The Relationship Between Humeral Rotation and Scapular Tipping

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ABSTRACT

Laura E. Conner: The relationship Between Humeral Rotation and Scapular Tipping.
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Background: Decreased shoulder range of motion as well as aberrant scapular mechanics are suggested as risk factors for shoulder pain. Minimal data describing scapular motion during humeral rotation exists even though it is evaluated clinically. The purpose of this study was to determine the relationship between humeral rotation and scapular tipping.

Methods: Twenty-five participants were studied. A universal goniometer was used to assess shoulder range of motion. Three-dimensional motion tracking was used to assess scapular kinematics.

Findings: Statistically significant negative relationships were found between shoulder internal rotation ROM and scapular tipping at maximum humeral IR range during passive rotation task ($r = -0.418$, $p = 0.033$), as well as, scapular tipping ROM at 90° of humeral flexion angle ($r = -0.367$, $p = 0.055$) during a functional diagonal task. The total arc of shoulder rotation ROM was also negatively related to both scapular tipping ROM at 90° of humeral flexion angle ($r = -0.397$, $p = 0.041$) and scapular tipping ROM at maximal humeral flexion angle during functional diagonal task ($r = -0.477$, $p = 0.017$). The posterior shoulder flexibility measure was positively related to scapular tipping ROM at 90° of humeral flexion angle (r = 0.414, p = 0.035) and scapular tipping ROM at maximal humeral flexion angle during functional diagonal task (r = .384, p = 0.048).

Interpretation: This study is the first to assess the relationship between clinical measures of shoulder ROM and scapular tipping ROM during functional tasks. Decreased shoulder ROM was related to increased scapular tipping ROM. Both decreased shoulder ROM and increased scapular tipping during shoulder rotation has been associated with shoulder pain.

Key words: scapular kinematics, scapular tipping, range of motion, 3-D motion tracking

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LIST OF ABBREVIATIONS

GIRD	Glenohumeral Internal Rotation Deficit
ROM	Range of motion
GH	Glenohumeral
RTC	Rotator Cuff
SGHL	Superior Glenohumeral ligament
MGHL	Middle Glenohumeral Ligament
IGHL	Inferior Glenohumeral ligament
ER	Humeral External Rotation
IR	Humeral Internal Rotation
ASMI	American Sports Medicine Institute
SLAP	Superior Labral tear Anterior to Posterior
GTO	Golgi Tendon Organ
C7	Seventh cervical spinous process
T8	Eighth thoracic spinous process
T12	Twelfth thoracic spinous process
IJ	Sternal Notch
PX	Xiphoid Process
TS	Medial Scapular Spine
AI	Inferior Acromion Angle
AA	Acromion Angle
EM	Medial Epicondyle
EL	Lateral Epicondyle

ICC	Intraclass Correlation
SEM	Standard Error of Measurement

Chapter One

INTRODUCTION

Shoulder injury is common in athletics, composing 8-13% of all athletic injuries. These injuries include traumatic injuries such as dislocations, subluxations and fractures. Shoulder injuries can also include overuse disorders such as impingement, scapular dyskinesis, and labral tears. Shoulder pain is common in overhead athletes. This group of athletes consists of those whose sports require elevation of the arm during a majority of time in participation. Overhead athletes are even more at risk to develop shoulder pain (Hill 1983). 43.8% of overhead athletes (volleyball players and swimmers) complained of shoulder problems and more specifically, 50% of adolescent pitchers report shoulder and/or elbow pain (Tullos and King 1973; Lo, Hsu et al. 1990).

Overhead athletics place a tremendous amount of stress on the shoulder. It has been shown that the angular velocity during pitching approximates 7000°/s while a tennis serve can approach 1500°/s (Kibler 1995; Williams and Kelley 2000). These high velocities produce distraction forces that can reach 860N or 80% of body weight (Williams and Kelley 2000; Burkhart, Morgan et al. 2003). Not only are there high velocities and large loads, but also overhead athletics are typically very repetitive. According to Neer, insidious shoulder pain typically occurs in the older population of greater than 40 years (Neer 1983). However, due to the repetitive nature of overhead athletics, the process of degeneration is catalyzed. According to Sokolovas (2000), freestyle swimmers will typically train approximately

60,000 to 77,000 yards per week. That results in about 10,000 yards per day amounting to approximately 8,000 revolutions per day. Pitchers are limited to an estimated 100 pitches per game resulting in approximately 1400 pitches per season (Sokolovas 2003; Howell 2005).

The shoulder motion during pitching results in four times the kinetic energy as compared to the leg motion during kicking (Harryman, Sidles et al. 1990). Over time cumulative stress along with abnormal force couple and length tension relationships can lead to breakdown in the musculoskeletal system.

The musculoskeletal breakdown of the shoulder is most often indicated by pain. One common source of shoulder pain in the overhead athlete is mechanical impingement, which is characterized by compression or abrasion of the rotator cuff as it passes under the coracoacromial arch during shoulder elevation (Ludewig and Cook 2000). I An asymmetrical capsule, implicating capsuloligamentous laxity or contracture, and poor scapular mechanics have been suggested as possible mechanisms that create shoulder impingement (Williams and Kelley 2000). Many overhead athletes display posterior shoulder inflexibility which is thought to result from repetitive hyper-external rotation and deceleration of the humerus. Burkhart et al. (2003) suggested that the anterior glenohumeral (GH) laxity many athletes display is the result of repetitive stretching of the anterior capsule and anterior inferior GH ligament during humeral abduction and humeral external rotation (ER). Laxity diminishes static stability within the joint allowing greater humeral head translation in the glenoid fossa. Posterior shoulder tightness resulting from posterior capsule contracture or posterior rotator cuff (RTC) tightness and anterior laxity produce a superior and anterior migration of the humeral head in the glenoid further putting the athlete at risk for impingement and labral tears (Tyler, Nicholas et al. 2000). Posterior shoulder tightness is clinically seen as a loss of humeral internal rotation (IR). Glenohumeral Internal Rotation Deficit (GIRD) is defined as the loss of 25 º of internal rotation as compared to the non-throwing shoulder (Burkhart, Morgan et al. 2003). Burkhart et al. (2003) described the loss of IR as the most important pathological process that occurs in throwers.

Another risk factor for shoulder pain is aberrant scapular mechanics (Burkhart, Morgan et al. 2003). As humeral elevation increases, the scapula upwardly rotates, posteriorly tips and externally rotates. Clinical theory suggests adequate scapular upward rotation during humeral elevation elevate the lateral acromion to clear the greater tuberosity (Litchfield, Hawkins et al. 1993; Lukasiewicz, McClure et al. 1999). Traditionally, scapulohumeral rhythm has been defined as the ratio between glenohumeral elevation and scapular upward rotation, which is approximately 2:1. However, recent evidence shows that the relationship is more complex. Earlier kinematic studies observed motion in two dimensions, often with X-ray imaging. Advances in technology have allowed many recent studies to use three-dimensional tracking systems to report the scapulohumeral relationship. The relationship of humeral elevation and scapular motion has been studied by numerous authors (Ludewig, Cook et al. 1996; Ludewig and Cook 2000; Borsa, Timmons et al. 2003; Myers, Laudner et al. 2005). Some research has been done to detect differences in scapular kinematics between injured and uninjured individuals (Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000; McClure, Bialker et al. 2004). Individuals with impingement exhibit altered scapular kinematics resulting in increased anterior tipping at the end of range of motion (ROM) (Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000). Recent research has studied scapular motion during passive and active humeral elevation (Price, Franklin et al. 2000; Ebaugh, McClure et al. 2005). Ebaugh et al. (2005) indicated that level of muscle activity influenced scapular motion. They found there was increased scapular upward rotation and scapular posterior tipping during active humeral elevation due to activity of the serratus anterior and upper and lower portions of the trapezius.

While it is clear that humeral elevation influences scapular motion, the effect of humeral rotation on scapular kinematics is not well understood. There is minimal data describing accessory scapular motion during humeral rotation even though it is evaluated clinically. During humeral IR, the scapula remains internally rotated and anteriorly tipped (Thigpen, Padua et al. 2006). It is hypothesized that contracture of the posterior capsule or cuff will cause "pulling" of the scapula resulting in earlier scapular anterior tipping and delayed scapular posterior tipping. Both early scapular anterior tipping and delayed scapular posterior tipping would theoretically decrease the space between the acromion and the humerus for the rotator cuff to glide. It is vital to understand the changes that occur in scapular motion, specifically scapular tipping because of its potential to exacerbate impingement syndromes.

Statement of Purpose

Therefore, the purpose of this study is to determine the relationship between humeral rotation and scapular tipping during active and passive rotation tasks, humeral flexion task and functional diagonal task. A secondary purpose of the study is to determine the relationship of clinical measures of shoulder ROM and scapular tipping during active and passive rotation task, humeral flexion and functional diagonal task.

Research Questions

1: Is there a relationship between humeral rotation and tipping of the scapula during a passive rotation task, active rotation task, flexion task and functional diagonal task?

2: Is there a relationship between shoulder ROM measures and range of scapular tipping during humeral rotation and elevation?

Null Hypothesis

1. H_o: There will be no relationship between humeral rotation and scapular tipping during a passive rotation task, active rotation task, flexion task and functional diagonal task.
2. H_o: There will be no relationship between shoulder ROM measures and range of scapular tipping during humeral rotation and elevation.

Research Hypothesis

1. H_A: There will be a negative relationship between humeral rotation and scapular tipping during a passive rotation task, active rotation task, flexion task and functional diagonal task.
2. H_A: There will be negative a relationship between shoulder ROM measures and range of scapular tipping during humeral rotation and elevation.

Definition of Terms

Scapular anterior and posterior tipping: rotation about an axis parallel to the scapular spine

Dynamic stability: stability accomplished through dynamic restraints such as muscles and tendons

Electromagnetic tracking: three-dimensional tracking system utilizing an electromagnetic transmitter and sensors to detect position, angles, and movement.

Static stability: stability accomplished through static restraints such as capsule, ligaments, labrum.

Glenohumeral Internal Rotation Deficit: deficit of internal rotation greater than 25° as compared to the non-throwing arm

Shoulder kinematics: the study of the positions, angles, velocities, and accelerations of shoulder during motion

Scapulothoracic motion: movement of the scapula on the thorax at the scapulothoracic articulation.

Scapulohumeral rhythm: degrees of upward rotation as a function of humeral elevation. It is the ratio between glenohumeral and scapular rotation, which is approximately 2:1.

Shoulder impingement: compression or mechanical abrasion of the rotator cuff as it passes under the coracoacromial arch during shoulder elevation.

Definition of Operational Terms

Overhead athletes: athletes participating in sports in which the upper extremity is elevated 60-120° repetitively.

Diagonal pattern: proprioceptive neuromuscular facilitation D2 pattern moving into flexion and extension.

Dominant arm: the arm the subject would throw a ball with.

Posterior shoulder: the posterior capsule and posterior rotator cuff

Assumptions

1. Subjects will answer the medical history truthfully.
2. Subjects will perform the skills to the best of their abilities.
3. Subjects will understand instructions given to them by the primary investigator.
4. Subjects will be fully relaxed during passive humeral rotation.
5. Instrumentation will be properly calibrated and testing will be accurate and precise.

Limitations

1. Subjects may answer dishonestly on the medical history form.
2. There may be accessory movement of sensors.
3. Subjects may not be completely relaxed during passive testing.

Delimitations

1. Subjects consisted of 25 healthy individuals ages 18-35 with no previous history of instability or shoulder injury within the past year.
2. All subjects will perform the same rotation, flexion and diagonal motions.
3. Subjects were all tested on their dominant arm.
4. All tests will be performed by the primary investigator.

Significance of the Study

Previous studies have shown the importance of scapular tipping in prevention of impingement syndromes. Because it is not yet known how humeral rotation affects scapular motion, it is important to establish this relationship to give clinicians a better understanding of potential causes of shoulder pain in overhead athletes. The overhead athlete presents a challenge to the clinician to needs to promote proper humeral and scapular mechanics in order to establish the greatest amount of dynamic stability, allow the maximum amount of mobility, and prevent debilitating injury.

Chapter Two

LITERATURE REVIEW

The shoulder's purpose is to position the hand for functional tasks. Due to the large ROM, the shoulder is able to create thousands of hand positions (Houglum 2001). It is a unique joint that presents complexity because of its extreme ROM, ability to adapt to physical demands, enormous force production and its innate instability. These issues present challenges for clinicians dealing with the athletic shoulder. It is, therefore, important for the clinician to understand the relationship between performance and injury risk factors.

Shoulder Anatomy

A review of the significant anatomy will provide a map to navigate through the structures that play a vital role in the shoulder's function. The shoulder consists of three joints and one articulation. The sternoclavicular joint, acromioclavicular joint, glenohumeral (GH) joint, and the scapulothoracic articulation make up the shoulder girdle.

Bony Anatomy

Bony anatomy of the sternoclavicular joint involves the articulation between the sternum and the proximal clavicle. This is a very stable joint with little movement, reinforced by the capsule and sternoclavicular, costoclavicular and intersclavicular ligaments.

Movements at this joint include elevation, depression and retraction. The acromioclavicular joint is comprised of the acromion process of the scapula and the distal end of the clavicle. The acromioclavicular, coracoclavicular and coracoacromial ligaments reinforce this joint. The GH joint consists of the humeral head articulating with the glenoid fossa of the scapula. The humeral head is larger than the surface area of the glenoid fossa, therefore, the congruency in the GH joint is minimal.

Soft Tissue Anatomy

Due to the incongruence of the GH joint, the joint relies on the soft tissue structures to create optimal congruency and stability. The soft tissue structures include the capsule, labrum, ligaments, muscles and tendons. The joint capsule surrounds the articulating bones holding the humeral head in the glenoid fossa. The capsule is made of dense collagen able to withstand the forces acting on the shoulder. The glenoid labrum, made of dense cartilage, attaches to the rim of the glenoid fossa creates more depth in the articulation. The labrum also acts as a seal around the humeral head. The capsule creates a negative intra-articular pressure that assists keeping the head of the humerus in place within the fossa. The periscapular and RTC muscles and tendons surrounding the shoulder complex provide dynamic stability. The broad RTC tendons insert into the capsule; therefore, when the muscles contract, they generate greater compression within the articulation, thus creating more stability.

Functional Anatomy

The anatomy of the human shoulder is required to function within an intricate balance between mobility and stability. The stabilizing mechanisms of the shoulder must compensate for the greater ROM. The shoulder also capable of creating movement at great speeds, forces the stabilizers to work at extreme speeds and forces. The shoulder relies on the capsuloligamentous and musculotendinous structures to maintain stability. The interaction among the capsule, ligaments, muscles and tendons is not completely understood nor has been fully explained (Curl and Warren 1996). This complex interaction warrants further discussion.

Dynamic Stability

As discussed previously, the musculature surrounding the shoulder acts as dynamic stabilizers. These muscles include the RTC and periscapular muscles. The RTC muscles are the supraspinatus, infraspinatus, teres minor and subscapularis. The supraspinatus runs from the supraspinous fossa through the subacromial space and the labrum to the superior part of the greater tuberosity of the humeral head. It acts concentrically to initiate shoulder elevation, eccentrically to resist superior migration of the humeral head and isometrically to stabilize by pulling the head into the fossa. It is most active during the late cocking phase of pitching/throwing (Meister 2000). The infraspinatus originates off the infraspinous fossa of the scapula inserting on the middle facet of the greater tuberosity of the humerus. It acts concentrically to externally rotate the humerus and assists with some humeral extension. The infraspinatus peak activity occurs in the late cocking phase where it contributes approximately 90% of the humeral ER power (Bramhall 1998). Activity also peaks during follow through, where the muscle acts to decelerate the arm. The teres minor originates off the middle 1/3 of the lateral border of the scapula wrapping around the humerus inserts on the lower portion greater tuberosity of the humerus. It acts alongside the infraspinatus to externally rotate the humerus, resisting humeral IR, and stabilizes in this motion. The subscapularis originating off the subscapular fossa on the undersurface of the scapula inserts on the lesser tubercle of the humeral head pulling the humerus into IR. The subscapularis acts to stabilize and resist humeral ER torque. Its peak activity occurs during late cocking while it contracts eccentrically and during acceleration creating the greatest amount of humeral IR force (Meister 2000). These muscles act throughout the ROM to create stability of the humerus in the glenoid. One mechanism by which they create stability is they blend into the GH capsule and ligaments. Therefore, as these muscles contract, they pull the capsule taught and tension is produced within the capsule, compressing and centering the head of the humerus into the glenoid fossa. Another mechanism by which they create stability is by acting as force couples with the surrounding muscles to create optimal joint contact.

The periscapular muscles also create stability at the shoulder. These muscles include the levator scapula, trapezius (upper, middle, and lower), rhomboids, serratus anterior, and some portion of the latissumus dorsi. The levator scapulae act to produce scapular elevation as well as scapular downward rotation. The upper trapezius produces scapular elevation and scapular upward rotation. The middle trapezius creates scapular retraction. The lower trapezius generates scapular depression and scapular upward rotation. The rhomboids, major and minor, retract and downwardly rotate the scapula. The serratus anterior produces scapular protraction, scapular upward rotation and acts to stabilize the scapula on the thorax.

The latissimus dorsi acts along with the teres major to produce humeral extension, humeral IR and humeral adduction. Scapular stabilizers can be grouped into elevators, depressors, protractors, retractors, upward rotators and downward rotators. The levator scapula and upper trapezius act to elevate the scapula. A portion of the latissimus dorsi, lower trapezius, lower serratus anterior and pectoralis minor all act to depress the scapula. The scapular protractors are the serratus anterior and the pectoralis muscles. Scapular retraction is produced by the rhomboid major and minor, middle trapezius. Scapular upward rotation is accomplished by the trapezius and serratus anterior; while scapular downward rotation is produced by a combination of levator scapula and rhomboids (Bramhall 1998). The pectoralis major acts to adduct, horizontally adduct and internally rotate the humerus. Pectoralis minor protracts, depresses and downwardly rotates the scapula. The deltoids act on the shoulder to create humeral flexion, humeral adduction, and humeral extension as well as humeral IR and ER. These muscles act to create optimal stability and positioning of the scapula.

All these motions act to produce a scapulohumeral rhythm that is essential to the proper functioning of the shoulder complex. By stabilizing the scapula, the shoulder is able to transmit the force generated by the lower extremity and trunk to the hand.

Static Stability

The static stabilizers include the capsule, the ligaments and the glenoid labrum. The capsule surrounds the head the glenoid fossa and the head of the humerus. The ligaments are thickenings of the capsule. The ligaments of the shoulder consist of the superior GH ligament (SGHL), middle GH ligament (MGHL), and inferior GH ligament (IGHL) complex.

The IGHL is comprised of three bands: the anterior band, and the posterior band and the axillary pouch. The anterior component of the IGHL prevents anterior translation in humeral ER and the posterior component prevents posterior translation in humeral IR. The superior GH ligament (SGHL) provides static restraint to inferior and posterior translation in humeral adduction. The MGHL provides static restraint to anterior humeral head translation. The coracohumeral ligament also contributes to the static stability of the shoulder (Curl and Warren 1996). The coraocoacromial ligament prevents superior humeral head translation and assists in prevention of inferior translation. The posterior capsule provides passive control of humeral horizontal adduction and humeral IR in the abducted GH joint (Nyland, Caborn et al. 1998).

Shoulder Kinematics

Normal motions at the shoulder occur at the GH joint and scapulo-thoracic articulation. Motions occurring at the GH joint include flexion, extension, abduction, adduction, internal rotation, external rotation and horizontal abduction and adduction. The humerus translates on the glenoid during movement. During humeral abduction, the humerus translates superiorly and inferiorly. The humerus translates posteriorly during humeral extension and humeral ER. This is thought to be due to tightening of the anterior capsule (Harryman, Sidles et al. 1990). Harryman, Sidles et al. showed that during passive humeral flexion beyond mid range of motion at approximately 55º the humeral head moves anteriorly and superiorly; while passive humeral extension after 35º caused the head to translate posteriorly. After incising the capsuloligamentous structures, the humerus did not translate. Passive humeral IR and ER at 0º of humeral abduction produce anterior and posterior displacement, respectively. Cross body adduction revealed anterior translation of the head on the glenoid. After surgical tightening of the capsule, the translations occurred to a greater degree (Harryman, Sidles et al. 1990). Howell, Galinat et al. reported that translation also occurs during combinations of movements at the shoulder (Howell, Galinat et al. 1988).

Normal motion at the scapulothoracic articulation includes scapular upward and downward rotation, scapular depression and elevation, scapular retraction and protraction, and scapular anterior and posterior tipping. During humeral elevation, the clavicle retracts and elevates. The scapula upwardly rotates, posteriorly tips, and externally rotates(Ludewig, Cook et al. 1996; Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000). These motions occur to elevate the acromion preserving subacromial space during humeral elevation. The relationship between scapular motion and GH motion is referred to as scapulohumeral rhythm. In the literature, the ratio of humeral elevation to scapular rotation has been described as 2:1 during the mid ranges of the total arc of elevation. During active humeral elevation, the scapula upwardly rotates which increases with increasing angles of elevation. The scapula posteriorly tips slightly up to 90º of humeral elevation after which it moves to anterior tipping (Ebaugh, McClure et al. 2005).

Scapulohumeral rhythm can be influenced by actively or passively performing humeral elevation. Ebaugh et al. (2005) found that decreased amounts of scapular upward rotation occurred when the humerus was passively elevated. Their findings concurred with the findings of McQuade and Smidt (McQuade, Dawson et al. 1998; Ebaugh, McClure et al. 2005).

Myers et al. (2005) studied scapular position and orientation in throwing athletes as compared to a non-throwing control group. Their results indicated that throwing athletes' scapular position is more upwardly rotated, internally rotated and retracted. They theorized that scapular upward rotation was an adaptive change to decrease impingement pathologies and retraction facilitated maximum cocking position thus creating a more explosive acceleration. They posited that the scapular internal rotation change could be problematic because it decreases the subacromial space (Myers, Laudner et al. 2005).

Ludewig et al. (2000) found that individuals with subacromial impingement have an altered scapulohumeral rhythm. The scapula in shoulders with impingement shows decreased upward rotation during elevation and demonstrates a more anteriorly tipped position (Ludewig, Cook et al. 1996; Ludewig and Cook 2000). Scapulohumeral rhythm is also altered in individuals with shoulder instability. Individuals with inferior instability or multidirectional instability also demonstrate a decrease in scapular upward rotation (Ozaki 1989; Ludewig, Cook et al. 1996).

Tsai et al. (2003) researched the effects of muscle fatigue on scapular kinematics. They found the greatest differences at resting position or the beginning of humeral elevation. The scapula assumed a more anteriorly tipped, internally rotated, and downwardly rotated after fatigue of the humeral external rotators. Often throwers have a low ratio of humeral ER to IR strength; therefore, fatigue of weaker muscles can decrease stabilization and force production (Tsai, McClure et al. 2003). Birkelo et al. (2003) found that scapular upward rotation and external rotation were decreased after a simulated 5 innings of pitching (Birkelo, Padua et al. 2003).

Kebaetse et al. (1999) found that thoracic posture can also affect scapular position and motion. The study demonstrated a superior translation between 0º and 90º of humeral abduction, less scapular upward rotation along with less scapular posterior tipping between

90º and maximum humeral abduction. They also found more scapular internal rotation throughout the ROM (Kebaetse, McClure et al. 1999). Similarly, Finley et al. (2003) conducted a study examining the effects of thoracic posture on scapular kinematics. The results demonstrated a slouched posture was associated with increased scapular anterior tipping and increased scapular upward rotation at rest. During humeral elevation, scapular posterior tipping decreased (Finley and Lee 2003). Poor position and movement of the scapula can lead to changes to the length and tension of each muscle, thus adversely affecting muscle force generation and dynamic stability.

Athletic Shoulder

Overhead athletes are a unique population of athletes that are required to function in a position of humeral elevation above the head for the majority of their participation. These athletes utilize the shoulder's extreme mobility repetitively on a daily basis in practice or competition. Overhead athletes participate in sports such as baseball, softball, volleyball, swimming and tennis. All of these sports demand considerable force production from the trunk and shoulder to accelerate the arm sufficiently to transmit the force to the ball, racket or to propel the body through the water.

Physical Demands of Athletic Shoulder

Pitching and throwing create extreme loads about the shoulder complex. Pitching is a smooth motion that occurs within seconds. There are six phases delineated in the literature that are used to describe the pitching/throwing motion. The first phase is the windup. Minimal stress is placed on the shoulder during this phase with minimal muscular activity.

The windup is followed by the second phase, known as early cocking, which moves the shoulder into 90º of abduction. The third phase or late cocking readies the shoulder for force generation. It begins when the lead leg is planted and ends in maximal humeral ER. Late cocking is followed by acceleration in which the humerus rotates in abduction until ball release. During this phase, the loads placed on the GH joint are minimal even though speeds of humeral rotation exceed 7000º/second (Burkhart, Morgan et al. 2003). Deceleration, the fifth phase, is recognized as the most violent of the throwing motion, lasting approximately 0.1 second (Moynes, Perry et al. 1986). The humeral external rotators must act to decelerate the arm and work against the distraction momentum. Posterior shear forces of 400 N, inferior shear forces of 300 N and compressive forces of greater than 1000 N have been recorded during deceleration (Meister 2000). The distraction force at the GH joint approximates 1 to1 ½ times body weight. The posterior RTC muscles are responsible for dissipating these forces. Upon examination, overhead throwing athletes demonstrate significant posterior musculature weakness and tightness (Wilk and Arrigo 1993). The sixth and final phase of throwing, the follow-through, involves the body moving forward to rebalance until motion is complete. Muscle activity diminishes to resting levels, joint loads decrease; however, compressive forces can still approximate 400 N. Of the six segments of the pitch, acceleration and deceleration are the two that create the greatest amount of stress. During cocking, the shoulder is in a position of maximal humeral external rotation at 90º of humeral abduction. During acceleration, the humeral internal rotators are most active concentrically to accelerate the hand for ball release. This is most likely the fastest motion in any of the sports (Meister 2000).

Incidence of Injury in Athletic Shoulder

Shoulder injuries are common in athletics composing 8-13% of all athletic injuries. Overhead athletes are even more at risk to experience shoulder injury (Hill, 1983). Due to the repetitive nature of these sports, chronic injuries are common. An epidemiological study done in 1990 revealed that of 372 overhead athletes, 43.8 % complained of shoulder problems (Lo, Hsu et al. 1990). Twenty-nine percent of these athletes complained of shoulder pain, among them most prevalently volleyball players and swimmers (Lo, Hsu et al. 1990). A survey done by the ASMI found over 50,000 injuries per year in baseball and that 50% of pitchers experience shoulder or elbow pain. The most common injuries seen in pitchers are chronic injuries that result from soft tissue trauma. Many throwers experience what is known as the “dead arm syndrome”(Myers, Pasquale et al. 2005). Burkhart et al. (2003) defined “dead arm” syndrome as any pathological shoulder condition in which the thrower is unable to throw with pre-injury velocity and/or control because of pain or subjective unease at the shoulder. They reported this typically occurs in late cocking or early acceleration and was most often related to labral tears (Burkhart, Morgan et al. 2003).

Shoulder Instability

Instability is a clinical syndrome that occurs when shoulder laxity produces symptoms of pain or inability to stabilize the joint dynamically. Often the term “instability” is confused with the term “laxity”. However, laxity is used to describe the increase in translation of the joint. Congenital hypermobility, traumatic injury, or repetitive stretching of the static restraints may cause instability.

Shoulder Impingement

Mechanical impingement is another injury that affects overhead athletes. Subacromial impingement involves the supraspinatus tendon, long head of biceps tendon, or subacromial bursa trapped under the coracoacromial arch which is made up of the coracoid, acromion, and coracoacromial ligament. Subacromial impingement is subdivided into two types classified by their mechanism. Primary impingement is a compressive RTC disease. In primary impingement, there is mechanical impingement of the tendons under the coracoacromial arch that may be due to the morphology of the acromion. Typically, primary impingement is seen in the older recreational athlete; however, the repetitive nature of overhead athletics expedites the process of tendon failure. These individuals will demonstrate positive impingement signs and negative instability signs. Secondary impingement also falls under subacromial impingement and is associated with GH instability due to capsular injury or labral injury, and/or functional scapulothoracic instability. Individuals will display joint hypermobility, positive impingement signs, and positive instability signs. Often secondary impingement is due to overuse; stretched static stabilizers that allow translation of the humerus in glenoid, leading to increased load on RTC. Increased demands on RTC lead to fatigue and ultimately failure of the tendons resulting in anterior superior migration of humeral head. Scapular dysfunction exacerbates the pathology because asynchronous motion of scapula and humerus can lead to decrease subacromial space increasing compression on the RTC tendons. Another type of impingement, first described by Walch (1992), is an intra-articular impingement of the undersurface of the posterosuperior RTC between the posterosuperior labrum and greater tuberosity of the humerus (Walch, Marechal et al. 1992). This type of impingement is known as internal impingement. Jobe

(1995) theorized that internal impingement was associated with anterior instability (Jobe 1995). However, Halbrecht et al. (1999) showed an anteriorly translated humeral head created by anterior instability would have less contact with the posterosuperior glenoid thereby lessening the internal impingment (Halbrecht, Tirman et al. 1999). Wilk et al. (2003) demonstrated this type of impingement was a normal phenomenon that occurs in normal shoulders as well as athletic shoulders. In 90º of humeral abduction and 90º of elbow flexion, the undersurface of the posterosuperior RTC contacts the posterosuperior glenoid labrum and becomes pinched between the labrum and greater tuberosity, which can become aggravated by the hyperexternal rotation of 130º in throwers (Wilk and Arrigo 1993). The last type of impingement involves the subscapularis tendon. The tendon becomes pinched between the coracoid process of the scapula and the lesser tuberosity of the humerus. Burkhart et al. (2003) associated coracoid impingement and pain with scapular dyskinesis and malposition (SICK Scapula) associated with pectoralis minor and short head of biceps tightness (Burkhart 2003).

The pathological cascade leading to impingement in overhead athletes involves abnormal function of static and dynamic stabilizers. Failure of RTC to dynamically stabilize produces excessive translation and instability. The inferior RTC consisting of infraspinatus, teres minor, subscapularis act to depress and compress the humeral head. Research has shown that in individuals with impingement the subscapularis is stronger (IR) than the infraspinatus and teres minor (ER), creating abnormal force couple that pulls the humeral head anteriorly. Weakness in inferior RTC creates abnormal force couple with deltoid that pulls the humeral head superiorly into the acromion. Weakness in supraspinatus allows for superior migration of humeral head. As previously discussed, the RTC tendons blend into capsule; thereby, creating tension in capsule when contracted. However, weakness in the RTC can produce dynamic instability. Repetitive humeral ER creates posterior cuff tightness and capsular contracture producing an anterosuperior migration of the humeral head further decreasing space between the greater tuberosity and undersurface of acromion. Scapular muscles are needed to stabilize the shoulder with appropriate length-tension relationship with the RTC and to produce movement at the acromion in order for the greater tuberosity to clear it during humeral abduction, flexion and rotation. Weakness in the levator scapula or upper trapezius creates decreased scapular elevation. Weakness in lower trapezius decreases scapular depression allowing scapular anterior tipping. Middle trapezius and rhomboid weakness positions the scapula more externally rotated. It is clear that malfunction of the musculotendinous structures around the shoulder result in a pathological cascade resulting in shoulder pain due to impingement.

Relationship between shoulder impingement and instability

There is a clear relationship between shoulder instability and shoulder impingement. As the static stabilizers are stretched, translation of the humeral head in the glenoid fossa increases. The RTC and periscapular muscles must compensate by dynamically stabilizing the joint. However, by attempting to limit translation often the RTC and the periscapular muscles fatigue resulting in overuse syndromes of the tendons. As the process ensues, the muscles are unable to control the humeral head because of muscle weakness and tendon failure. As the muscles and tendons of the RTC fail, the humeral head migrates anteriosuperiorly in the glenoid. As the periscapular muscles and tendons fail, the scapular upward rotation decreases and anterior tipping increases. Both conditions cause a decrease in the subacromial space, which increases pinching of the RTC.

<u>Glenohumeral internal rotation deficit</u>

Most overhead throwers exhibit range of motion disparity, having excessive humeral ER and a compensatory loss of humeral IR measured at 90º of humeral abduction. It has been shown that the difference is about 7º of increase in humeral ER and about 7º loss of humeral IR. Pitchers have an average of 129.9º of humeral ER and 62.6º of humeral IR, while normal ROM ranges from 90-100º of humeral ER and 80-90º of humeral IR. Although total ROM is not significantly different between the dominant and nondominant shoulders in baseball players, there is a significant difference in isolated humeral ER and IR between the dominant and nondominant shoulders (Ellenbecker, Roetert et al. 2002). The backward shift of ROM can be attributed to changes in integrity of the capsule, musculotendinous structures and alterations in bony orientation. This change in the ROM is explained by the significant laxity of the GH capsule and ligaments. This laxity has been referred to as acquired laxity (JR Andrews) and is a result of repetitive throwing. This hypermobility in humeral ER allows the athlete to increase the speed and force of the throw (Wilk and Arrigo 1993). Overhead athletes over time show an increase in humeral ER. It has been hypothesized that this is due to the repetitive lengthening of the anterior capsule and ligaments. This may result in repetitive trauma to the anterior capsule allowing excessive movement of the humerus within the glenoid fossa predisposing the athlete to impingement pain, SLAP or "dead arm syndrome". Burkhart et al. (2003) stated that the loss of humeral IR was the most important pathological process that occurs in overhead athletes. The loss of humeral IR is also affected by the accumulation of fibrous tissue within the musculotendinous structures creating tightness and inextensibility (Burkhart, Morgan et al. 2003). The last factor contributing to a loss in humeral IR is changes in the orientation of the humeral head. A retroverted humeral head has been revealed on CT scans of professional baseball players. Sixteen degrees of retroversion was measured between the dominant and nondominant shoulders. The implications for this retroversion include a predisposition for impingement because it predisposes instability within the GH joint (Ellenbecker, Roetert et al. 2002).

Glenohumeral internal rotation deficit (GIRD) is a recent termed used to define a loss of humeral IR ROM of the throwing shoulder as compared to the non-throwing shoulder (Burkhart, Morgan et al. 2003). There have been two proposed causes of this loss in humeral IR. One factor may be a thickening in the posterior capsule resulting in a contracture of the tissue (Burkhart, Morgan et al. 2003). Burkhart et al. (2003) found arthroscopically that patients with severe pathological GIRD have a contracture or a thickening of 6mm or more in the posterior band of the IGHL (Burkhart, Morgan et al. 2003). The second factor is a loss in the extensibility of the external rotators of the RTC. This factor was proposed after an inconclusive arthroscopic study revealing no thickening of the capsule (Wilk and Arrigo 1993).

The clinical consequence of this humeral IR loss is that there is a high correlation between losses in humeral IR and SLAP lesions, some type of chronic inflammation of the tendons or chronic pain in the musculature including the teres minor, infraspinatus and long head of the biceps resulting in tears or tightness. The pathological cascade may result in further damage to the shoulder complex with internal impingement, “acquired” anterior instability, Bankart lesions and undersurface RTC tears (Ellenbecker, Roetert et al. 2002; Burkhart, Morgan et al. 2003); (Morgan 2003).

Stretching protocol for overhead throwing athletes

Wilk et al. (1993) describe a protocol for improving flexibility of the shoulder in overhead throwing athletes (Wilk and Arrigo 1993). They suggest initiating humeral IR and horizontal adduction stretches to normalize shoulder motion. Burkhart et al. (2003) suggest using the side-lying sleeper stretch to increase humeral IR. The sleeper stretch is done by positioning the shoulder at 90º of flexion and the elbow at 90º of flexion. The rollover sleeper stretch was also suggested as an effective stretch of the posterior shoulder. During this stretch, the shoulder is flexed 50-60º. The individual is instructed to roll over onto the arm about 30-40º. Finally, the cross arm stretch applies a stretch to the posterior shoulder. The shoulder flexed to 90º in the starting position. A passive humeral adduction force is then applied with the uninvolved shoulder. These stretches focus on the posterior-inferior capsule and posterior musculature. No protocol involving duration or frequency was included in the report (Burkhart, Morgan et al. 2003).

Proprioception

The motor control system explains the integration of sensory, motor and central components to maintain functional joint stability. The sensorimotor system is the component of the motor control system most responsible for creating a defense mechanism that protects joints from injury during functional activities. The umbrella term, sensorimotor system, can be further broken down into two mechanisms controlling movement: neuromuscular control and proprioception. Reimann and Lephart, 2002, described neuromuscular control as the unconscious activation of dynamic restrains in preparation and in response to joint motion with the purpose of maintaining functional joint stability (Riemann and Lephart 2002). Proprioception was defined by Sherrington at the beginning of the 20th century as type of feedback sent from the limb and received by the nervous system. The term was initially used to describe afferent information from “proprioceptors” about extremity position and direction of movement.

Sherrington described proprioception was vital for maintaining posture, equilibrium, joint stability and muscle sense. These ideas have fused into what is now termed kinesthesia, joint position sense and sense of resistance. Kinesthesia is defined as the detection of active and passive motion. Joint position sense is a static sense of the posture of a segment, while sense of resistance is sensation of heaviness or force placed on the soft tissue (Riemann and Lephart 2002).

Anatomical Structures

Proprioception is mediated by peripheral receptors in the joints, muscles and the skin (Warner, Lephart et al. 1996). What Sherrington called “proprioceptors” at the turn of the 20th century, we now call “mechanoreceptors”. Mechanoreceptors send sensory information from the joint to the brain. Previously, the anatomy and function of mechanoreceptors had been studied in the cat model. Only within the last ten years, these studies have been conducted on the human knee and shoulder. Vangsness et al. (1995) conducted a study that showed the neural anatomy of the GH ligaments, labrum and subacromial bursa. Mechanoreceptors are located throughout the shoulder complex (Vangsness, Ennis et al. 1995). One type of receptors called Ruffini corpuscles is low threshold, slowly adapting sensors were found to be the most abundance in the joint capsule and ligaments (Nyland, Caborn et al. 1998). It is hypothesized that the abundance of these receptors in the shoulder ligaments is due to the protective need for joint sense during extreme range of motion. A second receptor, Pacini corpuscles are low threshold, rapidly adapting receptors that sense movement and velocity. These again are mainly located in the capsule and ligaments. Vangsness et al. (1995) found that the glenoid labrum showed no evidence of mechanoreceptors (Vangsness, Ennis et al. 1995). The next two types of proprioceptors are located in the musculotendinous units. The muscle spindles are located within the muscle in the intrafusal fibers. The muscles spindles are sensitive to changes in length and the rate of length change within the muscle and create muscle contraction to protect the muscle from overstretch. The final receptor we will discuss is the Golgi tendon organs (GTOs) that are located at the muscle tendon juncture. The GTOs sense changes in tension within the muscle and initiates muscle relaxation. Vangsness provided a muscle spindle density review that suggests that there is a greater density of muscle spindles within the muscles that attach at the corocoid process and those that cross the GH joint anteriorly. These muscles include the long head of the biceps, teres minor and latisimuss dorsi (Vangsness, Ennis et al. 1995).

Role in injury prevention

The aforementioned receptors fire in response to extreme ranges of motion in order to protect the joint from reaching unstable positions. The muscle spindles act to protect the muscle from injury. Sensing the muscles' length, they will create a reflex contraction that will shorten the muscle, pulling it out of a potential tear that would occur from increased forces acting to create excessive length. The GTOs act to create relaxation in the muscle when there are forces that exceed the muscles' contraction threshold. At the shoulder, these mechanoreceptors fire activating the muscle to stabilize by creating optimal compression and positioning for functional activities.

Factors Affecting Proprioception

Many factors have been shown to have an impact on proprioceptive ability. These factors have been studies in the knee, ankle and shoulder. Muscle fatigue has been demonstrated in some studies to have a negative effect on proprioception. Fatiguing muscle contractions can increase the amount of intramuscular concentrations of metabolites and inflammatory substances. This reduces the sensitivity of the muscular mechanoreceptors, therefore, decreasing the ability to sense position and activity. Carpenter et al. (1998) found that after introducing a fatigue protocol there was no difference between dominant and nondominant shoulders (Carpenter, Blasier et al. 1998). They did find, however, in a threshold to detection protocol, fatigued shoulders performed worse than pre-exercise measures. The previous studies have shown that there is no relationship between fatigue and decreases in proprioception. Lee et al. (2003) only found significant changes during an active repositioning task in humeral ER (Lee, Liau et al. 2003). All other tasks of active and passive repositioning in humeral IR and ER were not statistically significant. However, obvious discrepancies are found because not all studies have followed the same testing procedure or tested the same measure of proprioception.

Position in the ROM also has an effect on the ability of the shoulder to detect proprioceptive information. As discussed previously, there is an abundance of Pacini corpuscles and Ruffini whatevers located in the capsuloligamentous structures of the shoulder creating increased sensitivity allowing these structures to send large amounts of information to the brain. Most studies show an increase in proprioception at end range in ER and IR as compared to midrange when using a threshold to detection protocol or repositioning tasks (Janwantanakul, Magarey et al. 2001).

Instability of the GH joint has demonstrated detrimental effects on proprioception. It is thought that injury or repetitive microtrauma causes deafferentation or soft tissue lengthening which, in turn, diminishes proprioceptive sensitivity. Lephart et al. (1994) and Forwell and Carnahan (1996) demonstrated significant deficits in position sense in unstable shoulders (Lephart, Warner et al. 1994) (Forwell and Carnahan 1996). Blasier et al. (1994) demonstrated that proprioceptive deficits are also present in individuals with multidirectional instability or joint hypermobility with no history of instability or injury (Lephart, Myers et al. 2002); (Blasier, Carpenter et al. 1994); (Myers and Lephart 2002). Most studies have shown that dominant shoulders of overhead athletes demonstrate deficits in kinesthesia when compared to the non-dominant or uninvolved shoulder. This confirms the idea that joint instability plays a major role in effecting kinesthesia. In his study on surgically repaired shoulders, Lephart et al. (1994) reported no significant differences between normal subjects and surgically repaired subjects bilaterally, therefore demonstrating a restoration of normal kinesthesia post-operative as compared to the non-dominant shoulder (Lephart, Warner et al. 1994). Lephart et al. (2002) indicate that shoulder proprioception is possibly restored or improved post-surgically because of rehabilitation and the re- establishment of normal capsular integrity (Lephart, Myers et al. 2002). These results also confirm that joint hypermobility or laxity decreases the proprioception sense in the shoulder.

Instability in the static stabilizers of the shoulder has been shown to have an effect on the dynamic stabilizers as demonstrated in the motor program and muscle recruitment patterns. Glousman et al. (1988) conducted an EMG study of pitching in individuals with instability. They showed compensatory increase recruitment of the supraspinatus and long head of the biceps. Decreases in activity were shown in the subscapularis, pectoralis major, latissimus dorsi and serratus anterior during lack cocking (Glousman, Jobe et al. 1988). The decreased muscular activity is problematic because activation of these muscles is necessary to generate anterior stability in its vulnerable position. Ligamentous laxity creates changes in the motor programs and recruitment patterns thus altering the force couple relationships between the muscles and perpetuating the instability by reducing optimal muscle contractions.

Strength training has also been proposed to improve joint kinesthesia especially after injury. A study done by Docherty et al. (1998) showed that ankle joint position sense in inversion and plantar flexion improved with ankle strengthening exercises in those individuals with functional ankle instability. They proposed that the change was due to increases in muscle spindle sensitivity (Docherty, Moore et al. 1998). Another similar study done on the shoulder compared open and closed kinetic chain exercises. Rogol et al. (1998) found that both the groups experienced improved joint position sense from pretest to posttest. They suggested training might refine proprioceptive awareness. The researchers found that performing one resistance exercise three days a week for six weeks made significant improvements in proprioception (Rogol, Ernst et al. 1998).

Proprioception and Stretch

Recent research studies have suggested that stretching may induce a stretch tolerance within the muscles. This may be due to alterations in muscle spindle and GTO activity. Muscle spindles are affected by muscle contraction and stretching. A study done by Larsen et al. (2005) showed that there was no significant decrease in proprioception at the knee after an acute stretch of the quadriceps and hamstring muscles (Larsen, Lund et al. 2005). The investigators measured joint position sense by using the reproduction of a specific target position method. A thixotropic behavior of the muscles spindles was discussed in the article as having an effect on the receptor's ability to send input. It was discussed that this behavior is only observed for a very short period of time, therefore having no lasting effects on proprioception at the knee as determined by target position replication (Larsen, Lund et al. 2005). McNeal and Sands (2005) conducted a study on the effects of acute static stretch on joint position sense in the shoulder. They utilized a three-dimensional motion tracking system to test position replication. They did not report differences in joint position sense but suggested that three-dimensional tracking be used to assess joint position sense (McNeal and Sands 2005).

Chapter Three

METHODOLOGY

Subjects

Twenty-five college-age individuals (age, 21.6 ± 2.18 years; mass, 77.0±14.6 kg; height, 178.7 ± 10.9 cm) from the student population at The University of North Carolina participated in this study. Four subjects were left-handed, and 21 were right handed. Subjects were healthy volunteers. Subjects were recruited with informational flyers and verbal requisition. Subjects were excluded if they suffered any shoulder pain during testing. Subjects were also excluded if they had undergone shoulder surgery or formal rehabilitation for shoulder injury within the last year; in addition, if they had sustained a GH joint dislocation or subluxation within the past year or had missed more than two weeks of activity because of an upper extremity injury during the past year. Thirteen males and 12 females participated in this study. The principal investigator evaluated all subjects. Descriptive statistics for the subjects are presented in Table 1.

Instrumentation

The three-dimensional kinematics of humeral and scapular motion was measured using the Flock of Birds ® electromagnetic motion analysis system (Ascension Technology Corporation; Burlington, VT) controlled by Motion Monitor (Innovative Sports Training, Inc.; Chicago, IL) data acquisition computer software. Lightweight electromagnetic sensors (2.3 X 2.8 X 1.5 cm, 17 g) were attached to the test arm using double-sided adhesive tape. A standard range direct current transmitter containing three orthogonal coils that generate an electromagnetic field was mounted on a plastic shelving unit near each subject allowing joint and segment orientation to be collected by Motion Monitor. The three sensors attached to the subject recorded the electromagnetic changes in the field generated by the transmitter and then transferred the signals to a recording computer via hard wiring. The electromagnetic motion analysis system was calibrated prior to data collection. A universal goniometer was used to measure ROM of supine shoulder flexion, shoulder external rotation, shoulder internal rotation, total shoulder rotation, and shoulder sleeper internal rotation. A standard tape measure was used to assess posterior shoulder tightness as proposed by Tyler et al. (2000). A bubble level was attached to the stationary arm of the goniometer.

Procedures

Before data collection, subjects were briefed on the testing procedures and were asked to sign an informed consent approved by the IRB and complete a brief medical history questionnaire prior to testing. The subjects reported to the Sports Medicine Research Laboratory on one occasion for testing. Testing lasted approximately 60 minutes. The subject’s height (cm), mass (kg), age (yrs) and dominant arm were all recorded at this time. During the testing session, ROM and scapular kinematics were assessed. The order of ROM and scapular kinematics testing were counterbalanced to limit learning, investigator bias, and error.

Range of Motion Assessment

To assess shoulder flexion ROM the subject lay supine on a standard treatment table. The goniometer axis was positioned over the glenoid fossa, the stationary arm was aligned parallel to the coronal plane or thorax, and the distal arm was aligned with the lateral epicondyle. The subject moved his or her arm into flexion. Starting position was defined as the arm at his or her side; this was described as 0º of flexion. End position was determined by a cessation of movement (Figure 1). Subjects were instructed to limit spinal extension. The procedure was repeated for three trials and was measured in degrees.

Shoulder internal rotation ROM was measured with the arm abducted to 90º and the elbow flexed to 90º with a towel to support the humerus. In this position, the tester passively moved the arm into internal rotation. Using the manual stabilization method proposed by Ellenbecker et al. (1996) the principal investigator measured shoulder internal rotation ROM by passively internally rotating the arm, while stabilizing the scapula at the coracoid process. The subject began with the forearm perpendicular to the floor. This position was defined as the starting position and describes 0º of rotation. The end range of motion was defined as the cessation of rotation or sensation of scapular movement (Figure 2). Measurements were taken with a universal goniometer with a bubble level attached to the stationary arm. According to the method proposed by Norkin and White (1985), the goniometer axis was placed over the olecranon process, the stationary arm was positioned parallel to the floor, and the movable arm was align with the ulnar styloid (Norkin and White 1985). Awan et al. (2002) demonstrated that this technique had an interrater reliability of .50 and an intrarater reliability of .65(Kibler, Chandler et al. 1996; Awan, Smith et al. 2002). We demonstrated this technique revealed intersession reliability of .97 (SEM = 2.415) and intrasession reliability of .98 (SEM = 2.068). This procedure was repeated for three trials and was measured in degrees. The mean degree of ROM was recorded. The subject's arm was then passively moved into external rotation. External rotation was measured with similar techniques as internal rotation (Figure 3). The procedure was repeated for three trials and was measured in degrees. The subject's shoulder internal rotation was then measured in the sleeper position which was proposed to better isolate humeral rotation (Burkhart, Morgan et al. 2003). The subject was positioned in side-lying on the side of their dominant arm. The shoulder was positioned in 90º of flexion with both acromion processes level and perpendicular to the table. The elbow was positioned in 90º of flexion. The subject began with the forearm perpendicular to the table/floor, which was defined as the starting position. The subject then grasped and pushed their forearm of the dominant arm toward the table. The end position was indicated by the cessation of rotation (Figure 4). A normal ROM consists of 60-70º. The procedure was repeated on the non-dominant arm as well. Three trials were performed and the ROM was measured in degrees.

Posterior shoulder flexibility was also assessed. A procedure introduced by Tyler et al. (1999) measures shoulder horizontal adduction. The amount of shoulder horizontal adduction indicates the amount of posterior shoulder tightness or inflexibility. This procedure required the subject to lie on the side of the non-dominant arm. The knees were flexed to 90º while the hips were flexed to 90º. The back was positioned perpendicular to the table. The non-dominant arm was placed under the subject's head. A mark with a felt tip marker was placed on the medial epicondyle of the dominant arm. The shoulders were aligned perpendicular to the treatment table. The investigator faced the subject and stabilized the lateral border of the scapula in a retracted position, in order to restrict scapular movement. The procedure started in a position of 90º of humeral abduction and 0º of humeral rotation. The subject was instructed to relax as the tester lowered his or her arm into shoulder horizontal adduction while maintaining scapular stabilization and 0º of humeral rotation. End ROM was defined as maximal horizontal adduction or initiation of scapular movement (Figure 5). Using a standard tape measure, the investigator measured the distance from the bottom of the treatment table to the mark on the medial epicondyle. The procedure was performed three times on each limb and was measured in centimeters. Posterior shoulder flexibility was calculated as the difference in measured horizontal adduction between the dominant arm and non-dominant arm.

Shoulder Kinematics Protocol

The electromagnetic motion analysis was set up according to the International Society of Biomechanics Shoulder Group (van der Helm 2004). At a sampling rate of 50 Hz, wooden stylus attached to a sensor was configured and the three-dimensional world axis system was defined with a point 0.2m down the X-axis which is anterior or in the direction the subject is facing. The Z-axis was defined by a point 0.2m from the origin in the lateral direction or to the right of the subject. The Y-axis was defined as the vertical axis. Electromagnetic sensors were adhered on the subject's dominant shoulder on the distal humerus, the broad surface of the acromion angle, and the C7 spinous process (Figure 6). The electromagnetic sensors were adhered using double-sided tape. The distal humerus sensor was secured onto a thermoplastic cuff in order to better represent humeral motion (Figure 7). The thermoplastic cuff was custom-made for each subject. Ludewig et al. (2002) reported a surface-mounted sensor closely represented underlying angular movements when compared to a bone-fixed sensor. The study revealed valid measures of movement to the last 5º of motion with a thermoplastic cuff and valid measures of movement to the last 15º of motion without a thermoplastic cuff (Ludewig, Cook et al. 2002). Next, the subjects stood in a neutral position with arms at their sides while body segments were digitized by using the stylus to locate particular anatomical landmarks. Anatomical landmarks digitized include T12/L1, T8, C7, sternal notch (IJ), xiphoid process (PX), medial scapular spine (TS), inferior angle of scapula (AI), acromion angle (AA), and medial and lateral epicondyles of humerus (EM, EL) (van der Helm 2004). The thorax was defined by the positions of the C7, T8, T12, xiphoid process, and sternal notch. The position of the scapula was defined by the medial scapular spine, inferior angle of the scapula, and the acromion angle. The digitized points on the lateral and medial epicondyles of the humerus were used to define the position of the humerus during data collection (Figures 8 & 9).

Subjects were tested in the active and passive rotation tasks while seated. An adjustable tripod was used as an armrest in order to limit humeral elevation. A small platform constructed of thermoplastic material was attached onto the tripod in order to allow the subject to maintain the abducted position and decrease translation of the elbow on the tripod. Subjects were seated with their shoulder propped at 90º of abduction and elbow at 90º of flexion.

Active rotation task was performed. The starting position was defined as the palm of the hand facing caudally with the forearm positioned parallel to the floor (Figure 10). Each subject was taken through the available ROM passively before performing the task to become familiar with the ROM. The subject was given three practice trials. During these trials, the subject was given verbal feedback to correct the motion. The investigator verbally instructed the subjects to initiate movement into internal rotation followed by external rotation (Figures 11 &12). Seven test trials were done. The mean range of scapular tipping taken at maximum humeral IR and maximal humeral ER during the middle five test trials was recorded.

The passive rotation task was then performed. The subject was instructed to relax and allow the investigator to take his or her arm through the entire available ROM. The starting position was defined as the palm of the hand facing caudally with the forearm positioned parallel to the floor (Figure 13). Three practice trials were done to assure the subject was relaxed and was not assisting with motion. The investigator initiated movement into IR followed by ER (Figures 14 & 15). The investigator performed seven test trials. The mean range of scapular tipping taken at maximum humeral IR and maximum humeral ER during the middle five test trials was recorded.

The subject then performed a humeral flexion task. The subject was instructed to stand in anatomical position with their thumbs pointing forward which was defined as the starting position (Figure 16). The subject was instructed to maximally elevate the arm in the sagittal plane (Figure 17). The subject was given three practice trials, followed by seven test trials. The mean range of scapular tipping taken at 90º of flexion, 120º of flexion and maximum humeral flexion of the middle five test trials was recorded.

The subject then performed a functional diagonal pattern, consisting of a proprioceptive neuromuscular facilitation pattern (PNF D2 pattern). D2 flexion encompassed humeral flexion, abduction, and ER. D2 extension consisted of humeral extension, adduction, and IR. The subject was instructed to begin the functional diagonal pattern with his or her thumb resting at the opposite anterior superior iliac spine (ASIS)

(Figure 18). The subject was instructed to keep the thumb pointed behind him or her to ensure that the subject's humerus was externally rotated at the end of the functional diagonal pattern (Figure 19). The subjects were allowed three practice trials. The subject completed seven test trials. The mean range of scapular tipping taken at 90º of flexion and maximum humeral flexion during the functional diagonal pattern moving into flexion of the middle five test trials was recorded. A metronome set at 69 Hz was used for all tasks in order to standardize velocity.

Data Reduction

Raw data was processed using Motion Monitor software and mechanical axes were defined by the digitized anatomical landmarks on the thorax, humerus, and scapula as recommended by the International Society of Biomechanics Shoulder Group (van der Helm 2004). The mechanical axes were converted to coordinate axes for each segment. The coordinate system was defined as the x-axis being horizontal with positive direction pointing anteriorly or in the direction the subject is facing, the y-axis being vertical with positive direction pointing upward, and the z-axis being horizontal with positive pointing to the right of the subject. Kinematic data were smoothed through a Butterworth low pass digital filter at an estimated optimal cutoff frequency of 3.5 Hz. Scapular rotations were expressed as Euler angles in relation to the trunk with the first rotation about the y-axis, which is the axis pertaining to scapular protraction and retraction; the second rotation was about the z-axis, which is the axis explaining upward and downward scapular rotation; and the third rotation was about the x-axis, which is the axis involved in anterior and posterior scapular tipping (Figures 20-22).

Data Analysis

Statistical analysis was performed with SPSS 13.0 (SPSS, Inc.; Chicago, IL). Separate Pearson Product moment correlations were used to determine the relationship for the following pairs of variables: 1) range of scapular tipping and its relationship to maximal humeral IR measured during active and passive rotation tasks; 2) range of scapular tipping during humeral rotation during active and passive rotation tasks and its relationship with maximum shoulder IR ROM as measured by supine and sleeper IR; 3) range of scapular tipping and its relationship with humeral flexion measured at 90º, 120º and maximum flexion; 4) range of scapular tipping at 90º, 120º and maximal humeral flexion and the association with maximum shoulder IR ROM as measured by supine IR and sleeper IR; 5) range of scapular tipping and its relationship with humeral flexion measured at 90º and maximal humeral flexion in a functional diagonal task; 6) range of scapular tipping at 90º of humeral elevation and maximal humeral elevation during a functional diagonal task and the association with maximum shoulder IR ROM as measured by supine IR and sleeper IR. For the purpose of this study correlation coefficients were interpreted as follows: below .50 was poor, .50-.75 was good, and above .75 was excellent. An a priori alpha level of 0.05 was used (Borsa, Timmons et al. 2003). A summary of the analysis is presented in Table 2.

Chapter Four

RESULTS

Descriptive Statistics

The Interclass Correlation Coefficients (ICC) $_{(2,1)}$ for shoulder ROM measurements were above 0.9, suggesting excellent within subject reliability. The standard error of measurement (SEM) for each shoulder ROM measure ranged from 0.28° to 2.4°. The shoulder flexion range of motion measure exhibited good reliability with an ICC $_{(2,1)}$ value of .80 with an SEM value of 2.96°. The ICC $_{(3,k)}$ values for three-dimensional scapular tipping and humeral kinematic measures were analyzed at maximal humeral IR and ER angles; 90°, 120° and maximal humeral flexion angles; maximal humeral IR and ER angles at 90° of humeral flexion angle and maximal humeral flexion angle during functional diagonal task. All measures displayed excellent reliability within trials with ICC values ranging from .98 to .99, and SEM values ranging from 0.68º to 3.8º.

Means, standard deviations, ICC, and SEM values for goniometric shoulder ROM and three-dimensional scapular and humeral motion tracking for each task are presented in Tables 3, 5, 7, and 9.

Passive Rotation Task

Correlation analyses revealed that shoulder IR ROM as measured by a goniometer was negatively correlated with scapular tipping ROM at the maximum humeral IR angle during passive rotation task ($r = -0.418$, $p = 0.033$) (Figure 23). Regression analysis reveals that 17.5% of variance in scapular tipping ROM can be explained by shoulder IR ROM ($r^2 = 0.175$). As shoulder IR ROM increases, scapular tipping ROM decreases. No other ROM variables were significantly correlated with scapular tipping ROM ($p > 0.05$). However, the total arc of shoulder rotation ROM approached a significant correlation with scapular tipping ROM at maximum humeral IR angle during passive rotation task ($r = -.372$, $p = 0.053$) indicating a strong trend (Figure 24). Regression analysis did reveal an r^2 value of 0.139, representing 13.9% of variance in scapular tipping ROM can be explained by the total arc of shoulder rotation ROM. Correlation analysis is presented in Table 4.

Active Rotation Task

Correlation analyses revealed no shoulder ROM variables were significantly correlated with scapular tipping ROM ($p > 0.05$). Shoulder IR ROM approached significance when correlated with scapular tipping ROM at maximum humeral IR angle during active rotation task ($r = -0.368$, $p = 0.055$). This finding indicates a strong trend that as shoulder IR ROM increases, scapular tipping ROM decreases. Regression analysis revealed that 13.5% variance of scapular tipping ROM can be explained with shoulder internal rotation ROM (Figure 25). Correlation analysis is presented in Table 6.

Functional Diagonal Task

Correlation analyses revealed the shoulder IR ROM approached significance with scapular tipping ROM at 90° of humeral flexion angle during functional diagonal task ($r = -0.367$, $p = 0.055$). As shoulder IR ROM increases, there is less scapular tipping ROM.

Regression analysis revealed that 13.5% of variance in scapular tipping ROM can be explained with shoulder IR ROM ($r^2 = 0.135$) (Figure 26). The total arc of shoulder rotation ROM was also significantly correlated with both scapular tipping ROM at 90° of humeral flexion angle ($r = -0.397$, $p = 0.041$) and scapular tipping ROM at maximal humeral flexion angle during the functional diagonal task ($r = -0.477$, $p = 0.017$) (Figures 27 & 28). These findings demonstrate that as total arc of shoulder rotation ROM increases there is less scapular tipping ROM. Twenty-three percent of variance of scapular tipping ROM at 90° of humeral flexion angle can be explained by total arc of shoulder rotation ROM ($r^2 = 0.228$); while, 16% of variance of scapular tipping ROM at maximal humeral flexion angle can be explained by total arc of shoulder rotation ROM ($r^2 = 0.15.8$). The posterior shoulder flexibility measure was positively correlated with scapular tipping ROM at 90° of humeral flexion angle ($r = 0.414$, $p = 0.035$) and scapular tipping ROM at maximal humeral flexion angle during functional diagonal task ($r = .384$, $p = 0.048$) (Figures 29 & 30). This was the only significant finding with the posterior shoulder flexibility measure. This indicates that the greater distance recorded during the posterior shoulder flexibility measure, the less flexible the posterior shoulder and; moreover, the more scapular tipping ROM observed. Regression analysis revealed r^2 values of 0.174 and 0.147 for scapular tipping ROM at 90° of humeral flexion angle and maximal humeral flexion angle, respectively. Correlation analysis is presented in Table 8.

Flexion Task

Correlation analyses revealed no shoulder ROM variables were significantly correlated with scapular tipping ROM ($p > 0.05$). Correlation analysis is presented in Table 10.

Range of Motion

The shoulder IR ROM measure is highly associated with the sleeper shoulder IR ROM measure ($r = .712$, $p < .001$). However, neither measure was correlated with the posterior shoulder flexibility measure ($p < 0.05$).

Chapter Five

DISCUSSION

The purpose of this study was to examine the relationship of clinical measures of shoulder range of motion (ROM) with scapular tipping ROM. Our results indicate that scapular tipping ROM is significantly related to passive shoulder IR ROM during the passive rotation task and the functional diagonal task. Scapular tipping ROM approached a significant relationship with passive shoulder IR ROM during the active rotation task. The total arc of shoulder rotation ROM was significantly related to scapular tipping ROM during the functional diagonal task. And, finally, the posterior shoulder flexibility measure was significantly related to scapular tipping ROM during the functional diagonal task. These results suggest decreases in clinical measures of shoulder ROM were related to greater scapular tipping ROM. This suggests that shoulder ROM influences scapular tipping ROM supporting the interdependence of humeral and scapular motion in shoulder function.

Our results show that during the passive rotation task at maximum humeral IR angle, shoulder IR ROM was negatively correlated with scapular tipping ROM. Passive shoulder IR ROM also approached significance when correlated with scapular tipping ROM at maximal humeral IR angle during the active rotation task. These results indicate that greater shoulder IR ROM was related to smaller ranges of scapular tipping ROM during the active and passive rotation tasks.

The differences between the relationship of shoulder ROM measures and scapular tipping ROM during the passive and active rotation tasks may be the result of muscle activity. All shoulder ROM measures were taken passively. This was done in order to better represent true joint mobility. Typically, active ROM is less than passive ROM signifying weakness or lesion in the active contractile tissue (Starkey, book). Moreover, active ROM assesses the ability of the muscles to function and move. Consistency of measure was another reason the shoulder ROM was taken passively. Both the shoulder sleeper internal rotation ROM and posterior shoulder flexibility measure are assessed passively. However, this may have impacted our results. The dynamic structures may have inhibited the ability to assess the static structures during functional tasks. Because the dynamic structures are controlling the motion, they may limit the scapular ROM during the active rotation task. If during active humeral rotation, the external rotators are functioning normally, they may influence the amount of anterior tipping during IR. Our results are in agreement with Borsa et al. (2003) who found weak relationships between humeral IR and ER and elevation ROM and scapular upward rotation during humeral elevation in the scapular and sagittal planes. Similarly, the investigators had taken shoulder ROM passively and required the subjects to perform the humeral elevation task actively. They suggested that other factors, such as muscle force, contributed more significantly to scapular upward rotation than did static capsular restraints (Borsa, Timmons et al. 2003).

The observed difference between active and passive rotation tasks is supported by studies comparing scapular kinematics during active and passive shoulder elevation (Price, Franklin et al. 2000; Ebaugh, McClure et al. 2005). All have posited that scapulothoracic motion is influenced by whether the arm is actively or passively elevated. Price et al. (2000)

found that there were no statistically significant differences in motion between active elevation and passive elevation. The investigation, however, only studied motion from 10º to 50º of humeral elevation (Price, Franklin et al. 2000). McQuade et al. (1998) found decreased amounts of scapular upward rotation when the arm was passively elevated but did not quantify muscle activity (McQuade, Dawson et al. 1998). However, Ebaugh et al. (2005) found differences in scapular kinematics during active and passive elevation. They found that scapular upward rotation decreased when the arm was passively elevated. This indicated that the periscapular muscles (upper and lower trapezius and serratus anterior) were vital in production of scapular motion. They determined the scapula posteriorly tips up to 90º of humeral elevation after which it moved into an anteriorly tipped position. The study found no significant differences in posterior tipping between the active and passive conditions. It was suggested that other factors such as pectoralis minor length and posterior capsule length may have been responsible for producing tipping motion (Ebaugh, McClure et al. 2005).

During the functional diagonal task, at 90° of humeral elevation in the coronal plane, there was a significant relationship between the clinical measure of shoulder external rotation and scapular tipping ROM. Also, the total arc of shoulder rotation ROM was related to scapular tipping ROM at 90º and maximal humeral elevation angle during the functional diagonal task. Additionally, the measure of posterior shoulder flexibility was related to scapular tipping ROM 90° and maximal humeral flexion angle. Additionally, there was a trend observed between shoulder IR ROM and scapular ROM at 90º of humeral elevation angle during the functional diagonal task. This suggests that shoulder flexibility influences scapular tipping ROM during a functionl task. However, there were no significant relationships between shoulder flexibility during the flexion task. This highlights the relationship between humeral rotation and scapular tipping. The functional diagonal, active and passive humeral rotation tasks all required more humeral rotation ROM (total arc of humeral rotation: active rotation task, 130º; passive rotation task, 143º; functional diagonal task, 19º; flexion task, 8º) when compared to the flexion task. This agrees with the findings of Thigpen (2006) who observed differences in scapular kinematics between empty can and full can shoulder exercises. The results demonstrated greater scapular internal rotation and anterior tipping during the empty can exercise in which the humerus is internally rotated during humeral elevation (Thigpen, Padua et al. 2006). Together with our results, this suggests less humeral rotation was exhibited during the flexion task when compared to the active and passive rotation tasks as well as the functional diagonal task. Therefore, one would expect less scapular tipping ROM to be used.

The plane of humeral elevation chosen may also have influenced the results. This is consistent with Borsa et al. (2003) who observed greater scapular upward and downward rotation within the end ROM of humeral elevation in the scapular plane suggesting that greater humeral ROM results in greater scapular ROM. They did report, however, that scapular positioning varied significantly between the planes of humeral elevation (Borsa, Timmons et al. 2003). In sum, these results highlight the importance of humeral rotation on scapular kinematics and the potential influence of task selection.

The relationship between shoulder rotation ROM and scapular tipping ROM is consistent with the relationship between shoulder elevation ROM and scapular upward and downward rotation (Borsa, Timmons et al. 2003). The results demonstrate as shoulder ROM decreases, scapular tipping ROM increased. This is important based on clinical assumptions of GH capsular mobility related to scapular kinematics (Borsa, Timmons et al. 2003;

Thigpen, Padua et al. 2006). It is thought that the mechanism facilitating this alteration in scapular tipping patterns is posterior shoulder inflexibility (Tyler, Nicholas et al. 2000; Borsa, Timmons et al. 2003; Burkhart, Morgan et al. 2003). It has been suggested that as the humerus internally rotates the posterior capsule and RTC tension resulting in increased scapular internal rotation and scapular anterior tipping. As these posterior structures tighten, the humerus will pull the scapula into more internal rotation and anterior tipping (Thigpen, Padua et al. 2006). Borsa et al. (2003) proposed that decreased capsular mobility, as measured by shoulder ROM, may result in a "pulling" of the scapula during elevation causing an increase in scapular upward rotation (Borsa, Timmons et al. 2003).

Observed differences in scapular kinematics in overhead athletes also support the idea that shoulder rotation ROM influences scapular kinematics. Myers et al. (2005) found that throwers exhibited increased scapular upward rotation in a resting position in the dominant arm. When compared to non-throwers, throwers have increased scapular upward rotation, scapular internal rotation and scapular retraction (Myers, Laudner et al. 2005). Throwing athletes are thought to develop chronic adaptations to contribute to improved throwing skill, injury prevention and/or injury provocation. In a different study, Myers et al. (2005) demonstrated that throwing athletes with pathologic internal impingement demonstrated less shoulder internal rotation ROM and greater posterior shoulder inflexibility (Myers, Laudner et al. 2005). These findings indicate that a reduction in GH ROM influences scapular motion. Adaptive posterior capsule contracture and posterior RTC tightness along with a loss of humeral IR may contribute to shoulder pain.

While not a primary research aim, relationships between the proposed measures of ROM isolating the posterior shoulder may have important clinical implications. Passive shoulder internal rotation ROM was significantly related to the passive sleeper shoulder internal rotation ROM. However, neither was significantly related with measures of posterior capsular tightness. The sleeper internal rotation ROM measure was proposed by Burkhart et al. (2003) to isolate humeral internal rotation from scapular motion by stabilizing the scapula with the table (Burkhart, Morgan et al. 2003). This measurement attempts to isolate the posterior capsule and RTC of the shoulder. The supine internal rotation measure also attempts to isolate humeral rotation with stabilization of the coracoid process of the scapula; however, it may not isolate the posterior structures as well. The posterior shoulder flexibility assessment was determined by Tyler et al. (2000) to be a reliable measure of assessing the posterior capsule of the shoulder. They established a relationship between decreases in shoulder sleeper IR ROM and increases in the posterior shoulder measure. They posited that for every 4º of IR loss there would be 1 cm of posterior shoulder tightness (Tyler, Nicholas et al. 2000). We, however, did not find any significant relationships between the posterior shoulder flexibility measure and the sleeper internal rotation ROM measurement. The values we used in the correlation analysis were not side-to-side differences but the actual values obtained on the dominant arm; therefore, body size may have influenced the measure as well as its validity. In order to use those values, it may be beneficial to normalize to body height or length of humerus. When side-to-side differences of posterior shoulder flexibility were correlated with scapular tipping ROM, still no significant correlations were found ($p < .05$). The lack of strong significant correlations could be due to sampling size, which could have affected the statistical power of the research design. Downar and Sauers (2005) collected ROM measures on professional baseball players including shoulder internal rotation ROM and posterior shoulder flexibility. Their results failed to reveal significant differences between the throwing and the non-throwing arm. They suggested this was due to low statistical power. They also found no significant relationships between the clinical measures of shoulder mobility (Downar and Sauers 2005). The conflicting results concerning the relationship between clinical measures of shoulder mobility warrants further investigation.

Clinically, we use ROM measures to identify risk factors for injury. A question arises as to which measure of posterior shoulder tightness is better than the rest. Our results indicated a stronger relationship with the shoulder internal rotation ROM and shoulder sleeper internal rotation ROM. However, it may be important to assess multiple measures of internal rotation in overhead athletes because these different measures may result in evaluation of different structures.

Limitations

The subjects were normal healthy volunteers; therefore, caution must be used in extrapolating these findings to other populations such as an injured population or overhead athletes. In addition, the velocity of the movement during testing was much slower than normal velocities during sport activity or activities of daily living. Again, caution must be used in extrapolating these findings to athletic activity.

All ROM measures were taken passively. This could have been a potential limitation to the study. It would be beneficial to take the shoulder ROM actively to determine whether a stronger correlation existed between shoulder ROM and scapular tipping ROM during the active rotation task.

Although, we did see differences between the results of the active and passive rotation tasks, muscle activity was not quantified during the passive rotation task. Although the subjects were instructed to relax completely there may have been muscle activity still present that may have contributed to motion.

Another limitation was that skin-based sensors provide only a representation of scapular and humeral motion. However, the method has been validated and shown to be reliable within humeral elevation ranges from 30º to 120º (Ludewig and Cook 2000). Variability in findings due to skin artifact, selection of bony landmarks, plane and angle of elevation, as well as Euler angle decomposition have been suggested as reasons for differences in scapular motion.

The spread of ROM values may have suppressed the correlation values (spread of shoulder internal rotation ROM: 37.3º-79.5º; spread of shoulder sleeper internal rotation ROM: 25.7º-60.3º). Side-to-side differences for the shoulder sleeper internal rotation ROM ranged from 3º to 17.7º. Tyler et al. (2000) indicated that greater posterior shoulder tightness in the throwing arm compared to non-throwing arm may range from 2-7 cm (Tyler, Nicholas et al. 2000). However, statistically significant differences have been found at 2.1 cm (Borsa, Timmons et al. 2003). Our values ranged from 0.4 to 4 cm. Again, a greater sampling size may have provided with a greater spread between the ROM values created stronger relationships between the variables.

Future Research

Future research should seek to clarify the role of humeral rotation on scapular kinematics. Clinically, humeral rotation and scapular kinematics are thought to be important to shoulder function. The relationship of humeral rotation and scapular kinematics as well as their influence on the development of shoulder pain in not understood.

Conclusion

This study is the first to assess the relationship between clinical measures of shoulder range of motion and scapular tipping ROM during functional tasks. Decreased shoulder ROM was related to increased scapular tipping ROM. Both decreased shoulder ROM and increased scapular tipping during shoulder rotation has been associated with shoulder pain.

APPENDICES

Appendix A

Tables

Table 1. Means and standard deviations for subject characteristics

Variable	Mean	Standard Deviation
Age (yrs)	21.6	2.18
Height (cm)	178.7	10.9
Mass (kg)	77.0	14.6

Table 2. Summary of research questions and data analysis.

Research Question	Data Source	Data Analysis
1: Is there an association between humeral rotation and humeral elevation and scapular tipping during active and passive rotation tasks, humeral flexion task and functional diagonal pattern?	**Predictor**: Humeral Rotation **Explanatory**: Scapular tipping ROM at max IR, max ER; 90º, 120º and max flexion; and 90º and max flexion during diagonal task.	Separate Pearson Correlation
2: Is there a relationship between shoulder ROM measures and scapular tipping during humeral rotation and elevation?	**Predictor**: Shoulder ROM measures **Explanatory**: Scapular tipping ROM	Separate Pearson Correlation

Table 3. Descriptive statistics for clinical measures of passive humeral range of motion and three-dimensional measures of passive humeral rotation and scapular anterior/posterior tipping during passive humeral rotation task.

	Mean (deg)	St Dev	$ICC_{(2,1)}$	SEM
Supine Internal Rotation	53.36	12.78	0.97	2.41
Supine External Rotation	121.79	12.33	0.98	1.43
Total Arc of Rotation	175.15	20.89		
Sleeper Internal Rotation	45.72	10.65	0.99	0.71
Posterior Capsule	25.03	3.91	0.99	0.28
Maximum IR	64.95	18.83	0.99	3.21
Range of Scapular Tipping at Maximum IR	7.15	9.48	0.99	1.34
Maximum ER	79.57	19.14	0.99	1.97
Range of Scapular Tipping at Maximum ER	10.17	11.39	0.99	0.67

Table 4. Correlation analyses of clinical measures of humeral range of motion and passive humeral internal/external rotation and scapular anterior/posterior tipping range of motion during passive humeral rotation task.

		IR	ER	Total Arc	Sleeper IR	Posterior Capsule	Max IR	Scapular tipping @ Max IR	Max ER	Scapular tipping @ Max ER
IR	Pearson Correlation	1	.384*	.838*	.712*	-.163	-.340	-.418*	.559*	-.177
	Sig. (1-tailed)		.047	.000	.000	.246	.071	.033	.005	.227
ER	Pearson Correlation		1	.825*	.418*	-.263	-.314	-.197	.577*	.348
	Sig. (1-tailed)			.000	.033	.131	.088	.202	.004	.067
Total Arc	Pearson Correlation			1	.682*	-.255	-.394*	-.372	.682*	.097
	Sig. (1-tailed)				.000	.139	.043	.053	.000	.342
Sleeper IR	Pearson Correlation				1	-.016	-.091	-.211	.338	.027
	Sig. (1-tailed)					.473	.351	.186	.073	.455
Posterior Capsule	Pearson Correlation					1	.097	-.063	-.277	.014
	Sig. (1-tailed)						.342	.395	.118	.477
Max IR	Pearson Correlation						1	.528*	-.602*	.250
	Sig. (1-tailed)							.008	.003	.144
Scap tipping @ Max IR	Pearson Correlation							1	-.369	.458
	Sig. (1-tailed)								.055	.021
Max ER	Pearson Correlation								1	-.163
	Sig. (1-tailed)									.246
Scap tipping @ Max ER	Pearson Correlation									1

* Indicates significant Pearson r

Table 5. Descriptive statistics for clinical measures of passive humeral range of motion and three-dimensional measures of active humeral rotation and scapular anterior/posterior tipping range of motion during active humeral rotation task.

	Mean (deg)	St Dev	$ICC_{(2,1)}$	SEM
Supine Internal Rotation	54.18	12.23	0.97	2.41
Supine External Rotation	121.67	12.43	0.98	1.43
Total Arc of Rotation	175.85	20.61		
Sleeper Internal Rotation	45.27	10.19	0.99	0.71
Posterior Capsule	24.79	3.58	0.99	0.28
Maximum IR	55.65	17.51	0.99	2.10
Scapular Tipping at Max IR	7.80	9.96	0.99	1.06
Maximum ER	75.82	13.12	1.00	1.18
Scapular Tipping at Max ER	15.50	10.92	0.99	1.13

Table 6. Correlation analyses of clinical measures of humeral range of motion and passive humeral internal/external rotation and scapular anterior/posterior tipping range of motion during active humeral rotation task.

		IR	ER	Total Arc	Sleeper IR	Posterior Capsule	Max IR	Scapular tipping @ Max IR	Max ER	Scapular Tipping @ Max ER
IR	Pearson Correlation	1	.397*	.833*	.669*	-.233	-.257	-.368	.492*	-.235
	Sig. (1-tailed)		.041	.000	.001	.161	.137	.055	.014	.160
ER	Pearson Correlation		1	.839*	.461*	-.158	-.127	-.115	.440*	-.202
	Sig. (1-tailed)			.000	.020	.252	.297	.315	.026	.196
Total Arc	Pearson Correlation			1	.675*	-.234	-.229	-.287	.557*	-.261
	Sig. (1-tailed)				.001	.160	.166	.110	.005	.133
Sleeper IR	Pearson Correlation				1	.015	-.066	-.089	.263	-.009
	Sig. (1-tailed)					.475	.391	.355	.131	.484
Posterior Capsule	Pearson Correlation					1	-.193	.181	-.310	.168
	Sig. (1-tailed)						.207	.222	.092	.240
Max IR	Pearson Correlation						1	.548	-.266	.308
	Sig. (1-tailed)							.006	.128	.093
Scapular tipping @ Max IR	Pearson Correlation							1	-.453*	.726*
	Sig. (1-tailed)								.022	.000
Max ER	Pearson Correlation								1	-.246
	Sig. (1-tailed)									.147
Scapular Tipping @ Max ER	Pearson Correlation									1

* Indicates significant Pearson r

Table 7. Descriptive statistics for clinical measures of passive humeral range of motion and three-dimensional measures of active humeral rotation and scapular anterior/posterior tipping range of motion during diagonal task.

	Mean (deg)	St Dev	$ICC_{(2,1)}$	SEM
Supine Internal Rotation	54.13	11.83	0.97	2.41
Supine External Rotation	121.67	11.55	0.98	1.43
Total Arc of Rotation	175.80	18.97		
Sleeper Internal Rotation	45.92	10.18	0.99	0.71
Posterior Capsule	24.49	3.52	0.99	0.28
Humeral Rotation @ 90º of Flexion range	39.68	47.84	0.99	1.72
Scapular Tipping @ 90º of Flexion range	12.31	12.74	0.98	1.42
Humeral Rotation @ Max Flexion range	20.25	36.74	0.98	3.79
Scapular Tipping @ Max Flexion Range	25.13	13.46	0.98	1.74

Table 8. Correlation analyses of clinical measures of humeral range of motion and humeral rotation and scapular anterior/posterior tipping during diagonal task.

		IR	ER	Total Arc	Sleeper IR	Posterior Capsule	Humeral Rotation @ 90 deg of Flexion	Scapular tipping @ 90 deg of Flexion	Humeral Rotation @ Max Flexion	Scapular tipping @ Max Flexion
IR	Pearson Correlation	1	.316	.816*	.655*	-.172	.049	-.367	.098	-.275
	Sig. (1-tailed)		.087	.000	.001	.234	.419	.055	.340	.120
ER	Pearson Correlation		1	.806*	.341	-.252	-.179	-.407	-.052	-.371
	Sig. (1-tailed)			.000	.071	.142	.225	.037	.414	.054
Total Arc	Pearson Correlation			1	.616*	-.261	-.079	-.477*	.030	-.397*
	Sig. (1-tailed)				.002	.133	.370	.017	.451	.041
Sleeper IR	Pearson Correlation				1	.086	.007	.074	.160	.199
	Sig. (1-tailed)					.359	.488	.378	.250	.201
Posterior Capsule	Pearson Correlation					1	.097	.414*	.088	.384*
	Sig. (1-tailed)						.342	.035	.356	.048
Humeral Rotation @ 90 deg of Flexion	Pearson Correlation						1	.136	.934*	.062
	Sig. (1-tailed)							.284	.000	.398
Scapular tipping @ 90 deg of Flexion	Pearson Correlation							1	.213	.903*
	Sig. (1-tailed)								.184	.000
Humeral Rotation @ Max Flexion	Pearson Correlation								1	.147
	Sig. (1-tailed)									.268
Scapular tipping @ Max Flexion	Pearson Correlation									1

* Indicates significant Pearson r

Table 9. Descriptive statistics for clinical measures of passive humeral range of motion and three-dimensional measures of scapular anterior/posterior tipping range of motion during flexion task.

	Mean (deg)	St Dev	$ICC_{(2,1)}$	SEM
Supine Internal Rotation	52.77	12.71	0.97	2.41
Supine External Rotation	120.45	11.01	0.98	1.43
Total Arc of Rotation	173.22	18.46		
Sleeper Internal Rotation	45.39	10.05	0.99	0.71
Posterior Capsule	25.20	4.06	0.99	0.28
Scapular Tipping at 90 degrees of Flexion range	12.50	13.09	0.99	0.99
Scapular Tipping at 120 degrees of Flexion range	20.01	17.81	0.99	0.86
Scapular Tipping at Maximum Flexion Range	33.01	18.00	0.99	1.06

Table 10. Correlation analyses of clinical measures of humeral range of motion and humeral flexion and scapular anterior/posterior tipping during flexion task.

		IR	ER	Total Arc	Sleeper IR	Posterior Capsule	Scapular tipping @ 90º of Flexion	Scapular tipping @ 120º of Flexion	Scapular tipping @ Max Flexion
IR	Pearson Correlation	1	.208	.812*	.694*	-.179	-.240	-.284	-.185
	Sig. (1-tailed)		.176	.000	.000	.213	.141	.106	.205
ER	Pearson Correlation		1	.740*	.291	-.275	-.111	-.205	-.186
	Sig. (1-tailed)			.000	.094	.108	.312	.186	.204
Total Arc	Pearson Correlation			1	.651*	-.287	-.231	-.314	-.238
	Sig. (1-tailed)				.001	.098	.150	.083	.143
Sleeper IR	Pearson Correlation				1	.008	.069	.000	.106
	Sig. (1-tailed)					.485	.380	.500	.319
Posterior Capsule	Pearson Correlation					1	.256	.281	.249
	Sig. (1-tailed)						.125	.108	.132
Scapular tipping @ 90º of Flexion	Pearson Correlation						1	.972*	.805*
	Sig. (1-tailed)							.000	.000
Scapular tipping @ 120º of Flexion	Pearson Correlation							1	.940*
	Sig. (1-tailed)								.000
Scapular tipping @ Max Flexion	Pearson Correlation								1

* Indicates significant Pearson r

Appendix B

Figures

Figure 1. End position of shoulder flexion ROM

Figure 2. End position of shoulder internal rotation ROM.

Figure 3. End position of shoulder external rotation ROM.

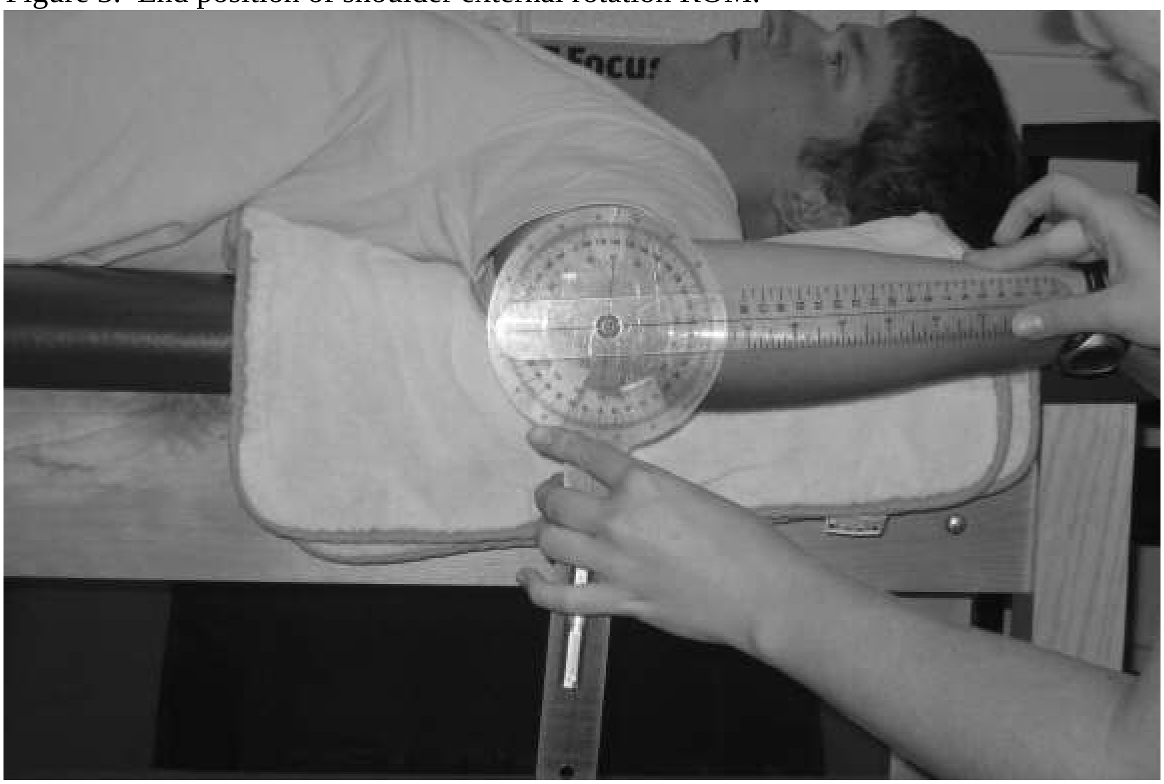

Figure 4. End position of shoulder sleeper internal rotation ROM.

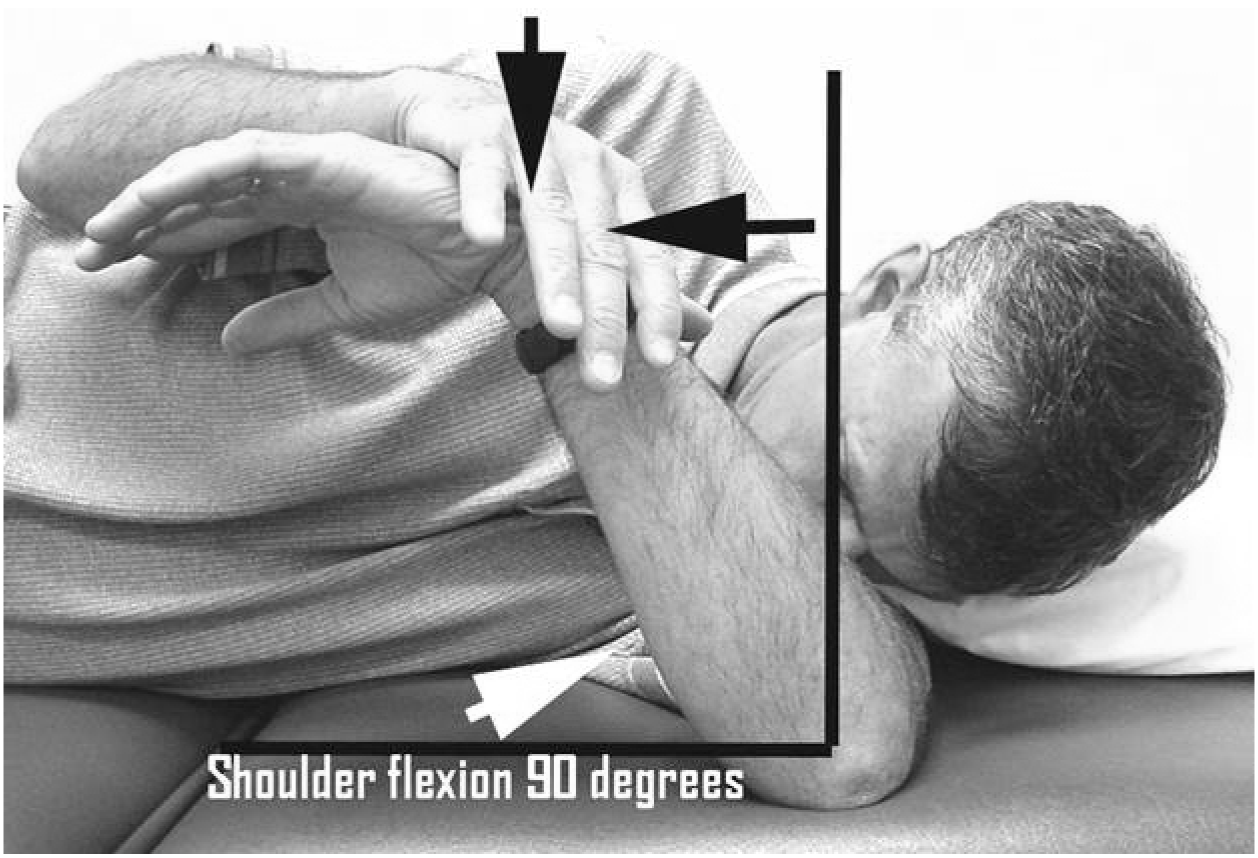

Figure 5. End position of posterior shoulder tightness measure.

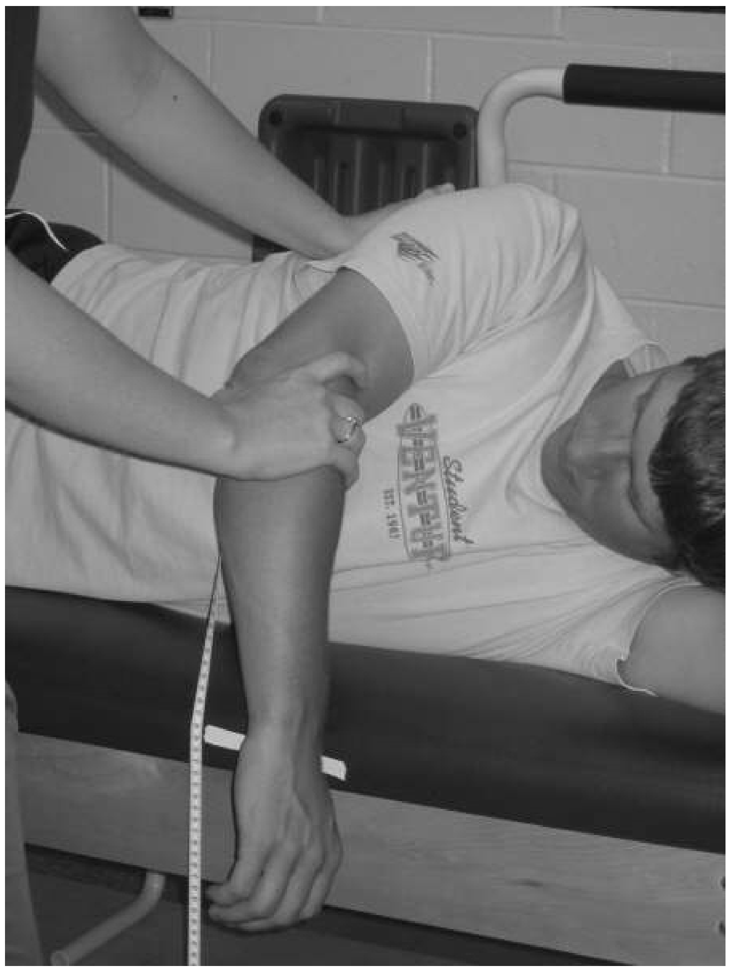

Figure 6. Set up of electromagnetic sensors on C7, acromion and posterior humerus according to ISB.

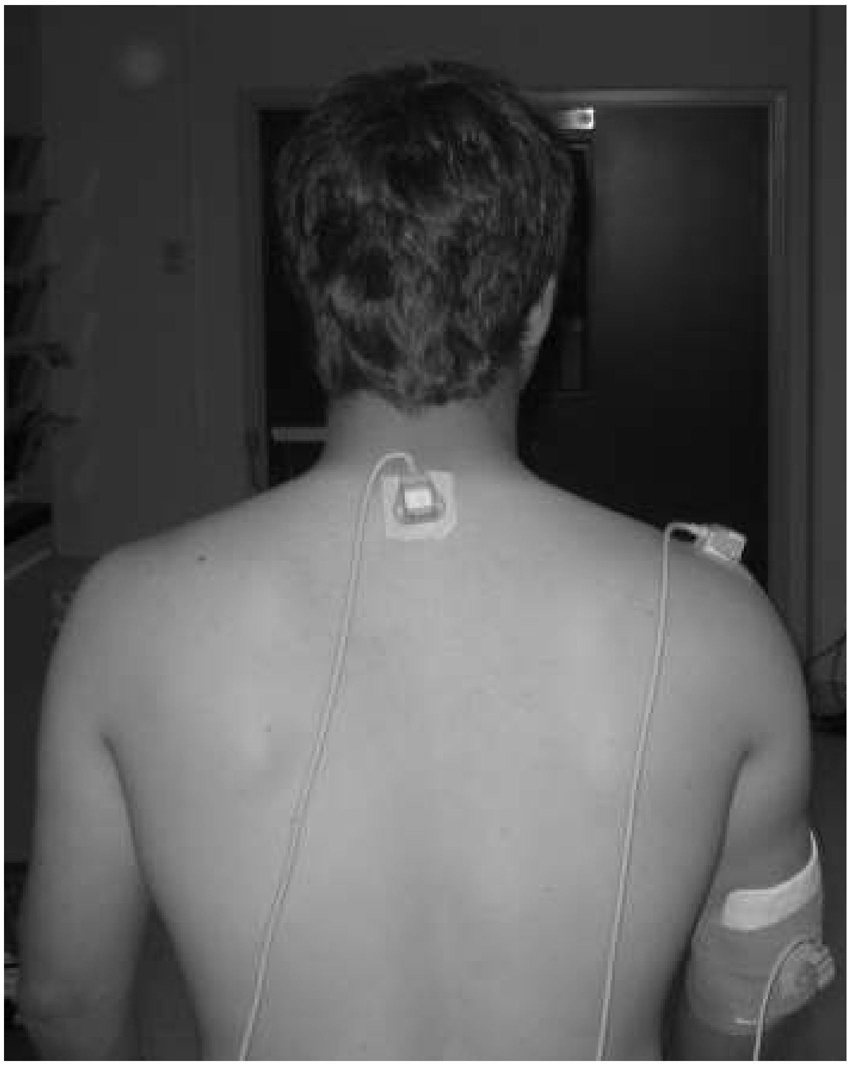

Figure 7. Thermoplastic cuff attached to posterior humerus

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Figure 8. Anterior digitized landmarks

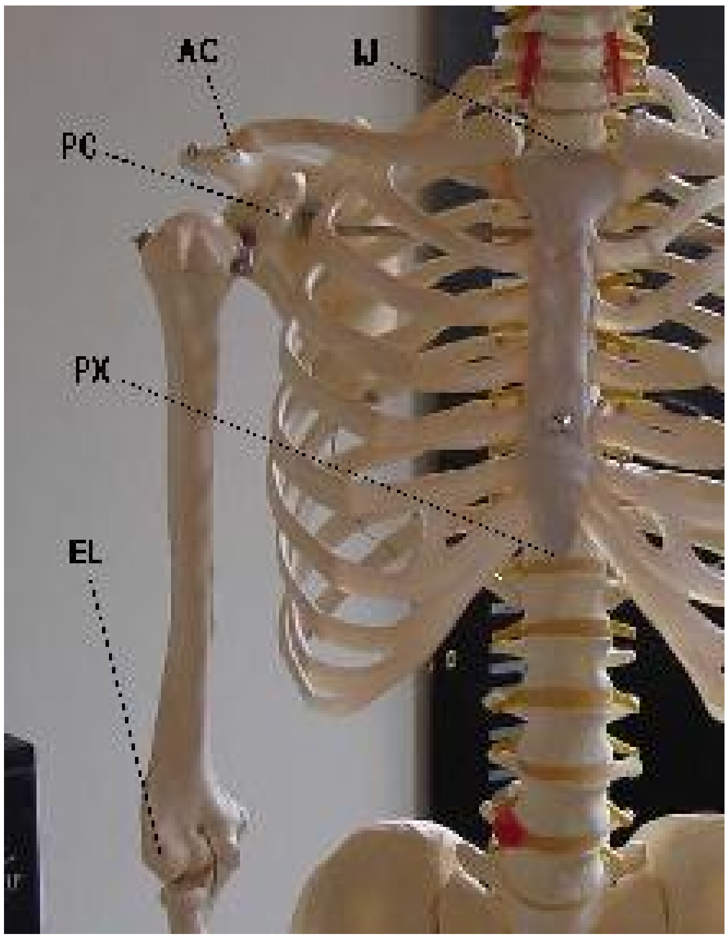


Figure 9. Posterior digitized landmarks

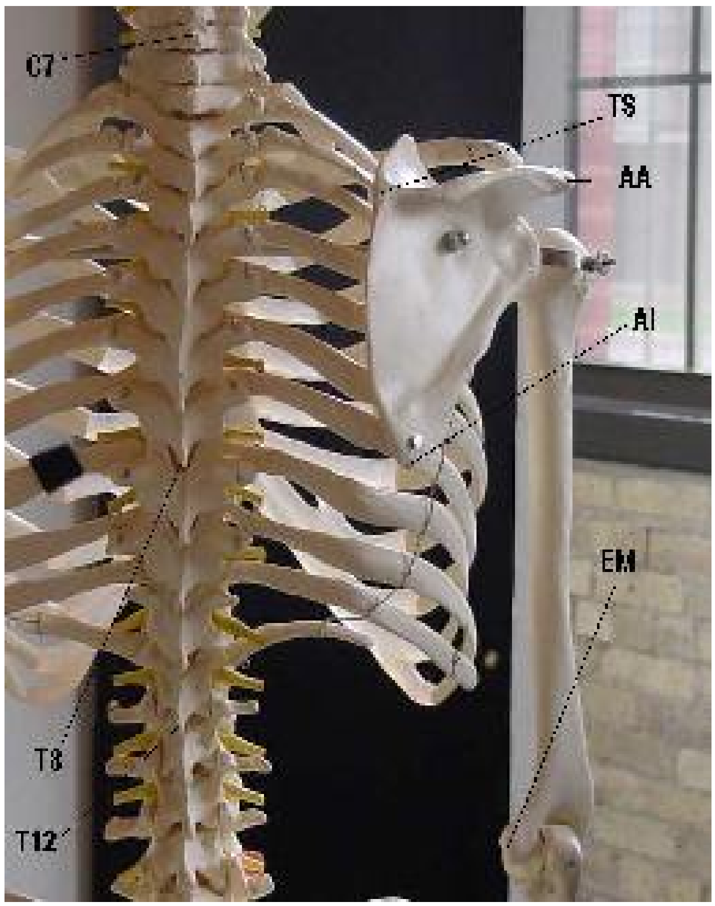


Figure 10. Starting position of active rotation task.

Figure 11. End position of maximum humeral IR during active rotation task.

Figure 12. End position of maximum humeral ER during active rotation task.

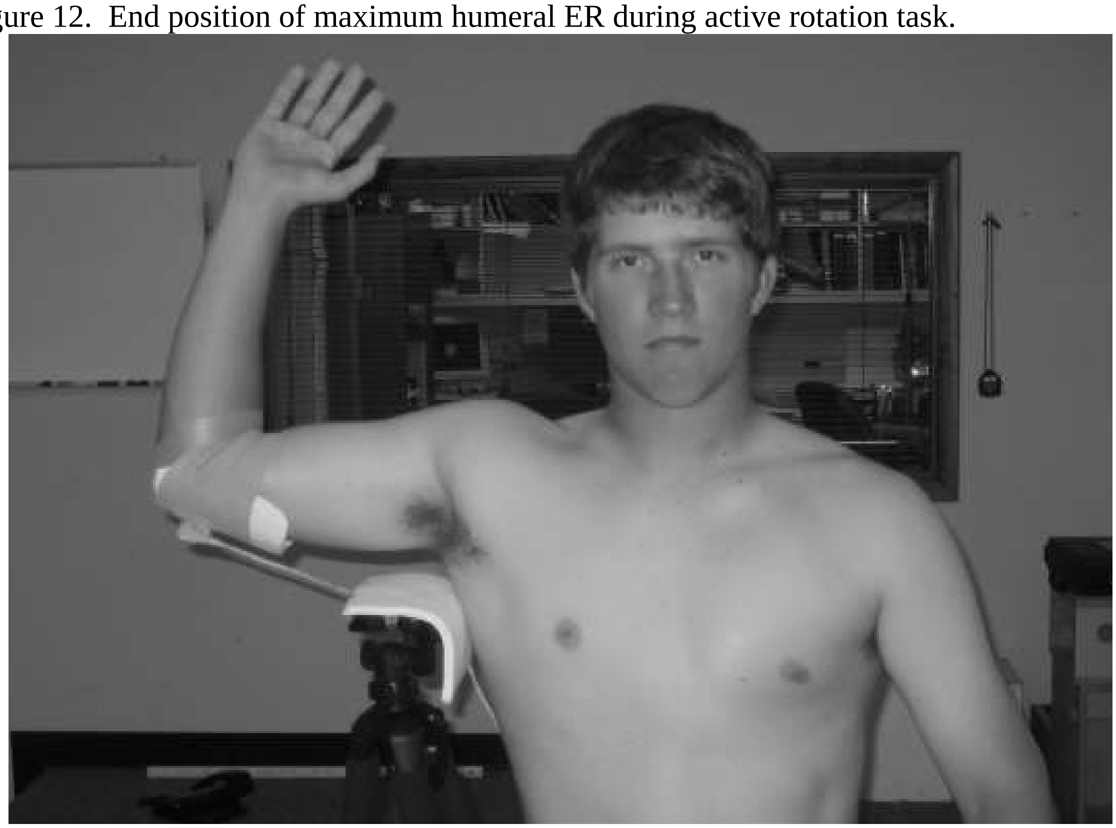


Figure 13. Starting position of passive rotation task.

Figure 14. Maximal humeral IR during passive rotation task.

Figure 15. Maximal humeral ER during passive rotation task.

Figure 16 & 17. Starting position of flexion task. End position of flexion task.

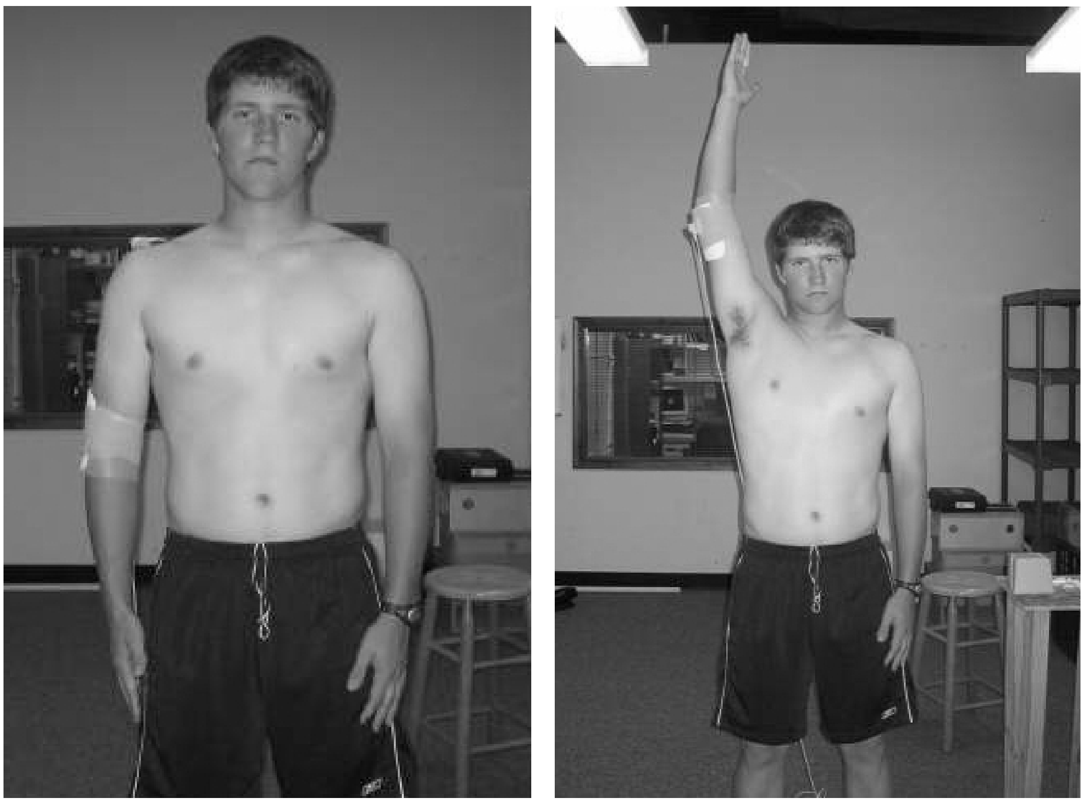


Figure 18 & 19. Starting position of functional diagonal pattern. End position of functional diagonal pattern.

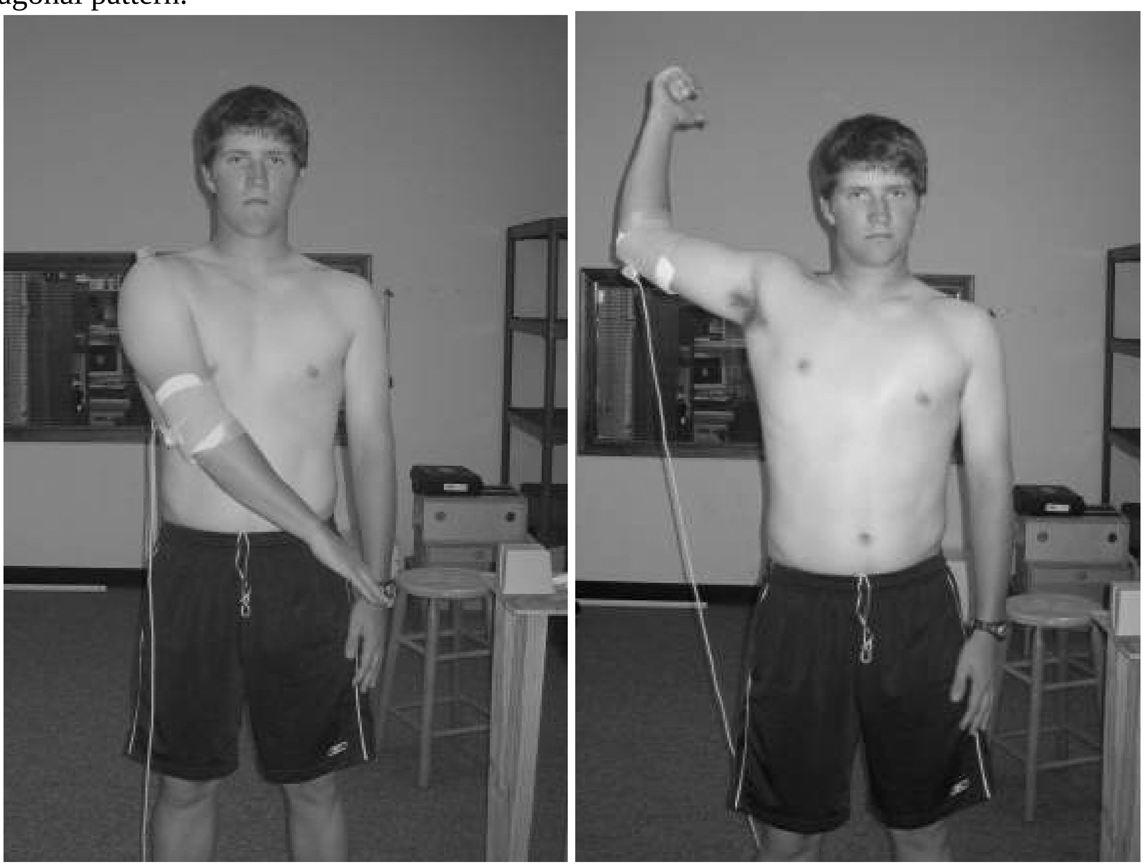


Figure 20. Scapular local axis system and bony landmarks.

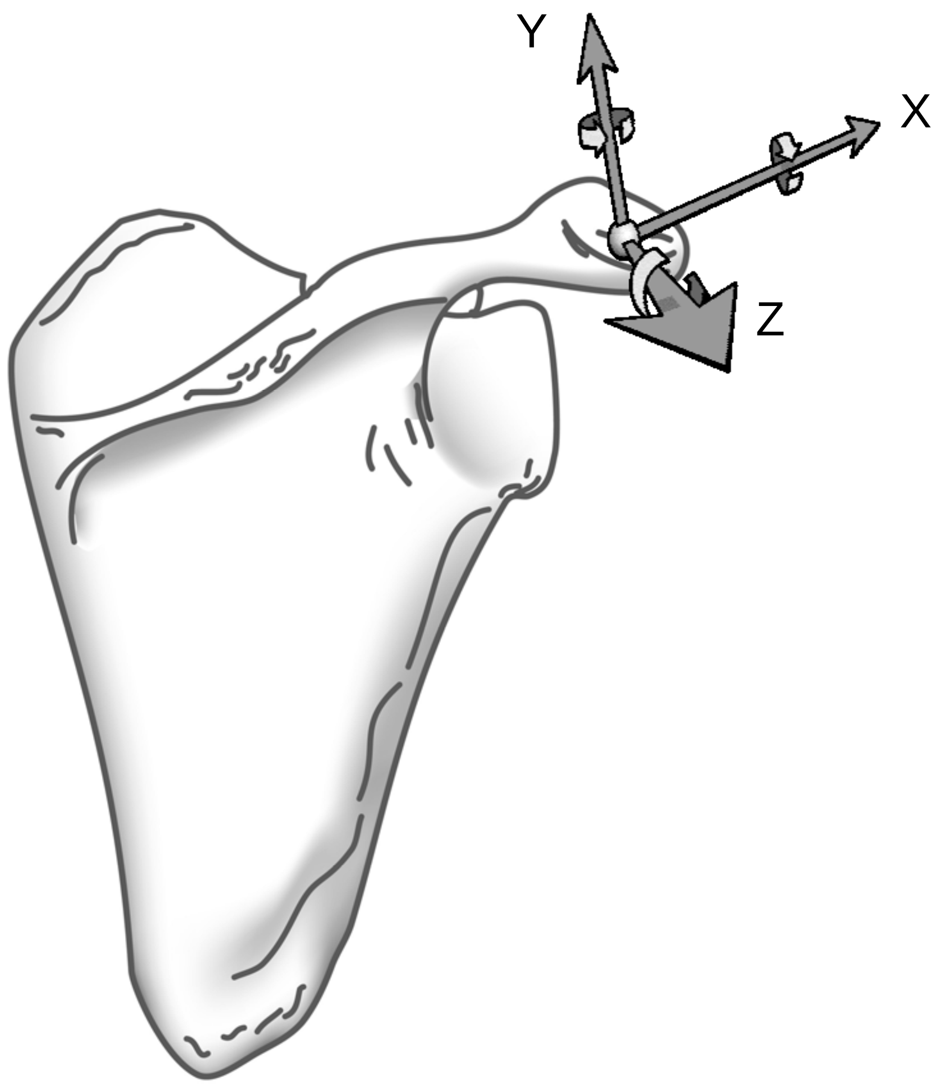


Figure 21. Humeral local axis system and bony landmarks

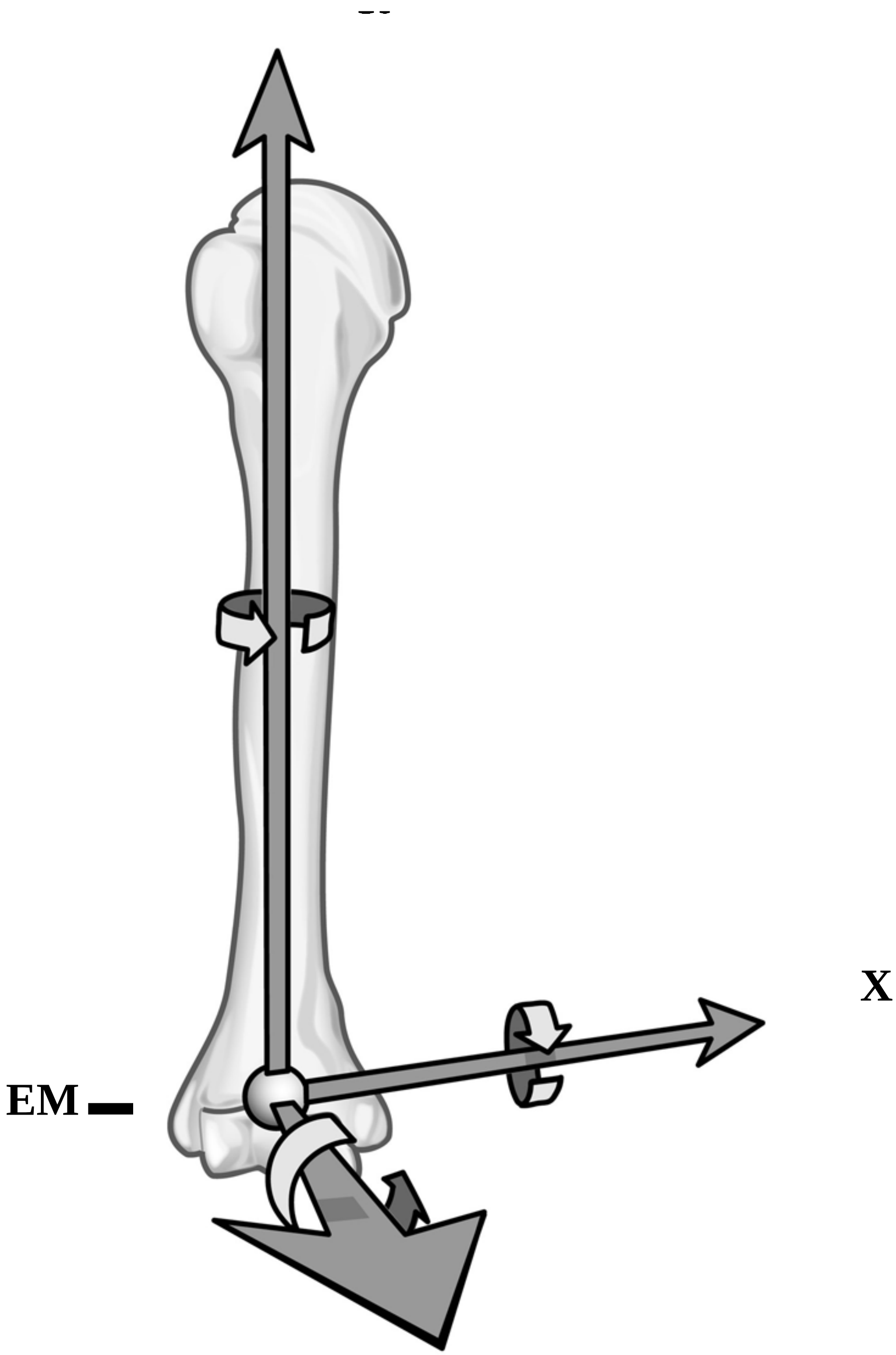


Figure 22. Thoracic local axis system and bony landmarks

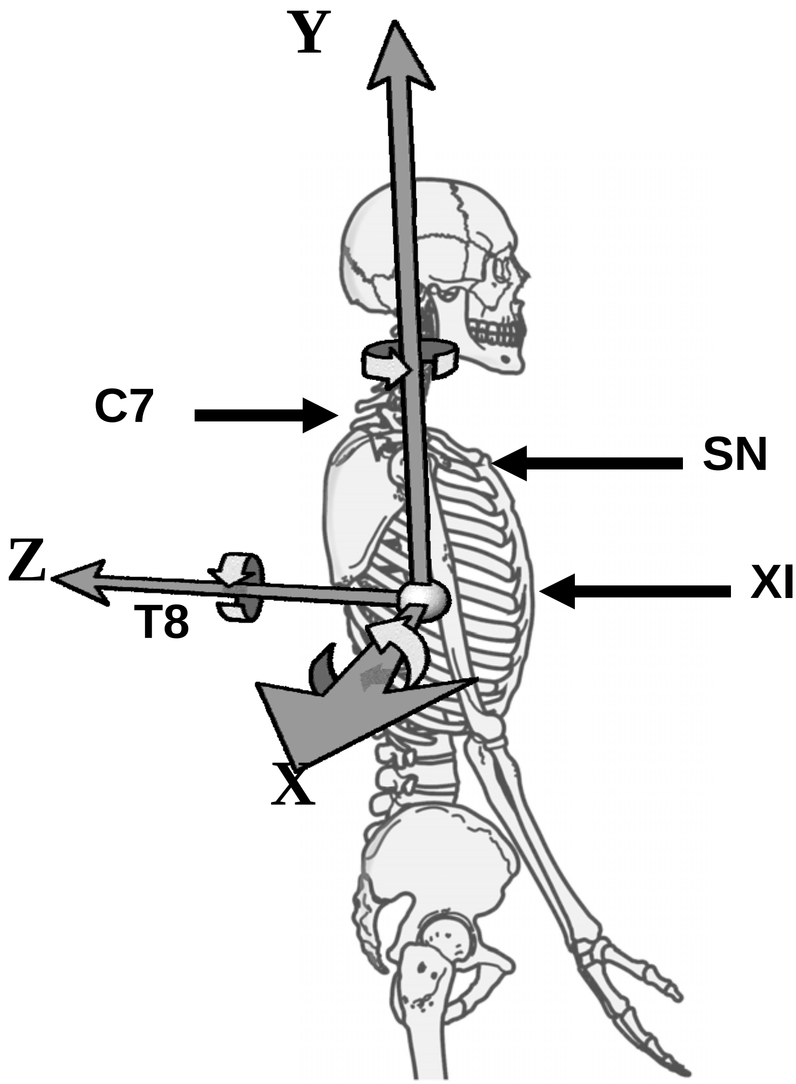


Figure 23. Scatter plot of shoulder internal rotation ROM and scapular tipping ROM at maximum humeral IR during the passive humeral rotation task.

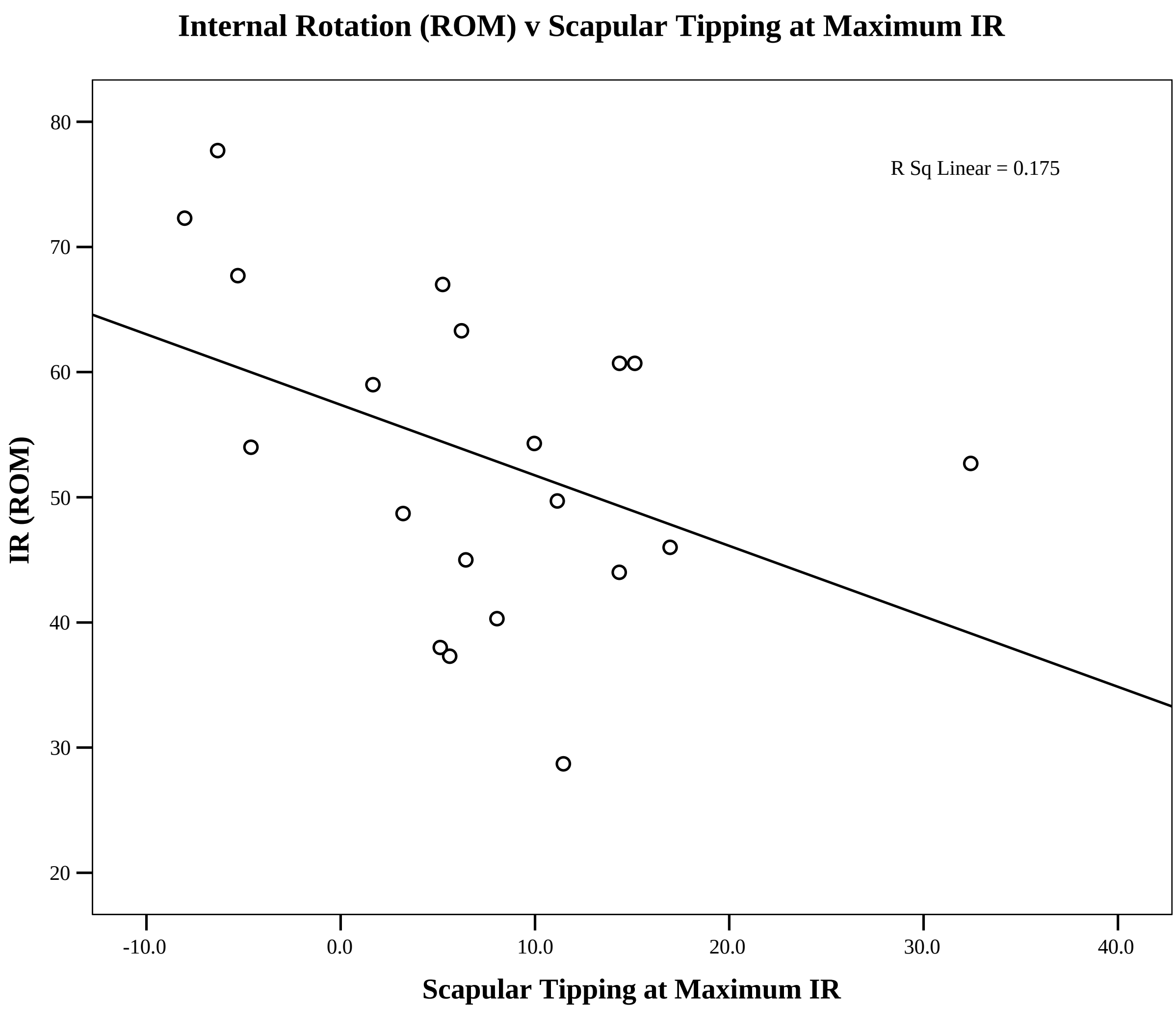


Figure 24. Scatter plot of total arc of shoulder rotation ROM and scapular tipping ROM at maximum humeral IR during the passive humeral rotation task.

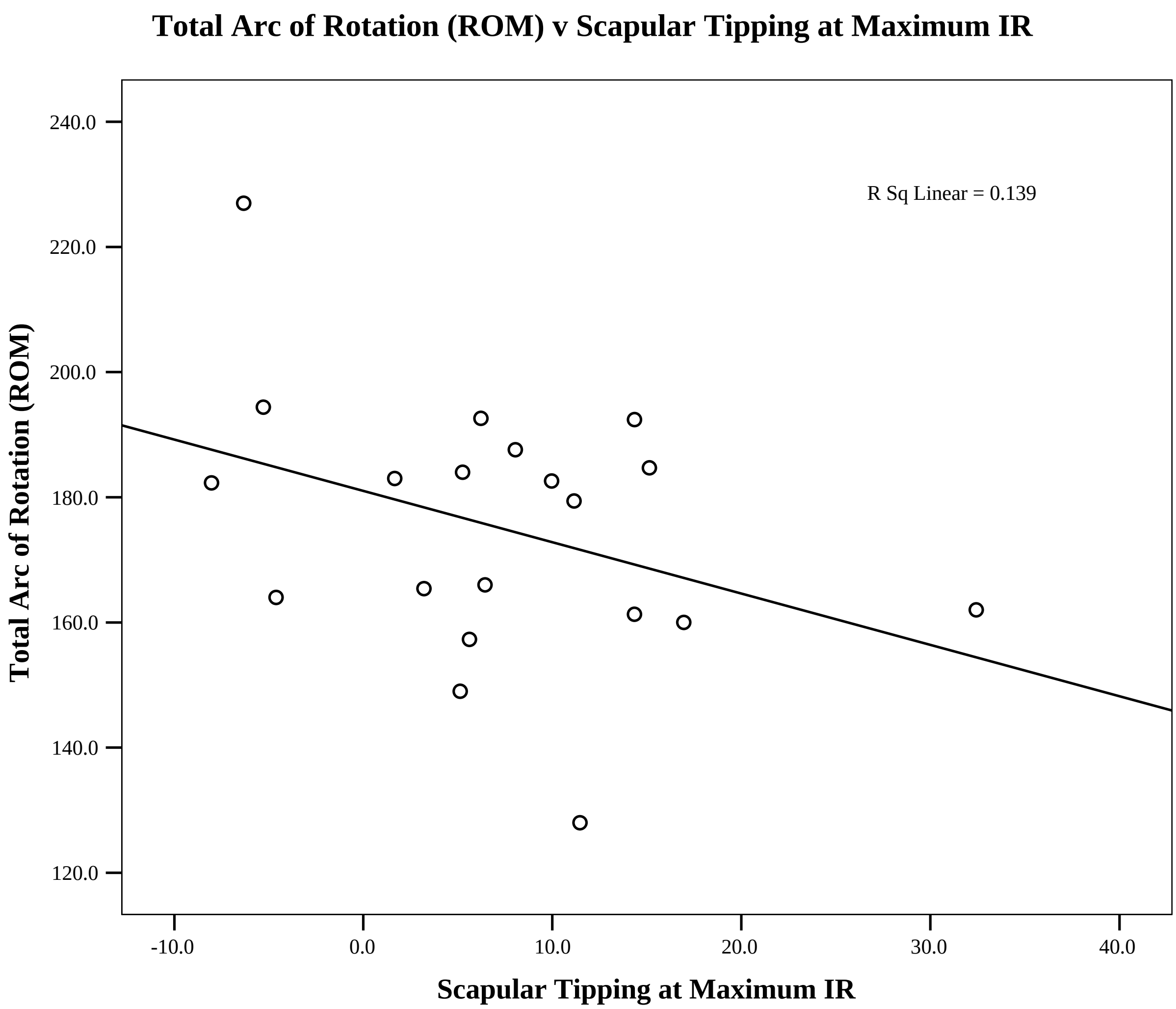


Figure 25. Scatter plot of shoulder internal rotation ROM and scapular tipping ROM at maximum humeral IR during the active humeral rotation task.

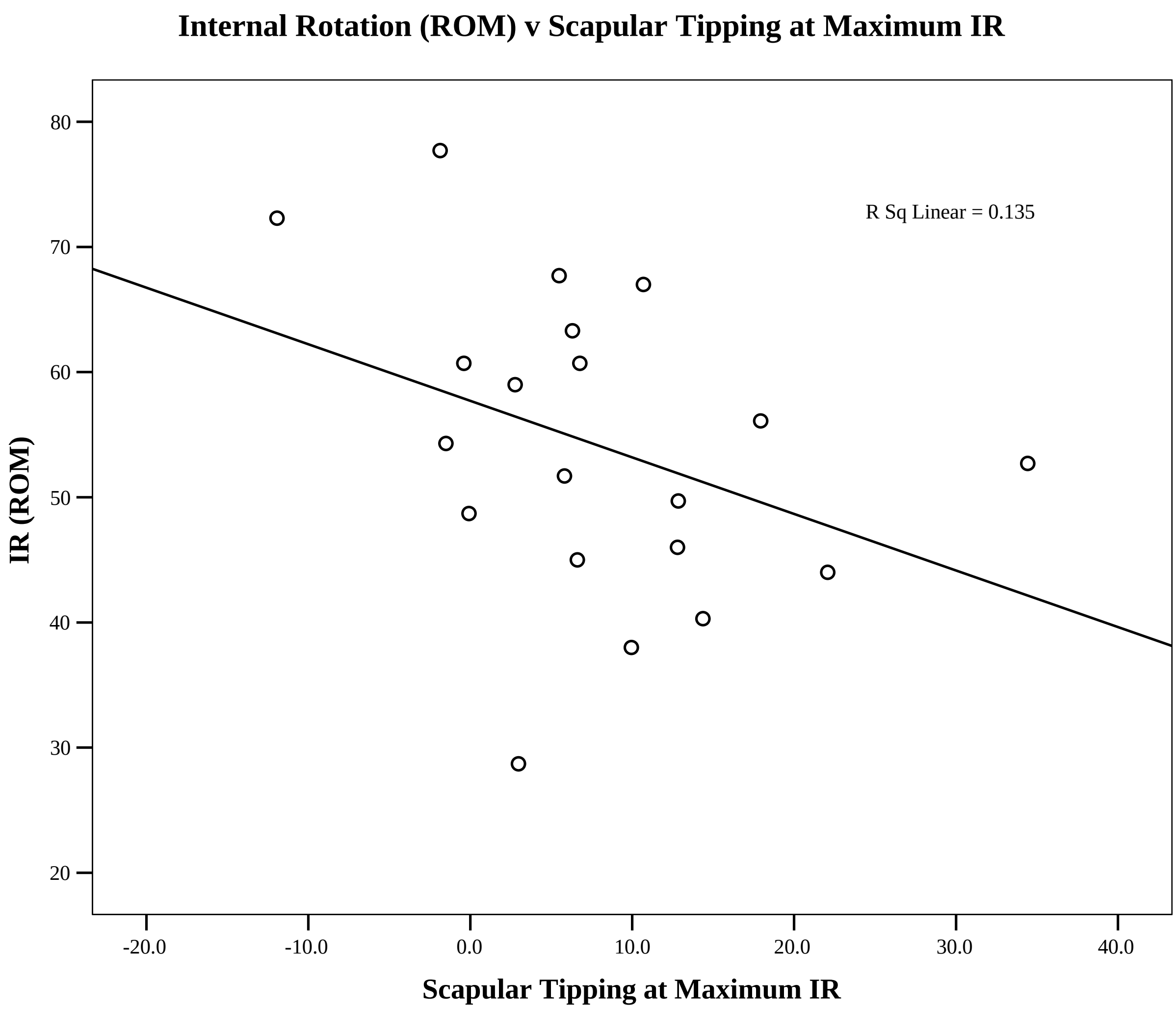


Figure 26. Scatter plot of shoulder internal rotation ROM and scapular tipping ROM at 90º of humeral flexion during the functional diagonal task

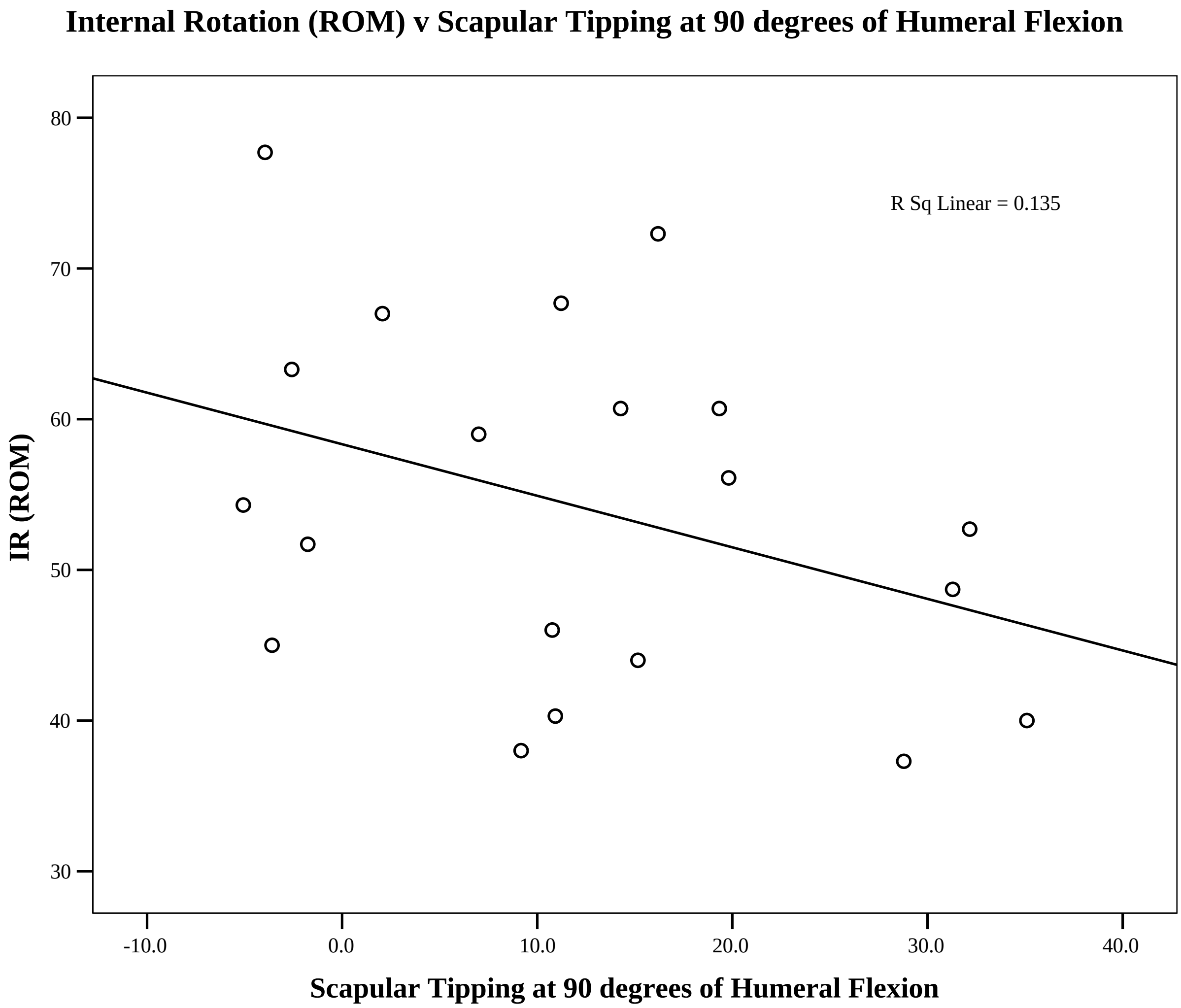


Figure 27. Scatter plot of total arc of shoulder rotation ROM and scapular tipping ROM at 90º of humeral flexion during the functional diagonal task.

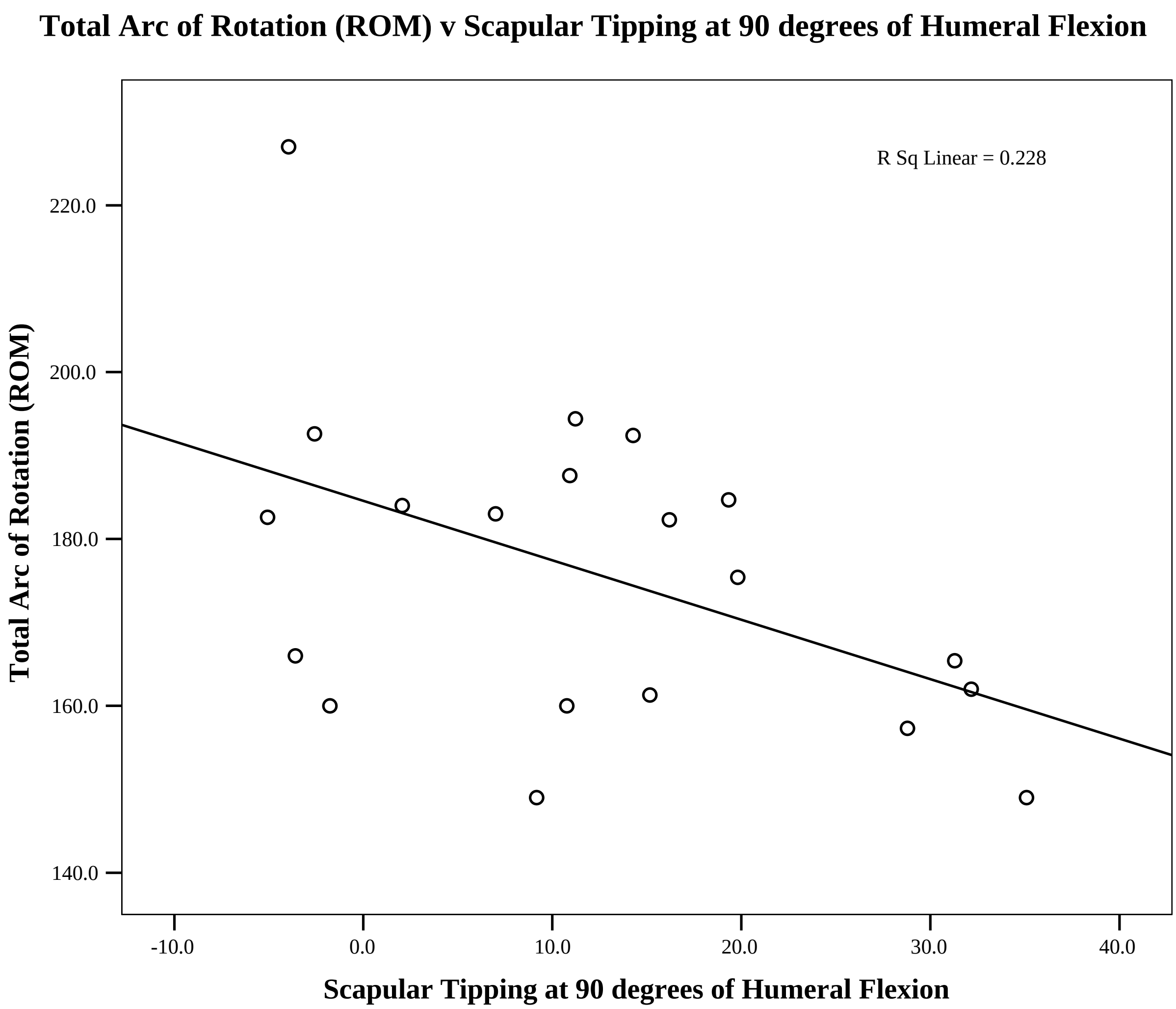


Figure 28. Scatter plot of total arc of shoulder rotation ROM and scapular tipping ROM at maximum humeral flexion during the functional diagonal task

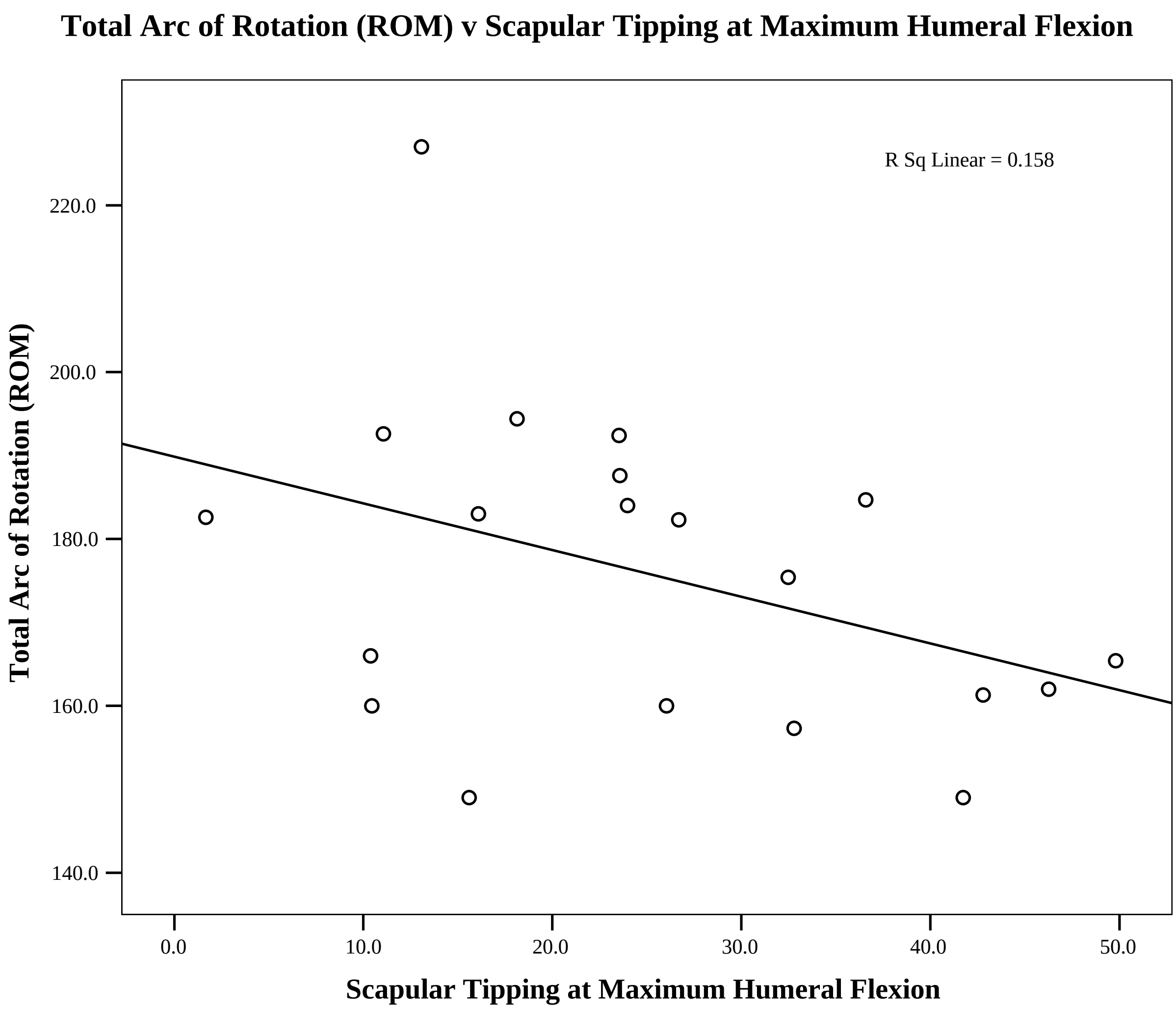


Figure 29. Scatter plot of posterior shoulder flexibility measure and scapular tipping ROM at 90º of humeral flexion during the functional diagonal task

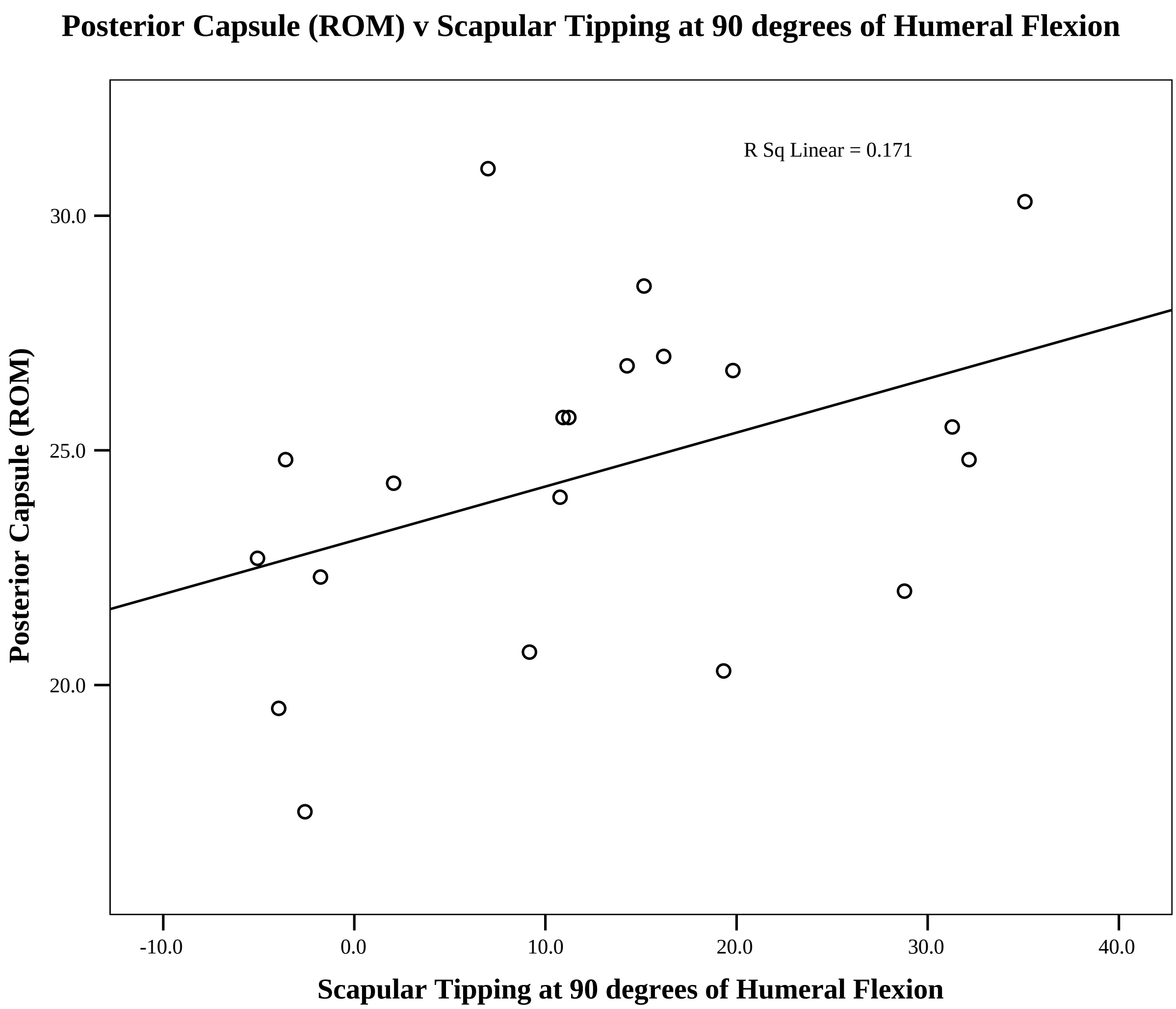
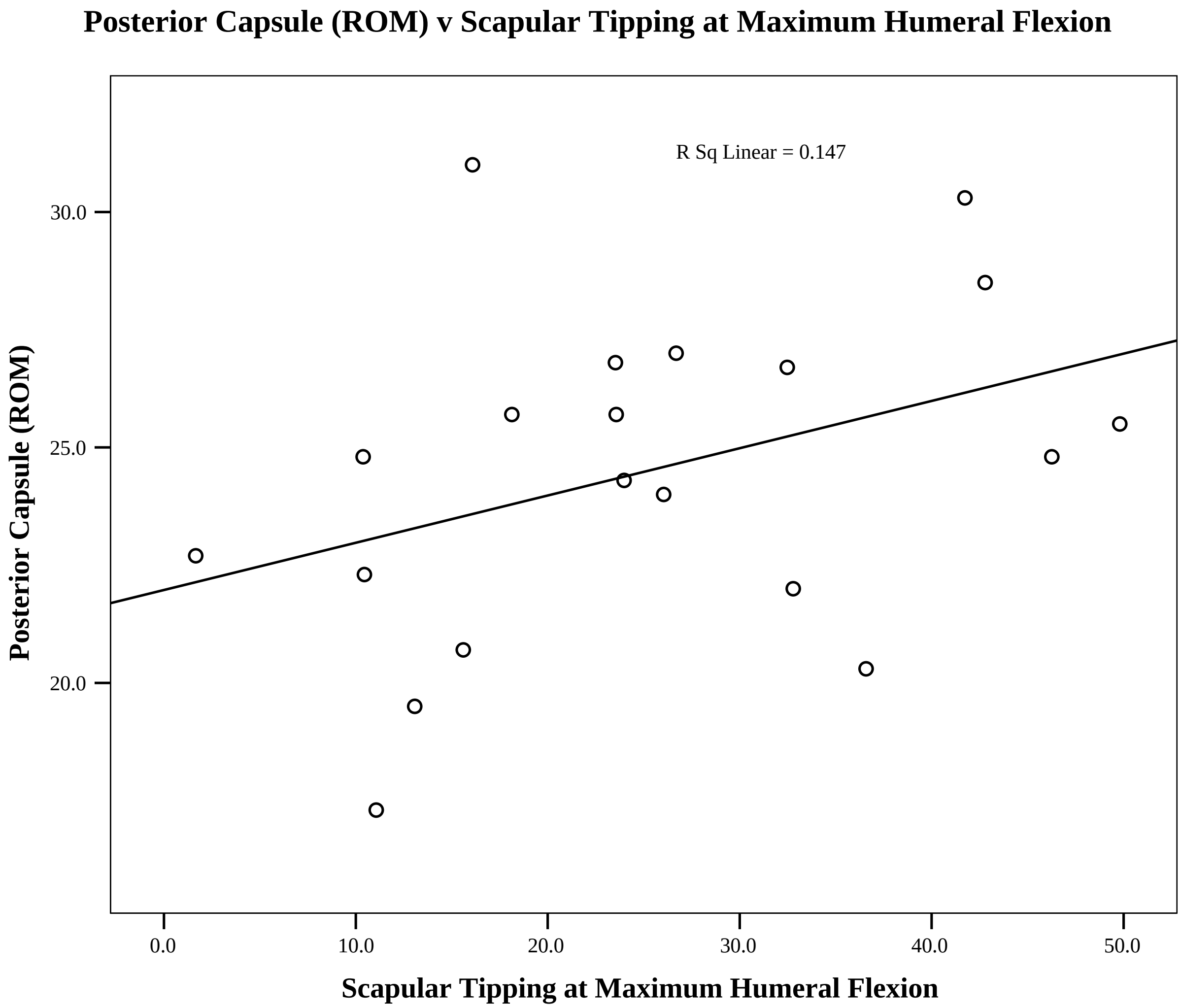


Figure 30. Scatter plot of posterior shoulder flexibility measure and scapular tipping ROM at maximum humeral flexion during the functional diagonal task



Appendix C

Manuscript

INTRODUCTION

Shoulder injury is a common complaint in athletics, accounting for 8-13% of all athletic injuries (Hill 1983). Overhead athletes are at risk to develop shoulder pain as evidenced by 43.8 % of volleyball players and swimmers reporting shoulder pain (Lo 1990). Additionally, 50% of adolescent baseball pitchers report a greater incidence of shoulder and/or elbow pain(Tullos and King 1973; Lo, Hsu et al. 1990). The increased incidence and prevalence of shoulder injuries is thought to be the result of the tremendous amount of stress on the shoulder. Angular velocity during pitching approximates 7000°/s while a tennis serve can approach 1500°/s (Kibler 1995; Williams and Kelley 2000). These velocities produce distraction forces that can reach approximately 80% of body weight (Williams and Kelley 2000; Burkhart, Morgan et al. 2003). Not only are there high velocities and large loads, but also overhead activities in athletics are typically very repetitive. The repetitive nature of overhead athletics is thought to accelerate the process of tissue degeneration leading to the development of shoulder pain (Neer 1983).

One common source of shoulder pain in the overhead athlete is subacromial impingement, which is characterized by compression or abrasion of the rotator cuff as it passes under the coracoacromial arch during shoulder elevation (Ludewig and Cook 2000). An asymmetrical capsule, implicating capsuloligamentous laxity or contracture, and poor scapular mechanics have been suggested as possible mechanisms that create subacromial impingement (Williams and Kelley 2000). Many overhead athletes display posterior shoulder inflexibility suggested to result from repetitive hyper-external rotation and deceleration of the humerus (Burkhart, Morgan et al. 2003). Posterior shoulder inflexibility resulting from posterior capsule contracture and/or posterior rotator cuff (RTC) tightness is clinically seen as a loss of glenohumeral (GH) internal rotation (IR). Glenohumeral Internal Rotation Deficit (GIRD) is defined as the loss of 25º of IR as compared to the non-throwing shoulder (Burkhart, Morgan et al. 2003). Burkhart et al. (2003) described the loss of IR as the most important pathological process that occurs in throwers. Overhead athletes display anterior GH laxity which is hypothesized to be a result of repetitive stretching of the anterior capsule and anterior inferior GH ligament during abduction and external rotation (ER) of the humerus (Burkhart, Morgan et al. 2003). It is thought that posterior shoulder inflexibility and anterior laxity results in a superior and anterior migration of the humeral head in the glenoid further putting the athlete at risk for impingement and labral tears (Tyler, Nicholas et al. 2000).

Another potential risk factor for shoulder pain is aberrant scapular mechanics (Burkhart, Morgan et al. 2003). Traditionally, scapulohumeral rhythm has been defined as the ratio between GH elevation and scapular upward rotation, which is approximately 2:1. However, recent evidence shows that the relationship of humeral elevation and scapular motion is more complex. The scapula upwardly rotates, posteriorly tips and externally rotates as humeral elevation increases. Clinical theory suggests adequate scapular upward rotation, posterior tipping, and external rotation during humeral elevation allows the lateral acromion to clear the greater tuberosity (Litchfield, Hawkins et al. 1993; Lukasiewicz, McClure et al. 1999). Individuals with subacromial impingement exhibit altered scapular kinematics resulting in increased scapular anterior tipping at the end of range of motion during elevation (ROM) (Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000; McClure, Bialker et al. 2004). Increased scapular upward and external rotation during humeral elevation have been reported following shoulder girdle fatigue (McQuade, Dawson et al. 1998; Ebaugh, McClure et al. 2005). This indicates greater scapulothoracic motion was observed with less GH motion. Additionally, decreased humeral rotation was observed during humeral elevation following the fatigue protocol during shoulder elevation (Ebaugh, McClure et al. 2005). This highlights the importance of scapular kinematics and humeral rotation.

While it is clear that humeral elevation influences scapular motion, the effect of humeral rotation on scapular kinematics is not well understood. Alterations in scapular motion have been attributed to changes in humeral rotation when the plane and degree of humeral elevation have been controlled (Ebaugh, McClure et al. 2005; Thigpen, Padua et al. 2006). It has been suggested that during humeral IR, the scapula remains internally rotated and anteriorly tipped because the posterior capsule and RTC tension pulling the scapula more forward. It is hypothesized that inflexibility of the posterior shoulder will cause "pulling" of the scapula resulting in earlier scapular anterior tipping during humeral IR and delayed scapular posterior tipping during humeral ER (Borsa, Timmons et al. 2003). These alterations in scapular anterior and posterior tipping may decrease the subacromial space. Understanding the relationship of humeral rotation and scapular tipping may be important in the treatment and prevention of shoulder pain.

Therefore, the purpose of this study is to determine the relationship between humeral rotation and scapular tipping during passive and active rotation tasks, humeral flexion task and functional diagonal task. A secondary purpose of the study is to determine the relationship clinical measures of ROM and scapular tipping during passive and active rotation tasks, humeral flexion task and functional diagonal task.

METHODS

Subjects

Twenty-five healthy individuals (Age, 21.6 ± 2.18 years; Mass, 77.0±14.6 kg; Height, 178.7 ± 10.9 cm) volunteered to participate in this study. Subjects were recruited with informational flyers and verbal requisition. Subjects were excluded if they suffered from any shoulder pain during testing. Subjects were also excluded if they had undergone shoulder surgery or formal rehabilitation for shoulder injury within the last year; in addition, if they had sustained a GH joint dislocation or subluxation within the past year or had missed more than two weeks of activity because of an upper extremity injury during the past year. The principal investigator evaluated all subjects. Subjects were briefed on the testing procedures and were asked to sign an informed consent approved by the University of North Carolina Biomedical Institutional Review Board and complete a brief medical history questionnaire prior to testing. Descriptive statistics for the subjects are presented in Table 1.

The subjects reported to the Sports Medicine Research Laboratory on one occasion for testing. The subject's height (cm), mass (kg), age (yrs) and dominant arm were all recorded at this time. Arm dominance was determined by the hand with which the subjects would throw a ball. During the testing session, ROM and scapular kinematics were assessed. The order of ROM and scapular kinematics testing were counterbalanced to limit learning, investigator bias, and error.

Instrumentation

The three-dimensional kinematics of humeral and scapular motion was measured using the Flock of Birds ® electromagnetic motion analysis system (Ascension Technology

Corporation; Burlington, VT) controlled by Motion Monitor (Innovative Sports Training, Inc.; Chicago, IL) data acquisition computer software. Lightweight electromagnetic sensors (2.3 X 2.8 X 1.5 cm, 17 g) were attached to the dominant or test arm using double-sided adhesive tape. A standard range direct current transmitter containing three orthogonal coils that generate an electromagnetic field was mounted on a plastic shelving unit near each subject allowing joint and segment orientation to be collected by Motion Monitor. The three sensors attached to the subject recorded the electromagnetic changes in the field generated by the transmitter and then transferred the signals to a recording computer via hard wiring. The electromagnetic motion analysis system was calibrated prior to data collection. The electromagnetic motion analysis was set up according to the International Society of Biomechanics Shoulder Group (van der Helm 2004). At a sampling rate of 50 Hz, a wooden stylus attached to a sensor was configured and the three-dimensional world axis system was defined with a point 0.2m down the X-axis which is anterior or in the direction the subject is facing. The Z-axis was defined by a point 0.2m from the origin in the lateral direction or to the right of the subject. The Y-axis was defined as the vertical axis. Electromagnetic sensors were adhered using double-sided tape on the subject's dominant shoulder on the distal humerus, the broad surface of the acromion angle, and the C7 spinous process (Figure 6). The distal humerus sensor was secured onto a custom thermoplastic cuff to better represent humeral rotation (Figure 7). Ludewig et al. (2002) reported a surface-mounted sensor closely represented underlying angular movements when compared to a bone-fixed sensor. The study revealed valid measures of movement to the last 5º of motion with a thermoplastic cuff and valid measures of movement to the last 15 º of motion without a thermoplastic cuff (Ludewig, Cook et al. 2002). Next, with the subjects standing in a neutral position with arms at their sides, body segments were digitized by using the stylus to locate specific anatomical landmarks. Anatomical landmarks digitized include T12/L1, T8, C7, sternal notch (IJ), xiphoid process (PX), medial scapular spine (TS), inferior angle of scapula (AI), acromion process (AA), and medial and lateral epicondyles of humerus (EM, EL) (van der Helm 2004) (Figures 8 & 9). The thorax was defined by the positions of the C7, T8, T12, PX and IJ. The position of the scapula was defined by TS, AI and AA. The digitized points on the EM and EL were used to define the position of the humerus during data collection.

A universal goniometer with an attached bubble level was used to measure shoulder flexion ROM, shoulder internal rotation ROM, shoulder external rotation ROM and shoulder sleeper internal rotation ROM. The total arc of shoulder rotation ROM was calculated using the ROM taken from the shoulder internal rotation ROM and shoulder external rotation ROM. A standard tape measure was used to assess posterior shoulder flexibility as proposed by Tyler et al. (Tyler, Nicholas et al. 2000).

<u>Range of Motion Assessment</u>

Shoulder flexion ROM was assessed according to the procedure described in Norkin and White (Norkin and White 1985). To assess ROM the subject lay supine on a standard treatment table with his or her arm at the side. This position was defined as the starting position and described as 0° of flexion. The subject moved his or her arm into flexion and given a slight overpressure by investigator at the end position. The end position was determined by a cessation of movement (Figure 1). The procedure was repeated for three trials and was measured in degrees.

Shoulder internal rotation ROM was measured in supine with the arm abducted to 90º and the elbow flexed to 90º with a towel to support the humerus. In this position, the tester passively moved the arm into internal rotation. Using the manual stabilization method proposed by Ellenbecker et al (1996), the principal investigator measured internal rotation ROM at the shoulder by passively internally rotating the arm, while stabilizing the scapula at the coracoid process (Ellenbecker, Roetert et al. 2002). The subject began with the forearm perpendicular to the floor. This position was defined as the starting position and describes 0º of rotation. The end position was defined as the cessation of rotation or sensation of scapular movement (Figure 2). The goniometer axis was placed over the olecranon process, the stationary arm was positioned perpendicular to the floor, and the movable arm was aligned with the ulnar styloid (Norkin and White 1985). We demonstrated this technique revealed intersession reliability of .97 (SEM = 2.415) and intrasession reliability of .98 (SEM = 2.068). This procedure was repeated for three trials and was measured in degrees. The mean degree of ROM was recorded.

External rotation was measured with similar techniques as internal rotation. The subject's arm was passively moved into external rotation (Figure 3). The procedure was repeated for three trials and was measured in degrees.

The subject's shoulder sleeper internal rotation ROM was then measured as a suggested method to better isolate humeral rotation from scapular motion (Burkhart, Morgan et al. 2003). The subject was positioned side-lying on the side of their dominant arm. Shoulder was positioned in 90° of flexion with both acromion processes aligned perpendicular to the table. The elbow was positioned in 90° of flexion. The subject began with the forearm perpendicular to the table, which was defined as the starting position and 0°

of rotation. The subject then grasped and pushed their forearm of the dominant arm toward the table. The end position was indicated by the cessation of rotation (Figure 4). A normal ROM consists of 60-70° of motion. The procedure was performed bilaterally, repeated for three trials and was measured in degrees.

Posterior shoulder flexibility was also assessed. A procedure introduced by Tyler et al. (2000) measures horizontal adduction (Tyler, Nicholas et al. 2000). The amount of horizontal adduction indicates the amount of posterior shoulder flexibility. This procedure required the subject to lie on the side of the non-dominant arm. The legs were positioned with the knees in 90º of flexion and hips in 90º of flexion. The back was perpendicular to the table. The non-dominant arm was placed under the subject's head. A mark with a felt tip marker was placed on the medial epicondyle of the dominant arm. Both acromion processes were aligned perpendicular to the treatment table. The investigator faced the subject and stabilized the lateral border of the scapula in a retracted position, in order to restrict scapular movement. The starting position consisted of 90º of abduction and 0º of rotation. The subject was instructed to relax and the tester lowered his or her arm into humeral adduction while maintaining 0º of rotation and scapular stabilization. End position was defined as maximal horizontal adduction or initiation of scapular movement (Figure 5). Using a standard tape measure, the investigator measured the distance from the bottom of the treatment table to the mark on the medial epicondyle. The procedure was performed three times on each limb and was measured in centimeters. Posterior shoulder flexibility was calculated as the difference in measured horizontal adduction between the dominant arm and non-dominant arm. A greater distance between the table and the medial epicondyle indicates greater shoulder inflexibility. Typical range of measurement is approximately 2-7 cm (Tyler et al. 2000)

Shoulder Kinematics Protocol

Subjects were tested in the active and passive rotation tasks while seated. An adjustable tripod was used as an armrest in order to limit humeral elevation. A small platform constructed of thermoplastic material was attached onto the tripod in order to allow the subject to maintain the abducted position and decrease translation of the elbow on the tripod. Subjects were seated with their shoulder propped at 90º of abduction and elbow at 90º of flexion. The investigator verbally instructed the subjects how to complete the task and gave feedback about ROM throughout the task.

Active rotation task was performed. The starting position was defined as the palm of the hand facing caudally with the forearm positioned parallel to the floor (Figure 10). Each subject was taken through the available ROM passively before performing the task to become familiar with the ROM. The subject was given three practice trials. During these trials, the subject was given verbal feedback to correct the motion. The investigator verbally instructed the subjects to initiate movement into internal rotation followed by external rotation (Figures 11 & 12). Seven test trials were done. The mean range of scapular tipping taken at maximum humeral IR and maximal humeral ER during the middle five test trials was recorded.

The passive rotation task was then performed. The subject was instructed to relax and allow the investigator to take his or her arm through the entire available ROM. The starting position was defined as the palm of the hand facing caudally with the forearm positioned parallel to the floor (Figure 13). Three practice trials were done to assure the subject was relaxed and was not assisting with motion. The investigator initiated movement into IR followed by ER (Figures 14 & 15). The investigator performed seven test trials. The mean range of scapular tipping taken at maximum humeral IR and maximum humeral ER during the middle five test trials was recorded.

The subject then performed a humeral flexion task. The subject was instructed to stand in anatomical position with their thumbs pointing forward which was defined as the starting position (Figure 16). The subject was instructed to maximally elevate the arm in the sagittal plane (Figure 17). The subject was given three practice trials, followed by seven test trials. The mean range of scapular tipping taken at 90º of flexion, 120º of flexion and maximum humeral flexion of the middle five test trials was recorded.

The subject then performed a functional diagonal pattern, consisting of a proprioceptive neuromuscular facilitation pattern (PNF D2 pattern). D2 flexion encompassed humeral flexion, abduction, and ER. D2 extension consisted of humeral extension, adduction, and IR. The subject was instructed to begin the functional diagonal pattern with his or her thumb resting at the opposite anterior superior iliac spine (ASIS) (Figure 18). The subject was instructed to keep the thumb pointed behind him or her to ensure that the subject's humerus was externally rotated at the end of the functional diagonal pattern (Figure 19). The subjects were allowed three practice trials. The subject completed seven test trials. The mean range of scapular tipping taken at 90º of flexion and maximum humeral flexion during the functional diagonal pattern moving into flexion of the middle five test trials was recorded. A metronome set at 69 Hz was used for all tasks in order to standardize velocity.

Data Reduction

Raw data was processed using Motion Monitor software and mechanical axes were defined by the digitized anatomical landmarks on the thorax, humerus, and scapula as recommended by the International Society of Biomechanics Shoulder Group (van der Helm 2004). The mechanical axes were converted to coordinate axes for each segment. The coordinate system was defined as the x-axis being horizontal with positive direction pointing anteriorly or in the direction the subject is facing, the y-axis being vertical with positive direction pointing upward, and the z-axis being horizontal with positive pointing to the right of the subject. Kinematic data were smoothed through a Butterworth low pass digital filter at an estimated optimal cutoff frequency of 3.5 Hz. Scapular rotations were expressed as Euler angles in relation to the trunk with the first rotation about the y-axis, which is the axis pertaining to scapular protraction and retraction; the second rotation was about the z-axis, which is the axis explaining upward and downward scapular rotation; and the third rotation was about the x-axis, which is the axis involved in anterior and posterior scapular tipping (Figures 20-22).

Data Analysis

Statistical analysis was performed with SPSS 13.0 (SPSS, Inc.; Chicago, IL). Separate Pearson Product moment correlations were used to determine the relationship for the following pairs of variables: 1) range of scapular tipping and its relationship to maximal humeral IR measured during active and passive rotation tasks; 2) range of scapular tipping during humeral rotation during active and passive rotation tasks and its relationship with maximum shoulder IR ROM as measured by supine and sleeper IR; 3) range of scapular tipping and its relationship with humeral flexion measured at 90º, 120º and maximum flexion; 4) range of scapular tipping at 90º, 120º and maximal humeral flexion and the association with maximum shoulder IR ROM as measured by supine IR and sleeper IR; 5) range of scapular tipping and its relationship with humeral flexion measured at 90º and maximal humeral flexion in a functional diagonal task; 6) range of scapular tipping at 90º of humeral elevation and maximal humeral elevation during a functional diagonal task and the association with maximum shoulder IR ROM as measured by supine IR and sleeper IR. For the purpose of this study correlation coefficients were interpreted as follows: below .50 was poor, .50-.75 was good, and above .75 was excellent. An a priori alpha level of 0.05 was used (Borsa, Timmons et al. 2003). A summary of the analysis is presented in Table 2.

RESULTS

The Interclass Correlation Coefficients (ICC) $_{(2,1)}$ for shoulder rotation range of motion measurements were above 0.9, suggesting excellent within subject reliability. The standard error of measurement (SEM) for each shoulder ROM measure ranged from 0.28° to 2.4°. The shoulder flexion ROM measure exhibited good reliability with an ICC $_{(2,1)}$ value of .80 with an SEM value of 2.96°. The ICC $_{(3,k)}$ values for three-dimensional scapular tipping and humeral kinematic measures were analyzed at maximal humeral internal and external rotation angles; 90°, 120° and maximal humeral flexion angles; maximal humeral internal and external rotation angles at 90° of humeral flexion angle during diagonal task and maximal humeral flexion angle. All measures displayed excellent reliability within trials with ICC values ranging from .98 to .99, and SEM values ranging from 0.68º to 3.8º.

Means, standard deviations, ICC, and SEM values for goniometric humeral ROM and three-dimensional scapular and humeral motion tracking for each task are presented in Tables 3, 5, 7, and 9.

Passive Rotation Task

Correlation analyses revealed that shoulder internal rotation ROM as measured by a goniometer was negatively correlated with scapular tipping ROM at the maximum humeral internal rotation angle during the passive rotation task ($r = -0.418$, $p = 0.033$) (Figure 23). Regression analysis revealed that 17.5% of variance in scapular tipping ROM can be explained by shoulder internal rotation ROM ($r^2 = 0.175$). As shoulder internal rotation ROM increases, scapular tipping ROM decreases. No other ROM variables were significantly correlated with scapular tipping ROM ($p > 0.05$). However, the total arc of shoulder rotation ROM approached a significant correlation with scapular tipping measures ROM at maximum humeral internal rotation angle ($r = -.372$, $p = 0.053$) indicating a strong trend (Figure 24). Regression analysis did reveal an r^2 value of 0.139, representing 13.9% of variance in scapular tipping ROM can be explained by the total arc of shoulder rotation ROM. Correlation analysis is presented in Table 4.

Active Rotation Task

Correlation analyses revealed no ROM variables were significantly correlated with scapular tipping ROM ($p > 0.05$). Again, shoulder internal rotation ROM approached significance when correlated with scapular tipping ROM at maximum humeral internal rotation angle during rotation task ($r = -0.368$, $p = 0.055$) indicating a strong trend that the greater shoulder internal rotation ROM, the less scapular tipping ROM. Regression analysis revealed that 13.5% variance of scapular tipping ROM can be explained with shoulder internal rotation ROM (Figure 25). Correlation analysis is presented in Table 6.

Functional Diagonal Task

Correlation analyses revealed the shoulder internal rotation ROM approached significance with scapular tipping ROM at 90° of humeral flexion angle ($r = -0.367$, $p = 0.055$). As shoulder internal rotation ROM increases, there is less scapular anterior tipping ROM. Regression analysis revealed that 13.5% of variance in scapular tipping ROM can be explained with shoulder internal rotation ROM ($r^2 = 0.135$) (Figure 26). The total arc of shoulder rotation ROM was also significantly correlated with both scapular tipping ROM at 90° of humeral flexion angle ($r = -0.397$, $p = 0.041$) and scapular tipping ROM at maximal humeral flexion angle ($r = -0.477$, $p = 0.017$) (Figures 27 & 28). These findings demonstrate that as total arc of shoulder rotation ROM increases there is less scapular tipping ROM. 23% of variance of scapular tipping ROM at 90° of humeral flexion angle can be explained by total arc of shoulder rotation ROM ($r^2 = 0.228$); while, 15.8% of variance of scapular tipping ROM at maximal humeral flexion angle can be explained by total arc of shoulder rotation ROM ($r^2 = 0.158$). The posterior shoulder flexibility measure was positively correlated with scapular tipping ROM at 90° of humeral flexion angle ($r = 0.414$, $p = 0.035$) and scapular tipping ROM at maximal humeral flexion angle ($r = .384$, $p = 0.048$) (Figures 29 & 30). This was the only significant finding with the posterior shoulder flexibility measure. This shows that the greater distance recorded during the posterior shoulder flexibility measure, the greater scapular tipping ROM. Regression analysis revealed r^2 values of 0.174 and 0.147 for scapular tipping ROM at 90° of humeral flexion angle and maximal humeral flexion angle, respectively. Correlation analysis is presented in Table 8.

Flexion

Correlation analyses revealed no ROM predictor variables were significantly correlated with scapular tipping ROM ($p > 0.05$). Correlation analysis is presented in Table 10.

Range of Motion

The shoulder internal rotation ROM measure is highly associated with the shoulder sleeper internal rotation ROM measure ($r = .712$, $p < .001$). However, neither measure was correlated with the posterior shoulder flexibility measure ($p < 0.05$).

DISCUSSION

The purpose of this study was to examine the relationship of clinical measures of shoulder range of motion (ROM) with scapular tipping ROM. Our results indicate that scapular tipping ROM is significantly related to passive shoulder internal rotation ROM during the passive rotation task and the functional diagonal task. Scapular tipping ROM approached a significant relationship with passive shoulder internal rotation ROM during the active rotation task. The total arc of shoulder rotation ROM was also significantly related to scapular tipping ROM during the diagonal task. Finally, the posterior shoulder flexibility measure was significantly related to scapular tipping ROM during the functional diagonal task. These results suggest decreases in clinical measures of shoulder ROM were related to greater scapular tipping ROM. This suggests that shoulder rotation ROM influences scapular tipping ROM supporting the interdependence of glenohumeral and scapular motion in shoulder function.

Our results show that during the passive rotation task at maximum humeral internal rotation angle, shoulder internal ROM was negatively related to scapular tipping ROM. The relationship between passive shoulder internal rotation ROM and scapular tipping ROM at maximal internal rotation angle during the active rotation task also approached significance. These results indicate that greater shoulder internal rotation ROM was related with less scapular tipping ROM during the active and passive humeral rotation tasks.

The differences between the relationship of shoulder ROM measures and scapular tipping ROM during the passive and active rotation tasks may be the result of muscle activity. All shoulder ROM measures were taken passively. This was done in order to better represent true joint mobility. Typically, active ROM is less than passive ROM signifying weakness or lesion in the active contractile tissue (Starkey 2002). Moreover, active ROM assesses the ability of the muscles to function and move. Consistency of measure was another reason the shoulder ROM was taken passively. Both the shoulder sleeper internal rotation ROM and posterior shoulder flexibility measure are assessed passively. However, this may have impacted our results. The dynamic structures may have inhibited the ability to assess the static structures during the functional tasks. Because the dynamic structures were controlling the motion, they may have limited the scapular ROM during the active rotation task. During active humeral rotation, the humeral external rotators may influence the amount of scapular anterior tipping during humeral IR. Our results are in agreement with Borsa et al. (2003) who found weak relationships between humeral IR and ER and elevation ROM and scapular upward rotation during humeral elevation in the scapular and sagittal planes. The investigators similarly had taken shoulder ROM passively and required the subjects to perform the humeral elevation task actively. They suggested that other factors, such as muscle force, contributed more significantly to scapular upward rotation than did static capsular restraints (Borsa, Timmons et al. 2003). This could have been a potential limitation to the study. It would be beneficial to take the shoulder ROM actively to determine whether a stronger correlation existed between shoulder ROM and scapular tipping ROM during the active rotation task.

The observed difference in the active and passive rotation tasks is supported by studies comparing scapular kinematics during active and passive shoulder elevation (Price, Franklin et al. 2000; Ebaugh, McClure et al. 2005). All have posited that scapulothoracic motion is influenced by whether the arm is actively or passively elevated. Price et al. (2000) found that there were no statistically significant differences in motion between active elevation and passive elevation. The investigation, however, only studied motion from 10º to 50º of humeral elevation (Price, Franklin et al. 2000). McQuade et al. (1998) found decreased amounts of scapular upward rotation when the arm was passively elevated but did not quantify muscle activity (McQuade, Dawson et al. 1998). However, Ebaugh et al. (2005) found differences in scapular kinematics during active and passive elevation. They found that scapular upward rotation decreased when the arm was passively elevated. This indicated that the periscapular muscles (upper and lower trapezius and serratus anterior) were vital in production of scapular motion. They determined the scapula posteriorly tips up to 90º of humeral elevation after which it moved into an anteriorly tipped position. The study found no significant differences in posterior tipping between the active and passive conditions. It was suggested that other factors such as pectoralis minor length and posterior capsule length may have been responsible for producing tipping motion (Ebaugh, McClure et al. 2005). Although, we did see differences between the results of the active and passive rotation tasks, muscle activity was not quantified during the passive rotation task. Although the subjects were instructed to relax completely there may have been muscle activity still present that may have contributed to motion.

During the functional diagonal task, at 90° of humeral elevation in the coronal plane, there was a significant relationship between the clinical measure of shoulder external rotation and scapular tipping ROM. Also, the total arc of shoulder rotation ROM was related to scapular tipping ROM at 90º and maximal humeral elevation angle during the functional diagonal task. Additionally, the measure of posterior shoulder flexibility was related to scapular tipping ROM at 90° and maximal humeral elevation angle. Additionally, there was a trend observed indicating that as shoulder internal rotation ROM decreased, scapular tipping ROM at 90º of humeral elevation angle increased. This suggests that shoulder flexibility influences scapular tipping ROM during a functional task. However, there were no significant relationships between shoulder ROM and scapular tipping ROM during the flexion task. This highlights the relationship between humeral rotation and scapular tipping. The functional diagonal, active and passive humeral rotation tasks all required more humeral rotation ROM (total arc of humeral rotation: active rotation task, 130º; passive rotation task, 143º; functional diagonal task, 19º; flexion task, 8º) when compared to the flexion task. This agrees with the findings of Thigpen et al. (2006) who observed differences in scapular kinematics between empty can and full can shoulder exercises. Their results demonstrated greater scapular internal rotation and anterior tipping during the empty can exercise in which the humerus is internally rotated during humeral elevation (Thigpen, Padua et al. 2006). Together with our results this suggests shoulder rotation was less during the flexion task when compared to the active and passive rotation tasks as well as the diagonal tasks. Therefore, one would expect less scapular tipping ROM to be used.

The plane of humeral elevation chosen may also have influenced the results. This is consistent with Borsa et al. (2003) who observed greater scapular upward and downward rotation within the end ROM of humeral elevation in the scapular plane. They did report, however, that scapular positioning did vary significantly between the planes of humeral elevation (Borsa, Timmons et al. 2003). In sum, these results highlight the importance and the potential influence of task selection.

The relationship between shoulder rotation ROM and scapular tipping ROM is consistent with the relationship between shoulder ROM and scapular upward and downward rotation (Borsa, Timmons et al. 2003). The results demonstrate as shoulder ROM decreases, scapular tipping ROM increased. This is important based on clinical assumptions of GH capsular mobility related to scapular kinematics (Borsa, Timmons et al. 2003; Thigpen 2006). It is thought that the mechanism facilitating this alteration in scapular tipping patterns is posterior shoulder inflexibility (Tyler, Nicholas et al. 2000; Borsa, Timmons et al. 2003; Burkhart, Morgan et al. 2003). It has been suggested that as the humerus internally rotates, the posterior capsule and RTC tension resulting in increased scapular internal rotation and scapular anterior tipping. As these posterior structures tighten, the humerus will pull the scapula into more internal rotation and anterior tipping (Thigpen, Padua et al. 2006). Borsa et al. (2003) proposed that decreased capsular mobility, as measured by shoulder ROM, may result in a “pulling” of the scapula during elevation causing an increase in scapular upward rotation (Borsa, Timmons et al. 2003).

Observed differences in scapular kinematics in overhead athletes also support the idea that shoulder rotation ROM influences scapular kinematics. Throwing athletes are thought to develop chronic adaptations to contribute to improved throwing skill, injury prevention and/or injury provocation. Throwing athletes with pathologic internal shoulder impingement demonstrated less shoulder internal rotation ROM and greater posterior shoulder inflexibility (Myers 2005). Throwing athletes have also been reported to exhibit increases in scapular upward rotation, scapular internal rotation and scapular retraction when compared to non-throwers (Myers, Laudner et al. 2005) These findings support the notion that a reduction in glenohumeral ROM influences scapular tipping ROM. Together with our results these studies provide evidence that adaptive posterior capsule and posterior rotator cuff tightness with subsequent glenohumeral internal rotation deficit may contribute to shoulder pain.

While not a primary research aim, relationships between the proposed measures of posterior shoulder tightness may have important clinical implications. Passive shoulder internal rotation ROM was significantly related to the passive shoulder sleeper internal rotation ROM. However, neither was significantly related with measures of posterior shoulder flexibility. The sleeper internal rotation ROM measure was proposed by Burkhart et al. (2003) to isolate humeral IR from scapular motion by stabilizing the scapula with the table (Burkhart, Morgan et al. 2003). This measurement attempts to isolate the posterior capsule and RTC. The supine internal rotation ROM measure also attempts to isolate humeral rotation with stabilization of the coracoid process of the scapula; however, it may not isolate the posterior structures as well. The posterior shoulder flexibility assessment was determined by Tyler et al. (2000) to be a reliable measure of assessing the posterior capsule of the shoulder. They established a relationship between decreases in shoulder internal rotation and increases in the posterior shoulder tightness. They posited that for every 4º of IR loss there would be 1 cm of posterior shoulder tightness (Tyler, Nicholas et al. 2000). We, however, did not find any significant relationships between the posterior shoulder flexibility measure and the shoulder sleeper internal rotation ROM measurement. The values we used in the correlation analysis were not side-to-side differences but the actual values obtained on the dominant arm; therefore, body size may have influenced the measure as well as its validity. In order to use those values, it may be beneficial to normalize to body height or length of humerus. When side-to-side differences of posterior shoulder flexibility were correlated with scapular tipping ROM, still no significant correlations were found ($p < .05$). The lack of strong significant correlations could be due to sampling size which could have affected the statistical power of the research design. Downar and Sauers (2005) collected ROM measures on professional baseball players including shoulder internal rotation ROM and posterior shoulder flexibility. Their results failed to reveal significant differences between the throwing and the non-throwing arm. They suggested this was due to low statistical power. They also found no significant relationships between the clinical measures of shoulder mobility (Downar and Sauers 2005). The conflicting results concerning the relationship between clinical measures of shoulder mobility warrants further investigation.

Clinically, we use ROM measures to identify potential risk factors for injury. A question arises as to which measure of posterior shoulder tightness is best. Our results indicated a stronger relationship with the shoulder internal rotation ROM and shoulder sleeper internal rotation ROM. However, it may be important to assess multiple measures of internal rotation in overhead athletes because these different measures may result in evaluation of different structures.

LIMITATIONS

The subjects were normal healthy volunteers; therefore, caution must be used in extrapolating these findings to other populations such as an injured population or overhead athletes. In addition, the velocity of the movement during testing was much slower than normal velocities during sport activity or activities of daily living. Again, caution must be used in extrapolating these findings to athletic activity.

Another limitation was that skin-based sensors provide only a representation of scapular and humeral motion. However, the method has been validated and shown to be reliable within humeral elevation ranges from 30º to 120º (Ludewig and Cook 2000). Variability in findings due to skin artifact, selection of bony landmarks, plane and angle of elevation, as well as Euler angle decomposition have been suggested as reasons for differences in scapular motion.

The spread of ROM values may have suppressed the correlation values (spread of shoulder internal rotation ROM: 37.3º-79.5º; spread of shoulder sleeper internal rotation ROM: 25.7º-60.3º). Side-to-side differences for the shoulder sleeper internal rotation ROM ranged from 3º to 17.7º. Tyler et al. (2000) indicated that greater posterior shoulder tightness in the throwing arm compared to non-throwing arm ranges from 2-7 cm. However, statistically significant differences have been found at 2.1 cm(Tyler, Nicholas et al. 2000). Our values ranged from 0.4 to 4 cm. Again, a greater sampling size may have provided with a greater spread between the ROM values created stronger relationships between the variables.

FUTURE RESEARCH

Future research should seek to clarify the role of humeral rotation and scapular kinematics. Clinically, humeral rotation and scapular kinematics are thought to be important to shoulder function. The relationship of humeral rotation and scapular kinematics as well as their influence on the development of shoulder pain is not understood.

CONCLUSION

This study is the first to assess the relationship between clinical measures of shoulder ROM and scapular tipping ROM during functional tasks. Decreased shoulder ROM was related to increased scapular tipping ROM. Both decreased shoulder ROM and increased scapular tipping during shoulder rotation has been associated with shoulder pain.

Appendix D

IRB Consent Form and Questionnaire

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

IRB Study #____05-EXSS-789______________
Consent Form Version Date: ___01/04/06_____

Title of Study: The Relationship between Humeral Rotation and Anterior/Posterior Tipping of the Scapula.

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Faculty Advisor: Darin Padua, PhD, ATC, LAT
Funding Source: none

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<u>What are some general things you should know about research studies?</u>
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.

<u>What is the purpose of this study?</u>
The mechanics of shoulder blade motion during arm elevation has been indicated in the development of shoulder pain. Often, the shoulder blade does not function ideally creating

faulty mechanics causing a risk factor for shoulder pain. Little is known about the relationship between arm rotation and shoulder blade motion. No research to date has explored the behavior of the shoulder blade during arm rotation.

Therefore, the purpose of this study is to examine shoulder blade motion during a rotation activity.

This will be accomplished by first assessing your total arm rotation range of motion including external rotation, and two internal rotation measurements. External rotation is described as rotation of the hand backwards in a position of 90 degrees of arm elevation to the side with elbow bent to 90 degrees. Internal rotation is described as rotation of the hand forward in a position of 90 degrees of arm elevation to the side with elbow bent to 90 degrees. During the testing session you will be asked to perform a rotation task, flexion task and a functional diagonal pattern 7 times. Your shoulder blade motion will be monitored during these tasks.

You are being asked to participate in this study because you represent the general student population.

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

You should not be in this study if you

- Suffer any shoulder abnormalities that cause pain during testing
- Have undergone shoulder surgery within the last year
- Perform formal rehabilitation for shoulder injury with in the last year
- Sustained a glenohumeral joint dislocation or subluxation within the past year
- Have missed more than 2 weeks of activity because of an upper extremity injury during the past year.

How many people will take part in this study?

If you decide to be in this study, you will be one of approximately 60 people in this research study.

How long will your part in this study last?

Testing will take approximately 75 minutes.

What will happen if you take part in the study?

During testing, you will be asked to do the following:

- You will be asked to report to the Motor Control Laboratory in Fetzer Gym.
- You will be briefed on the testing procedures
- You will be asked to read and sign an informed consent.
- If you have questions or concerns, at this time those will be discussed.
- You will be asked to lie on a treatment table in order to take several range of motion assessments with a goniometer, which is a tool that measures range of motion.

- You will be asked to relax.
- Your arm will be moved into the ranges of motion to be assessed.
- Three trials will be done of the range of motion assessment.
- You will be given 5 minutes to perform any self-selected stretches before you begin motion testing.
- Sensors will be placed on your arm just above your elbow, right on the tip of your shoulder and upper back right below your neck using double-sided adhesive tape. These sensors track arm movement.
- You will be seated or standing depending on the task.
- You will be instructed on the task and given three practice trials.
- You will be asked to perform several tasks including arm rotation, shoulder elevation and a diagonal pattern of movement.
- You will perform each task 7-10 times with 1 minute of rest in between each set.

Range of Motion Testing
You will be asked to wear comfortable pants, a sports bra or tank if you are female or no shirt if you are male. You will be asked to lie face up on a treatment table. Your arm will be placed in a 90/90 position (90 degrees of arm elevation and elbow bent to 90 degrees). You will be asked to relax and your arm will be taken through the available range of motion. This procedure will be repeated 3 times.

Shoulder Blade Motion

Females will be asked to wear a sports bra and/or a tank and comfortable pants. Males will be asked to remove their shirt for testing and to wear comfortable pants. You will have sensors attached to your neck, shoulder blade and arm that will track movement patterns. You will be asked to perform a series of tasks while sitting or standing in place. You will be instructed in the movement patterns and be allowed to practice 3 times to learn the motion, in order to become comfortable with the testing procedure. You will perform each task 7 times.

<u>What are the possible benefits from being in this study?</u>
Research is designed to benefit society by gaining new knowledge. There is no direct benefit from participating in this study. Copies of your shoulder range of motion and shoulder blade motion will be available to you to correct any deficiencies. The results of this study may aid the sports medicine community in understanding underlying causes of shoulder pain and in developing appropriate rehabilitation programs for individuals at risk to shoulder pain.

You may benefit from receiving information about your movement patterns and your range of motion. You will be able to ask the investigator questions about your shoulder motion in order to correct any problems.

<u>What are the possible risks or discomforts involved with being in this study?</u>

- Possibility of muscle soreness in your upper extremity

- Possibility of skin irritation from adhesive
- 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?
Your privacy is important. Your identifying information will not be seen by anyone except the principal investigator. We will protect your privacy in the following ways:
- All records will be stored either on a secure computer or in a locked filing cabinet in the Sports Medicine Research Laboratory or the Motor Control Research Laboratory.
- The consent form will be the only piece of identifying information from you. You will be assigned a code number that will be attached to all other data.

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.

What will happen if you are injured by this research?
All research involves a chance that something bad might happen to you. 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 get 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 injury, 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?
It will not cost you anything in addition to routine transportation costs to the Motor Control Research Laboratory in Fetzer Gym.

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 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.

What if you are a UNC employee?
Taking part in this research is not a part of your University duties, and refusing will not affect your job. You will not be offered or receive any special job-related consideration if you take part in this research.

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.

- -

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

Subject Information Form

Subject Number: ________

Circle One: Right handed Left handed

Age: _______ Height: ________ Weight: _________

Previous Experience:

Are you actively participating in competitive/collegiate overhead athletics such as volleyball, baseball/softball, swimming, or lacrosse? Yes No

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

In what sport?

Medical History:

Do you currently have any pain when you lift your arm overhead? Yes No

Are you currently being treated for any shoulder problems? Yes No

Have you been treated for a shoulder injury in the past year? Yes No

Range of Motion	**Trial 1**	**Trial 2**	**Trial 3**	**Mean**
Supine Flexion (Flex)				
Supine Passive Internal Rotation (IR)				
Supine Passive External Rotation (ER)				
Sleeper IR: Dominant (SIRd)				
Sleeper IR: Non-dominant (SIRnd)				
Posterior Capsule: Dominant (PCd)				
Posterior Capsule: Non-dominant (PCnd)				

Stylus Length: _____ RMS: ______
Humerus Length: _____ RMS: ______

Appendix E

Raw Data

Passive Rotation Task

Subject	Flexion	IR	ER	Total Arc	SIRd	Sirnd	PCd	PCnd	diff	maxIR_hflex	maxIR_hrot
1	172	44	117.3	161.3	45.3	60.7	28.5	22.8	5.7	-4.9617	63.5606
2	165.7	60.7	131.7	192.4	52	59.3	26.8	20.5	6.3	-4.9726	82.0439
3	171.7	72.3	110	182.3	56.7	61.3	27	28.3	-1.3	-111.7902	60.2289
4	168.7	52.7	109.3	162	49.3	61.3	24.8	23.5	1.3	-7.1945	85.4576
5	155.7	37.3	120	157.3	28.7	42.3	22	24.5	-2.5	-8.6485	71.2561
6	169.7	45	121	166	25.7	25.3	24.8	25.2	-0.4	-14.6491	37.0079
7	162.3	54	110	164	40	46	31.8	30.7	1.1	1.8848	70.3569
8	171.3	49.7	129.7	179.4	49.7	8	31	21.7	9.3	-28.4438	82.1019
9	168.3	40.3	147.3	187.6	51	58.3	25.7	23.3	2.4	6.2749	61.6500
10	163.3	48.7	116.7	165.4	59.3	44.3	25.5	18.7	6.8	-8.3821	67.7206
11	169	60.7	124	184.7	42.3	51.7	20.3	19.3	1	-15.9171	80.3385
12	159	46	114	160	43.7	52.7	24	23.3	0.7	3.0436	84.9914
13	160	38	111	149	32	37.3	20.7	17.3	3.4	-0.0409	43.5057
14	165.3	67.7	126.7	194.4	60.3	69.3	25.7	23.8	1.9	-1.8828	47.2954
15	168.7	54.3	128.3	182.6	45.3	50	22.7	16.8	5.9	-13.0945	45.9589
16	170.3	63.3	129.3	192.6	49.7	35.3	17.3	21.3	-4	0.5698	75.8294
17	174	77.7	149.3	227	59	53.7	19.5	14	5.5	-2.4022	48.5501
18	157.7	59	124	183	40	57.7	31	29.3	1.7	-7.4158	40.8362
19	171.7	67	117	184	55.7	35.7	24.3	20.7	3.6	-9.3215	44.4440
20	166.7	28.7	99.3	128	28.7	31.7	27.2	28.2	-1	5.5235	105.9426

maxIR_er	maxIR_ur	maxIR_tip	maxER_hflex	maxER_hrot	maxER_er	maxER_ur	maxER_tip
9.5084	-1.9807	14.3410	4.4361	50.5365	10.1309	-7.6928	24.6875
8.4354	-4.0892	14.3490	14.5837	84.7379	15.2957	1.4625	15.7207
2.5741	-12.0738	-8.0296	129.2002	94.2323	14.1210	-3.6196	-11.6828
13.1823	-10.3419	32.4250	14.6416	74.9924	7.6011	-7.7856	11.1541
4.2457	-3.0639	5.6134	10.1463	71.9638	17.6275	3.9755	13.7156
-2.7653	7.2515	6.4405	20.2144	93.9181	6.7037	12.0950	11.3456
9.2373	-6.6332	-4.6181	19.9155	80.3197	-0.8545	-8.9193	-14.9903
8.4561	8.0248	11.1473	38.8173	80.8596	22.2745	-4.4457	31.5928
-10.3940	16.7894	8.0441	-0.0748	97.9691	16.1354	11.6968	15.8877
2.6902	-0.4319	3.2101	17.5481	69.1604	8.8725	-5.3969	7.2207
8.8964	-3.6337	15.1349	17.6188	88.5663	13.5665	-6.1946	26.5458
-8.7623	26.0863	16.9510	2.8317	72.9922	16.4578	25.8786	10.0358
1.4541	8.4060	5.1220	-14.8453	98.2728	4.9139	12.7273	-1.2900
3.0889	-1.8041	-5.2901	-5.1917	91.0720	4.7662	8.6570	18.3849
-2.8864	6.9747	9.9624	-7.5431	75.2948	-3.0789	6.4203	1.8843
-5.4740	19.1475	6.2197	16.7546	79.5122	5.0210	9.5374	3.6881
4.5635	-1.1442	-6.3318	1.6421	105.7791	11.3733	14.6821	10.8696
2.9659	0.6582	1.6573	17.8373	80.8372	9.7010	13.6840	9.1799
-1.4474	5.4970	5.2490	7.7975	82.6919	6.3239	12.2085	6.7113
13.5099	6.8643	11.4606	2.3205	17.7426	15.5272	2.9308	12.8087

Active Rotation Task

Subject	Flexion	IR	ER	total arc	SIRd	Sirnd	PCd	PCnd	diff	maxIR_hflex	maxIR_hrot
1	172	44	117.3	161.3	45.3	60.7	28.5	22.8	5.7	1.3101	50.4189
2	165.7	60.7	131.7	192.4	52	59.3	26.8	20.5	6.3	-0.2485	36.8685
3	171.7	72.3	110	182.3	56.7	61.3	27	28.3	-1.3	-29.5117	21.3768
4	168.7	52.7	109.3	162	49.3	61.3	24.8	23.5	1.3	-3.0829	65.2753
5	169.7	45	121	166	25.7	25.3	24.8	25.2	-0.4	-7.3522	47.2921
6	171.3	49.7	129.7	179.4	49.7	8	31	21.7	9.3	-14.9346	69.6630
7	168.3	40.3	147.3	187.6	51	58.3	25.7	23.3	2.4	6.1323	60.0596
8	163.3	48.7	116.7	165.4	59.3	44.3	25.5	18.7	6.8	-13.9484	50.0101
9	169	60.7	124	184.7	42.3	51.7	20.3	19.3	1	-22.1032	50.6940
10	170.3	56.1	119.3	175.4	46	42.7	26.7	23.3	3.4	3.4651	60.7680
11	159	46	114	160	43.7	52.7	24	23.3	0.7	1.7811	90.3623
12	160.7	51.7	108.3	160	33.7	33.7	22.3	26.3	-4	10.9087	63.7271
13	160	38	111	149	32	37.3	20.7	17.3	3.4	-12.5072	76.8351
14	165.3	67.7	126.7	194.4	60.3	69.3	25.7	23.8	1.9	2.1064	75.5022
15	168.7	54.3	128.3	182.6	45.3	50	22.7	16.8	5.9	-7.9360	28.1124
16	170.3	63.3	129.3	192.6	49.7	35.3	17.3	21.3	-4	3.6421	72.2818
17	174	77.7	149.3	227	59	53.7	19.5	14	5.5	-16.6995	39.7088
18	157.7	59	124	183	40	57.7	31	29.3	1.7	-0.4548	41.1383
19	171.7	67	117	184	55.7	35.7	24.3	20.7	3.6	4.7033	66.4918
20	166.7	28.7	99.3	128	28.7	31.7	27.2	28.2	-1	-8.0383	46.4846

maxIR_er	maxIR_ur	maxIR_tip	maxER_hflex	maxER_hrot	maxER_er	maxER_ur	maxER_tip
11.4090	3.9632	22.0722	7.3453	44.9240	11.5604	-6.1294	22.0499
-0.1525	0.5806	6.7683	15.0968	77.8503	20.5773	-2.7778	17.8598
10.3012	2.9157	-11.9316	-8.4792	84.9802	3.7712	-3.4861	-5.6686
-27.4850	2.5687	34.4307	20.2616	79.0522	316.0393	-15.9776	49.8079
-2.9281	10.8322	6.6164	17.5680	72.3961	6.8385	18.8846	7.0869
7.4436	2.1283	12.8477	11.4346	64.3115	16.8447	-1.6444	22.6656
-7.0384	16.2147	14.3713	-6.7061	84.8238	10.7353	10.8396	11.7998
4.3932	-1.7616	-0.0765	21.0738	64.1296	7.9490	-6.7504	17.4240
2.0165	1.8066	-0.3945	22.5484	79.1599	12.6674	-8.1333	28.5944
7.1204	0.2339	17.9378	26.3955	59.8740	9.1661	-6.3748	17.7622
-9.5042	24.4943	12.7985	4.8279	73.0240	15.0551	24.1849	14.7898
8.5762	-21.2086	5.8167	-38.6166	70.3899	2.8592	-21.2839	11.5765
-1.5791	12.6761	9.9512	-0.8482	66.6547	0.4413	9.3514	8.7552
2.0788	11.3251	5.4924	-5.0210	88.1488	2.0825	6.1654	15.7714
2.6827	2.5574	-1.5018	16.7306	78.1110	-1.7907	14.3638	8.0690
-6.4603	18.5340	6.3117	9.0197	78.7422	5.9470	15.4628	9.7800
3.7486	3.1490	-1.8576	16.6705	109.9545	12.0912	9.1824	4.8818
5.4782	8.4417	2.7688	17.3985	84.5361	6.3427	18.0094	14.3486
2.5217	21.1356	10.6957	-1.5775	72.4294	2.4536	11.3022	13.8205
-3.2447	-8.3599	2.9837	-0.3522	82.9718	-20.7103	-8.7732	18.7796

Functional Diagonal Task

Subject	Flexion	IR	ER	Total Arc	SIRd	Sirnd	PCd	PCnd	diff	d90_flex	d90_rot
1	172	44	117.3	161.3	45.3	60.7	28.5	22.8	5.7	90.8822	-94.0903
2	155	40	109	149	42.7	51.3	30.3	31	-0.7	90.9642	-15.7224
3	165.7	60.7	131.7	192.4	52	59.3	26.8	20.5	6.3	90.6458	-33.3216
4	171.7	72.3	110	182.3	56.7	61.3	27	28.3	-1.3	90.9060	-4.6782
5	168.7	52.7	109.3	162	49.3	61.3	24.8	23.5	1.3	91.1159	-50.7607
6	155.7	37.3	120	157.3	28.7	42.3	22	24.5	-2.5	90.0011	-39.0441
7	169.7	45	121	166	25.7	25.3	24.8	25.2	-0.4	91.0812	-32.5397
8	168.3	40.3	147.3	187.6	51	58.3	25.7	23.3	2.4	90.9126	-35.5175
9	163.3	48.7	116.7	165.4	59.3	44.3	25.5	18.7	6.8	101.0713	12.2654
10	169	60.7	124	184.7	42.3	51.7	20.3	19.3	1	90.4089	-50.9017
11	170.3	56.1	119.3	175.4	46	42.7	26.7	23.3	3.4	90.9230	-76.3348
12	159	46	114	160	43.7	52.7	24	23.3	0.7	90.3575	-43.4554
13	160.7	51.7	108.3	160	33.7	33.7	22.3	26.3	-4	90.9023	91.3151
14	160	38	111	149	32	37.3	20.7	17.3	3.4	90.9588	-61.7332
15	165.3	67.7	126.7	194.4	60.3	69.3	25.7	23.8	1.9	89.8094	9.8407
16	168.7	54.3	128.3	182.6	45.3	50	22.7	16.8	5.9	90.5137	-139.3295
17	170.3	63.3	129.3	192.6	49.7	35.3	17.3	21.3	-4	90.6753	-83.8770
18	174	77.7	149.3	227	59	53.7	19.5	14	5.5	91.0269	-21.0651
19	157.7	59	124	183	40	57.7	31	29.3	1.7	100.6432	-40.2928
20	171.7	67	117	184	55.7	35.7	24.3	20.7	3.6	100.2396	-84.3844

d90_er	d90_ur	d90_tip	dMAX_flex	dMAX_rot	dMAX_er	dMAX_ur	dMAX_tip
0.6206	2.4948	15.1580	122.6330	-78.4153	19.9039	4.0304	42.7899
12.5527	0.6139	35.0889	97.4403	-11.6633	15.0088	-0.6251	41.7352
5.4578	4.7182	14.2738	125.9322	-15.2952	21.0975	-6.4939	23.5297
-2.3963	-7.0612	16.1896	113.4000	-12.2930	-9.9417	-3.4465	26.6892
3.1607	1.3848	32.1635	105.9890	-18.0887	15.2260	-2.8864	46.2607
24.2670	6.1899	28.7848	93.2257	-26.9496	29.9211	4.9609	32.7883
-2.9382	33.3161	-3.5933	129.5359	-19.8975	-6.3052	23.8074	10.3831
5.1939	32.4836	10.9257	109.2589	-9.3739	11.5035	41.2022	23.5689
3.6235	3.0775	31.2868	134.7223	51.6251	7.7597	-9.9768	49.8043
-9.5615	8.2218	19.3266	124.8083	-23.2457	9.9186	8.9546	36.5808
-7.8003	3.2109	19.8112	122.4429	-44.4312	8.5243	-7.4705	32.4776
-8.3944	32.5484	10.7669	111.2919	-33.1406	-4.9655	36.2732	26.0407
20.5636	-19.1973	-1.7657	152.6257	50.2138	13.0486	-37.9222	10.4510
-8.7772	9.8052	9.1693	108.2636	-32.6787	-4.9320	17.7153	15.5978
17.5397	26.2949	11.2237	95.2307	25.4281	19.8594	29.1259	18.1319
-7.0254	17.7753	-5.0651	127.8971	-99.4294	5.5772	39.4544	1.6669
-12.9195	16.1611	-2.5822	143.9770	-53.5405	-6.8024	39.7700	11.0644
6.6878	29.5447	-3.9528	113.7967	2.3278	15.2949	38.6685	13.0735
-4.4673	33.3830	6.9976	119.5592	-8.3075	1.1881	29.2750	16.0835
-14.7914	27.5768	2.0607	132.5328	-47.9207	-2.8721	34.6335	23.9787

Flexion Task

Subject	Flexion	IR	ER	Total Arc	SIRd	Sirnd	PCd	PCnd	diff	flex90_flexh	flex90_hrot
1	172	44	117.3	161.3	45.3	60.7	28.5	22.8	5.7	91.1306	-77.1737
2	155	40	109	149	42.7	51.3	30.3	31	-0.7	90.6395	-25.1905
3	165.7	60.7	131.7	192.4	52	59.3	26.8	20.5	6.3	90.3349	-25.3928
4	171.7	72.3	110	182.3	56.7	61.3	27	28.3	-1.3	90.1138	-3.5749
5	168.7	52.7	109.3	162	49.3	61.3	24.8	23.5	1.3	90.9521	-44.6558
6	155.7	37.3	120	157.3	28.7	42.3	22	24.5	-2.5	90.6860	-4.2846
7	169.7	45	121	166	25.7	25.3	24.8	25.2	-0.4	90.8442	-52.5417
8	162.3	54	110	164	40	46	31.8	30.7	1.1	90.2409	-101.7045
9	171.3	49.7	129.7	179.4	49.7	8	31	21.7	9.3	90.4480	-73.4047
10	168.3	40.3	147.3	187.6	51	58.3	25.7	23.3	2.4	90.3613	-9.7377
11	163.3	48.7	116.7	165.4	59.3	44.3	25.5	18.7	6.8	90.4245	-26.4460
12	169	60.7	124	184.7	42.3	51.7	20.3	19.3	1	90.4681	-49.2290
13	170.3	56.1	119.3	175.4	46	42.7	26.7	23.3	3.4	90.9391	-62.2809
14	159	46	114	160	43.7	52.7	24	23.3	0.7	91.3287	-55.0392
15	160	38	111	149	32	37.3	20.7	17.3	3.4	91.0584	99.5711
16	165.3	67.7	126.7	194.4	60.3	69.3	25.7	23.8	1.9	90.9666	-71.2552
17	170.3	63.3	129.3	192.6	49.7	35.3	17.3	21.3	-4	90.9217	-81.6987
18	168.3	79.7	123.7	203.4	57	55	20	22	-2	91.2600	-32.7906
19	157.7	59	124	183	40	57.7	31	29.3	1.7	91.4009	-54.5000
20	171.7	67	117	184	55.7	35.7	24.3	20.7	3.6	91.2159	-82.7348
21	166.7	28.7	99.3	128	28.7	31.7	27.2	28.2	-1	90.1781	-42.0699

flex90_er	flex90_ur	flex90_tip	flex120_hflex	flex120_hrot	flex120_er	flex120_ur	flex120_tip
-4.5169	8.4607	20.1468	121.0126	-78.0334	-0.7320	13.5212	36.2520
-7.8247	3.7823	19.1359	120.3629	-25.8040	-8.3969	-5.5475	36.4133
-10.2099	3.4997	7.8250	120.4821	-36.8101	-5.9468	-0.3055	12.0233
5.4689	-14.5041	16.1049	120.1406	8.0968	6.0287	-11.7852	21.7262
-3.7069	7.7111	36.3665	120.6377	-43.4487	-1.7432	8.7214	54.9982
1.0495	10.6053	37.4009	120.6774	-5.2128	4.8519	7.0981	54.9300
-8.5038	31.7774	-8.9228	120.8233	-58.5631	-10.6910	36.8375	-4.2152
3.7532	7.6516	25.6334	120.0167	-96.6841	5.6120	21.8368	29.0605
-7.4438	7.1001	20.1313	120.4313	-75.1125	-6.2843	5.5595	30.9920
-14.1468	28.3551	10.2930	120.2185	-6.1868	-16.4282	36.5329	13.6262
-6.9632	2.8924	29.2464	120.2984	-24.5660	-11.2697	3.5901	34.3674
-7.4848	11.0771	16.7480	120.4295	-46.0347	-4.9835	15.9636	28.8199
-10.3599	8.5418	13.9829	131.2317	-67.8186	-10.8431	6.4997	27.1002
-18.7392	33.5203	5.8064	121.2605	-52.8309	-21.9777	42.2432	10.5521
18.9734	-11.7259	-0.8473	120.6853	96.5158	20.6642	-24.0195	0.4676
-18.4417	26.8376	12.7182	121.1054	-73.4357	-20.0198	39.4436	19.9686
-17.6872	15.7857	-3.3102	120.8317	-83.8872	-22.6756	25.4747	0.8642
-10.5729	22.4985	-5.3658	120.9646	-37.2037	-15.0904	28.6633	-2.1612
-12.9676	21.6625	3.8124	121.2036	-51.0727	-16.6470	27.5955	5.7629
-21.3754	22.9466	-4.1883	121.4992	-80.3250	-23.8977	31.2312	-3.2443
6.4494	-17.6537	3.2623	119.8383	-46.5814	1.9082	-27.5645	12.0126

flexMAX_hflex	flexMAX_hrot	flexMAX_er	flexMAX_ur	flexMAX_tip
151.1855	-83.3044	10.4077	16.9206	61.2503
132.5669	-26.4775	-7.9881	-11.8496	44.1065
163.7173	-49.9251	2.6527	-12.8679	24.4494
150.4647	10.6766	9.8505	-1.8213	26.1577
135.0939	-40.2149	-0.3265	6.1892	65.2012
142.6651	-9.1218	9.9917	-0.5199	65.2938
144.7040	-58.3686	-10.3130	36.1057	6.2657
143.7593	-98.8796	6.3981	30.5473	28.5360
159.0015	-63.2502	1.3740	-10.5720	50.3806
151.4865	3.7087	-9.9766	53.4239	25.7424
151.6972	-17.8693	-9.6818	-2.0019	47.5193
158.7690	-36.3133	2.8406	11.9164	50.7544
169.4073	-55.8089	-5.9176	-6.6083	43.6494
153.6024	-45.7899	-13.5540	46.9126	30.0988
167.7735	85.1164	22.3495	-36.6095	11.7931
145.2961	-60.2556	-11.5941	48.8193	37.5259
169.4182	-78.0417	-14.1047	47.8028	18.8011
160.1478	-37.5968	-11.8504	47.5775	18.3373
155.7307	-51.7492	-12.7201	28.1784	21.2316
154.4820	-77.9083	-20.2585	36.7928	16.4114
132.9575	-86.9474	-7.0914	-34.7268	23.1548

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