscript{44}

No current research exists examining the length of the pectoralis minor in overhead athletes while in a static standing position. A shortened pectoralis minor has been implicated in altering scapular kinematics. This appears to have similar patterns of scapular movement to those affected by impingement syndrome.\textsuperscript{11,12,47} Therefore, overhead athletes with a shortened pectoralis minor may be more susceptible to impingement syndrome. This results in the need for measurement of the pectoralis minor in overhead athletes to prevent injury. In this study, the measurement was performed by using the medial coracoid process and the fourth intercostal space. To our knowledge, these landmarks have not been used in previous studies to measure linear scapular position. Since the use of these landmarks has been validated and found reliable in this study, future use by clinicians appears promising.

Dominant vs. non-dominant scapular position in overhead athletes using the electromagnetic tracking device
Little research has been published observing the static scapular position of the dominant shoulder in overhead athletes compared to his or her non-dominant shoulder. No differences in the resting scapular position of the dominant shoulder versus non-dominant shoulder were observed in this study. Pectoralis minor length, however, was shorter by 2 cm in the resting position of the dominant shoulder. Further changes were seen when the athlete was asked to hold 3% of his or her body weight in 90° of shoulder abduction. In the dominant shoulder, upward rotation was increased by more than 14°, anterior tipping increased by 6°, and pectoralis minor length decreased by 1 cm. This is similar to results from published studies comparing dominant scapular position to non-dominant scapular position.4, 5

Bastan et al. performed a comparable study using calipers and a digital inclinometer to analyze dominant shoulders versus non-dominant shoulders of professional baseball pitchers.5 At 0° of humeral elevation, the dominant shoulder was significantly more protracted and anteriorly tilted. At 90° of humeral elevation in the scapular plane, the dominant shoulder scapula was significantly more upwardly rotated but only by 2 degrees. At 90° of abduction and full external rotation, the dominant shoulder scapula was significantly posteriorly tilted.5 Lastly, at 90° of abduction and maximal internal rotation, the dominant shoulder scapula was significantly anteriorly tilted. In addition, Myers et al. found increased upward rotation by 8 degrees and internal rotation differences between the dominant shoulder of a throwing group versus a non-throwing group.4 Significant differences were found at 0°, 30°, 60°, and 120° of humeral elevation in the scapular plane. Downar and Sauers also observed increased upward rotation by 4 degrees in the dominant shoulder compared to the non-dominant shoulder at 90° of elevation.7 Increased upward rotation is believed to be a chronic adaptation that occurs in overhead athletes in order to
As concluded by previous research, this study demonstrates that adaptations occur in the dominant shoulder of overhead athletes. In each of these studies, the differences in degrees of upward rotation were much smaller than our findings. This may be due to the fact that in our study the subject was instructed to hold 3% of their body weight up at 90° of abduction while similar studies used no weight. Utilizing the weight may be more clinically applicable however, due to external forces that occur in sport specific movements for instance, throwing or hitting. Additionally, the clinician may be able to distinguish subtle changes in upward rotation in the dominant shoulder compared to the non-dominant shoulder by adding the weight.

**Clinical Relevance**

The use of the Palpation Meter while measuring static scapular position is highly feasible in sports medicine clinics. Although, only differences in scapular position were seen during 90° of abduction with the electromagnetic motion analysis system, the Palpation Meter was still found to be reliable, precise and valid when measuring scapular position at rest. The Palpation Meter was also shown to be valid and reliable while measuring pelvic levels. Thus, due to its ease of use and cost efficiency in comparison to an electromagnetic motion analysis system or other similar device, the Palpation Meter may be utilized by the clinician to gain easy, reliable, and objective measures of scapular position.

**Limitations**

The primary author of this study was a graduate student who had little experience using the Palpation Meter. Additionally, the author had modest clinical knowledge using the linear scapular measurements. A pilot test was performed prior to the study to familiarize the author with the Palpation Meter and linear scapular measurements. However, this study
indicated that comparable experience is needed to reliably measure scapular position with the Palpation Meter in a resting position. In addition, a previous study assessing scapular position using similar methods showed measurements from surface landmarks by inexperienced testers as reliable (ICC=.64-.84).\(^{38}\)

Another limitation to this study was measuring scapular position in resting and 90° of abduction positions instead of during the performance of a functional task. Although this would be ideal, measuring dynamic scapular positions while throwing or hitting overhead (even with the electromagnetic magnetic tracking system) would be nearly impossible due to the speed generated from the shoulder. Thus, the objective of the study was to determine a simple way to measure scapular position with a relatively inexpensive tool.

**Future Research**

Future research might look at using a digital inclinometer on the Palpation Meter to measure the angle of scapular position. Unfortunately, the Palpation Meter’s inclinometer only measures up to 30°, and scapular upward rotation angles were as high as 50° in this study. Using a digital inclinometer to measure scapular upward rotation has already been validated by a previous study.\(^ {39}\) Consequently, if the Palpation Meter was rebuilt or modified with a digital inclinometer, scapular angular measurements along with linear distance measurements may be easily obtained. Additionally, this study looked at intratester reliability during the same testing session, whereas future studies could look at the reliability of the Palpation Meter over several days and between testers. Lastly, only healthy, college-aged overhead athletes were tested. In the future, the Palpation Meter should be validated for use on a symptomatic population in order to confirm if changes in scapular position could be detected.
Conclusion
This study was the first to determine the validity, reliability, and precision of the Palpation Meter while measuring static scapular position in overhead athletes. The Palpation Meter was determined to be valid using criterion validity against the electromagnetic motion analysis system while the shoulder was in a resting position. The Palpation Meter may not be valid when measuring scapular position in 90° of abduction. Reliability of the Palpation Meter was determined as a good-to-excellent when the shoulder was at rest and at 90° of abduction. SEM values did not reach more than one centimeter for any of the measurements. Therefore, according to this study, clinicians can assume that there are scapular position differences between the dominant and non-dominant shoulder if the difference is greater than plus or minus one centimeter. The Palpation Meter is recommended as a clinical tool to measure static scapular position in a resting shoulder position for college-aged overhead athletes.

In addition, this study found significant differences between the dominant and non-dominant shoulder scapular position during static abduction when holding 3% of subjects’ weight. Only the lengths of the pectoralis minor and coracoid from the sternal notch were significantly different in the dominant shoulder. According to these findings and previous research, it is arguably safe to conclude that adaptations occur to the dominant shoulder of overhead athletes.
References


