MEASUREMENT OF SHOULDER JOINT STRENGTH AND MOBILITY IN COMMON COLLEGIATE AGED OVERHEAD ATHLETES

by

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Introduction: Previous research has stereotyped many overhead athletes as baseball pitchers. Due to the different physiological stresses in each overhead sport, it may not be appropriate to group all overhead athletes together. The objective of this study was to show sport specific physical adaptations in common overhead sports.

Methods: Forty-three healthy, male athletes participated in this cross-sectional study; fifteen baseball pitchers, fifteen volleyball athletes, thirteen tennis athletes and fifteen control athletes. Internal rotation (IR) and external rotation (ER) shoulder range of motion (ROM), glenohumeral internal rotation deficit (GIRD), external rotation gain (ERG), posterior shoulder tightness (PST) (supine and side-lying methods), shoulder strength and scapular kinematics were assessed in a neuromuscular research laboratory. ROM was assessed with a goniometer while PST was assessed with a goniometer (supine) and carpenters' square (side-lying). Strength was assessed with an isokinetic dynamometer and scapular kinematics with an electromagnetic tracking device.

Results: Pitchers had more dominant IR ROM than tennis athletes and less dominant IR ROM than control athletes. Tennis athletes had the lowest IR ROM of all groups included in this study. Volleyball athletes had less dominant IR ROM than control athletes. Pitchers and tennis athletes had more GIRD than control athletes had. Pitchers and tennis athletes had higher between limb differences with the supine method of assessing PST. With the supine assessment, tennis athletes had increased dominant PST compared to control athletes; additionally, all overhead athletes had decreased non-dominant PST. At 90° and 120° humeral elevation, pitchers had the most scapular elevation, volleyball athletes had more elevation than tennis athletes did, and tennis athletes had less elevation than control athletes did. There were no differences in external rotation ROM, total rotation ROM, or strength measures.

Conclusion: Not all overhead athletes had the same physical characteristics. The differences between sports in each of the variables could be due to the different amount of physiologic stress on the shoulder in each sport. These results may help to show healthy, sport specific adaptations to each sport. Clinicians should develop sport specific rehabilitation protocols and return to play criteria for athletes to return to play earlier and stronger.

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1.0 INTRODUCTION

Many prior studies have grouped overhead athletes together as one population[1-8]. Baseball pitchers have been studied as the stereotypical overhead athlete[1, 4, 6, 8-13]. For example, Wilk et al[8] presents rehabilitation techniques for the overhead throwing athletes, but only discuss baseball. Burkhart et al[12] state that the “dead arm” can be present in the overhead athlete, but go on to only use baseball pitchers as examples in their review paper. The term “dead arm” is defined as any pathologic shoulder condition in which the thrower is unable to throw with their pre-injury velocity and control because of a combination of pain and subjective unease in the shoulder[12]. Using the description by Burkhart et al[12] in regards to the dead arm presenting in the overhead athlete, there is the possibility that this etiology is capable of being present in non-throwing overhead athletes as well.

Physical characteristics of the shoulder in overhead athletes may differ among overhead sports. Shoulder internal rotation velocities may range from 6000^{o}/sec[14] to $10{,}000^{o}$/sec[15] for baseball pitchers. During the tennis serve, shoulder internal rotation velocities may reach 1500^{o}/sec[16]. There is no literature published, to the author’s knowledge, which calculates angular velocities for volleyball serving or spiking. The different degree of internal rotation velocity is an example of the different demands placed on the shoulder between each sport.

Research has suggested that the forceful, eccentric contractions as well as distraction forces may cause microtrauma to the external rotators during the follow through/deceleration phase in baseball, tennis and volleyball[5, 8, 10, 15, 17-20]. This may lead to a decrease in posterior shoulder mobility and induce a loss of range of motion[5, 9, 17-19, 21-24]. This assumption may explain the demonstrated differences in internal rotation loss between the different sports[5, 9, 18, 19, 24, 25]. Ellenbecker et al[17] hypothesize that adaptations of the posterior capsule as well as musculoskeletal adaptations may serve to maintain the overall stability of the glenohumeral joint versus a predisposing injury in elite junior tennis players. Some research suggests that an osseous adaptation of humeral retroversion coupled with posterior rotator cuff tightness are the culprits for the arc of motion shift[8, 26].

Internal rotation range of motion of the shoulder has been shown to be less in the dominant limb of baseball, tennis and volleyball players when compared to the non-dominant limb (Glenohumeral Internal Rotation Deficit or GIRD)[9, 18, 24, 27, 28]. This loss of internal rotation varied with baseball typically having the most decrease in motion followed by tennis and volleyball athletes. When compared bilaterally, athletes in overhead sports had an increase in external rotation (External Rotation Gain or ERG) and a decrease in internal rotation in the dominant limb[9, 19, 24]. Some research has shown that pitchers had a greater difference between dominant and non-dominant limbs for external rotation range of motion, with no differences in internal rotation, compared to position players[5]. These results suggest that external rotation gain is a further adaptation from the regular overhead throw to the pitching motion. These differences in range of motion are a good example of Wolff's Law that states that the tissues adapt to the stresses that are placed on them[29]. There is literature available that presents a "total motion concept" in that the total arc of shoulder rotation (external rotation + internal rotation) motion is the same when compared bilaterally[8].

Ellenbecker and colleagues[28] point out that although the GIRD between tennis and baseball players was roughly the same, there was a significant decrease in the total rotation range of motion in the dominant limb of tennis players but not in the non-dominant limb or in baseball players. In similar studies, results show a decrease in dominant arm internal rotation, and total rotational range of motion as well[17, 18]. It remains debatable in the literature if there is a decrease in internal rotation with accompanying increases in external rotation (total motion concept), or a loss of total rotational range of motion. Perhaps the differences can be associated with the adaptations that are dependant on the stresses placed on the involved structures (Wolff's Law). The shoulder must have enough laxity to allow excessive external rotation in throwers, but also maintain enough stability to prevent symptomatic humeral head subluxations[8]. This "throwers paradox" could apply to other overhead motions as well. Each of the overhead sports included in this study could have their own paradox since the demands of each on the shoulder are unique. There is no research, to the author's knowledge, that compares internal rotation to posterior shoulder mobility in asymptomatic athletes competing in tennis and volleyball.

Research suggest that a tightened posterior shoulder may be a precursor to injury[12, 19, 24, 30, 31]. Burkhart et al[12] suggest that a tight posterior capsule initiates the pathologic cascade that leads to a SLAP lesion. They predict that if it is possible to prevent the posterior capsule from tightening, the "dead arm" could be prevented. In order to prevent the dead arm, all throwing athletes should habitually stretch the posterior/inferior capsule[10]. Research shows that the humeral head tends to migrate in an anterior and superior direction from the tightened posterior capsule [32]. This altered kinematic pattern of the glenohumeral joint may lead to a decreased subacromial space, leading to subacromial impingement[32]. Fleisig et al[20] concluded from their study that a decrease in flexibility may inhibit proper throwing mechanics in baseball pitchers. By altering the throwing mechanics, further adaptations to the throwing motion may develop and lead to injury. This principle may apply to other overhead motions as well. The adaptations would vary depending on the sport. If it is possible to reduce the amount of posterior shoulder tightness, perhaps the SLAP lesion and other pathologies are avoidable.

Tyler et al[23] proposed a new method to reliably quantify posterior shoulder tightness (PST). This clinical measurement allows a quick and valid method to assess posterior shoulder mobility. With a larger database and more research to quantify posterior shoulder mobility in overhead athletes, clinicians and researchers may have a better understanding of the importance of this clinical measurement.

Scapula position and orientation in asymptomatic, throwing athletes has recently been investigated by Myers and associates[13]. The study showed that the throwing athletes (baseball players) have significantly increased upward rotation, internal rotation, and retraction of the scapula during humeral elevation compared to control subjects. These changes in scapular kinematics were speculated to be a chronic adaptation to a repetitive athletic task[13]. When interpreting the results, perhaps all overhead sports have a chronic adaptation to their respective athletic task. Due to the different degrees of biomechanical stresses previously mentioned, each sport may have different degrees of adaptations (Wolff's Law). If the scapular stabilizers are not able to perform optimally, pathologies may arise[33]. It is hard for research to show whether adaptations lead to pathologies or pathologies cause the adaptations. Since the current study population will be asymptomatic and cover several overhead sports, it is possible to gain a better understanding of how each overhead athlete adapts to their sport. This data, teamed with previous data, should help researchers gain insight on ways to possibly prevent pathologies that may be related to altered scapular kinematics [13, 33, 34].

Strength imbalance between the internal and external rotators may exist in overhead athletes due to the associated movements used for overhead sports[34-37]. In general, the tendency is that baseball athletes have the highest degree of imbalance (increased internal rotation with decreased external rotation strength) between internal rotation and external rotation followed by tennis and then volleyball[8, 9, 19, 24, 25, 34, 37, 38]. This research shows that throwers have an increase in internal rotation and a decrease in external rotation strength in the dominant limb when compared to the non-dominate limb. A balance between agonist/antagonist (external rotation/internal rotation) muscle groups in athletes with posterior cuff abnormalities of 65%-72% should provide dynamic shoulder joint stabilization[8, 38]. Excessive strength imbalance has also been suggested to be related to shoulder pathology[35, 36]. If the external rotators are not strong enough to control the forces that the internal rotators produce, the athlete may be predisposed to a shoulder injury[37]. When the external rotators fatigue, this could produce the same effects as an imbalance, potentially including glenohumeral instability and impingement [25]. It is difficult to compare exact strength ratios from study to study due to methodological differences. The proposed study will allow comparisons between the different sports populations included.

Another important aspect of shoulder strength to evaluate is the protraction and retraction strength ratio. Like internal and external rotator strength imbalances, a strength imbalance in the shoulder protractors and retractors could possibly be a predisposing factor for injury. Research has demonstrated that shoulders with impingement syndrome had a decrease in protraction force (decreased strength ratio) output when compared to the dominant shoulder of the healthy control group; as well as the contra-lateral side of the patient group[1, 7]. Data also show side to side differences in the healthy control group for the protraction/retraction strength ratios as well (dominant side had lower protraction values than non-dominant)[7]. If the serratus anterior and trapezius are not able to perform optimally, the possibility of altered scapular kinematics and associated pathologies arises[7, 33].

This idea of assessing the protraction/retraction strength ratio is a relatively new concept. Therefore, few studies use a validated method to gather the data. None of the previous studies has included the sport populations included in the current study. The data from this study, in addition to previous data, will help to determine the importance of not only the internal/external rotation strength ratios, but the protraction/retraction strength ratio as well.

All of the variables previously mentioned in this chapter (shoulder range of motion, posterior shoulder mobility, scapular kinematics, and strength assessment) could be adaptations to each sport. The current study employed asymptomatic athletes. This helped to demonstrate what adaptations might be present in healthy overhead athletes and help to develop a knowledge base for the healthy adaptations to each sport. The current research study will help to define the non-throwing, overhead athlete. Data from this study may help to develop prevention programs to focus strengthening exercises on certain muscles as well as define some of the healthy adaptations that the human body makes to repetitive, athletic overhead motions.

1.1 SPECIFIC AIMS AND HYPOTHESES

The purpose of this research project is to compare shoulder range of motion, posterior shoulder mobility, strength and scapular kinematics of collegiate aged athletes participating in common overhead sports. There are four specific aims to meet this purpose. The specific aims and hypotheses for the current research project include:

1.1.1 Specific Aim and Hypothesis 1

Specific Aim 1: Evaluate glenohumeral internal rotation and external rotation range of motion in asymptomatic overhead athletes (15 baseball pitchers, 15 tennis athletes and 15 volleyball athletes) and a control group (15 track and/or soccer athletes) with a standard goniometer.

Hypothesis 1: Baseball, tennis, and volleyball athletes will have a decrease in glenohumeral internal rotation range of motion of their dominant shoulder when compared bilaterally (GIRD). Pitchers will have the most GIRD followed by tennis athletes, volleyball athletes and the control group. Baseball, tennis and volleyball athletes will have a subsequent external rotation gain (ERG) with respect to the control group.

1.1.2 Specific Aim and Hypothesis 2

Specific Aim 2: Using the protocol set forth by Tyler et al[23], evaluate posterior shoulder tightness of 15 baseball pitchers, 15 tennis athletes, 15 volleyball athletes and 15 control subjects (track and/or soccer athletes).

Hypothesis 2: Baseball pitchers, tennis athletes and volleyball athletes will have increased posterior shoulder tightness of their dominant limb with respect to the contralateral limb and control group. Pitchers will have the most tightness followed by tennis athletes, volleyball athletes, and the control group.

1.1.3 Specific Aim and Hypothesis 3

Specific Aim 3: Using an electromagnetic tracking device, evaluate scapular kinematics of 15 baseball pitchers, 15 tennis athletes, 15 volleyball athletes, and 15 control subjects (track and/or soccer athletes) during a single elevation task.

Hypothesis 3: Baseball, tennis and volleyball athletes will have a unilateral change in scapular kinematics on the dominant side presenting as increased upward scapular rotation, increased internal rotation, and increased retraction when compared to the contra-lateral side and the control group.

1.1.4 Specific Aim and Hypothesis 4

Specific Aim 4: Evaluate shoulder internal/external rotation and protraction/retraction strength on an isokinetic dynamometer in 15 baseball pitchers, 15 tennis athletes, 15 volleyball athletes and 15 control subjects (track and/or soccer athletes).

Hypothesis 4a: All overhead athletes will have increased internal rotation strength with respect to controls to varying degrees; Baseball pitchers will have greatest internal rotation strength followed by tennis athletes, volleyball athletes and the control group. All overhead athletes will not have significantly increased external rotation strength but will be higher than the control groups. The internal rotation/external rotation strength ratio will be highest in the baseball pitchers, followed by tennis athletes, volleyball athletes and the control group.

Hypothesis 4b: All overhead athletes will have decreased protraction strength, increased retraction strength and associated lower protraction/retraction strength ratio when compared bilaterally. Baseball pitchers will have the lowest strength ratio followed by tennis athletes, volleyball athletes and the control group.

2.0 MATERIALS AND METHODS

2.1 SUBJECTS

Forty-five male overhead athletes (15 baseball, 13 tennis, and 15 volleyball) and 15 control athletes (male, soccer and/or track athletes) participated in the study. The control group of male soccer and/or track athletes as well as baseball athletes were from the same university. Since there are no men's tennis or volleyball varsity teams at this university, 15 volleyball and 13 tennis athletes who practice/compete 3-4 times a week for 1-2 hours at a time were enrolled from local tennis and volleyball clubs.

Exclusion criteria for all participants included history of fracture, sprain/strain, dislocation/subluxation of any soft tissue or bony tissue of the upper extremity; history of labral injury; and history of shoulder surgery of any kind. Further exclusion criteria included any injury to the spinal column, ribs, or upper arm. The control athletes were not eligible to participate in the study if they had a significant history of participation in any overhead sports (participation will be defined as 1-2 hours per practice, 3-4 times per week). The inclusion criteria included the demand that all subjects were male, had participated in their respective sport for at least the previous 5 years to the time they are tested (control subjects will have no significant history of overhead sports participation). Using an all male overhead athlete population for this study helped to control variability between genders.

A power analysis for the sample size revealed that through the use of previous literature[13] (mean 26.90 ± 7.08 baseball players and 18.01 ± 9.36 control subjects at 90° humeral elevation for upward/downward scapular rotation) as well as estimation, an effect size of 1.11 with an alpha level of .05 (two tailed hypothesis test) will require 15 subjects per group to show a power of .80. This enabled possible differences to be seen between each respective sport and the control group.

2.2 INSTRUMENTATION

2.2.1 Goniometer

Shoulder internal and external rotation range of motion was measured with a standard goniometer. A small bubble level attached to the stationary arm ensured a horizontal reference. Unpublished data conducted in the Neuromuscular Research Laboratory compared range of motion (ROM) measurements using a goniometer to an electromagnetic tracking device[39]. These two devices correlated moderately for ER (ICC=0.728 SEM=0.90) and good for IR (ICC=0.854 SEM=1.02). Intrasession reliability and precession were high for both ER (ICC=0.942 SEM=1.72) and IR (ICC=0.985 SEM=1.51) using the goniometer[39]. The tester can expect approximately 3^{o} of error for both ER and IR range of motion when using a standard goniometer[39].

2.2.2 MotionMonitor Electromagnetic Tracking Device

Humeral and scapular kinematics were recorded with the MotionMonitor (Innovative Sports Training, Chicago, IL) 6 degrees of freedom electromagnetic motion analysis system. The MotionMonitor system consists of a transmitter that creates an electromagnetic field. Subjects wore receivers that detect this electromagnetic field. Program software calculated the position and orientation of the receivers (Local Coordinate System, LCS) with respect to the electromagnetic transmitter and the X,Y, and Z axes of the Global Coordinate System (GCS) in the transmitter. Using the anatomical landmarks described in **Table 1** and the digitization process described later, calculations to determine the orientation of one body segment with respect to another are possible. The accuracy in determining position and orientation is expected to have a root mean square error of .007 meters / 0.27^{o} respectively[40]. Measurement of the mean intrasession in-vivo scapular kinematics has been reported to have high reliability (ICC=0.97±0.03) and high precision (0.99± 0.36°)[40]. The hardware used for this study consists of an extended range direct current transmitter and 6 receivers. Data collection occurs at 100Hz.

2.2.3 Biodex System 3 Isokinetic Dynomometer

Shoulder protraction/retraction and humeral internal/external rotation strength was measured on a Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY). The Biodex dynamometer contains strain gauges and potentiometers that are capable of measuring torque from many positions[13]. This isokinetic system has been demonstrated to have high reliability and validity (ICC=0.99~1.00) for torque and position measurements up to 300°/sec[41]. Test-retest reproducibility of shoulder protraction/retraction strength assessment was reported to be good to excellent (ICC=0.88-0.96) for the protocol used for the current research proposal[7].

2.3 PROCEDURES

All testing for this research project occurred in the Neuromuscular Research Laboratory (NMRL) at the University of Pittsburgh. Testing took approximately one hour to complete. Subjects signed the informed consent form before any testing procedures began. The subjects wore shorts and removed their shirts during testing procedures.

2.3.1 Range of Motion Assessment

Glenohumeral rotation range of motion (ROM) was measured with a standard goniometer[42]. The subject laid supine on a treatment table. The tester placed their shoulder in 90^o abduction with the elbow slightly off the edge of the table. The first tester provided a posterior directed, stabilizing force on the anterior aspect of the shoulder (coracoid and distal clavicle) for both internal rotation and external rotation throughout the ROM while moving the limb through the range of motion. This stabilization limited scapular motion to only allow glenohumeral motion[43]. The second tester measured the range of motion with the goniometer. The movement arm was aligned with the ulnar styloid. The axis of rotation for the goniometer was the middle of the olecranon process of the ulna. A small bubble level was affixed to the stationary arm of the goniometer to ensure a horizontal reference. A towel placed under the humerus ensured that both the humerus and scapula were in the same plane. All measurements started with the forearm perpendicular to the floor. The first tester provided passive external rotation (ER) while maintaining stabilization (**Figure 1**). End range of motion occurs when shoulder rotation ceases or scapular motion can no longer be restricted. The same goniometer landmarks and stabilization techniques as external rotation were used for shoulder internal rotation data collection. However, passive internal rotation (IR) range of motion was assessed (**Figure 2**). The mean of three measurements for each limb was saved for statistical analysis. Bilateral measurements allow ERG and GIRD to be calculated.

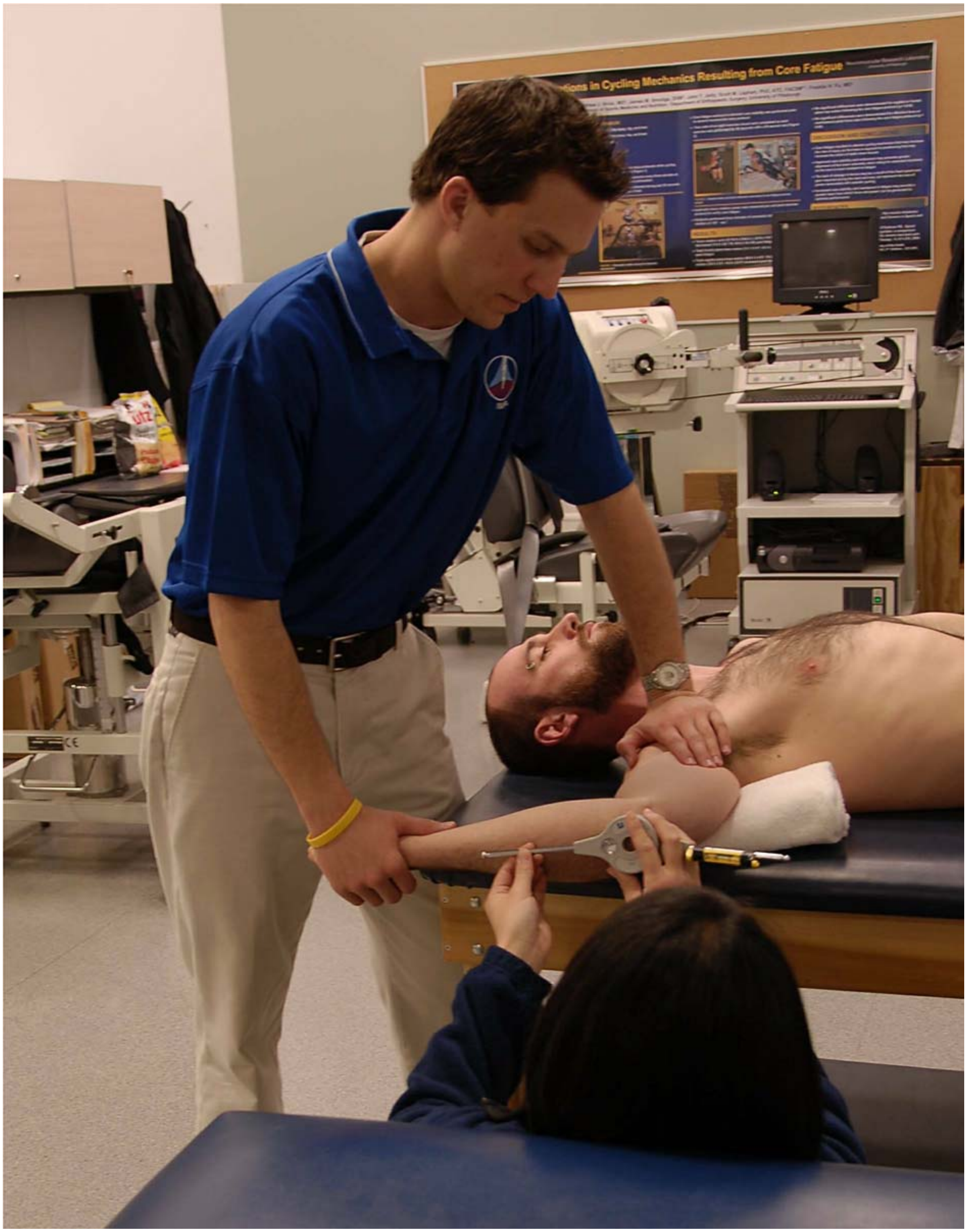

Figure 1 Tester/subject positioning for ER ROM assessment

Figure 2 Tester/subject positioning for IR ROM assessment

2.3.2 Posterior Shoulder Tightness Assessment (Side –Lying)

Posterior shoulder tightness (PST) was measured following the protocol set forth by Tyler et al[23]. The tester used a skin pen to mark the subjects' medial ulnar epicodyles bilaterally.

The subjects lay on the contra-lateral side to that being measured. The subjects were positioned on the treatment table with their hips and knees at approximately 90^o angles to ensure maximum stability. The tester aligned the subject so that both of the subject's acromion processes formed a line perpendicular to the table. For subject comfort, the non-testing arm (arm that is in contact with the tabletop) was positioned under their head (**Figure 3**). This subject position helped to promote neutral flexion, extension and rotation of the spine[23].

The tester stood facing the subject. With the subject's arm in 90^o of abduction with neutral shoulder rotation and elbow relaxed, the tester provided manual scapular stabilization in a fully retracted position by holding the lateral border of the subjects' scapula. The tester performed as many practice measurements as needed in order to maintain the scapula as close as possible to the retracted, starting position. Once adequate stabilization occurs, the tester brought the subject's arm into straight horizontal adduction without allowing humeral rotation. It was imperative that the subject be able to totally relax and let the researcher have complete control of the extremity throughout the duration of this assessment. If the subject was not able to relax or adequate scapular stabilization was not provided throughout the duration of horizontal adduction, that specific trial was rejected. If neutral rotation of the arm and shoulder was not maintained, the trial was rejected as well. An additional trial replaced any rejected trials. The second tester measured the distance from the medial epicondyle of the arm being tested to the tabletop. A perpendicular measurement to the table was ensured by the use of a metal carpenters' square. The shorter side of the square remained against the table (**Figure 3**). This distance represented the amount of posterior shoulder mobility. The mean of 3 measurements from each shoulder allowed the PST difference between dominant and non-dominant limbs to be calculated.

Figure 3 Tester/subject positioning for side-lying PST assessment

2.3.3 Posterior Shoulder Tightness Assessment (Supine Method)

Posterior shoulder tightness was assessed with the subject lying supine on the treatment table. The tester used a skin-marking pen to mark the lateral most border of the acromion. This mark represented the joint center during horizontal adduction of the upper limb. The subject was instructed to lie on his back comfortably and relax. The first tester placed a standard goniometer over the superior aspect of the shoulder (superior in relation to anatomical position) with the axis of rotation centered over the mark on the lateral aspect of the acromion. The second tester stabilized the subject's scapula. In order to do this, the subject was asked to raise his shoulder off the table so the tester could grasp his scapula. Once the tester was able to grasp the scapula, the tester instructed the subject to relax his shoulder and relax once again on the table. With the subject totally relaxed, the tester then passively pushed the subject's scapula into a position of maximum retraction. Once the scapula was sufficiently stabilized in this retracted position, the subject's limb was placed in a position of neutral horizontal adduction/abduction (parallel to the table and floor). This was the starting position for the range of motion assessment. While the first tester followed the limb with the movement arm of the goniometer, the second tester passively horizontally adducted the subject's limb while maintaining sufficient scapular stabilization. Slight over pressure was applied to the limb once an end range of motion was reached. This helped to ensure that this was the anatomical end range of motion and not as result of the subject contracting their muscles to prevent further motion. This arc of horizontal adduction range of motion represented the posterior shoulder mobility. It was imperative that the subject be able to totally relax and let the researcher have complete control of the extremity throughout the duration of this assessment. If the subject was not able to relax or adequate scapular stabilization was not provided throughout the duration of horizontal adduction, that specific trial was rejected. An additional trial replaced any rejected trials. The mean of 3 measurements from each shoulder allowed the supine PST difference between dominant and non-dominant limbs to be calculated. The tester/subject positioning is shown in **Figure 4**.

Figure 4 Tester/Subject positioning for Supine PST assessment

2.3.4 Scapular Kinematic Assessment

Subjects were fitted with electromagnetic tracking receivers used in conjunction with the Motion Monitor system to track scapular kinematics. The subjects removed their shirts to make marker placement more accurate and secure. Electromagnetic receivers were placed on the seventh cervical vertebrae (C7), bilateral acromia, and one on the mid-shaft of each humerus. Hypoallergenic tape (The Kendall Co. Mansfield, MA) as well as double-sided adhesive disks (3M Health Care, St. Paul, Minn.) secured all receivers. The acromion receivers were affixed to the flat portion of the superior, scapular spine between the acromion angle (AA) and acromioclavicular joint (AC). The thoracic receiver was placed on the spinous process of the seventh cervical vertebrae. Humeral receivers were attached by means of a neoprene cuff around the upper arm at the mid-point of the humerus. The last receiver was attached to a plastic stylus to digitize bony landmarks on the thorax, scapula and humerus. This digitization process allowed transformation of the receiver data from a global coordinate system (GCS) to an anatomically based, local coordinate system (LCS)[44].

In order to develop a LCS with respect to the GCS of the research lab, each bone/region involved for the assessment (scapula, humerus, and thorax) must have at least three anatomical points included in the digitization process. There are only two anatomical landmarks on the humerus, the medial and lateral epicondyle. In order to produce an orthogonal LCS for the humerus, the glenohumeral joint center is determined by a least square algorithm for the point of the humeral head with the least movement during several short arc movements of the humerus[45]. Twenty short arc movements were adequate for this calculation. The glenohumeral joint center is the third anatomical landmark on the humerus and allowed calculations to create a LCS for the humerus. The anatomical points are presented and in **Table 1**. The anatomical landmarks that were used for digitization are the ones suggested by the International Shoulder Group of the International Society of Biomechanics[46]. **Figure 5** demonstrates the LCS for each respective body segment. For each anatomical landmark, the point was palpated and then digitized by the examiner.

Table 1 Description of antomical landmarks

Bone Segment	Bony Landmark	Description of Landmark
Thorax		
	Eighth thoracic spinous process (T8)	Most dorsal point
	Processus xiphoideus (PX)	Most caudal point of sternum
	Seventh cervical spinous process (C7)	Most dorsal point
	Incisura jugularis (IJ)	Most cranial point of sternum (suprasternal notch)
Scapula		
	Angulus acromialis (AA)	Most lateral-dorsal point of scapula
	Trigonum spinae (TS)	Midpoint of triangular surface of medial border of scapula in line with scapular spine
	Angulus inferior (AI)	Most caudal point of scapula
Humerus		
	Medial epicondyle (ME)	Most medial point on the medial epicondyle
	Lateral epicondyle (LE)	Most lateral point on the lateral epicondyle
	Glenohumeral joint center (GH)	Estimated with a least squares algorithm for the point of humerus with the least motion during several short arc humeral movements

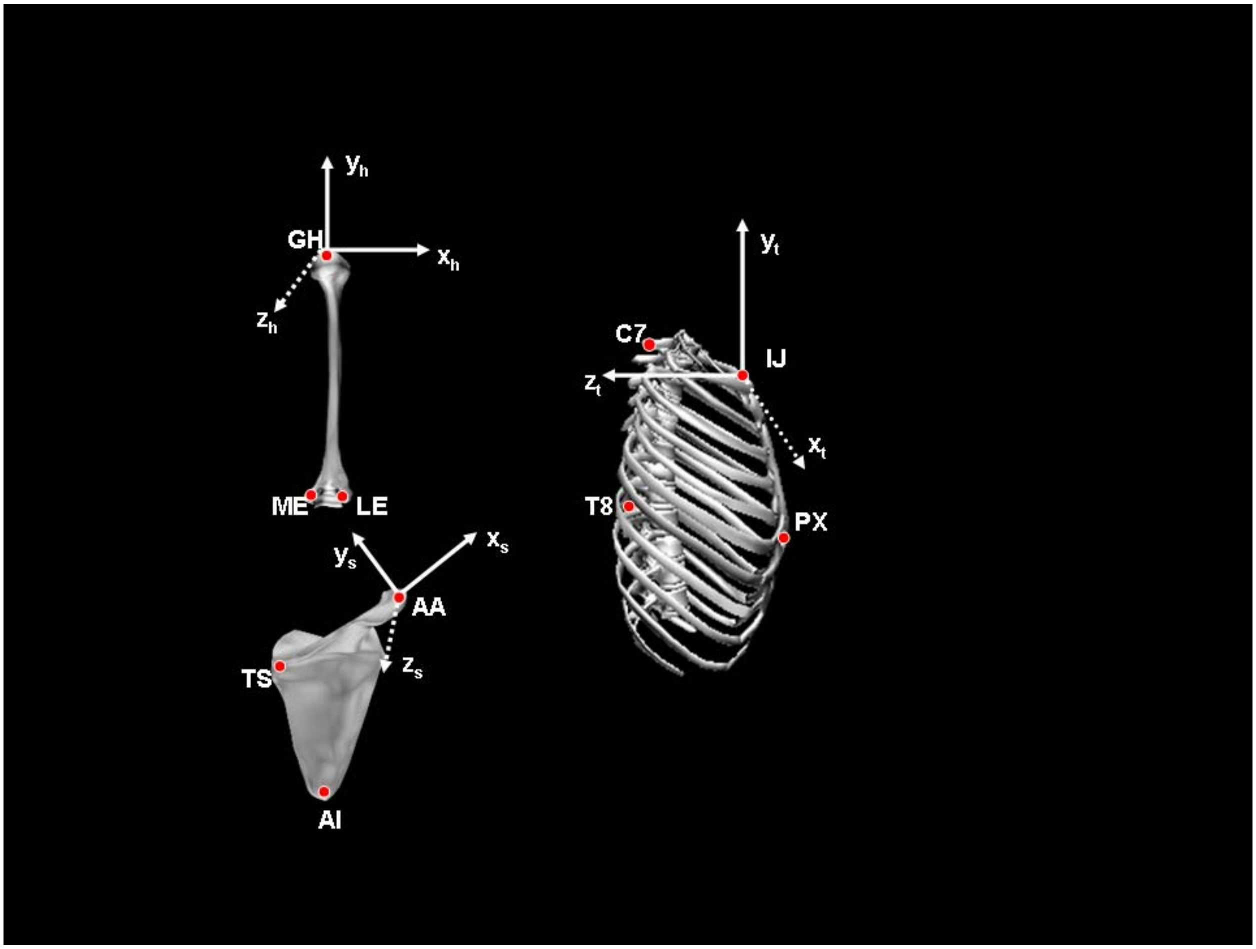

Figure 5 ISG definitions of LCS for anatomical regions

A PVC pipe guide kept the subjects' arms in the scapular plane (**Figure 6**). The scapular plane was identified as 30^o anterior to the frontal plane for this study. Shoulder rotation was in the neutral position. The subject maintained this position by keeping their thumbs pointing towards the ceiling. The subject performed 10 elevation motions at a rate of 4 seconds for one repetition (2 seconds raising and 2 seconds lowering) aided by a metronome. The mean of the middle five elevation motions was saved for statistical analysis. The motions that were analyzed during statistical analysis were scapular: protraction/retraction, elevation/depression, upward/downward rotation, anterior/posterior tipping and internal/external rotation and are presented in **Figure 7**.

Figure 6 Plastic guide tubes to keep elevation in scapular plane

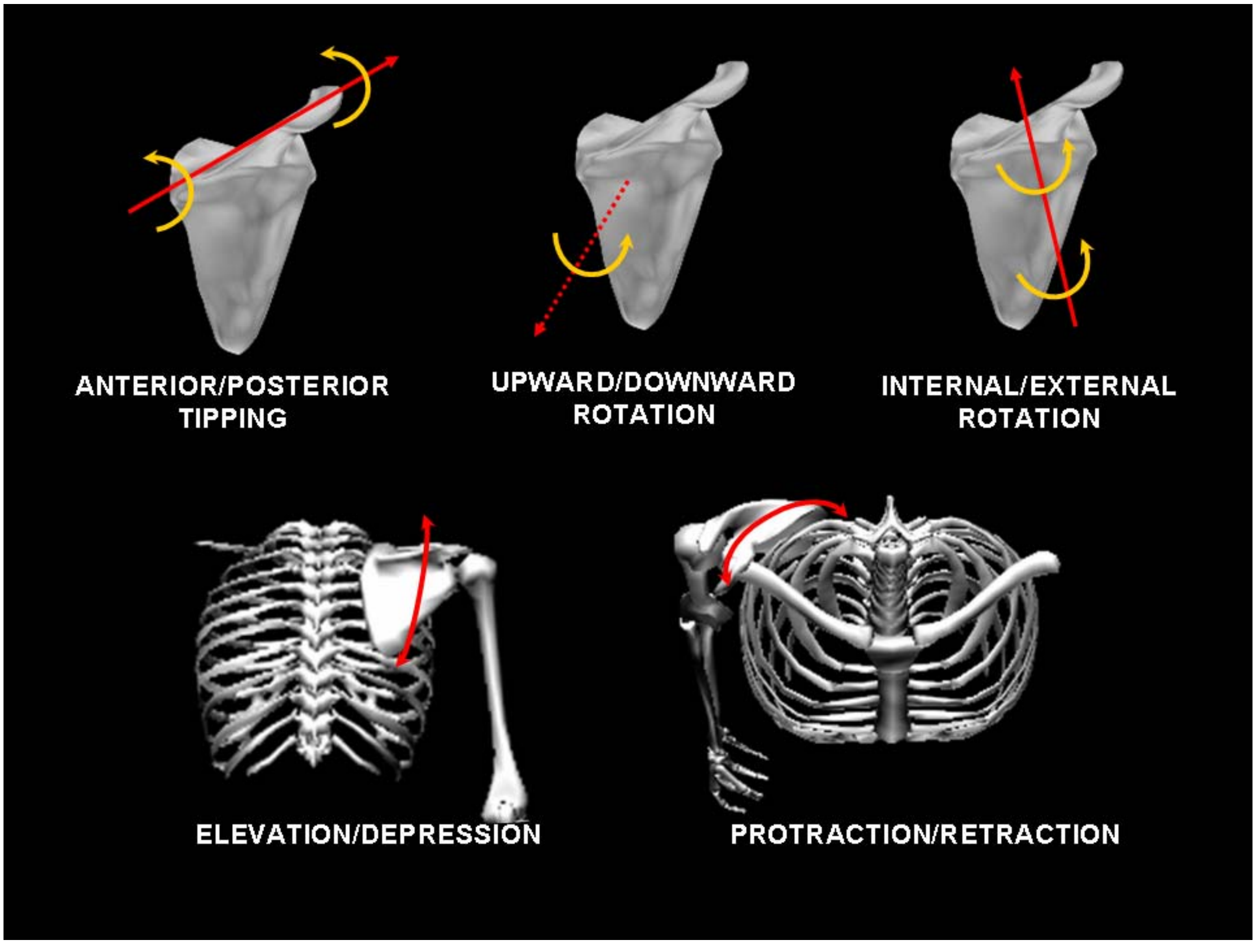

Figure 7 ISG definitions of scapular motions that were assessed

2.3.5 Strength Assessment

In an effort to minimize the effect of fatigue on scapular position/kinematics that has been documented by Crotty and colleagues[47], strength assessment was the last variable collected.

The Biodex setup for protraction and retraction followed the protocol described by Cools et al[48]. Shoulder protraction and retraction is not an angular movement. For that reason, the close kinetic chain (CKC) device was attached to the Biodex and aligned in the horizontal plane. In order to maintain a neutral shoulder internal/external rotation, the handgrip for the CKC device was set so that the handle was vertical. The chair and the dynamometer were rotated in the same direction in order to place the subject's upper extremity in the scapular plane (30^{o} anterior to the frontal plane). The chair was rotated to 15^o and the dynamometer to 45^o. Chest and waist straps helped to secure the subject in the chair. A handle was also available for the subject to hold onto with the non-testing hand for added stability (**Figure 8**). The first test speed was set at 12.2 cm/s (60^o/s), followed by the faster speed of 36.6 cm/s (180^o/sec). The test range of motion was set by having the subject perform a protraction and retraction motion throughout his maximum range of motion. Gravity correction was not calculated because this test will occur in the horizontal plane and is a linear motion. Since scapular protraction and retraction are not common motions, the tester instructed the subject on the movements. Five repetitions at minimal effort followed by three repetitions at the test speed allowed a familiarization period at each test speed.

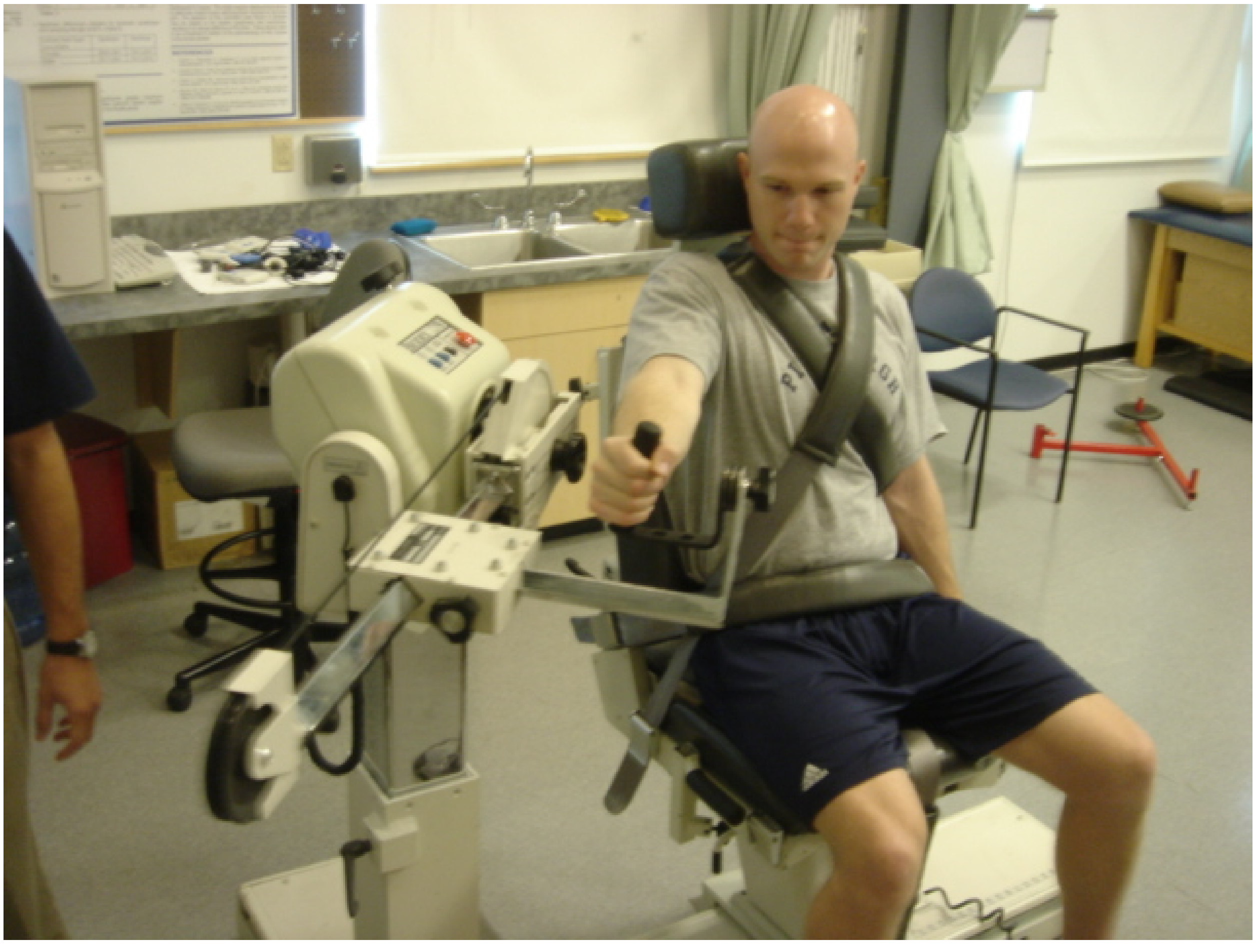

Figure 8 Biodex setup for shoulder protraction/retraction strength assessment

The subject performed five repetitions at 12.2 cm/s followed by ten repetitions at 36.6cm/s. There was a ten second rest period between the test speeds. There was no verbal encouragement during the data collection. For the purposes of this study, only concentric data was collected and analyzed for protraction and retraction strength. Data collection occurred bilaterally. The protraction/retraction strength ratio at each speed and average peak torque normalized to bodyweight for protraction and retraction at each speed was saved for statistical analysis.

Following a five-minute rest period after the conclusion of the protraction/retraction strength assessment, internal/external rotation strength was assessed on the Biodex. Proper patient positioning is essential in order to allow the rotator cuff to perform optimally (i.e. length tension relationship, least amount of constraint on the rotator cuff)[34]. The subject's arm was placed in 45° abduction and 30° anterior to the frontal plane (scapular plane) (**Figure 9**). Care was taken to ensure the proper positioning of the subject so that the axes of both the glenohumeral joint and the dynamometer were aligned. The range of motion for internal and external rotation was set at 50° IR and 90° ER (160° arc of motion). The subject then performed five repetitions at 60°/sec. There was a 1-minute rest period before the ten repetitions began at 300°/sec. The internal/external rotation strength ratio at each speed as well as average peak torque normalized to bodyweight was collected bilaterally at each speed and used for statistical analysis.

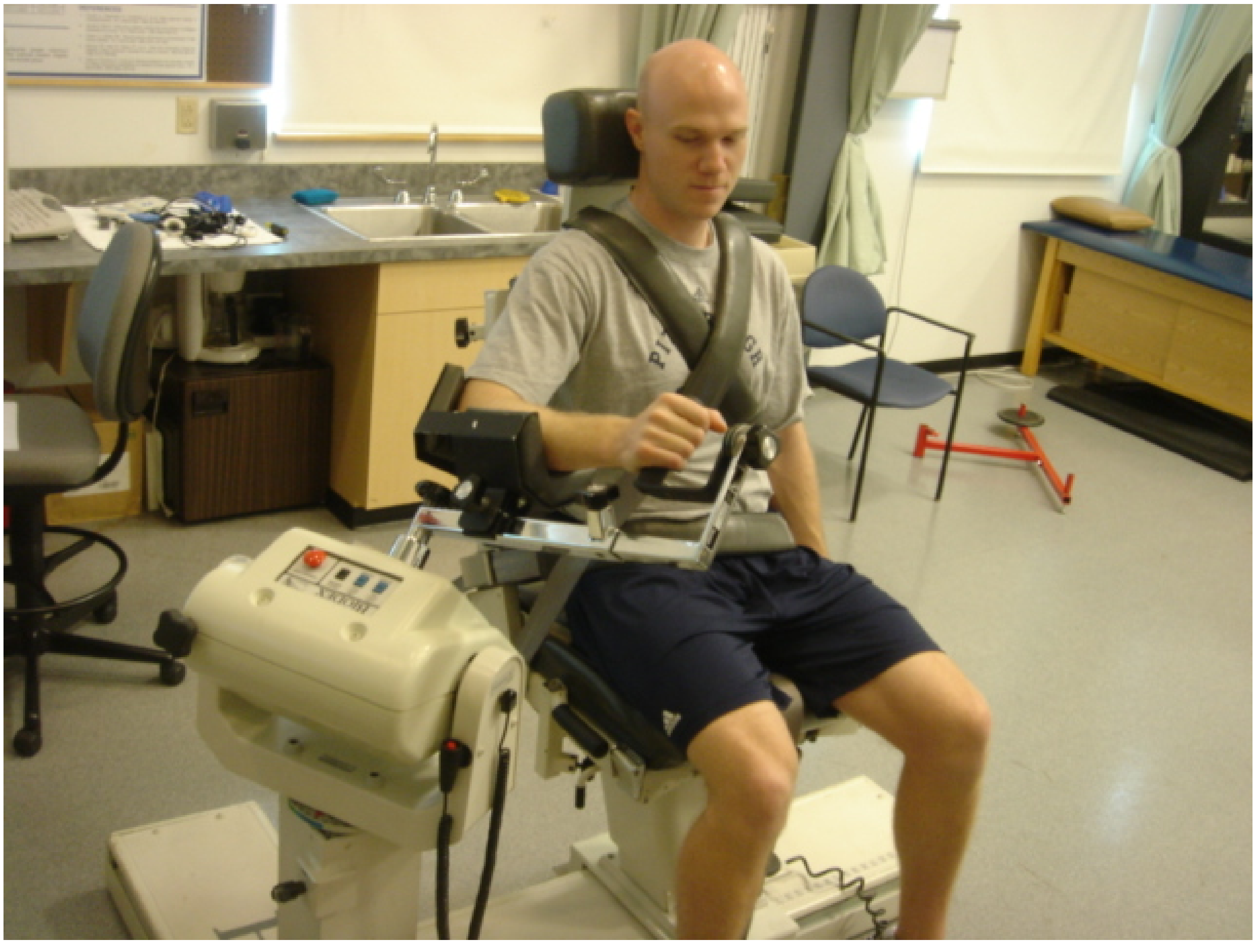

Figure 9 Biodex setup for shoulder IR/ER strength assessment

2.4 DATA REDUCTION AND ANALYSIS

Table 2 presents all of the dependant variables for the current study that were included in the statistical analysis.

Table 2 List of dependant variables

Type of tests	Dependant Variables	
ROM		
	Internal rotation ROM (deg.)	
	External rotation ROM (deg.)	
	GIRD (IR non-dominant - IR dominant) (deg.)	
	ERG (ER non-dominant - ER dominant) (deg.)	
Strength		
	ER average peak torque normalized to bodyweight @ 60°/sec (Nm/kg)	
	IR average peak torque normalized to bodyweight @ 60°/sec (Nm/kg)	
	IR/ER strength ratio @ 60°/sec*	
	IR average peak torque normalized to bodyweight @ 300°/sec (Nm/kg)	
	ER average torque normalized to bodyweight @ 300°/sec (Nm/kg)	
	IR/ER strength ratio @ 300°/sec*	
	Protraction average peak force normalized to bodyweight @12.2 cm/sec (Nm/kg)	
	Retraction average peak force normalized to bodyweight @ 12.2 cm/sec (Nm/kg)	
	Protraction/Retraction strength ratio @ 12.2 cm/sec*	
	Protraction average peak force normalized to bodyweight @ 36.6 cm/sec (Nm/kg)	
	Retraction average peak force normalized to bodyweight @ 36.6 cm/sec (Nm/kg)	
	Protraction/Retraction strength ratio @ 36.6 cm/sec*	
PST		
	Non-dominant/dominant PST ratio	
Scapular Kinematics		
	Scapular internal/external rotation (deg.)	@ 30, 60, 90, and 120° of humeral elevation
	Scapular upward/downward rotation (deg.)	
	Scapular anterior/posterior tilt (deg.)	
	Scapular protraction/retraction (deg.)	
	Scapular elevation/depression (deg.)	

*****The strength ratios are ratios between the peak torques normalized to bodyweight

In order to calculate the scapular kinematic dependent variables, scapular kinematic data was filtered with a low-pass, fourth-order, zero-phase shift, filter with a cutoff frequency of 10 Hz. The position and orientation data from the thoracic, humeral and scapula receivers were used to form local coordinate systems (LCS) in accordance with the International Shoulder Group (ISG) of the International Society of Biomechanics. **Figure 4** demonstrates the LCS and **Table 3** defines the LCS.

Table 3 ISG definitions of LCS

Local Coordinate System	Axis	Definition
Thorax	y_t	Vector from midpoint of PX and T8 to the midpoint of IJ and C7
	x_t	Vector perpendicular to the plane fitted by midpoint of PX and T8, the midpoint of IJ and C7, and IJ
	z_t	Vector perpendicular to x_t and y_t
	Origin	IJ
Scapula	x_s	Vector from TS to AA
	y_s	Vector perpendicular to the plane fitted by TS, AA, and AI (scapular plane)
	z_s	Vector perpendicular to x_s and y_s
	Origin	AA
Humerus	y_h	Vector from midpoint of ME and LE to GH
	x_h	Vector perpendicular to the plane fitted by GH, ME, and LE
	z_h	Vector perpendicular to y_h and x_h
	Origin	GH

With the subject standing in the anatomical position, the positive Y-axis is vertical, positive X-axis is horizontal and positive Z-axis is posterior. Internal/external scapular rotation was determined as motion about the Y-axis, upward/downward rotation about the Z-axis, and anterior/posterior tipping about the X-axis as chosen by the International Shoulder Group[46]

(**Figure 5**). Scapula and humeral orientation with respect to the thorax was determined by Euler angle decompositions. Rotation sequences of Euler angles were chosen based on standards set by the International Shoulder Group[46]. The clavicle attaches the scapula to the thorax. Thus, the position of the scapula can be described as the orientation of the vector from the jugular notch (IJ) to the acromion (AA) with respect to the thorax LCS since the clavicle is a rigid body with a fixed length. This vector closely relates to the anatomical orientation of the clavicle. Scapular protraction and retraction angles were calculated as the angle between the clavicular vector (IJ to AA) and the frontal plane; scapular elevation/depression angles used the same vector with respect to the transverse plane of the thorax. Scapular position and orientation at the different humeral elevation angles (0^o, 30^o, 60^o, 90^o, 120^o) were recorded. Research has shown that above 120^o humeral elevation, data tends to be inaccurate[49]. Scapular kinematic variables were calculated and processed using Matlab 12 (The MathWorks, Inc., Natick, Mass.). The mean for the variables that Matlab produced was entered into SPSS 13.0 (SPSS Inc, Chicago, Ill.) for statistical analysis.

Subject demographics, PST difference, and the amount of GIRD and ERG were analyzed for between group differences with a one-way ANOVA. A one-within, one-between analysis of variance (two-way ANOVA) was performed on range of motion, total rotation range of motion, supine and side-lying PST assessment data with a between factor of group and within factor of limb. Strength variables were analyzed with a one-within, one-between ANOVA at each speed to compare between group and limb for both the slow speed (60°/sec for internal/external rotation and 12.2 cm/sec for protraction and retraction) and fast speed (300°/sec for internal/external rotation and 36.6 cm/sec for protraction and retraction). A one-within, one-between (two-way) ANOVA was run on scapular kinematic data at each angle for each variable (separate ANOVA for upward/downward rotation at 0°, separate ANOVA for upward/downward rotation at 30°, etc.) to compare between group and limb at each humeral elevation angle. Scapular kinematic data and strength variables had a between factor of group and within factor of limb. A Bonferroni minimally significant difference (MSD) showed where any significant differences arose for the one-within, one between ANOVA. All statistical analyses were performed in SPSS Version 13.0 (SPSS Science Inc, Chicago, Ill.). The level of significance was set at an alpha level of 0.05 *a priori*.

3.0 RESULTS

The demographics for the subjects are presented in **TABLE 4**. Fifty-eight athletes participated in the current study (fifteen baseball pitchers, fifteen volleyball athletes, fifteen control athletes (track and/or soccer athletes), and thirteen tennis athletes). All subjects were college-aged, male athletes who were symptom free from any shoulder pathology with no prior history of a diagnosed pathology in the shoulder or upper extremity. Statistical analysis showed that there was a significant interaction between sport and height ($p < 0.001$). Volleyball athletes were taller than baseball pitchers ($p = 0.016$), tennis athletes ($p < 0.001$), and control athletes ($p < 0.001$). There was also a significant interaction between sport and weight ($p < 0.001$). Control athletes were lighter than baseball pitchers ($p = 0.001$) and volleyball athletes ($p = 0.006$).

Table 4 Subject Demographics

	Baseball (n=15)		**Tennis (n=13)**		**Volleyball (n=15)**		**Control (n=15)**	
	Mean	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**
Height (cm)	181.54	7.08	177.38	5.04	188.40	2.76	177.67	5.30
Mass (kg)	88.05	14.78	75.75	6.64	82.58	4.58	72.43	8.57
Age (years)	20.00	1.73	21.20	1.10	21.33	1.51	20.71	1.25

3.1 RANGE OF MOTION ASSESSMENT

3.1.1 Shoulder Internal Rotation Range of Motion

Shoulder internal rotation range of motion is presented in **TABLE 5** and **Figure 9**. The Minimum Significant Difference (MSD) and the mean differences between each group are presented in **TABLE 6** and **TABLE 7**. With an adjusted alpha level of $p = 0.00625$, a statistically significant group by limb interaction ($p < 0.001$, MSD = 3.258) was found with internal rotation range of motion. Post hoc comparisons revealed that baseball, volleyball and tennis athletes had less dominant limb, internal rotation range of motion than their non-dominant limb (Mean Difference = 12.6, 4.4, 11.0 respectively). Baseball pitchers had more dominant limb internal rotation than tennis athletes (Mean Difference = 6.99) and less internal rotation than control athletes (Mean Difference = 4.62) did. Volleyball athletes had less dominant limb internal rotation than control athletes (Mean Difference = 11.61). Tennis athletes had less dominant internal rotation than volleyball athletes did (Mean Difference = 4.92) and control athletes (Mean Difference = 11.61) as well. Baseball players had more non-dominant limb internal rotation than volleyball athletes (Mean Difference = 10.34), tennis athletes (Mean Difference = 8.56), and the control athletes (Mean Difference = 6.69). Volleyball athletes had less non-dominant limb internal rotation than the control athletes (Mean Difference = 3.64).

Table 5 Shoulder Rotation Range of Motion

	Baseball		Tennis		Volleyball		Control	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Dominant								
Internal Rotation (°)	41.7	5.9	34.7	7.5	39.6	7.7	46.3	13.1
External Rotation (°)	132.0	10.4	129.6	11.5	126.1	8.4	120.3	7.0
Total Rotation ROM (°)	173.7	10.3	164.3	12.8	165.7	8.4	166.6	14.1
Non-Dominant								
Internal Rotation (°)	54.3	8.3	45.7	7.5	44.0	7.7	47.6	12.9
External Rotation (°)	119.7	9.5	120.7	12.7	118.8	5.9	114.3	5.8
Total Rotation ROM (°)	174.0	13.9	165.4	13.6	162.8	8.1	161.9	15.5

Table 6 Mean Differences for Dominant Shoulder Internal Rotation

MSD = 3.25	**Baseball 41.71**	**Volleyball 39.64**	**Tennis 34.72**	**Control 46.33**
Baseball 41.71	-----			
Volleyball 39.64	2.07	-----		
Tennis 34.72	*6.99	*4.92	-----	
Control 46.33	*4.62	*6.69	*11.61	-----

* Significant mean difference

Table 7 Mean Differences for Non-Dominant Shoulder Internal Rotation

MSD = 3.25	**Baseball 54.30**	**Volleyball 43.96**	**Tennis 45.74**	**Control 47.60**
Baseball 54.30	-----			
Volleyball 43.96	*10.34	-----		
Tennis 45.74	*8.56	1.78	-----	
Control 47.60	*6.69	*3.64	1.86	-----

* Significant mean difference

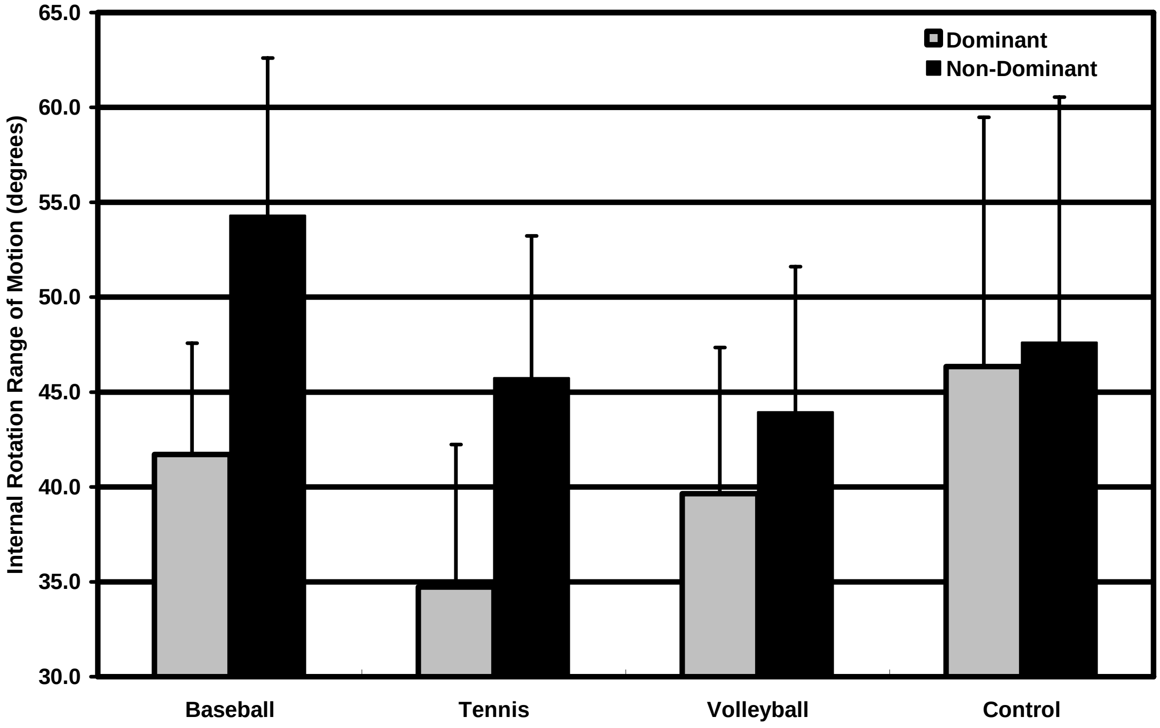

Figure 10 Shoulder Internal Rotation Range of Motion

3.1.2 Shoulder External Rotation Range of Motion

External rotation range of motion results are presented in **TABLE 5**. No statically significant group by limb interaction was found (p = 0.103) for external rotation range of motion.

3.1.3 Total Shoulder Rotation Range of Motion

The results for total rotation range of motion are presented in **TABLE 5.** No statistically significant differences were present with group by limb interactions (p = 0.250) for total rotational range of motion.

3.1.4 Glenohumeral Internal Rotation Deficit (GIRD) and External Rotation Gain (ERG)

GIRD and ERG results are presented in **TABLE 8** and **Figure 11**. There was a statistically significant between group interaction for GIRD (p < 0.001). Baseball pitchers had more GIRD than control athletes had (p = 0.001). Tennis athletes had more GIRD than control athletes had (p = 0.006) as well. No statistically significant differences were found with between group comparisons (p = 0.119) for ERG.

Table 8 Glenohumeral Internal Rotation Deficit / External Rotation Gain Measurement

	Baseball		Tennis		Volleyball		Control	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Glenohumeral Internal Rotation Deficit (°)	-12.6	7.9	-11.0	5.9	-4.3	7.8	-1.3	7.3
External Rotation Gain (°)	12.3	8.1	8.8	9.1	7.3	7.0	6.0	7.4

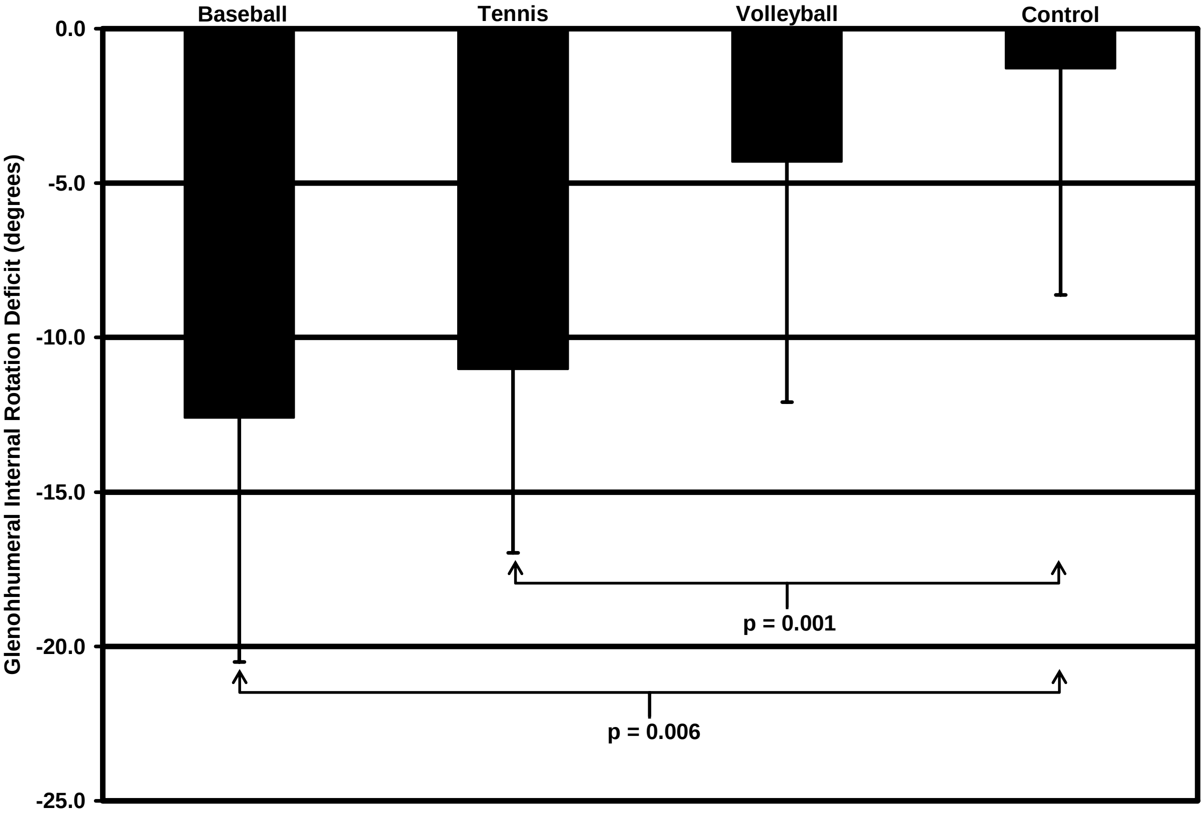

Figure 11 Glenohumeral Internal Rotation Deficit

3.2 POSTERIOR SHOULDER TIGHTNESS

Posterior shoulder tightness (PST) results are presented in **TABLES 9, 10, 11**, **Figure 12**. The mean differences for dominant and non-dominant PST assessment with the supine method are presented in **TABLE 10** and **TABLE 11.** Post Hoc comparisons revealed that baseball pitchers, volleyball athletes, and tennis athletes all had more between limb difference in horizontal adduction than control athletes with the supine method of assessment (Mean Difference = 8.03, 6.15, 8.05 respectively). With an adjusted alpha level of p = 0.00625, a significant group by limb interaction was found for posterior shoulder tightness with the supine assessment method (p = 0.002; MSD = 2.72). Tennis athletes had less dominant shoulder horizontal adduction than control athletes (Mean Difference = 3.23). Baseball pitchers, volleyball athletes, and tennis athletes all had more non-dominant shoulder horizontal adduction than control athletes (Mean difference = 6.67, 5.33, 4.66 respectively). There was also a significant between group interaction (p = 0.002) for the supine assessment difference (dominant–non-dominant). Baseball pitchers (p = 0.005) and tennis athletes (p = 0.008) had a larger difference than control athletes. No significant interactions were found for the side-lying assessment method (p = 0.214) or the side-lying difference (p = 0.224).

Table 9 Posterior Shoulder Tightness Measurement

	Baseball		Tennis		Volleyball		Control	
	Mean	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**
Dominant								
Supine (°)	105.93	5.88	103.90	7.62	106.47	5.98	107.13	6.85
Side-Lying (cm)	31.94	1.70	33.39	1.46	32.48	1.09	30.82	1.13
Non-Dominant								
Supine (°)	113.96	9.25	111.95	6.52	112.62	4.54	107.29	10.27
Side-Lying (cm)	29.67	1.44	31.13	1.35	31.79	1.20	30.16	1.48
Supine PST Difference (°)	-8.02	7.08	-8.05	5.92	-6.16	3.44	-0.16	7.23
Side-Lying PST Difference (cm)	2.27	1.77	2.26	0.75	0.69	0.64	0.66	0.85

Table 10 Mean Differences for Dominant Shoulder, Supine PST Assessment

MSD = 2.72	**Baseball 105.93**	**Volleyball 106.47**	**Tennis 103.90**	**Control 107.13**
Baseball 105.93	-----			
Volleyball 106.47	0.54	-----		
Tennis 103.90	2.03	2.57	-----	
Control 107.13	1.20	0.66	*3.23	-----

* Significant mean difference

Table 11 Mean Differences for Non-Dominant Shoulder, Supine PST Assessment

MSD = 2.72	**Baseball 113.96**	**Volleyball 112.62**	**Tennis 111.95**	**Control 107.29**
Baseball 113.96	-----			
Volleyball 112.62	1.34	-----		
Tennis 111.95	2.01	0.67	-----	
Control 107.29	*6.67	*5.33	*4.66	-----

* Significant mean difference

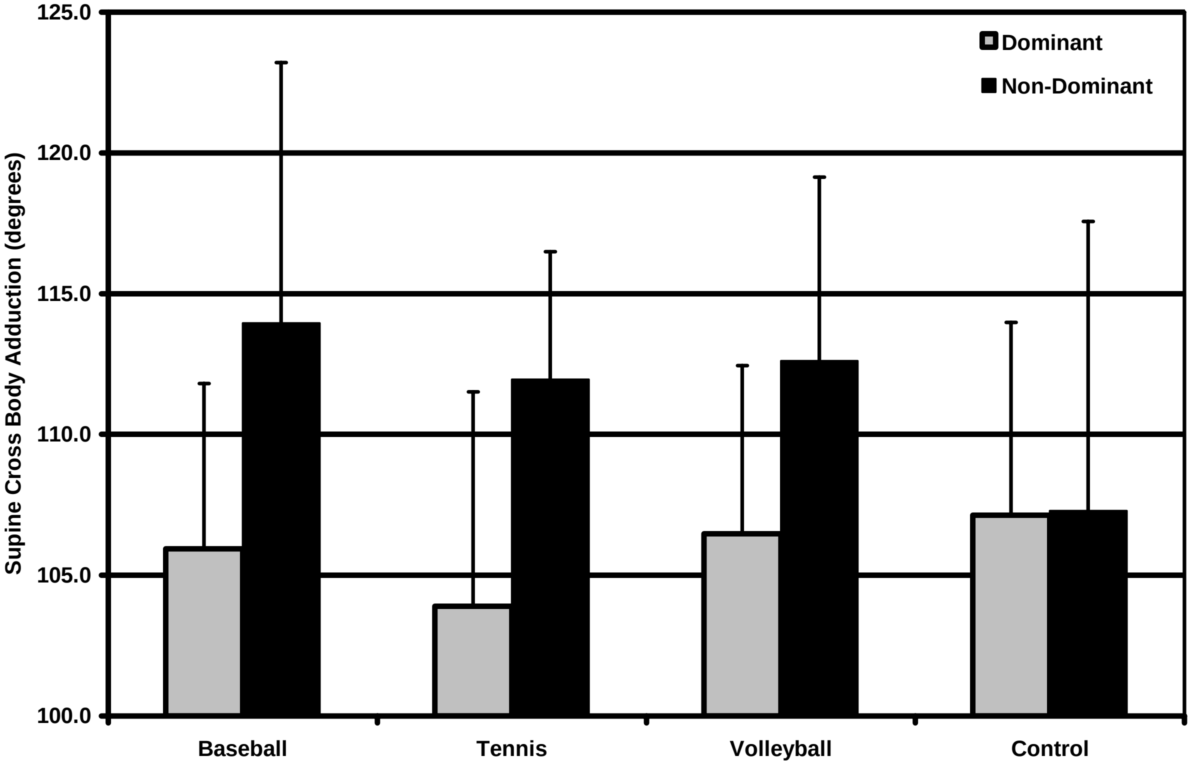

Figure 12 Supine Posterior Shoulder Tightness Assessment

3.3 STRENGTH ASSESSMENT

3.3.1 Shoulder Internal Rotation/External Rotation Strength Assessment

Internal/external rotation strength assessment results are presented in **TABLE 12** and **TABLE 13**. There were no statistically significant sport by limb interactions for internal rotation strength (p = 0.309), external rotation strength (p = 0.968) or the external/internal strength ratio at 60º/sec (p = 0.275). There were no statistically significant sport by limb interactions for internal rotation strength (p = 0.361), external rotation strength (p = 0.493), or external/internal rotation strength ratio at 300º/sec (p = 0.493).

Table 12 Internal/External Rotation Strength at 60°/sec

	Baseball		Tennis		Volleyball		Control	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Dominant								
Internal rotation (N*m/kg)	0.49	0.12	0.53	0.13	0.59	0.11	0.54	0.13
External rotation (N*m/kg)	0.37	0.07	0.36	0.07	0.41	0.06	0.39	0.04
ER/IR ratio	0.75	0.25	0.67	0.13	0.69	0.10	0.73	0.16
Non-Dominant								
Internal rotation (N*m/kg)	0.49	0.10	0.46	0.11	0.56	0.16	0.53	0.16
External rotation (N*m/kg)	0.35	0.06	0.35	0.06	0.40	0.07	0.39	0.06
ER/IR ratio	0.72	0.11	0.74	0.09	0.70	0.15	0.74	0.14

Table 13 Internal/External Rotation Strength Assessment at 300°/sec

	Baseball		Tennis		Volleyball		Control	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Dominant								
Internal rotation (N*m/kg)	0.40	0.10	0.32	0.13	0.40	0.14	0.34	0.11
External rotation (N*m/kg)	0.28	0.08	0.20	0.06	0.22	0.05	0.21	0.05
ER/IR ratio	0.69	0.20	0.61	0.20	0.54	0.16	0.61	0.64
Non-Dominant								
Internal rotation (N*m/kg)	0.37	0.09	0.28	0.08	0.41	0.13	0.34	0.12
External rotation (N*m/kg)	0.27	0.08	0.17	0.06	0.22	0.05	0.21	0.10
ER/IR ratio	0.72	0.13	0.61	0.17	0.54	0.12	0.61	0.27

3.3.2 Shoulder Protraction/Retraction Strength Assessment

Protraction/retraction strength assessment results are presented in **TABLE 14** and **TABLE 15**. No significant sport by limb interactions for protraction strength (p = 0.224), retraction strength (p = 0.642) or the protraction/retraction strength ratio (p = 0.989) for the 12.2 cm/sec testing speed were present. No significant sport by limb interactions for protraction strength (p = 0.120), retraction strength (p = 0.492) or the protraction/retraction strength ratio (p = 0.260) for the 36.6 cm/sec testing speed were present.

Table 14 Protraction/Retraction Strength Assessment at 12.2 cm/sec

	Baseball		Tennis		Volleyball		Control	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Dominant								
Protraction (N/kg)	2.46	1.06	2.09	0.63	2.30	1.05	2.40	1.00
Retraction (N/kg)	2.24	0.87	2.05	0.73	2.56	1.16	2.47	1.05
Pro/Re Ratio	1.10	0.30	1.02	0.34	0.90	0.30	0.97	0.36
Non-Dominant								
Protraction (N/kg)	2.34	0.99	2.36	0.56	2.72	1.00	2.29	1.06
Retraction (N/kg)	2.10	0.91	2.19	0.73	2.68	0.77	2.35	1.22
Pro/Re Ratio	1.12	0.20	1.08	0.20	1.01	0.23	0.98	0.41

Table 15 Protraction/Retraction Strength Assessment at 36.6 cm/sec

	Baseball		Tennis		Volleyball		Control	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Dominant								
Protraction (N/kg)	1.93	0.79	1.48	0.51	1.51	0.69	1.80	0.82
Retraction (N/kg)	1.98	0.95	1.59	0.51	1.98	1.02	2.01	0.85
Pro/Re Ratio	0.98	0.35	0.93	0.20	0.76	0.20	0.90	0.41
Non-Dominant								
Protraction (N/kg)	1.70	0.68	1.69	0.65	1.80	0.64	1.73	0.58
Retraction (N/kg)	1.73	0.72	1.56	0.52	2.07	0.91	1.97	0.86
Pro/Re Ratio	0.98	0.18	1.08	0.18	0.87	0.26	0.88	0.16

3.4 SCAPULAR KINEMATICS

Dominant scapular kinematics are presented in **TABLE 16** and non-dominant scapular kinematics are presented in **TABLE 17**. The mean differences for scapular elevation/depression are presented in **TABLES 18-21**. Scapular elevation data are presented in **FIGURES 13-16**. With an adjusted alpha level of $p = 0.00625$, there was a significant limb by sport interaction with scapular elevation/depression at 90° ($p = 0.001$; MSD = 1.92) and 120° ($p < 0.001$; MSD = 2.25). At 90°, baseball pitchers showed more dominant limb elevation than volleyball, tennis and control athletes (mean difference = 2.15, 4.61, 2.23 respectively), volleyball athletes showed more elevation than tennis athletes did (mean difference = 2.46), and tennis athletes had less elevation than the control athletes did (mean difference = 2.31). Volleyball athletes had more non-dominant scapular elevation than baseball pitchers and control athletes (mean difference = 3.19, 2.06 respectively) at 90° of humeral elevation. At 120° of humeral elevation, baseball pitchers showed more dominant limb elevation than volleyball, tennis and control athletes (mean difference = 3.29, 5.89, 2.29 respectively), volleyball athletes showed more elevation than tennis athletes did (mean difference = 2.60), and tennis athletes had less elevation than the control athletes did (mean difference = 3.60). Baseball pitchers had less non-dominant scapular elevation at 120° humeral elevation than volleyball and control athletes (mean difference = 5.58 and 3.08 respectively). Volleyball athletes had more non-dominant elevation than tennis and control athletes did at 120° (mean difference = 3.67 and 2.50 respectively). No statistically significant differences were found for scapular upward/downward rotation at 0°, 30°, 60°, 90° or 120° (p=0.190; 0.136; 0.472; 0.380; or 0.144, respectively), internal/external rotation at 0°, 30°, 60°, 90° or 120° (p=0.026; 0.021; 0.035; 0.096; or 0.104 respectively), anterior/posterior tilting at 0°, 30°, 60°, 90° or 120° (p=0.384; 0.183; 0.014; 0.019; or 0.153 respectively) or protraction/retraction at 0°, 30°, 60°, 90° or 120° (p=0.023; 0.017; 0.022; 0.033; or 0.120 respectively).

Table 16 Dominant Scapular Kinematic Results

	Baseball		Tennis		Volleyball		Control	
	Mean	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**
Scapular Upward/ Downward Rotation								
0° Humeral Elevation	2.32	6.93	4.18	6.76	3.97	4.29	1.04	7.13
30° Humeral Elevation	8.23	5.82	9.33	6.38	10.71	3.93	6.75	6.01
60° Humeral Elevation	20.35	6.76	19.81	6.87	21.43	3.82	18.12	5.98
90° Humeral Elevation	32.20	9.17	29.55	7.53	30.74	5.48	28.13	6.15
120° Humeral Elevation	41.00	13.88	35.61	6.82	35.48	7.34	36.53	8.11
Scapular External/Internal Rotation								
0° Humeral Elevation	30.72	8.22	32.28	7.53	28.27	6.90	29.02	9.34
30° Humeral Elevation	27.70	8.41	29.79	7.60	24.77	7.98	26.21	8.53
60° Humeral Elevation	25.88	8.90	29.04	7.09	24.90	8.54	25.13	8.22
90° Humeral Elevation	26.09	11.89	30.57	7.78	29.14	9.55	27.85	7.28
120° Humeral Elevation	28.67	15.07	35.96	10.07	40.70	13.21	36.47	8.02
Scapular Posterior/Anterior Tilt								
0° Humeral Elevation	-16.22	3.81	-13.95	6.88	-17.28	3.00	-15.60	5.11
30° Humeral Elevation	-12.83	4.21	-10.86	6.74	-14.05	3.79	-12.56	5.41
60° Humeral Elevation	-12.29	4.88	-8.74	8.50	-11.84	5.89	-10.30	6.68
90° Humeral Elevation	-11.86	7.12	-7.17	9.06	-10.27	8.39	-8.34	7.85
120° Humeral Elevation	-5.59	9.37	-2.89	9.29	-6.32	12.54	-3.51	8.72
Scapular Protraction/Retraction								
0° Humeral Elevation	-15.79	5.11	-15.06	7.46	-17.83	3.96	-17.30	5.72
30° Humeral Elevation	-18.70	4.65	-17.79	7.09	-21.37	5.05	-20.46	5.53
60° Humeral Elevation	-22.16	4.66	-21.13	6.81	-24.74	5.81	-24.39	5.82
90° Humeral Elevation	-26.59	5.46	-24.81	6.82	-27.53	6.05	-28.25	5.49
120° Humeral Elevation	-34.67	6.17	-32.07	7.08	-34.26	6.22	-35.14	5.00
Scapular Elevation/Depression								
0° Humeral Elevation	6.99	4.75	5.57	5.19	7.68	4.90	6.78	4.43
30° Humeral Elevation	9.15	4.16	7.45	5.41	10.64	4.27	8.90	4.33
60° Humeral Elevation	15.96	3.98	12.88	5.67	16.03	4.01	14.92	4.64
90° Humeral Elevation	23.16	4.75	18.55	5.49	21.01	4.14	20.93	4.51
120° Humeral Elevation	30.34	5.40	24.45	6.12	27.05	5.78	28.05	4.19

Table 17 Non-Dominant Scapular Kinematic Results

	Baseball		Tennis		Volleyball		Control	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Scapular Upward/ Downward Rotation								
0° Humeral Elevation	1.16	7.20	6.05	7.34	-0.86	5.78	1.00	8.40
30° Humeral Elevation	6.17	6.69	12.01	7.47	5.68	4.43	7.41	8.30
60° Humeral Elevation	15.37	6.77	22.48	8.48	16.03	5.72	17.75	9.13
90° Humeral Elevation	21.94	8.05	31.82	9.68	24.80	6.60	26.75	10.19
120° Humeral Elevation	26.24	7.38	37.44	9.22	32.90	7.24	35.23	10.18
Scapular External/Internal Rotation								
0° Humeral Elevation	29.37	8.80	24.99	7.53	24.87	4.72	23.06	7.85
30° Humeral Elevation	26.00	7.87	22.51	7.91	22.69	4.03	19.83	6.46
60° Humeral Elevation	23.84	6.89	21.84	7.00	23.39	3.94	19.99	7.06
90° Humeral Elevation	24.50	6.97	23.56	7.63	26.52	5.78	23.70	9.47
120° Humeral Elevation	30.80	10.78	28.16	10.02	35.61	10.05	33.87	16.03
Scapular Posterior/Anterior Tilt								
0° Humeral Elevation	-13.18	5.49	-11.68	6.16	-16.89	2.61	-14.87	8.88
30° Humeral Elevation	-10.26	5.62	-9.59	6.16	-14.96	2.13	-12.46	8.21
60° Humeral Elevation	-8.40	6.39	-8.35	7.34	-14.32	3.03	-10.83	7.02
90° Humeral Elevation	-6.07	7.96	-7.99	8.29	-13.26	4.48	-9.33	7.21
120° Humeral Elevation	-1.10	9.10	-3.73	7.88	-10.42	6.34	-6.37	9.07
Scapular Protraction/Retraction								
0° Humeral Elevation	-18.92	6.71	-21.00	4.64	-16.72	4.38	-20.79	5.48
30° Humeral Elevation	-22.22	6.09	-23.91	4.64	-20.17	4.88	-24.82	4.79
60° Humeral Elevation	-25.94	6.05	-27.06	4.18	-22.86	5.04	-28.13	4.74
90° Humeral Elevation	-30.64	6.44	-30.54	4.17	-25.38	5.53	-31.23	5.59
120° Humeral Elevation	-38.20	6.64	-36.73	3.76	-32.37	5.74	-37.35	6.53
Scapular Elevation/Depression								
0° Humeral Elevation	6.90	4.40	7.50	4.94	7.72	4.31	6.77	3.51
30° Humeral Elevation	8.65	4.32	9.58	4.85	10.60	3.48	9.32	4.06
60° Humeral Elevation	14.10	3.89	15.10	5.42	16.60	3.61	14.99	4.64
90° Humeral Elevation	19.49	3.99	21.22	5.73	22.68	3.90	20.62	5.31
120° Humeral Elevation	25.31	5.43	27.22	5.90	30.89	4.88	28.39	5.93

Table 18 Mean Differences for Dominant Limb Scapular Elevation at 90° Humeral Elevation

MSD = 1.92	Baseball 23.16	Volleyball 21.01	Tennis 18.55	Control 20.93
Baseball 23.16	-----			
Volleyball 21.01	*2.15	-----		
Tennis 18.55	*4.61	*2.46	-----	
Control 20.93	*2.23	0.08	*2.38	-----

* Significant mean difference

Table 19 Mean Differences for Non-Dominant Limb Scapular Elevation at 90° Humeral Elevation

MSD = 1.92	Baseball 19.49	Volleyball 22.68	Tennis 21.22	Control 20.62
Baseball 19.49	-----			
Volleyball 22.68	*3.19	-----		
Tennis 21.22	1.73	1.46	-----	
Control 20.62	1.13	*2.06	0.06	-----

* Significant mean difference

Table 20 Mean Differences for Dominant Limb Scapular Elevation at 120° Humeral Elevation

MSD = 2.25	Baseball 30.34	Volleyball 27.05	Tennis 24.45	Control 28.05
Baseball 30.34	-----			
Volleyball 27.05	*3.29	-----		
Tennis 24.45	*5.89	*2.60	-----	
Control 28.05	*2.29	1.00	*3.60	-----

* Significant mean difference

Table 21 Mean Differences for Non-Dominant Limb Scapular Elevation at 120° Humeral Elevation

MSD = 2.25	Baseball 25.31	Volleyball 30.89	Tennis 27.22	Control 28.39
Baseball 25.31	-----			
Volleyball 30.89	*5.58	-----		
Tennis 27.22	1.91	*3.67	-----	
Control 28.39	*3.08	*2.50	1.17	-----

* Significant mean difference

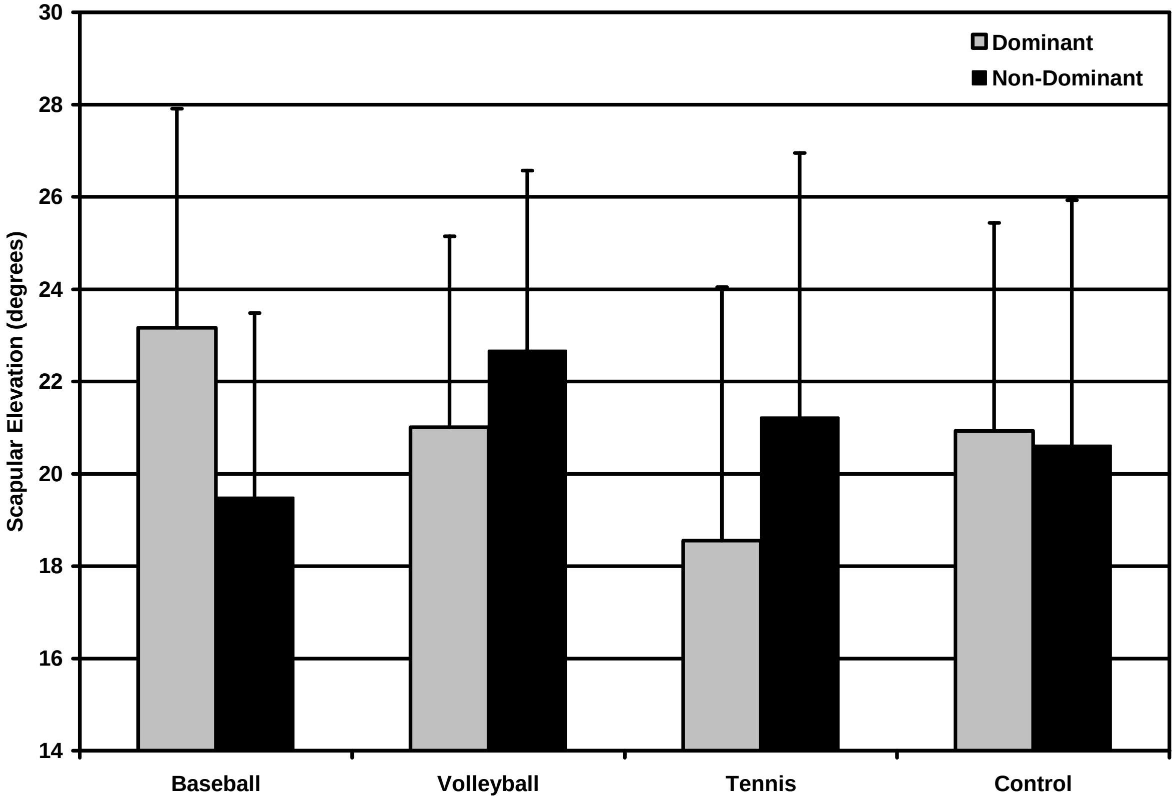

Figure 13 Between Limb Scapular Elevation at 90° Humeral Elevation

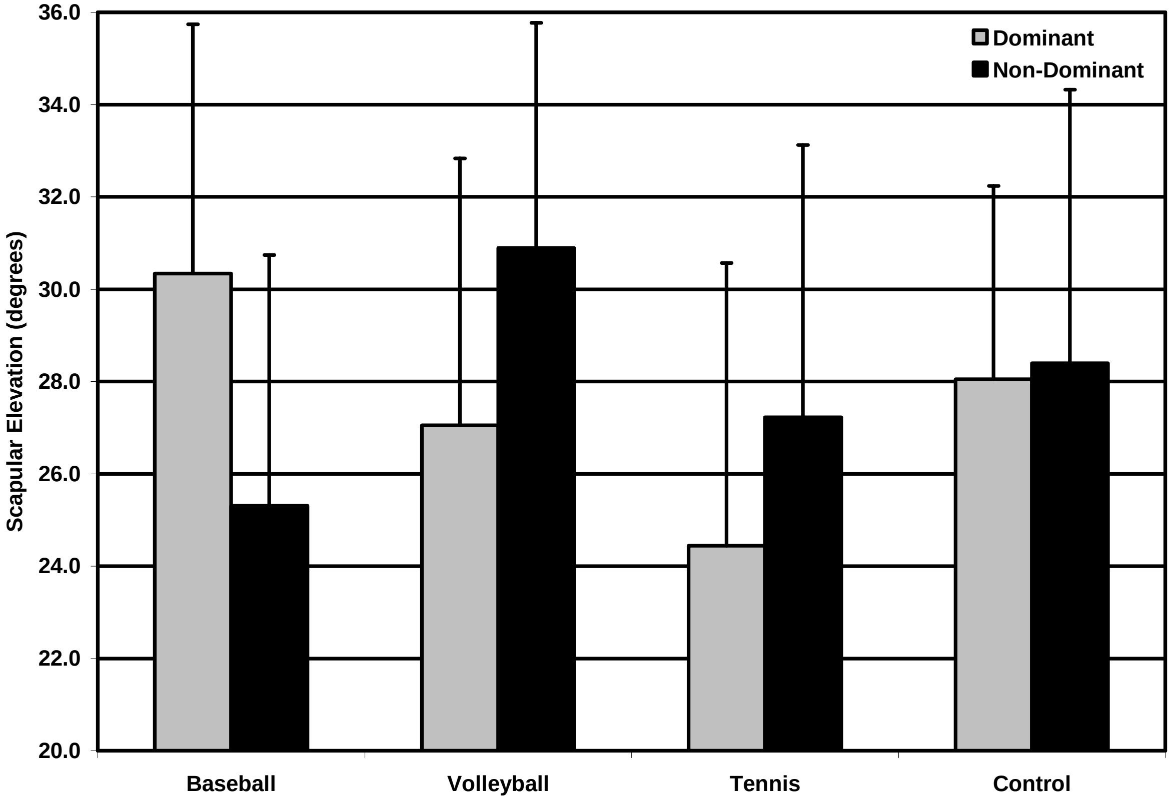

Figure 14 Between Limb Scapular Elevation at 120° humeral Elevation

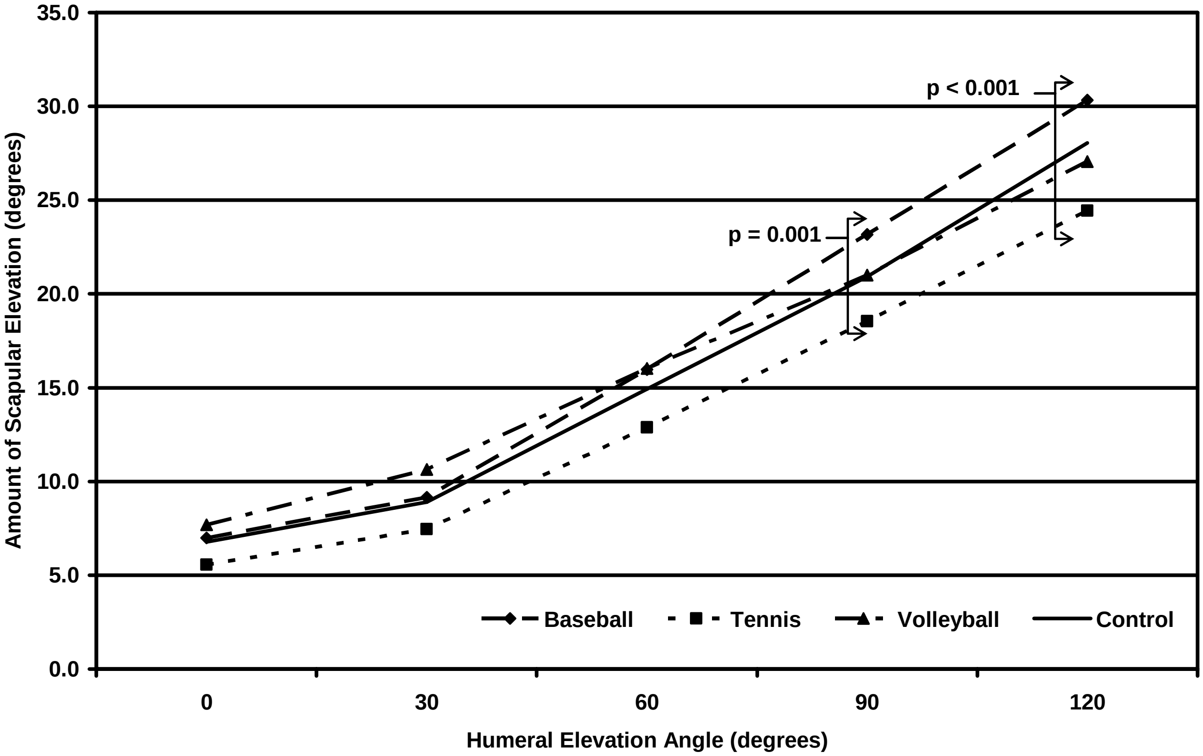

Figure 15 Dominant Scapular Elevation

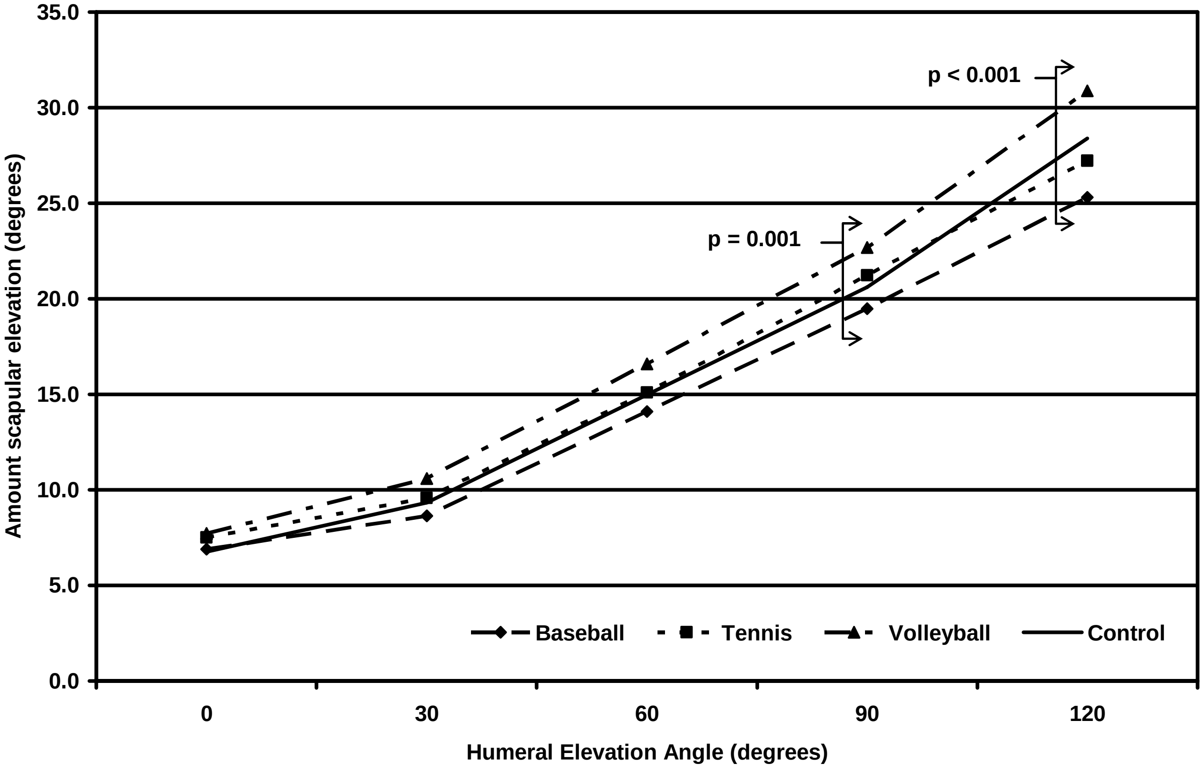

Figure 16 Non-Dominant Scapular Elevation

4.0 DISCUSSION

4.1.1 Range of Motion

All athletes participating in overhead sports in the current study exhibited less dominant internal rotation ROM than non-dominant internal rotation ROM. This result has been reported by many previous studies on overhead athletes[5, 17-19, 24, 26-28, 50-52]. Although the exact mechanism is unknown, the loss of internal rotation may be caused by tightening in the posterior aspect of the shoulder[5, 8, 10, 15, 17-20] or an osseous adaptation of the humerus[17, 19, 27, 53, 54].

A significant decrease in internal rotation was present in overhead athletes, while there was no significant difference for total rotation range of motion in all groups. However, there were slight variations in the difference between GIRD and ERG. Tennis athletes had 2.2° more GIRD than ERG. Volleyball and control athletes had more ERG than GIRD (3.0° and 4.7° respectively), while baseball pitchers had an equal amount of GIRD and ERG (0.3° difference). This result may suggest that different sports have a decrease in internal rotation ROM for different reasons (contribution of bony versus soft tissue adaptations).

When the total arc of motion is roughly the same bilaterally, an osseous adaptation most likely is the cause for any altered ROM[8, 26, 28, 53-55]. Humeral retroversion is an osseous adaptation of the humerus[17, 19, 27]. Humeral retroversion can be defined as the angle between the axis of the elbow joint and the axis through the center of the humeral head[53]. This angle demonstrates the degree to which the humeral head is shifted more inward and backward[53]. Compared to the contralateral limb, having a higher degree of humeral retroversion will allow more external rotation ROM with the same amount of humeral head motion. The cost of having increased external rotation is a decrease in internal rotation ROM with the same amount of glenohumeral rotation as the contralateral limb. Since humeral retroversion is an osseous adaptation, the total arc of motion (internal ROM + external ROM) should remain equal when compared bilaterally. Since there were no significant differences in total shoulder rotation ROM between any sports, osseous adaptations may be the cause for the decrease in internal rotation. Borsa et al[26] suggest that pitchers develop this retroversion at a young age from the high humeral torques that occurs with pitching. The possibility remains that humeral retroversion occurs at a young age due to the adaptation of the body to the stresses of overhead motion. Researchers have suggested that bony adaptation occurs before the athlete is skeletally mature[53, 55, 56]. This shift in humeral orientation should help to reduce the stress at the glenohumeral joint while allowing the athlete to achieve the relatively high amount of external rotation needed during the late cocking phase of the throwing motion[26, 53, 57]. This adaptation may spare the anterior capsule from increased stresses and possible failure.

On the other hand, research has suggested the forceful eccentric contractions of the shoulder external rotator muscles during follow through cause tightening in the posterior aspect of the shoulder[5, 8, 10, 15, 17-20]. This increased posterior shoulder tightness may cause an associated decrease in internal rotation ROM[5, 9, 17-19, 21-24]. The results of this study support this theory. Baseball pitchers and tennis athletes have been shown to have this associated decrease in internal rotation ROM from a tightened posterior shoulder not only the current study, but previous studies as well[23, 51]. Tennis athletes have been shown to have increased dominant internal rotation ROM deficits as their years of play increase[58]. In the study, Kibler et al[58] did not address the age at which their population began participating in tennis, only the total number of years played. As other researchers[19, 27, 56] have hypothesized, both bony and soft tissue adaptations may occur and contribute to the decrease in internal rotation ROM. As it is difficult to pinpoint a specific structure that tightens in the posterior shoulder, it is probably difficult to state whether an internal rotation ROM loss is strictly bony adaptation or soft tissue adaptation. Due to the nature of the throwing motion, both mechanisms likely play a role. The contribution of one theory relative to the other may be highly sport specific and warrants further research.

When a volleyball athlete strikes the ball midway through the hitting motion, the majority of the internal rotation torque that is produced during the acceleration phase could be transferred to the ball. Although transferring energy to an object is the goal of the overhead throwing motion, the amount transferred in volleyball may be larger than other sports. The transfer of energy might help to slow the limb to the point that there is little overload to the posterior shoulder structures, and therefore, limited tightening of those structures occur. According to

Wolff's law, if there is a lower amount of stress, there will be less adaptation to that stress, in this case less tissue tightening [29]. Further research is needed to determine the amount of energy transferred to sport specific objects during the throwing motion. If the posterior shoulder structures of volleyball athletes' are not as tight as those in other overhead athletes, there should be less internal rotation ROM lost in volleyball athletes. However, the total arc of motion was the same bilaterally for volleyball athletes. As stated previously, when the total arc of motion is the same bilaterally, humeral retroversion is thought to be the cause for the shift in the rotational ROM. Volleyball athletes may have humeral retroversion as the primary cause for the altered ROM since their total ROM was the same bilaterally. These different mechanisms (bony versus soft tissue adaptations) of internal rotation ROM alterations help to show that the mechanisms may be highly sport specific.

The role of the tennis racket affecting the forces during follow through must be examined. Using a tennis racket to hit the ball increases the lever arm of the upper limb and may alter the torque at the shoulder when hitting a tennis ball. This increase in torque may cause the soft tissues to adapt accordingly by tightening the posterior structures more so than with baseball pitching. The increased lever arm, along with the increased joint torque accompanying the increased lever arm, may possibly explain the greater amount of posterior shoulder tightness in tennis athletes compared to the baseball pitchers despite the slower rotational velocities. Krahl et al[59] suggested that there were bony adaptations of the humerus as a result of the "constantly strained extremity" in tennis athletes. This adaptation may be a result of the increased stresses, but further research is needed to identify the exact cause of the adaptation.

Although none of the differences were statistically significant, it should be noted that the difference between GIRD and ERG for tennis and volleyball athletes were not the same as baseball pitchers (2.2°, -3.0° and 0.3° respectively). This result may be due to different mechanisms of GIRD. There is no research on volleyball kinetics, but the forces and energy that are required during tennis[16] and volleyball do not appear to be similar to that of pitching[15, 20, 57]. Due to Wolff's law, if there is not enough stress on the tissue to cause an adaptation, the tissue has no reason to adapt to that stress[29]. Volleyball and tennis do not require the velocity needed for baseball pitching and therefore impose less stress to the shoulder. However, the stresses that are encountered in volleyball and tennis may stress only the soft tissues of the shoulder instead of the bony tissue. Performing any kind of forceful overhead, internal rotation activity as a young child and through development may allow the humerus to adapt slowly over time to the increased stresses. As previously pointed out, researchers suggest that this bony adaptation occur before the athlete is skeletally mature[53, 55, 56]. Since there was only a significant difference with GIRD and not with ERG for tennis and volleyball athletes, the cause of the internal rotation ROM loss is most likely a result of a more tightened posterior shoulder rather than humeral retroversion. Future research should analyze the contributions of both humeral retroversion and a tight posterior shoulder to ROM alterations and see if there are differences between overhead sports.

4.1.2 GIRD/ERG

The results for the GIRD measurements show that baseball and tennis had a larger deficit than the control group. These results are in agreement with many prior studies that show the same results[5, 17, 18, 26-28, 51]. In a study of professional baseball athletes there was a significant difference in internal rotation ROM between dominant and non-dominant limbs[5]. Other research reports GIRD values of between 9.7°[26] and 12.0°[27] for baseball pitchers. The current study's GIRD measurement of 12.6º in baseball pitchers is similar to previously reported data. Ellenbecker and colleagues[28] compared professional baseball pitchers to elite junior tennis players and found tennis players to have higher values of GIRD than the pitchers (11.8º vs. 10.9º). Others[18] have looked at professional tennis players and showed a mean GIRD value of 17º. The current study found that tennis athletes have a mean GIRD value of 11º, which is slightly lower than previous reports. However, the results for tennis athletes and baseball pitchers in the current study tend to agree with previous literature[28]. More research should be performed in order to collect normative data for GIRD values in tennis athletes, and possibly determine the contribution of bony and soft tissue adaptations to the range of motion alteration in tennis athletes.

The current results tend to support the idea of a total arc of motion concept around the glenohumeral joint as proposed by other researchers[17, 18, 26-28]. Baseball pitchers tend to have the same amount of total arc of motion when compared bilaterally[26, 27, 50, 51, 54], whereas tennis athletes are usually reported to have a decreased total arc of motion on their dominant limb of about 10° compared bilaterally[17, 18, 28]. There was no significance with total rotation ROM in the current study between any of the groups. However, there was a slightly smaller arc of motion for tennis athletes than baseball pitchers. The subject population may explain why there was no significance with total rotation ROM. The majority of previous research has been conducted on either semi-professional or elite tennis athletes. The current study used competitive college athletes. The decreased internal rotation ROM may not have had a chance to manifest in the college athletes as opposed to the higher-level athletes. The demands of a higher level of competition require an athlete to hit harder and serve faster. In order to achieve this, the athlete needs to develop a higher amount of torque to swing the racket harder and faster. The external rotators must still decelerate this increased torque. The increased demand on the external rotators may cause an increased amount of posterior shoulder tightness; therefore decreasing the internal rotation ROM and subsequently the total rotation ROM. Soft tissue adaptations in the posterior shoulder may explain why tennis athletes had a higher degree of GIRD as well as lower total rotation ROM in the shoulder. Further research should help to determine why the GIRD in tennis players tends to be higher than in other overhead throwing sports as well as whether the decreased rotational ROM is due to bony or soft tissue adaptations.

4.1.3 Posterior Shoulder Tightness

Posterior shoulder tightness has received a lot of attention lately in research. Many previous studies suggest that having increased posterior shoulder tightness leads to shoulder pathologies[12, 19, 24, 31, 32, 51, 52, 60]. Research states that with a tightened posterior shoulder capsule, the humeral head tends to migrate in an anterior/superior direction[32]. This altered position will decrease the subacromial space and possibly lead to injury. Once the posterior structures tighten and alter the humeral head position, a pathological cascade begins that ultimately may lead to a SLAP lesion[12]. Many researchers believe that during the follow through phase of throwing, the eccentric contractions of the external rotators overload the tissue and cause an adaptive tightening of the tissue[5, 8, 10, 15, 17-20, 51]. This tightening has been shown to correlate well with a decrease in internal rotation ROM[23, 51, 61], and it is suggested that it alters scapular upward rotation[62, 63].

A pilot study to the current study has suggested that assessment of the posterior shoulder tightness can be performed with higher accuracy and precision when the assessment is done with the subject lying supine[64], instead of side-lying as described previously by Tyler et al[23]. However, there is a question about where to stabilize the scapula. Laudner et al[65] suggest stabilizing the scapula in the resting position when the athlete lays supine. Myers et al[64] suggest using a retracted scapula as the starting point. Although both methods are new and should be researched further, beginning the measurement in a retracted position may allow for a more repeatable measurement as this will help to normalize a starting point.

Baseball pitchers, volleyball athletes, and tennis athletes had less dominant horizontal adduction than the control group. This was not surprising as they are all overhead sports and all have a follow through phase in their respective sporting activities. Baseball pitchers and tennis athletes had about the same bilateral difference while volleyball athletes had a slightly lower value, which indicated that there was less of a decrease on the dominant limb compared to the non-dominant limb. The fact that the results are not all the same can relate to their sport specific activities as well. Baseball pitchers have very high joint velocities during pitching. Although tennis athletes do not perform their respective motion as fast, they perform with a racket, which may increase the momentum of the arm and increase the amount of torque that the external rotators must decelerate. According to Wolff’s law, if there is increased stress, the tissues must adapt to that stress[29]. If there is more stress present during the follow through in tennis than in baseball, tennis athletes should be expected to have a greater amount of dominant posterior shoulder tightness compared to baseball pitchers. The fact that tennis athletes had significantly less horizontal adduction than control athletes did, should not be a surprise then. This result should help to back up the idea that tennis athletes have more stress to the dominant posterior shoulder than baseball pitchers, possibly due to the fact that tennis players use a racket in their overhead motion. This increased stress may cause a decreased amount of horizontal adduction

Volleyball athletes had the least amount of between-limb difference (with the exception of control athletes) for posterior shoulder tightness. This may be due to their sport specific activity. As discussed previously, hitting a volleyball in the middle of the hitting motion may decrease the amount of momentum and torque of the limb and thus decrease the amount of stress to the external rotators during follow through. Volleyball athletes are not allowed to hit the net while hitting the volleyball. Although this may increase the stress on the external rotators to decelerate the limb faster, the distraction forces at the glenohumeral joint may not be as high as they are with baseball pitching since the volleyball athletes do not perform as much of a follow through as pitchers do. There is no research that quantifies the kinetics or kinematics in the shoulder while hitting a volleyball. This idea, along with the idea of performing this activity in the air versus on the ground, should be analyzed further in future research. When an athlete jump serves or hits the ball in the air, he does not have a stable base to push off of to generate more energy. This may affect the amount of energy that the athlete can exert during the hitting motion and possibly decrease the amount of torque and momentum in the limb to decelerate. This would decrease the amount of stress on the shoulder compared to tennis athletes and baseball pitchers and possibly not cause as much tightening in the posterior structures.

An interesting result of this study is that of the non-dominant posterior shoulder tightness. Baseball pitchers, tennis athletes and volleyball athletes all had more horizontal adduction than control athletes did. This has not been reported in previous literature. Each of the overhead motions needs to be performed with as much torque as possible in an effort to throw faster or hit harder. Biomechanically, if an athlete were to use their entire body to increase the momentum they could exert on the ball, they would be able to increase the shoulder torque and hopefully increase their pitching speed or hit the ball harder. Each of the motions in these sports begins roughly the same way, with a wind up. During that wind up, the non-dominant shoulder moves from a horizontally adducted position and then begins to horizontally abduct in an effort to start the athlete’s momentum moving towards where they are throwing or hitting. This repetitive horizontal adduction of the non-dominant shoulder may maintain or possibly increase posterior shoulder mobility. Compounding that fact, since the non-dominant limb usually does not perform a forceful internal rotation motion, there is no stress to the external rotators to adapt to. Research should continue to look at both dominant and non-dominant posterior shoulder tightness values in the supine position in order to develop normative data of posterior shoulder tightness values.

4.1.4 Internal/External Rotation Strength

No statistically significant differences were found for internal rotation strength, external rotation strength or external/internal rotation strength ratio. Compared to previous literature, this result was not expected. The majority of the research available states that overhead athletes (baseball, tennis, volleyball and handball) tend to have lower external rotation strength and increased internal rotation strength when compared bilaterally[19, 24, 25, 34, 37, 38]. Most overhead sports require forceful internal rotation in order to accelerate their arm to throw a ball, spike a ball or swing a racket to hit a ball. Previous research that shows external rotator strength lower than internal rotation strength for overhead athletes usually state that the decrease is due to tensile failures and possible pathologies related to repetitive, eccentric contractions of the external rotators during the follow through stage[24, 25, 34, 37, 66]. Further, some of that research states that when isokinetically assessing external rotator strength concentrically, differences may not arise[24, 37, 38]. Since the external rotator muscles perform mostly eccentrically during the overhead motion, if eccentric external rotator strength was assessed, significant differences might have presented.

Due to many methodological differences between studies, direct comparisons of results are difficult to make for each strength variable. Some studies include male and female subjects as one group[19, 37]. Some studies use older athletes[18, 24, 38, 58] while others use younger athletes[17, 19]. This study is the first study that included only male subjects in baseball, tennis and volleyball and compared them to a control group. For that reason, direct comparisons could have been made between sports. Unfortunately, no statistically significant differences were found with the average peak torque normalized to bodyweight variable. Perhaps other strength variables would have been more sensitive to differences showing agreement with previous studies.

4.1.5 Protraction/Retraction Strength

Assessing isokinetic scapular protraction and retraction strength is a relatively new assessment with little research available to compare. Cools et al[1, 7] have studied this variable on healthy subjects as well as pathologic subjects. For healthy overhead athletes, their research shows decreased protraction/retraction ratios on the dominant side versus non-dominant side at both 12.2 cm/sec and 36.6 cm/sec[7]. Caution must be taken when interpreting their results because their subject population consisted of males and females as well as a mix of overhead athletes as one group (volleyball, tennis and other). When looking at the protraction/retraction strength ratio at both testing speeds, both of Cools et al[1, 7] study's as well as the current study's strength ratios were lower on the dominant limb at both testing speeds (although not significant in the current study). Wilk et al[8] assessed isometric scapular protraction and retraction strength with a hand held dynamometer. Their results show roughly the same values as the current study. Both studies show that the dominant limb tends to have a lower strength ratio than the non-dominant limb. Since both the between group and between limb differences were statistically insignificant, it is hard to compare all studies (Cools et al, Wilk et al and current study). Dominant ratios are lower than the non-dominant ratios across all studies, however.

These strength ratio results make sense when considering the stresses that are applied to the shoulder during the overhead throwing motion. During the follow through phase, the external rotators and scapular retractors must contract eccentrically to control the deceleration of the scapula and the throwing limb. The external rotator muscles must slow the humerus from the extremely high internal rotation torque. The scapular retractor muscles must decelerate the scapula from protracting during follow through. There may be more stress on the external rotator muscles due to the larger lever arm of the entire limb as opposed to only the scapula during protraction and retraction. This difference may affect the amount of force on the muscle during follow through. The force on the external rotator muscles, coupled with the high amount of overhead activity, may overtrain the tissue and cause atrophy if there is not an adequate recovery period[67]. Decelerating the scapula from protraction during follow through may not cause the high amounts of stress to the scapular retractor muscles and thus would not approach the physiologic limits. If the retractor muscles are not overtrained, they can adapt to the overload stress that is placed on them to decelerate the scapula. Since the baseball pitchers tend to perform the most overhead activities in this study's sample population, it makes sense that the ratios are the lowest (higher retraction strength) in the dominant limb of pitchers. Wilk et al[68] showed baseball pitchers and catchers to have a larger between limb difference (larger values on dominant than non-dominant) in protraction strength than position players. The authors did not speculate as to this cause of these differences; however, the volume of throws per game as well as the velocity of those throws could be a possible cause for the differences between pitchers and catchers and all other field players. As previously speculated, hitting a volleyball may decrease the shoulder torque, and thus, decrease the stress on the posterior aspect of the shoulder as well as the scapular retractors. If the limb has less torque, the retractors would not have to contract as forcefully to control scapular protraction. The muscle would not adapt as much as it would during the pitching motion.

4.1.6 Scapular Kinematics

Researchers have suggested that an overhead athlete may need more scapular upward rotation than other people in an effort to maintain the subacromial space at higher levels of humeral elevation[13, 62, 69]. Myers et al[13] have shown that asymptomatic throwing athletes have significantly more upward rotation, internal rotation and retraction of the scapula with humeral elevation. Since there were no differences found in the current overhead athlete population, it is difficult to apply that theory to this study. In the study by Myers et al[13], the subjects raised a predetermined amount of weight for their humeral elevation task. Having the subject lift weight may require different muscle recruitment and possibly change scapular kinematics. Prior research has suggested that fatigue in the external rotators may alter scapular upward rotation as well[63, 70, 71]. More research is needed to establish normative data for scapular upward rotation in overhead athletes.

Following statistical analysis, the only scapular kinematic variable with a significant interaction was elevation. Although there is little research on scapular kinematics in healthy overhead athletes, none of the previous literature has reported this result. As stated previously, athletes did not raise any weight in this study. This may have changed the kinematics and caused the different result as compared to Myers et al[13]. Between limb differences were significant for baseball pitchers at 90º and 120º of humeral elevation and volleyball athletes at 120º of humeral elevation. Baseball pitchers showed more scapular elevation on the dominant side than non-dominant at both 90º and 120º while volleyball had less dominant scapular elevation than non-dominant at 120º. This may related to the motions that each of the respective athletes perform for each sport. Baseball athletes must hold their humerus near 90º of humeral elevation throughout the majority of the pitching motion. Perhaps the increased scapular elevation is due to increased muscle tone/activity of the deltoid, trapezius and levator scapulae muscles in order to maintain the limb (scapula and humerus) at roughly a 90º abduction angle throughout the pitch. Wilk et al[68] present data that show baseball pitchers and catchers to have significantly more scapular elevation strength than position players. Perhaps their subjects had increased strength because they must maintain the subacromial space by elevating the scapula throughout the throwing motion. Volleyball athletes must get their hand over their shoulder in order to make quick corrections before they hit the ball. This way they can place different spins on the ball, similar to the different pitches in baseball. Baseball pitchers can use their wrist and fingers to alter the spin on the ball. Since a volleyball is larger than a baseball, the volleyball athlete must use their entire hand and upper limb to alter the spin on a volleyball. Performing the hitting motion at the extremes of humeral elevation may cause the body to make adaptations accordingly and elevate the scapula to maintain the subacromial space.

At 90º and 120º of humeral elevation, baseball pitchers had significantly greater elevation than all other groups. It is also worth pointing out that tennis and volleyball athletes actually had more non-dominant scapular elevation than dominant. Perhaps the baseball pitchers have increased muscle development of the deltoid, trapezius and levator scapulae on the dominant side and that is why they possess more dominant limb scapular elevation. Since all subjects were healthy, further research should be performed to confirm the fact that tennis and volleyball athletes actually had less humeral elevation than baseball pitchers. Having less dominant elevation must be an adaptation to sport as none of the tennis or volleyball athletes had an injury or complained of pain. Another possibility relates to external rotation gain and scapular elevation. In sports that have an increased amount of external rotation gain compared to control athletes, perhaps there is an increased demand to maintain the subacromial space. Maintaining this space could help to prevent damage to the structures (supraspinatous/rotator cuff, and subacromial bursa) that pass through that space as well as prevent the greater and lesser tubercles of the humerus from contacting the acromion. Compression in the subacromial space could damage the subacromial bursa and cause injury to the rotator cuff. When the posterior shoulder structures are tightened, the humeral head tends to migrate posteriosuperiorly with abduction and external rotation due to the cam effect[12]. Wilk et al[68] showed that baseball pitchers have significantly more scapular elevation strength than position players. With excessive external rotation, perhaps the body adapts to this altered humeral position by having the scapular elevator muscles (upper trapezius, levator scapulae) contract to elevate the acromion and maintain the subacromial space. This adaptation could be a preventative measure for subacromial impingement during external rotation at 90° of humeral elevation.

The fact that there were differences between overhead sports for some of the variables included in this study was a goal of the study. If all overhead athletes were the same, as the majority of the research tends to stereotype, then there should not have been any difference between the overhead groups. There has only been limited research that has compared variables between overhead sports. Differences in shoulder kinetics and kinematics during tennis strokes/ serves and pitching should be explored as a possible reason for some of the differences between overhead athletes and tennis athletes found in the current study. The possibility that striking a volleyball during the hitting/serving motion should be explored as well as a possible explanation for some of the differences between volleyball athletes and other overhead athletes. Variability in the kinematics, lever arm length, humeral rotation velocity, weight of the sport specific equipment may have resulted in different stress at the shoulder joint, which lead to the difference in physical characteristics between groups.

Another possible explanation for the differences between volleyball athletes and the other overhead athletes may relate to the fact that the majority of the spiking motion is performed entirely in the air. At the higher levels of participation, even the serving motion is performed with a jump serve. Perhaps this detail could explain some of the differences between overhead sports. Once the athlete is in the air, they cannot push against the ground unlike pitching a baseball or hitting a tennis ball. If the athlete is in the air, they can only use the energy in their body to place on the ball. According to Kibler[72], when the athlete is on the ground, the athlete funnels the energy from the ground, through the body and out through the ball. Further research should look at the difference between performing the volleyball spike/serve on the ground as opposed to performing it in the air.

This study is the first to compare baseball, tennis, and volleyball athletes to a control group all in the same study using the same methods. Although there has been at least some research on each of these overhead sports, few studies have been completed using the same methodology to allow direct comparisons. There has been no research, to the author's knowledge, performed on scapular kinematics for tennis or volleyball athletes. For that reason, there are many questions that arise from this research study. Performing the forceful, overhead, internal rotation motion with different loads to the limb (swinging a tennis racket versus pitching a baseball versus striking a volleyball) may prove to have differing effects on physical characteristics of the shoulder. Further research should be performed on these overhead sports to determine the kinetics at the shoulder joint during the respective overhead motion of each sport.

This information may shed light on some of the differences between baseball pitching and other overhead sporting activities.

4.2 STUDY LIMITATIONS

The methods used to measure posterior shoulder tightness are relatively new when compared to other ROM measurements (i.e. shoulder internal/external rotation ROM). Holding the scapula in a firm position throughout the entire measurement is subjective. However, pilot work shows low clinician error[64]. Those results also show that stabilization of the scapula is possible in a retracted starting position[64]. Some controversy exists as to whether a fully retracted measurement starting position or a "neutral" starting position (stabilizing wherever the scapula is when the subject lies supine) produces a more meaningful measurement. A retracted position was used as the starting point in the current study as the reliability of the measurement had already been established[64].

The position of internal and external rotation strength assessment was not in a functional position. Although the testing protocol for the current study is an accepted one, perhaps the results would have been different if the testing position was in an overhead position. The protraction and retraction strength assessment was an uncommon position and motion for the athlete. Many subjects had trouble learning the movement for the test. Even after sufficient practice repetitions with minimal resistance, subjects often needed instruction during testing. It should be noted that overhead athletes appeared to learn this motion faster than the control group. Some of the limitations with this motion relate to arm position. During the testing protocol, the subjects must keep their arm straight. Sometimes the subject would slightly flex the elbow as an accessory movement to help pull the dynamometer into the retraction position. Perhaps future studies that employ this strength protocol could use an elbow brace locked at full extension to help eliminate the contribution of the elbow flexors during the retraction strength measurement

Karduna and collegues[49] show that scapular kinematic data collected above 120º of humeral elevation has been shown to have decreased accuracy. Although their research states that the most accurate measurements occur below 120º, their research shows that as humeral elevation angles increase, the root mean square values increase as well. The authors also point out that increased errors may be due to different skin movement patterns in different subjects[49]. The current method of assessing scapular kinematics is generally accepted and has been used in previous research[13, 44, 49, 64, 73]. As with the strength assessment, the scapular kinematic assessment was not completed during a functional motion. Furthermore, the subjects were not holding their respective sport specific equipment (i.e. baseball or tennis racket). Incorporating both of these aspects may produce different results.

4.3 FUTURE RESEARCH

Future research should begin with including more overhead sports. Many sports that are not traditionally thought of as “overhead” include overhead motions. Throwing the javelin, many motions in water polo and throwing a football are a few examples of overhead motions that should be taken into consideration for future research. Although this study used a generally accepted protocol to assess shoulder strength, perhaps performing the internal and external rotation strength assessment in a functional position (90º humeral abduction) may produce different results. Including a pathologic group to the study might shed some light on some of the adaptations that the body makes when pain or pathologies are present in the overhead athlete’s shoulder.

Research that looks at the distraction forces at the shoulder during sport specific activities (baseball pitching vs. volleyball spiking/hitting vs. tennis serving/spiking) might help to explain the between group differences found for GIRD. It might also help to explain why volleyball athletes do not exhibit this deficit even though they perform roughly the same motion. Determining the distraction forces may help to explain some of the scapular kinematic adaptations as well since there is some research that suggests that tightened posterior shoulder structures may alter scapular kinematics[62, 63, 74]. Research performed in these sports should also analyze the respective sport specific motions while the subjects are using their respective equipment, i.e. throwing a baseball, swinging tennis racket and spiking a volleyball.

Future research should also determine if there is a difference in kinetics and kinematics of the volleyball spike between standing and jumping. As discussed earlier, when the subject is on the court hitting, they can push against the ground to generate more torque. On the other hand, when they perform a spike in the air or a jump serve, the athletes can only use whatever energy is in their body to hit the ball. This may reduce the amount of force they can produce against the ball and therefore alter shoulder characteristics. Further research is necessary to determine if this decrease in torque occurs between standing and jumping.

Research shows that there is increased upward rotation in the scapular plane compared to the sagittal plane in healthy shoulders during an elevation task[62]. The limb does not usually perform strictly in the scapular plane in overhead motions. It may be a better assessment to measure in the sagittal, frontal and scapular plane (or a combination of) and compare between them to somewhat replicate the throwing motion. By the time the throwing limb is in the scapular plane, the external rotators are eccentrically contracting to decelerate the limb during follow through. The possibility that muscle adaptations in the scapular plane may alter scapular kinematics compared to other planes should be researched in the future.

4.4 CLINICAL RELEVANCE

The current research study shows a difference between overhead sports. Baseball pitchers tend to exhibit different characteristics than tennis, volleyball and the control group, although some of those differences were not significant. In the future, overhead athletes should not be stereotyped as one “overhead athlete” group; instead, they should be subdivided into their respective sports. This subdivision will allow the sports medicine clinician to administer and prescribe a better treatment and rehabilitation plan. Rehabilitation protocols should be tailored to the specific demands of each sport. A sport specific return to play criteria will possibly allow a healthier and faster return to sport.

5.0 CONCLUSION

The current study of 58 subjects (15 baseball pitchers, 15 volleyball athletes, 13 tennis athletes, and 15 control athletes) measured shoulder rotation ROM, posterior shoulder tightness, internal/external rotation strength, protraction/retraction strength, and scapular kinematics during an elevation task. The results show that not all overhead athletes posses the same shoulder characteristics. The exact explanation for some of these results is not possible as there is little research available on tennis and volleyball athletes' shoulder characteristics. However, the majority of these differences may be due to the stresses that are placed on the structures and how the body adapts to those stresses (Wolff's Law).

The main goal of this study was to compare the characteristics of common overhead sports. The results show that the overhead sports in this study are not the same in healthy, college aged, male athletes. Many previous research studies have stereotyped the overhead athlete as a baseball pitcher/player. The results of this study suggest this may not to be the case. When reviewing the results, baseball, tennis, and volleyball athletes do not have the same characteristics for all variables. For this reason, sport specific rehabilitation programs should be developed in order to not only return the athlete to sport as soon as possible, but to regain the necessary physical characteristics specific to the respective sport. In the future, researchers should not group all overhead athletes together as one stereotypical "overhead athlete" group, but subdivide that group into the respective sports. Only with more research in this area will these subgroups be able to be thoroughly understood and defined.

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