

A COMPARISON OF SHOULDER RANGE OF MOTION ACCOUNTING FOR
HUMERAL TORSION IN COLLEGIATE BASEBALL AND SOFTBALL ATHLETES

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ABSTRACT

Justin Andrew Tatman: A Comparison of Shoulder Range of Motion Accounting for
Humeral Torsion in Collegiate Baseball and Softball Athletes
(Under the direction of Dr. Joseph Myers, PhD., ATC)

Objective: To compare range of motion and humeral torsion of the shoulder in baseball and softball players. **Design:** A cross sectional between groups study design. **Subjects:** Fifty-five baseball players (age = 19.5 ± 1.1) and twenty-eight softball position players (age = 19.3 ± 1.2) **Statistical Analysis:** ANOVA model was used to compare range of motion and humeral torsion variables across the limbs and groups. Variables collapsed across limb utilized independent sample t-tests for comparisons. A priori alpha level set at .05. **Main outcome measure(s):** Internal rotation, external rotation, horizontal adduction, and humeral torsion. **Results:** Significant interactions effects were found for internal rotation, humeral torsion and total range of motion variables. Significant differences were found between sport for GIRD and total range of motion difference. **Significance:** Softball players exhibited less pronounced variation in dominant limb range of motion variables. Both groups demonstrated significant differences in humeral torsion measurements. **Keywords:** humeral torsion

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Chapter 1

Introduction

Shoulder and elbow pain are common complaints among overhead athletes that are often addressed by sports medicine clinicians, as a result of the repetitive nature of overhead sport. Specifically, repetitive high velocity overhead motions performed by baseball players has been suggested to contribute to a higher susceptibility to shoulder injury (Souza 1994; Altchek and Dines 1995; Fleisig, Barrentine et al. 1996; Kibler 1998; Wilk, Meister et al. 2002; Burkhart, Morgan et al. 2003; Burkhart, Morgan et al. 2003; Kibler and McMullen 2003). While the shoulder of the baseball player has received substantial attention, sports medicine research assessing the shoulder of the softball player is limited, despite the fact that the prevalence of shoulder injuries in softball players parallels that of baseball athletes (Loosli, Requa et al. 1992; Flyger, Button et al. 2006; Wang 2006; Marshall, Hamstra-Wright et al. 2007). Although more research focusing on the shoulder of the softball player has started to appear in the literature (Maffet, Jobe et al. 1997; Barrentine, Fleisig et al. 1998; Dover, Kaminski et al. 2003; Hill, Humphries et al. 2004; Werner, Guido et al. 2005; Flyger, Button et al. 2006; Werner, Jones et al. 2006; Dun, Kingsley et al. 2008), the amount of literature available on softball injuries still falls far behind that of the baseball player, despite similar injury incidence.

While softball and baseball exhibit differing pitching motions and participation habits (pitching frequency and pitch count), the repetitive motion used in both games is the primary

factor placing the upper extremity, particularly the shoulder and elbow, at high risk for overuse injuries (Lyman, Fleisig et al. 2002). In addition to pitchers, the position players in both baseball and softball exhibit high injury patterns to the upper extremity (Barrentine, Fleisig et al. 1998; Powell and Barber-Foss 2000). In an analysis of the NCAA Injury Surveillance System data from 1988 to 2004, 45% of all time lost from baseball (for practice and games) due to injury were attributed to upper extremity injuries (Dick, Sauers et al. 2007). More specifically, shoulder injuries accounted for 23% of the injuries during practice and 16% during games for that entire time period. In addition, elbow injuries accounted for 6-7% of all injuries for both practice and games respectively. Another study of the youth baseball population found that the incidence of elbow and shoulder injury could be estimated at 26-35 per 100 pitchers per season (Lyman, Fleisig et al. 2001; Lyman, Fleisig et al. 2002). Analysis of the NCAA Injury Surveillance System data from 1988 to 2004 reveals strikingly similar injury rates for collegiate softball players (Marshall, Hamstra-Wright et al. 2007). One third of all softball injuries were located in the upper extremity. In addition, shoulder injuries including muscle-tendon strains and tendonitis accounted for 10% of all practice time lost. National Athletic Training Association Injury Surveillance data from 1995 to 1997 showed similar injury rates of all reported injuries in softball and baseball for shoulder/arm (19.7% in baseball, 16.3% in softball) and forearm/wrist/hand injuries (24.6% in baseball, 22.3% in softball) (Powell and Barber-Foss 1999). Furthermore, a study of only shoulder injuries in high school athletics between 2005-2007 indicated that sprains/strain injuries to the shoulder accounted for 55-52 percent of all injuries for both baseball and softball (Bonza, Fields et al. 2009 & Dawn Comstock, 2009). The same study also indicated that the throwing motion was twice as likely to be the cause a shoulder injury in the population of

softball players (50.2%) than in the baseball players (24.3%), who were not pitchers in both sports. Additionally, the same study found the softball athlete's shoulder had slightly higher rates of injury due to overuse/chronic mechanism than those of baseball players.

The female athlete overall has less mass, height, overall size, muscles mass, limb length, and absolute muscle strength (Wells 1991). Biomechanically, the motions used by baseball and softball pitchers differ greatly; however, the motion exhibited by the field players, the majority of the players on the field, is strikingly similar. The biomechanics of baseball pitching have been well researched and documented in the literature (Atwater 1979; Feltner and Dapena 1986; DiGiovine 1992; Dillman, Fleisig et al. 1993; Werner, Fleisig et al. 1993; Fleisig, Andrews et al. 1995; Fleisig, Barrentine et al. 1996; Fleisig, Barrentine et al. 1999; Park, Loebenberg et al. 2002; Park, Loebenberg et al. 2002; Sabick, Kim et al. 2005; Escamilla, Barrentine et al. 2007; Dun, Kingsley et al. 2008; Keeley, Hackett et al. 2008). The overhead motion of baseball pitching places the upper extremity in a highly dynamic position. High magnitudes of energy are absorbed through the anatomical structures of the shoulder and elbow during the varying phases of throwing; specifically the deceleration phase, making this portion of the throwing mechanism the most likely to cause injury (Dillman, Fleisig et al. 1993; Meister 2000). Horizontal abduction is maintained during the majority of the throwing motion, as forceful internal rotation at speeds of over 7000 degrees per second provide the velocity of the pitch (Dillman, Fleisig et al. 1993; Fleisig, Andrews et al. 1995; Fleisig, Barrentine et al. 1996). These extreme kinematic factors lead to microtrauma within the structures of the upper extremity responsible for producing and absorbing the kinetic forces produced. The field players in both baseball and softball

perform this overhead motion repeatedly, indicating that the forces and stresses placed upon the shoulder of these two populations are comparable.

In one of the only direct comparisons of the overhead male and female athlete, Chu et al (Chu, Fleisig et al. 2009) completed a contrast of the overhead throwing motion of male and female amateur baseball players. They found that while females may have smaller body size, muscle mass, and limb length, when normalized to body weight and height, the kinetics at maximum shoulder external rotation were similar for both males and females (Chu, Fleisig et al. 2009). Specifically, internal rotation torque and elbow varus torque were found to be directly comparable to pre-existing data (Fleisig, Andrews et al. 1995; Escamilla, Fleisig et al. 2002) on baseball athletes. From these findings, it could be inferred that the softball field player experience similar forces as the baseball field player.

While the injury surveillance data and kinetics research demonstrate similarities in softball and baseball injury patterns and forces, softball and baseball vary in many ways. Sport differences include field size, ball size and weight, game length, and pitching motion. In particular, it is the difference in pitching frequency between the two sports that has been proposed to cause overuse injury (Loosli, Requa et al. 1992; Barrentine, Fleisig et al. 1998). The requirement for the softball pitchers to pitch in consecutive games is highly due to the fact that softball teams carry a mere fraction of the number of pitchers seen on a baseball roster. A review of the roster for the recent Olympic Games in Beijing revealed that there were 5 pitchers on the 15 woman United States softball team, in contrast with 12 pitchers on the 24 man United States baseball team. More specific to the population of this study, pitchers accounted for 21% of total softball players (31 of 148) while baseball pitchers accounted for 49% of all baseball players (137 of 279) as listed on the fall 2008 rosters from

eight universities within the Atlantic Coast Conference that house both baseball and softball programs. Although the implications for pitchers is highlighted by the small fraction of pitchers per team, this ratio also indicates that the majority of softball players are field players, experiencing similar forces and stresses as baseball players. Still, the amount of literature on these softball field players, and their shoulder characteristics, is very limited.

To date, research surrounding the overhead athlete's range of motion characteristics at the shoulder has favored baseball players as the research subjects. As mentioned, there is substantial evidence showing alterations in range of motion characteristics of baseball players dominant shoulder as compared to their non-dominant arm, and to non-overhead athletes (Bigliani, Codd et al. 1997; Crockett, Gross et al. 2002; Reagan, Meister et al. 2002; Meister, Day et al. 2005; Levine, Brandon et al. 2006; Myers, Laudner et al. 2006; Ruotolo, Price et al. 2006; Chant, Litchfield et al. 2007; Lintner, Mayol et al. 2007; Borsa, Laudner et al. 2008; Reinold, Wilk et al. 2008). The general pattern of adaptation in the baseball players shoulder presents as increased external rotation, and decreased internal rotation, horizontal adduction and total range of motion (Altchek, 2001; Bigliani, 1997; Borsa, 2008; Borsa, 2005; Burkhart, 2003; Chant, 2007; Clabbers, 2007; Izumi, 2008; Jobe, 1989; Kibler, 1998; Krah, 1947; Laudner, 2008; Lephart, 1994; Levine, 2006; Lintner, 2007; Lintner, 2008; Mair, 2004; Meister, 2000; Meister, 2005; Murray, 2001; Myers, 2006; Myers and Oyama, In Press; Myers, 2007; Osbahr, 2002; Park, 2002; Park, 2002; Reinold, 2008; Ruotolo, 2006; Sabick, 2004; Safran, 2001; Tyler, 2000; Werner, 1993; Whiteley, 2009; Wilk, 2002). Although the primary purpose of their research was to evaluate proprioception in softball athletes, Dover et al (Dover, Kaminski et al. 2003) also discovered a significant increase in external rotation and decrease in internal rotation of the dominant throwing arm compared

bilaterally in a female overhead athletes (10 pitchers and 40 position players). In addition, Werner et al (Werner, Guido et al. 2005) while investigating kinematic and kinetic variables of softball windmill pitching also recorded range of motion results. This data revealed a significant side-to-side difference between dominant and non-dominant arms in clinical internal and external rotation, suggesting similar range of motion characteristics about the glenohumeral joint as baseball players. Whiteley et al (Whiteley, Ginn et al. 2009) are the only group to evaluate humeral torsion in softball players, to date. This initial study of humeral torsion in softball players indicated that there was no significant difference in torsion measurement of both adult and adolescent baseball and softball players. In this study, there was no comparison to internal and external rotation range of motion values, or posterior shoulder tightness. The mean difference in dominant limb torsion for both the adult and adolescent population was 1.7 and 0.5 degrees respectively. The population of softball players studied was recruited from an amateur competition for older adults and an adolescent population that had not yet achieved physical maturity.

In the current sports culture, most overhead athletes begin playing their sports of choice at a young age, and generally before the closing of epiphyseal plates through physical maturation (Crockett, Gross et al. 2002; Mair, Uhl et al. 2004; Levine, Brandon et al. 2006). As the frequency of participation increases, so does the potential for greater local physical adaptations, which in turn may directly alter variations in the physical characteristics of shoulder. Specifically, the proximal humerus' is at high risk for variations when repetitively overloaded with overhead activity at a high velocity. This change in local bone structure is consistent with Wolff's Law (Frost 2004), and has been demonstrated in numerous studies of range of motion alterations in the shoulder joint of the dominant arm of overhead athletes

(Altchek and Dines 1995; Tyler, Nicholas et al. 2000; Altchek and Hobbs 2001; Crockett, Gross et al. 2002; Reagan, Meister et al. 2002; Burkhart, Morgan et al. 2003; Mair, Uhl et al. 2004; Sabick, Torry et al. 2004; Borsa, Wilk et al. 2005; Levine, Brandon et al. 2006; Myers, Laudner et al. 2006; Chant, Litchfield et al. 2007; Clabbers, Kelly et al. 2007; Lintner, Mayol et al. 2007; McClure, Balaicuis et al. 2007; Myers, Oyama et al. 2007; Borsa, Laudner et al. 2008; Laudner, Sipes et al. 2008; Reinold, Wilk et al. 2008). These osseous adaptations of the humerus in overhead athlete have a direct influence on range of motion characteristics (Crockett, Gross et al. 2002; Borsa, Wilk et al. 2005) and is referred to as humeral torsion (Crockett, Gross et al. 2002; Borsa, Wilk et al. 2005). Crockett et al (Crockett, Gross et al. 2002) found a strong correlation between increased humeral torsion and the shift of total range of motion in the direction of external rotation. Humeral torsion occurs in response to repetitive opposing muscle torques acting upon the humerus during physical maturation as the proximal humeral physis is directly influenced (Sabick, Torry et al. 2004; Chant, Litchfield et al. 2007). As the angle between the axis through the center of the humeral head and the axis of the elbow increases over time, the range of motion characteristics of the players shoulder permanently change. Furthermore, contracture of the posterior capsule and musculature leads to decreased horizontal adduction range of motion, known often as posterior shoulder tightness (PST). In response to the combination of decreased horizontal adduction (Karduna, Williams et al. 1996; Kuhn, Huston et al. 2005) and humeral torsion (Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Reagan, Meister et al. 2002) alterations in glenohumeral range of motion present clinically, most notably through internal rotation. Baseball players have increased torsion, decreased horizontal adduction, and shifts

in their total arc of motion due to the repetitive nature of their sport, specifically during physical maturation.

While a wealth of literature has traditionally attributed these shifts in range of motion to the contracture of the posterior shoulder capsule and musculature (Tyler, Nicholas et al. 2000; Myers, Laudner et al. 2006; McClure, Balaicuis et al. 2007; Laudner, Sipes et al. 2008), recent evidence has suggested that torsion has a greater role in predicting range of motion alterations. A study performed by Myers et al (Myers and Oyama, In Press) suggests that when glenohumeral rotation range of motion alterations within the dominant limb of overhead athletes is adjusted for humeral torsion, the differences side-to-side, and compared to control subjects, is much less observable in healthy overhead athletes. Traditionally, decreases in internal rotation and horizontal adduction are addressed through soft tissue stretching programs in the direction of the deficit. However, if the deficits in internal range of motion are mostly caused by osseous adaptation, range of motion cannot be manipulated by a clinical stretching program (Pieper 1998; Crockett, Gross et al. 2002; Sabick, Kim et al. 2005; Schwab and Blanch 2009). While internal and external rotation individually are affected by repeated overhead activity and humeral torsion, the total humeral rotation range of motion should not be manipulated by the presence of torsion differences. This allows the measurement of total humeral rotation range of motion to be used as a direct clinical assessment of shoulder soft tissue tightness, however the direction of the deficit can not be determined by this value.

Injury rates of baseball and softball players, regardless of position, are similar (Loosli, Requa et al. 1992; Maffet, Jobe et al. 1997; Hill, Humphries et al. 2004; Werner, Guido et al. 2005; Werner, Jones et al. 2006; Rojas, Provencher et al. 2009). In addition, the

stresses placed on shoulder of both baseball and softball field players have been found to similar (Barrentine, Fleisig et al. 1998; Werner, Guido et al. 2005; Chu, Fleisig et al. 2009; Miller, Kaminski et al. 2009; Rojas, Provencher et al. 2009). Field position players in softball and baseball complete repetitive overhead throwing in a similar motion that can lead to overuse injuries. The repetitive motion of throwing has been found to cause alterations in range of motion of baseball players during physical maturation (Lyman, Fleisig et al. 2001; Mair, Uhl et al. 2004; Meister, Day et al. 2005), but has not been directly linked to softball players. The female overhead athlete has been found to exhibit alterations in range of motion (Dover, Kaminski et al. 2003; Werner, Guido et al. 2005). However, the alteration is often believed to be not as significant as their male counterparts, and the literature on range of motion characteristics of the softball players is still very limited (Dover, Kaminski et al. 2003; Werner, Guido et al. 2005; Flyger, Button et al. 2006; Whiteley, Ginn et al. 2009). Further investigation into the presence of these characteristics is needed in the population of softball players.

Purpose and Clinical Relevance

It is the purpose of this study to compare range of motion and humeral torsion characteristics of the overhead baseball and softball athletes. The similarity between baseball and softball's injury rates has not been directly related to range of motion and humeral torsion. Furthermore, the effect of humeral torsion on range of motion characteristics has not been investigated in the softball shoulder, and continues to be developed as it affects the baseball shoulder. Comparison of the range of motion characteristics of softball players to that of baseball players may allow a better approach to clinical practice; both injury

prevention and treatment, of female softball athletes. Specifically, comparison of both osseous and soft tissue characteristics can lead to a specified direction for stretching programs to treat the overhead athlete.

Research Question

Is there a difference in range of motion and humeral torsion characteristics of the shoulders of collegiate baseball and softball players?

Specific Aims:

1. Compare glenohumeral joint range of motion characteristics between baseball and softball players
2. Compare humeral torsion characteristics between baseball and softball players
3. Compare glenohumeral joint range of motion characteristics adjusted for humeral torsion between baseball and softball players.

Research Design

A cross sectional between groups study design will be utilized to compare groups of collegiate baseball and softball players

Dependent Variables

Humeral Torsion

Clinical Internal Rotation

Clinical External Rotation

Horizontal Adduction

Total Range of Motion
Glenohumeral External Rotation Gain (ERG)
Glenohumeral Internal Rotation Deficit (GIRD)
Humeral Torsion adjusted Internal Rotation
Humeral Torsion adjusted External Rotation
Humeral Torsion adjusted ERG
Humeral Torsion adjusted GIRD

Independent Variables

Sport

Baseball

Softball

Hypotheses

Research Hypothesis

Softball players will demonstrate significantly less adaptation in shoulder range of motion characteristics and humeral torsion, as compared to the baseball players' shoulders.

Specifically, softball players will demonstrate compared to baseball players:

- A. Greater glenohumeral internal rotation range of motion in the dominant limb
- B. Less glenohumeral external rotation range of motion in the dominant limb
- C. Less horizontal adduction in the dominant limb
- D. Greater total range of motion in the dominant limb
- E. Greater total range of motion difference

- F. Less humeral torsion in the dominant limb
- G. Less External Rotation Gain (ERG)
- H. Less Glenohumeral Internal Rotation Deficit (GIRD)
- I. Less internal rotation adjusted for humeral torsion in the dominant limb
- J. Less external rotation adjusted for humeral torsion in the dominant limb
- K. Less ERG adjusted for humeral torsion
- L. More GIRD adjusted for humeral torsion

Null Hypothesis

Softball players will demonstrate no significant differences compared to baseball players in shoulder physical characteristics and humeral torsion. Specifically softball players will demonstrate:

- A. No decreased glenohumeral internal rotation range of motion in the dominant limb
- B. No increased glenohumeral external rotation range of motion in the dominant limb
- C. No increased horizontal adduction in the dominant limb
- D. No decreased total range of motion in the dominant limb
- E. No increase in total range of motion difference
- F. No increased humeral torsion in the dominant limb
- G. No increased External Rotation Gain (ERG)
- H. No increase Glenohumeral Internal Rotation Deficit (GIRD)
- I. No increased internal rotation adjusted for humeral torsion in the dominant limb

- J. No increased external rotation adjusted for humeral torsion in the dominant limb
- K. No increased ERG adjusted for humeral torsion
- L. No decreased GIRD adjusted for humeral torsion

Operational Definitions

Overhead athlete: Athletes who participate in baseball or softball requiring their arm to be above their shoulder height on a repetitive basis. Athletes will be considered eligible if they participate in NCAA Division I baseball or softball for the duration of at least 30 minutes per session for at least 4 individual sessions per week.

Assumptions

- All instrumentation is reliable and valid
- Measurement of humeral torsion using diagnostic ultrasound is valid

Delimitations

- Subjects are excluded if they exhibit:
 - o Current shoulder or elbow pain that has limited participation
 - o History of rotator cuff tear within the past year.
 - o History of neck injury within the past year.
 - o Recurring subluxations/ dislocations of the glenohumeral joint
 - o Upper extremity nerve pathology (Cervical Plexus and Accessory Nerve)
 - o Cervical spine pathology
 - o Scoliosis

Limitations

- Researchers are not blinded
- Subjects are not randomized
- Groups are opposing sexes.

Chapter 2

Review of the Literature

Introduction

Shoulder and elbow pathology is a common complaint addressed by the sports medicine clinician. Specifically in overhead athletes, upper extremity injuries account for the greatest time lost from practice and game participation (Powell and Barber-Foss 1999; Lyman, Fleisig et al. 2002; Wang 2006; Dick, Sauers et al. 2007; Marshall, Hamstra-Wright et al. 2007). The sport of baseball is nearly the most commonly played sport with 8.6 million participants among 6 to 17 years olds within the United States, second only to basketball in 1995, and still growing (1996). The sport of softball has over 3 million participants annually, just in leagues within the United States sanctioned by the American Softball Association (<http://www.asasoftball.com/about/index.asp>).

Much of the research effort directed to investigation of shoulder biomechanics and injuries have been based on baseball players' shoulder. Despite the fact that the upper extremity injuries, particularly the shoulder injuries, are just as common in fast-pitch softball players as in baseball players, available literature on softball injuries is scarce. The lack of literature on softball players' shoulder may prompt the clinician to treat the softball players using the set of clinical guidelines and recommendation available for the baseball players. However, the recommendations and guidelines were made based on the evidence from the research studies targeting the baseball players, and therefore may not be tailored to the

softball players. Although the game of baseball and softball is similar, there are differences in the sports including equipment, biomechanics of pitching, proportion of pitchers on the team, and pitch count regulation. These dissimilarities are experienced at all levels of baseball and softball, from the introductory leagues to the professional ranks. Consequently, these differences may pose different stress to the musculoskeletal system of baseball and softball players.

Collegiate level baseball and softball players start participating in their sport as early as 3 or 4 years of age, and continue to participate in the sport over their developmental ages. During the developmental years, the musculoskeletal system is adaptable to the stress applied to it, and therefore participation in the overhead sports is believed to result in various osseous and soft tissue adaptations (Powell and Barber-Foss 2000; Crockett, Gross et al. 2002; Hill, Humphries et al. 2004; Mair, Uhl et al. 2004; Werner, Guido et al. 2005; Keeley, Hackett et al. 2008). Based on the differences existing between the sports discussed above, the shoulder characteristics exhibited by baseball and softball players may be different.

Therefore, the purpose of this study is to provide normative descriptive data on shoulder range of motion characteristics including humeral torsion in softball players, and compares them to characteristics observed in baseball players. This literature review will discuss the difference in biomechanics of pitching/throwing and equipment between baseball and softball. Prior to discussing the differences between the sports, shoulder anatomy as it relates to shoulder range of motion characteristics and epidemiology of injury in softball and baseball will be discussed.

Critical Shoulder Anatomy

To best develop an understanding of the biomechanics of the throwing shoulder, there must be a thorough knowledge of shoulder anatomy. Both static and dynamic structures at the shoulder encompass a complex structure that allows for optimal movement for the overhead athlete. The shoulder complex consists of 4 articulations: the sternoclavicular joint, the acromioclavicular joint, the glenohumeral joint and the scapulothoracic articulation.

Glenohumeral Joint

The glenohumeral (GH) joint is the barely congruent ball and socket articulation between the head of the humerus and the glenoid fossa of the scapula. The large head of the humerus articulates against, as opposed to within the glenoid fossa, allowing for increased mobility at the expense of stability. Therefore, the static and dynamic soft tissue structures acting upon the GH joint along with limited joint volume and a negative articular pressure (Speer 1995) provide the restraint to the joint. However, because of its mobility the glenohumeral joint remains one of the most unstable joints in the body. Dislocation at the glenohumeral joint accounts for approximately 45% of all bodily dislocation (Garrett 2000).

The static constraints of the glenohumeral joint consists of the shoulder capsule, the glenohumeral ligaments, which are a thickening of the joint capsule, and the labrum. Furthermore, the static stabilizers can be attributed to surface area conformity and intra-articular pressure. Humeral and glenoid version are resting position angles of the humeral head and glenoid fossa that encourage stabilization of the ball and socket joint. While the humeral neck shaft angles lying between 130-140 degrees and the humeral head retroverted approximately 30 degrees in reference to the transepicondylar axis of the elbow (Garrett 2000). The glenoid fossa's natural superior tilt of 5 degrees helps prevent inferior translation

of the humeral head (Kikuchi, Itoi et al. 2008). As noted, the humeral head is much larger than the glenoid fossa it lies upon. It has been proposed that uniform contact of approximately 25% between the two surfaces exists through the range of motion, meaning the joint is congruent, just lacking equality of surface area (Garrett 2000). Glenoid labrum help increase the small articular contact area and to deepen the glenoid socket to up to 50% of its overall depth (Howell and Galinat 1989). In addition to maximizing the contact surface, the labrum acts as a site for the glenohumeral ligaments and capsule. As the glenohumeral joint capsule is an enclosed envelope, a negative articular pressure exists within the capsule (Itoi, Motzkin et al. 1993). The greatest role of this pressure is to centralize the humeral head and to provide stability (Itoi, Motzkin et al. 1993; Speer 1995). Primarily, static stabilization at the glenohumeral joint is provided by the glenohumeral joint capsule and its thickenings known as the glenohumeral ligaments which are collagen fiber bundles laid down in several layers that vary in direction and thickness (Howell and Galinat 1989; Garrett 2000; Rockwood 2004). The superior glenohumeral ligament (SGHL) exhibits a true longitudinal ligament collagen arrangement as it extends from the superior glenoid rim into the lesser tubercle of the humerus. It acts as the primary restraint to external rotation in the adducted shoulder (Turkel, Panio et al. 1981; Speer 1995). The overlying coracohumeral ligament acts a primary restraint against to external rotation and in the adducted arm to inferior translation (Turkel, Panio et al. 1981; Warner, Deng et al. 1992). The middle glenohumeral ligament (MGHL) restricts anterior translation with the arm abducted 45 degrees, but may be absent in some of the population. The ligament extends from the varying locations on the glenoid into an anterior portion of the lesser tuberosity with the subscapularis tendon (Warner, Deng et al. 1992). The inferior glenohumeral ligament

(IGHL) engulfs the entire inferior capsule and varies in thickness across its broad triangular band. A thicker portion anteriorly is referred to as the anterior or superior band and becomes thicker near the glenoid as opposed to the humerus (Bigliani, Pollock et al. 1992). This increase in size at this position allows for greater static stabilization against anterior-inferior translation (Bigliani, Pollock et al. 1992).

Although the capsuloligamentous structures provide joint stability, additional stability from constant dynamic stabilization is required to prevent recurrent subluxations and dislocations of the glenohumeral joint during dynamic movement. The rotator cuff and bicep muscles compress the head of the humerus into the glenoid fossa to prevent translation of the humeral head. The entire cuff acts in cooperation to properly compress and stabilize the joint (Garrett 2000). However, the rotator cuff itself does not comprise the total dynamic stabilization of the glenohumeral joint. In addition to the individual components of the rotator cuff acting in unison to stabilize, joint proprioceptors, scapular kinematics, and shoulder position attribute to stabilization. Specifically, joint proprioceptors have been found to deteriorate in subjects with increased laxity (Lephart, Warner et al. 1994; Zuckerman, Gallagher et al. 2003). In result, a synergist pattern about the coordinated arm and scapula produce glenohumeral stability through a range of motion, permitting arm motion to reach controlled end ranges of motion, all the while depending upon joint and angle proprioception feedback (Kibler, 2001).

The Overhead Athlete's Shoulder

Overhead athletes are susceptible to shoulder pathology due to the increased demand placed on the structures that support and facilitate movement during repeated overhead

activity (Burkhart, 2003). Wilk et al (Wilk, Meister et al. 2002) referred to the intricate and delicate balance between mobility and stability required in overhead throwing athletes' shoulder as the "throwers paradox." The overhead athlete can be defined as athletes who participate in a sport that requires their arm to be above their shoulder height on a repetitive basis during throwing or striking activities, such as swimming, tennis, volleyball, baseball, and softball. Repetitive overload has been shown to cause adaptations in the overhead athlete's shoulder, which can lead to the pathologic shoulder in overhead baseball and softball players.

Range of Motion

It has been well documented that the overhead athlete experiences alterations in range of motion at the glenohumeral joint (Borsa, 2008; Borsa, 2005; Borstad, 2006; Burkhart, 2003; Clabbers, 2007; McClure, 2007; Myers, 2006; Myers, 2007; Reinold, 2008; Tyler, 2000). Specifically, the baseball players exhibit an increase in external rotation and a decrease of internal rotation when measured at 90 degrees of abduction (Wilk, 2002; Borsa, 2008; Borsa, 2005; Borstad, 2006; Burkhart, 2003; Clabbers, 2007; McClure, 2007; Myers, 2006; Myers, 2007; Reinold, 2008; Tyler, 2000). Wilk et al (Wilk, 2002) found in an investigation of 372 professional baseball players an average of 7° increased external rotation and decreased internal rotation as compared to the contralateral non-throwing arm. It was introduced that overhead baseball athletes exhibit a shift in their "total arc of motion", allowing for increased velocity during the throwing (Reinold, 2008; Wilk, 2002). Commonly, the increase in external rotation is referred to as External Rotation Gain (ERG), and the decrease in internal rotation is classified as Glenohumeral Internal Rotation Deficit

(GIRD). ERG is theorized to be the cause of gradual attenuation of the anteroinferior ligament and extended capsule stabilizers, as well as humeral torsion (Gowan, Jobe et al. 1987; Borsa, Wilk et al. 2005). GIRD is theorized to be the cause of increased posterior inferior joint capsule contracture, tight posterior rotator cuff musculature, and osseous adaptations (Lintner, Mayol et al. 2007). GIRD is characterized by a loss in internal rotation range of motion as compared bilaterally. Extensive data show GIRD in professional and collegiate level overhead athletes (Fleisig, Andrews et al. 1995; Bigliani, Codd et al. 1997; Tyler, Nicholas et al. 2000; Lyman, Fleisig et al. 2001; Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Park, Loebenberg et al. 2002; Reagan, Meister et al. 2002; Wilk, Meister et al. 2002; Mair, Uhl et al. 2004; Sabick, Torry et al. 2004; Borsa, Wilk et al. 2005; Levine, Brandon et al. 2006; Myers, Laudner et al. 2006; Chant, Litchfield et al. 2007; Lintner, Mayol et al. 2007; McClure, Balaicuis et al. 2007; Myers, Oyama et al. 2007; Borsa, Laudner et al. 2008; Reinold, Wilk et al. 2008). It was found by Lintner et al (Lintner, Mayol et al. 2007) in a study of 85 professional baseball players that GIRD is effectively altered by stretching of soft tissue structures (posterior capsule and rotator cuff). While some argument exists to the attributing factors in GIRD, this study indicates that soft tissue structures contribute to adaptive GIRD, while contribution of the humeral torsion was not assessed in the study. No matter the cause, GIRD and its direct effect on pathology has been demonstrated in the literature. Burkhart et al (Burkhart, Morgan et al. 2003; Burkhart, Morgan et al. 2003) proposed that GIRD was the initial step in “dead arm” syndrome. This theory was further defined to be possible only when compounded by an unequal increase in ERG (Myers, Laudner et al. 2006; Trakis, McHugh et al. 2008). In addition to dead arm, GIRD has been attributed to lead to anterior instability, SLAP lesion, internal impingement,

and partial rotator cuff tears (Warner, Micheli et al. 1990; Bigliani, Codd et al. 1997; Sauers, Borsa et al. 2001; Burkhart, Morgan et al. 2003; Burkhart, Morgan et al. 2003; Myers, Laudner et al. 2006; Lintner, Mayol et al. 2007; Lintner, Noonan et al. 2008). Measurement of total shoulder rotational motion, first introduced by Wilk et al (Wilk, Meister et al. 2002) is called total arc of motion. Total arc of motion values are a sum of the total external rotation and internal rotation values as measured at 90 degrees of abduction (Reinold, Wilk et al. 2008). The total arc has repeatedly not been found to be significant between dominant and non dominant arms, just shift in the external rotation direction (Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Reagan, Meister et al. 2002; Wilk, Meister et al. 2002; Borsa, Wilk et al. 2005; Myers, Laudner et al. 2006; Lintner, Mayol et al. 2007; Borsa, Laudner et al. 2008). Recently, more attention has been directed towards osseous adaptations of the overheard athlete and its direct relationship to total arc shift (Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Reagan, Meister et al. 2002; Sabick, Torry et al. 2004; Borsa, Wilk et al. 2005; Yamamoto, Itoi et al. 2006; Chant, Litchfield et al. 2007; Borsa, Laudner et al. 2008; Whiteley, Adams et al. 2008).

Posterior Shoulder Tightness

The presence of posterior shoulder tightness (PST) in baseball players is well documented in the literature (Borsa, 2008; Borsa, 2005; Burkhart, 2003; Burkhart, 2003; Clabbers, 2007; Crockett, 2002; McClure, 2007; Myers, 2006; Myers, 2007; Sabick, 2004; Tyler, 2000; Wang, 1999; Wilk, 2002). Burkhart et al (Burkhart, 2003) suggested that contracture of the posterior inferior glenohumeral capsule was the cause of PST, and was likely to lead to pathology. PST is characterized by a reduction in glenohumeral internal

rotation, flexion, and horizontal adduction (McClure, Balaicuis et al. 2007). PST is suggested to cause inadequate glenohumeral kinematics, leading to impingement, labral pathology or rotator cuff pathology (Michener, 2003; Myers, 2006; Tyler, 2000; Wang, 1999). Inflexibility of the posterior shoulder as a result of capsular or muscular tightness deviates the motion about the glenohumeral joint creating increased forward and inferior movement of the scapula during shoulder flexion (Gowan, Jobe et al. 1987; Kibler 1998). Tyler et al (Tyler, Nicholas et al. 2000) found a direct relationship between posterior shoulder tightness and a limitation in glenohumeral range of motion. During bouts of throwing, the posterior shoulder structures are repetitively used in an eccentric fashion to decelerate the arm (Gowan, Jobe et al. 1987; Reinold, Wilk et al. 2008). Internal rotation during throwing occurs at angular velocity between 6000 and 7000 deg/s (Fleisig, Barrentine et al. 1996; Reinold, Wilk et al. 2008). The posterior musculature of the shoulder contributes to deceleration of the limb rotating at this high velocity through eccentrically contraction. This leads to tightness and soreness seen clinically in baseball players after repetitive throwing. In the acute repair phase after a bout of pitching, it should be the goal of the clinician to stretch the posterior shoulder tightness. Both the sidelying measurement of adduction and the modified supine assessment of PST were found to be low in clinical error and exhibited good precision (Myers, Oyama et al. 2007). In addition to horizontal adduction stretch for PST, the “sleeper stretch” for PST has recently gained increased clinical use. McClure et al (McClure, Balaicuis et al. 2007) compared the cross body adduction stretch with the sleeper stretch over a 4-week period. They found that while the cross body adduction stretch did not account for scapular stabilization, it provided greater increases in measurements of internal rotation at 90 degrees of adduction. Ideally, the clinician should

apply a reliable means of measuring and stretching the posterior shoulder in order to minimize posterior inferior joint capsule contracture.

Glenohumeral Laxity

Compression and concavity at the glenohumeral joint must be maintained at a maximal level. The alignment of the humerus into the glenoid must be proper, thus assuring optimum positioning of the intrinsic rotator cuff musculature to allow compression into the glenoid socket during shoulder motion, resulting in proper stabilization (Kibler 1998). While the capsuloligamentous structures of the shoulder work in accordance with balanced musculature acting upon the glenohumeral joint, within the throwing athlete this relationship is often altered (Myers, 2002; Wilk, 2002). Anterior and inferior capsuloligamentous structures have been found to exhibit laxity as determined by Sulcus sign in a study of professional baseball players (Bigliani, Codd et al. 1997). Whether this laxity is inherent or acquired is still undetermined, but the challenges of controlling this “thrower’s laxity” remains for the clinician (Myers, 2002; Wilk, 2002). Jobe et al (Jobe, Kvitne et al. 1989; Kvitne and Jobe 1993) theorized that overhead athletes develop acquired hyperlaxity of the anterior structures of the shoulder. Further development of this theory linked the laxity with stretching of the anterior structures such as the inferior glenohumeral ligament complex that is placed in maximal stretch during abduction and external rotation, the terminal point of the pitching motion (Jobe, Kvitne et al. 1989; Wilk, Meister et al. 2002). Recent work by Sethi et al (Sethi, Tibone et al. 2004) found significant glenohumeral translation in pitchers, but not in position players.

Humeral Torsion

The development of humeral torsion as one of the primary contributors to changes in shoulder range of motion is now well-documented, and gaining increased attention (Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Chant, Litchfield et al. 2007; Reinold, Wilk et al. 2008). Torsion of the humerus into humeral retroversion is thought to be the result of muscular forces acting on the humerus, as the humerus experiences torsion moments during the overhead throwing motion (Sabick, Kim et al. 2005; Chant, Litchfield et al. 2007). Krahl first demonstrated the effects of muscle force on humeral torsion, and theorized that there were two forms of torsion: primary hereditary and secondary that is caused by muscles acting above and below the proximal humeral physis (Krahl 1947). Humeral retroversion is a more anteriorly directed humeral head (Whiteley, Adams et al. 2008). Humeral retroversion results in relative twisting between the proximal and distal humerus, or humeral torsion. The development of humeral torsion is an example of Wolff's law that states that the architecture of bone response to changes in the form and function (Frost 2004). While variations in glenohumeral range of motion were originally attributed only to soft tissue changes, it is now considered a combination of soft tissue and osseous adjustments. Specifically, humeral torsion is defined as the acute angle between the axis through the center of the humeral head and the axis of the elbow, in the medial and posterior direction (Pieper 1998). The proximal physis of the humerus accounts for 89% of the growth within the humerus during physical maturation; therefore, this area is considered a weak area during this time (Whiteley, Adams et al. 2008). Given this weak spot, the repetitive loads and muscle forces acting on the proximal humerus during this time in overhead athletes leads directly to increased humeral torsion (Whiteley, Adams et al. 2008).

Effects of repetitive throwing in developmental athlete are not completely understood due to the complexity of the developing skeleton (Sabick, Kim et al. 2005). The developing shoulder has joint laxity, underdeveloped musculature and open epiphyseal plates. Two major types of loading have been implicated at the proximal humerus during throwing. They are significant rotational stress applied to the proximal humeral physis and distraction of the physis. The rotational torques as high as 92 N m act about the long axis of the humerus found in professional pitchers. A proximally directed force counteracts the distraction forces at the shoulder at the time of ball release via the rotation cuff, keeping the glenohumeral joint intact. The location of the rotator cuff inserted at the proximal humeral physis creates proximally directed forces across this proximal humeral physis by the rotator cuff during overhead throwing.

Both rotational torques and distraction forces about the shoulder have been implicated as either pathological or beneficial responses at the shoulder. Although both rotational torques and distraction forces occur, Sabbick et al (Sabick, Kim et al. 2005) suggested that the rotational torques place the proximal humeral at the highest risk for alteration and possibly injury.

Just prior to maximal external rotation of the humerus during throwing, an internal rotation torque is created while the arm is still moving in the external rotation direction. During this time muscles attached at the proximal humerus that create internal rotation (subscapularis, pectoralis major, and latissimus dorsi). In contrast, the distal aspect of the arm is creating an external rotation torque on the humerus, driven by the moment of inertia of the upper limb. This causes a twisting effect on the humerus, and the subsequent adaptation in humeral torsion over time in the direction of this torque. The failure point of

the humerus has been found to be less than the applied torque of about 90 N m (Sabick, Kim et al. 2005). Although humeral fracture can occur, this increased torque value indicates that every maximal force throw, specifically during physical maturation, can have a dynamic effect on the cortical development.

Torsion is the result of both evolutionary torsion (primary torsion) and the effect of muscular forces acting on the humerus (secondary torsion). Humans are born with bilateral retroversion in their humerus, that gradually anteverts during skeletal maturity. This suggests the forces and torques experienced by an overhead population during physical maturity actually delays the natural progression of anteverision, as opposed to creating a direct retroversion movement (Sabick, Kim et al. 2005).

Whether or not humeral torsion benefits the overhead athlete in both performance and injury prevention is still undetermined. It has been suggested that humeral torsion acts as a protective adaptation for the anterior capsulolabral complex. The increased external rotation attained through increased torsion decreases the stress on the anterior soft tissue restraints (glenohumeral joint capsule and ligaments)(Pieper 1998; Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Reagan, Meister et al. 2002; Sabick, Kim et al. 2005). Given the increased length of external rotation range of motion and the decreased tension experienced, the throwing shoulder experiences an optimal length-tension relationship that decreased joint laxity and placed these shoulders at a throwing advantage (Crockett, Gross et al. 2002). In a sense, increased torsion prepares the humerus to reach increased values of external rotation while simultaneously decreasing the amount of stress on the anterior joint capsule and ligaments (Crockett, Gross et al. 2002). In the only study to directly address humeral torsion as a protective mechanism, Pieper et al (Pieper 1998) found a group of elite handball players

with chronic shoulder pain displayed no significant difference in humeral retroversion between limbs. This was in contrast to a large group of players who had an overall significant greater mean difference bilaterally in increased torsion, and were not classified as pathologic. Pieper et al (Pieper 1998) concluded that this suggests humeral torsion increased developed during physical maturation is a protective mechanism against injury to the anterior shoulder; however, this has only been theorized and is not known for certain at this time.

The first research based study to confirm torsion of the humerus in overhead athletes was completed on team handball players (Pieper 1998). In this study, 51 professional handball players, 13 symptomatic for shoulder pathology, were measured for humeral torsion through a radiographic analysis. These 51 subjects were compared to 37 control subjects above the age of bone maturation, and without any history of overhead sport activity. The radiographic analysis utilized two views: an standard AP view at 40° of external rotation and a view that showed the projected torsional angle of the humerus without elbow projection interference. Pieper found a significant difference in shoulder retroversion between the dominant and non-dominant limbs within the subject and between groups. An average difference of 9.4° in retroversion was found within the professional handball players between dominant and non-dominant shoulders. In addition, a 7.62° increase in torsion was found between the handball players group and the control group's dominant shoulder retroversion angle (Pieper 1998).

Stemming from the findings of Pieper (Pieper 1998), studies of retroversion in baseball overhead athletes (Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Reagan, Meister et al. 2002; Chant, Litchfield et al. 2007) found similar results. Crockett et al (Crockett, Gross et al. 2002) studied humeral retroversion in 25 male professional baseball players. The

retroversion angle was compared bilaterally and to a group of matched control subjects. Measurements of humeral retroversion were derived through computed tomographic (CT) analysis of axial cuts of the humerus at the humeral head and the capitellum and trochlea. Torsion was calculated as the difference between a line parallel to the distal articular surface and a line bisecting a spherical section of the head (Crockett, Gross et al. 2002). In addition to humeral torsion measurement, the analysis of glenoid version was also examined. Crockett et al found significant differences across the board in side-to-side within subject and between groups measurements of humeral head retroversion and external rotation range of motion. The humeral head retroversion measurements within the professional baseball players' dominant to non-dominant shoulder was $40 \pm 9.9^\circ$ in the dominant arm, compared to $23 \pm 10.4^\circ$ in the non-dominant.

In a study of collegiate baseball players, Reagan et al (Reagan, Meister et al. 2002) furthered the base of support for consistent humeral retroversion across the dominant shoulder of elite baseball players. A single study group of 45 college baseball players were measured for supine forward elevation, internal rotation, external rotation range of motions, and humeral retroversion. Retroversion was measured using radiographic analysis, through a semiaxial view that permitted a measurement of the angle between the humeral neck axis and the humeral condyle axis to be interpreted as the humeral retroversion angle. A significant difference was found between dominant ($36.6 \pm 9.8^\circ$) and non-dominant ($26 \pm 9.4^\circ$) humeral retroversion angles. In addition to comparing bilaterally, the results from internal and external rotation range of motion were found to correlate significantly with humeral retroversion measurements. Interestingly, when dissected into pitchers and non-pitchers group, the external rotation measurements still correlated significantly for both groups. In

the pitcher group only, there was no significant correlation significant difference found between internal rotation and humeral retroversion. The authors stated this significant correlation indicated that the exhibited increased GIRD was from soft tissue structures.

Chant et al (Chant, Litchfield et al. 2007) completed a more recent study of 19 professional baseball players, with an aged matched control group to assess the validity of the humeral retroversion measurement. Their methods adopted those of Crockett (Crockett, Gross et al. 2002) as CT was used to analyze the amount of humeral retroversion. Once again, the dominant limb ($44.9 \pm 10.9^\circ$) was significantly more retroverted compared to the non-dominant ($34.3 \pm 6.9^\circ$) shoulders. Similar to the study by Reagan et al, correlations were calculated between the measurements of internal and external rotation range of motion, and humeral retroversion. While all found to be significantly correlated, the authors did note their confidence intervals were fairly high, potentially due to factors such as glenohumeral translation, passive stiffness, posterior capsule tightness, and soft tissue tightness (Chant, Litchfield et al. 2007).

In the current study, the method for measuring humeral torsion was adapted from an investigation by Whiteley et al (Whiteley, Ginn et al. 2006). This two fold study first evaluated diagnostic ultrasound as a means of measuring humeral torsion in a population of non overhead athletes. Second, it evaluated humeral torsion in a group of elite youth baseball athletes, as compared to their non-dominant arm. The major outcomes included of the first study showed strong inter-tester reliability for the use of diagnostic US as a means of measuring humeral torsion, in contrast with poor results for palpation method of assessing humeral torsion. The second portion of the study revealed variable side-to-side results of humeral torsion for a non-overhead population. However, the baseball population showed a

significant difference in non-dominant less dominant humeral torsion difference. This result again confirmed the presence of increase humeral torsion in baseball players, as well as an accurate method for continued assessment of humeral torsion. The portability and simple operation for diagnostic ultrasound, as well as good reliability and validity, make assessing humeral torsion in the clinic a realistic tool.

The only documented humeral torsion data on softball players was recently completed by Whiteley et al (Whiteley, Ginn et al. 2009). Using the modified ultrasonography technique, they investigated the presence of humeral torsion in adolescent baseball, softball and swimming athletes, adult baseball and softball amateur athletes, and a control population. Worthy of note, they did not find significant differences between the baseball and softball population. The mean difference between limbs in the adult baseball and softball players was -1.7 degrees different. Analyzing the dominant limb results only, the baseball players had a greater mean difference of nearly 6 degrees from the softball players; however, the non-dominant limb data were not similar between the two sports. The adolescent population of baseball and softball players had nearly identical results in the mean difference between limbs, and when broken down by limb, their results were nearly equal. In accordance with previous data, the comparison of the control group to the throwing group (adults baseball and softball players) was significantly different, with the throwing group averaging 12 degrees of humeral torsion difference between limbs.

Correction for Humeral Torsion

Given the knowledge that humeral torsion exists within the dominant shoulder of overhead athletes, the sports medicine clinician must now determine how to implement this

knowledge into the clinical setting. Recent research has begun to adjust range of motion values after determining the amount of humeral torsion in a given shoulder. This adjustment is referred to as correction for torsion, or adjusted for humeral torsion. The traditional belief in sports medicine has been that decreased in internal rotation, shifts in total arc of motion and increased posterior shoulder tightness are due to contracture of the posterior shoulder musculature and joint capsule and laxity of the anterior capsule. This belief has led to the clinical practice of increased stretching of the posterior shoulder (through internal rotation, horizontal adduction and flexion stretching) in order to decrease the amount of shoulder pain and risk for injury. However, the results of a study by Myers indicates that GIRD and ERG are less influenced by soft tissue contracture; rather, humeral torsion significantly influences the amount of range of motion alterations exhibited in overhead throwing athletes.

Therefore, when assessing range of motion characteristics in this study, the results include the correction for humeral torsion measurements. These results utilize the measured humeral torsion within the individual limb, and use that angle as the neutral position for internal and external rotation, rather than the traditional neutral position at 90 degrees perpendicular to the treatment table. Given this adjustment, the baseball players in the study by Myers had no differences in internal rotation between limbs. This indicates that the amount of posterior shoulder soft tissue elasticity in the dominant limb could be considered normal when the adjusted values are near equal between dominant and non-dominant limbs. If adjusted internal rotation and external rotation are created near equal to the opposing limb through adjusting for the osseous adaptations, it would indicate any variation left is due to soft tissue contracture. Traditionally, these alterations in range of motion were attributed completely to soft tissue alterations and an aggressive internal rotation stretching program was utilized. In

contrast, given the humeral torsion value for a given limb, the subsequent direction of stretching utilized and the appropriate amount can be isolated. For example, a dominant limb that has 40 degrees of clinical internal rotation and 80 degree of torsion would display an adjusted IR value of 30 degrees. This value in turn would be compared to the non-dominant limb's adjusted IR value. If the adjusted value of the non-dominant limb were similar to the dominant limbs' value, it would indicate little internal rotation deficit due to soft tissue structure. Continuing on, if this same subjects external rotation values are also assessed, the same principal is applied. If the two adjusted ER values between dominant and non-dominant limbs are not near equal, it is believed that the variation in range of motion is purely due to soft tissue alterations. This process would then directly affect the clinical protocol for stretching and range of motion in the future.

While internal rotation is often the primary variable addressed by the clinician, posterior shoulder tightness can also be directly affected by humeral torsion. Given the adjustment of rotational neutral discussed above, the orientation of the posterior shoulder fibers may be different at clinical neutral as opposed to measured humeral torsion neutral, therefore affecting the measurement of horizontal adduction. In addition to the study by Myers, a report by Schwab and Blanch uses the measurement of humeral rotational range of motion accounting for humeral torsion. Their results were less pronounced than those of Myers, due in large part to the use of volleyball players are their overhead athlete population. However, adjustments for humeral torsion were said to almost entirely account for the lost range of motion through the measurement of humeral torsion, as opposed to alterations in soft tissue. As sports medicine research into the overhead athlete advances, the presence of humeral torsion must be accounted for. Given the consistent reporting of humeral torsions

direct effect on shoulder range of motion, applying torsion adjusted measurements to effectively treat the flexibility of overhead athletes shoulders is vital in providing the most appropriate clinical care.

Epidemiology

Based on a database from the National Collegiate Athletic Association (NCAA) Injury Surveillance Systems (ISS) on baseball injuries collected between 1988 and 2004, players who missed practice and games were complaining of an upper extremity injury 45% of the time (Dick, 2007). Furthermore, shoulder injuries accounted for 23% of the injuries during practices, and 16% during games for that entire time period. A large cohort prospective study completed by Lyman et al (Lyman, Fleisig et al. 2001) evaluated 298 pitchers over two seasons of little league baseball. Broadly, they found a 32% complaint rate of shoulder pain and a 25.5% complaint rate of elbow pain after pitching during the two-year period. It was found that factors such as increased total pitch count, arm fatigue, and perceived pitching performance have an impact on the increased likelihood of experiencing pain subsequent of pitching. A direct comparison of a large sample of baseball and softball injury rates in high school athletes based on the data collected by the National Athletic Trainer's Association (NATA) (Powell and Barber-Foss 2000) demonstrated comparable injury rates for the two sports, especially in the upper extremity. Powell reported shoulder injuries accounting for 19.7% of all injuries in baseball and 16.3% of all injuries in softball.

A study completed in 1989 by Loosli et al (Loosli, Requa et al. 1992) during the NCAA fast pitch softball championships was the first study to specifically focused on

injuries in fast pitch competitive softball. The study found almost half of the pitchers in the study (11 of 24) sustained an injury that led to time-loss during the season. Of the total of 25 injuries sustained throughout the season by these 24 subjects, 9 of them were shoulder injuries, and 17 were within the upper extremity. This was the first study to demonstrate that fast pitch softball players are susceptible to upper extremity injuries, much like baseball athletes. In the most recent release of NCAA ISS data regarding softball injuries, Marshall et al (Marshall, Hamstra-Wright et al. 2007) reported that 10% of all practice injuries were attributed to shoulder strains or tendonitis, as well as 5.5% of injuries resulting in ten or more days lost in practice were attributed to shoulder tendonitis. Hill et al (Hill, Humphries et al. 2004), completed a survey study in order to examine the injuries occurring across the three division of NCAA softball. The survey revealed that of a total of 92 injuries reported as chronic or overuse, 60 involved the upper extremity, and 33 of which were isolated to the shoulder. It was also reported within this study that the number of pitched innings from the previous season by all pitchers who reported an injury was between 82 and 93.

More recent epidemiological data that analyzed only the shoulder in high school athletes completed by Bonza et al (Bonza, Fields et al. 2009) exhibits similar injury patterns between baseball and softball players. They found that softball was the most common female sport to cause shoulder injuries. In relation to recurrent injuries, baseball accounted for 22 % of all recurrent injuries to the shoulder in all sports, while softball accounted for 16% in the same category. The types of injuries sustained at the shoulder were similar between both sports; 55.3% and 52.9% for baseball and softball respectively. Softball players were found to have slightly higher rates of injuries due to overuse/chronic mechanisms at the shoulder. Most interesting to note, throwing as the activity that led to

injury was 24.3% in non-pitching baseball players, and in accounted for twice that in softball non-pitchers at 50.2%. However, baseball pitchers cause of injury as throwing was significantly higher than softball pitchers.

Differences Between Sports

The most significant difference between baseball and softball is the management of the pitchers. While management of the athletes may stand out as a primary difference, the characteristics of each sport also have a direct effect on long-term outcomes from participation. The ball used in both sports is drastically different. The official Major League Baseball (MLB) is a sphere formed by yarn wound around a small core of cork, rubber or similar material, covered with two strips of white horsehide or cowhide, tightly stitched together. It can not weigh less than five nor more than 5¼ ounces and can not measure less than nine or more than 9¼ inches in circumference (http://mlb.mlb.com/mlb/official_info/official_rules/foreword.jsp). In contrast, the official softball from Official Rules of Softball from the International Softball Federation Playing Rules Committee is a completed 30.5cm (12 in) ball between 30.2cm (11 7/8 in) and 30.8cm (12 1/8 in) in circumference, which weighs between 178.0g (6 1/4 ounces) and 198.4g (7 ounces). The flat seam style cannot have less than 88 stitches in each cover, sewn by the two-needle method (www.internationalsoftball.com/english/rules_standards/rules_standards.asp). The larger softball creates a different gripping technique as compared to the baseball.

In addition to the different ball size, the two sports are played on fields that are drastically different in overall size. The standard baseball field for professional baseball has

the four bases separated in an even square at a distance of 90 feet apart. The pitchers mound, which is raised from the remainder of the surface, is 60 feet and 6 inches from the back of the pitching rubber or plate to the front of home base. The plate is placed 18 inches behind the center of the mound, which is 18 feet in diameter. The mound is then declined at a rate of 1 degree per 1 foot from the 6 inches in front of the plate. As of June 1958, any field constructed for professional use can not have a distance of less than 325 feet to any point in the outfield wall from home plate. These overall settings create a large amount of space to play the game of baseball, therefore a larger amount of space to throw the baseball overhead (http://mlb.mlb.com/mlb/official_info/official_rules/foreword.jsp). In contrast, the softball field has four bases separate in a perfect square at a distance of 60 feet. The pitching plate, which is not elevated on a mound, is 43 feet from home base. The overall distance of home plate to the outfield wall must exceed 220 feet. Overall, the size of the softball field and distance between areas is significantly smaller than that in baseball. Despite the smaller size of the field, the reaction time for batters in softball is directly comparable to that of baseball batters (Werner, Guido et al. 2005). To date, there has been no research that has evaluated the differences in field size and ball size between baseball and softball, and their implications on injuries in their respective sport.

Biomechanics of Throwing

The Baseball Pitch-

The overhead baseball throw is perhaps the most arduous motions in all sports (Dillman, Fleisig et al. 1993; Fleisig, Andrews et al. 1995; Fleisig, Barrentine et al. 1996; Fleisig, Barrentine et al. 1999; Sabick, Kim et al. 2005; Dun, Kingsley et al. 2008; Keeley,

Hackett et al. 2008). The kinetics and kinematics of the baseball pitch have been repeatedly studied in the laboratory, allowing a better understanding of proper pitching mechanics and implications for injuries (Atwater 1979; Dillman, Fleisig et al. 1993; Fleisig, Andrews et al. 1995; Fleisig, Barrentine et al. 1996; Fleisig, Barrentine et al. 1999; Park, Loebenberg et al. 2002; Park, Loebenberg et al. 2002; Sabick, Torry et al. 2004; Sabick, Kim et al. 2005; Dun, Kingsley et al. 2008; Keeley, Hackett et al. 2008). Tremendous joint torques and joint reaction forces are involved in the baseball throw, placing the arm at high risk of injury during the entire motion. Pitching mechanics can be broken into six different phases (Figure 2) ;windup, the stride, arm cocking, arm acceleration, arm deceleration, and follow through.

The windup phase begins as the pitcher initiates the throwing motion. The goal of this phase is to place the athlete in the most advantageous position to begin the pitch. The windup is the least involved phase of the pitch, in terms of muscular activity and total motion (DiGiovine 1992). The pitcher lifts their lead leg through hip flexor contraction; maintain the lead side towards the plate. Proper form ensures that the lead leg does not move towards the plate until the stride phase begins. At this point the stride phase begins, highlighted by initiation of the movement of the lead leg towards the target and the separation of the hands.

The stride phase begins with the lead leg moving towards the target as the pitcher pushes off and falls off the rubber towards the batter. Directly in front or slightly to the dominant arms side of the plant foot is where the lead foot should land. The toes should be pointing between 5-25 degrees to the dominant arms side. In order to generate the most force through the kinetic chain to the arm, the pitcher should avoid excessive toeing out, wide stance, and a stance where the lead foot is inside of the stance foot. The distance between the lead and plant foot should be just under the pitchers height. The time point when the lead

foot touches the ground is considered foot contact. At foot contact, a throwing shoulder is elevated 90-110 degrees, externally rotated between 40-80 degrees, and horizontally abducted 20-30 degrees, while the elbow is flexed between 80-100 degrees. The stride phase ends when the lead foot contacts the ground,

Arm cocking is the next phase and is lasts from foot contact to maximal shoulder external rotation. This phase is highlighted by rapid trunk rotation with shoulder external rotation to physiological limits (Park, Loebenberg et al. 2002). In a study of a simulated baseball game, Escamilla et al (Escamilla, Barrentine et al. 2007) found maximum pelvis angular velocities between 501 to 720 degrees per second. Furthermore, maximum upper torso angular velocities were between 1083 and 1239 degrees per second. In a study by Fleisig et al (Fleisig, Andrews et al. 1995), forces and torques were measured during the arm cocking phase. The study reported that peak shoulder internal rotation torque is achieved just prior to maximal external rotation (Fleisig, Andrews et al. 1995; Park, Loebenberg et al. 2002). It was also found that the shoulder produces 660 ± 110 Newtons of compressive force to counteract the distractive force created by the pelvis and upper torso rotation as they accelerate towards the plate. Additionally, anterior shear force at the shoulder between 393 and 556 newtons has been reported during the arm cocking phase (Escamilla, Barrentine et al. 2007). The joint compression force to counteract the distraction and anterior sheer forces is produced primarily by the rotator cuff. The EMG activity data demonstrated that the activation level of the rotator cuff muscles were highest during this phase (DiGiovine 1992). The compression force produced by the rotator cuff muscles minimizes joint translation. Additionally, the inferio-medially directed compression force help neutralize the superiorly

directed force produced by the deltoid muscle, allowing the humeral head to be centered within the glenoid fossa (Fleisig, Andrews et al. 1995).

At maximal external rotation, the arm acceleration phase begins. This phase can be missed with the blink of an eye, as it tends to last 0.030 to 0.058 seconds (Werner, Fleisig et al. 1993; Park, Loebenberg et al. 2002). Elbow extension and shoulder internal rotation are the trademarks of this phase. Shoulder internal rotation during this phase can reach up to 8000 degrees per second (Dillman, Fleisig et al. 1993). Elbow extension is achieved through a combination of torso rotation and triceps extension (Park, Loebenberg et al. 2002). Ideally, the activation of the rotator cuff, trapezius, serratus anterior, rhomboids and latissimus dorsi muscle groups will be greatest during this phase and well coordinated to ensure the least amount of stress on the glenohumeral joint (DiGiovine 1992). Coordination of these muscles produce maximal glenohumeral joint compression force during this phase and at the time of ball release (DiGiovine 1992).

Once the ball is released, the deceleration phase begins. This phase is characterized by large eccentric forces at the shoulder and elbow, leading to large susceptibility to injury as kinetic energy not transferred through the ball needs to be dissipated through the soft tissue (Park, Loebenberg et al. 2002). Motions achieved during this phase include large amounts of shoulder internal rotation and horizontal adduction. The entire posterior soft tissue complex of the shoulder is primarily responsible for decelerating the limb. Teres minor activation was shown to be the highest during third phase, as well as during any phase of throwing (DiGiovine 1992). However, the size of the teres minor in relation to the other posterior shoulder muscles insists a synergistic relationship between the entire posterior complex to achieve deceleration without soft tissue injury. Proper coordination of the posterior shoulder

musculature during a follow through phase is elemental in reducing injury rates. A continuation of eccentric contraction in the posterior shoulder musculature should be added to a long follow through that placed the pitching hand towards the opposite knee to ankle. The highest activation of serratus anterior has been recorded during this phase as it functions to maintain the scapula against the torso (DiGiovine 1992; Fleisig, Andrews et al. 1995; Park, Loebenberg et al. 2002).

The Softball Throw –

The biomechanics of the softball pitch vary considerably from those of the baseball pitch. Unlike the baseball pitching motion, the available data on softball underhand pitching biomechanics is limited (Maffett, Jobe et al. 1997; Barrentine, Fleisig et al. 1998; Werner, Guido et al. 2005; Flyger, Button et al. 2006; Werner, Jones et al. 2006). Similar to the baseball pitch, the softball pitch can be broken down into phases (Figure 3): the wind-up, stride, delivery, and follow through (Barrentine, Fleisig et al. 1998). From wind-up to follow through, the total circumference of the arm about the glenohumeral joint can reach 485°, with the majority of that motion in full elbow extension. Increased resistance to distraction is experienced during the delivery phase of softball pitching. In contrast to the common belief that posterior shoulder structures are less stressed during the softball pitch in comparison to the baseball pitch, Maffett et al (Maffett, Jobe et al. 1997) found similar activation levels of the teres minor during deceleration in both sports. Posterior shoulder injuries in softball pitching are second to anterior shoulder pathology. Anterior shoulder muscles, such as pectoralis major and subscapularis muscles primarily contribute to the high velocity of internal rotation reaching 4000°/sec (Maffett, Jobe et al. 1997; Barrentine, Fleisig et al. 1998).

As shown by the study by Barrentine et al, the shoulder anterior force during the delivery phase can reach 38% of the body weight, which is comparable with baseball.

While the softball pitch is a highly dynamic motion, as previously mentioned, the majority of softball players are not pitchers. Due to this, and the considerable difference between the baseball and softball pitch, none of the subjects used within the current study were softball pitchers, only field position players. To date, there has not been a study that analyzed the biomechanics of a female softball overhead throwing population in direct contrast to baseball overhead throwers. In an unpublished dissertation from 1970, Atwater (Atwater 1970) analyzed the varying biomechanical contributions to ball velocity in overhead throwing, performed by a male and female. It was reported that the male thrower utilized more shoulder action and the female athlete exhibited greater trunk rotation to develop her throwing velocity. The shoulder range, angular velocity and linear velocity were all considerably less for the female subject, coupled with a significantly smaller ball velocity (pitch speed).

Chu et al (Chu, Fleisig et al. 2009) completed the most recent direct comparison of male and female overhead throwing while analyzing overhead baseball athletes, both male and female. Although this population was not throwing softball, it is the most applicable biomechanical study on male and female throwing kinematics and kinetics to date. The authors compared 11 males and 11 female overhead throwers from a group that represented elite amateur baseball pitchers. The kinematic variables studied included foot positions, trunk orientations, shoulder and elbow angles, and angular velocities. Kinetic variables analyzed described the net forces and torques applied at the throwing shoulder and elbow. Their kinematic variables for the males were found to be comparable to earlier research

(Dillman, Fleisig et al. 1993; Fleisig, Barrentine et al. 1996; Fleisig, Barrentine et al. 1999). The female group demonstrated similar maximum shoulder external rotation angles during the throwing motion. In contrast, females had significantly less elbow extension angular velocity, which was found to be parallel to the results found by Atwater (Atwater 1970). The overall pitch speed for females was significantly less in this study. One result of significance was the time from foot contact to ball release was significantly greater in females; and in companion with the shorter arm length, helps to explain the decrease in ball velocity seen in females. Elbow varus forces were found to be 75% of males at maximum shoulder external rotation. Most important to note, was the female group demonstrated 55% of maximum elbow and shoulder proximal forces compared to males. This result was still significantly less when scaled to body weight. The proximal forces placed upon the shoulder at the proximal humerus have a momentous effect on the amount of torsion placed upon the humerus, a direct link to humeral torsion variables. The conclusion presented by Chu (Chu, Fleisig et al. 2009) indicates that females can generate similar change to internal rotation velocity during throwing in internal rotation as males, leading to increased demands and stresses placed upon the posterior shoulder during deceleration. However, the proximal forces experienced at the shoulder near the humeral head were found to be much less in females, indicating less effect of humeral torsion moments. How these results affect the amount of internal rotation, external rotation, horizontal adduction and humeral torsion characteristics in female throwers is still undefined.

Purpose and Clinical Application

Little attention within the literature has been focused upon softball field players; who throw in the overhead motion that is nearly identical in biomechanics and frequency as the baseball player. Moreover, it has been found that injury patterns within the two sports are noticeably similar, both the total number of injuries per participants and the types of injuries (Loosli, Requa et al. 1992; Powell and Barber-Foss 2000; Axe, Windley et al. 2002; Hill, Humphries et al. 2004; Werner, Guido et al. 2005; Dick, Sauers et al. 2007; Marshall, Hamstra-Wright et al. 2007). In addition, kinetic data of the two sports support the notion that forces and torques at the shoulder in both sports are parallel (Maffet, Jobe et al. 1997; Barrentine, Fleisig et al. 1998; Werner, Guido et al. 2005; Werner, Jones et al. 2006; Chu, Fleisig et al. 2009; Miller, Kaminski et al. 2009; Rojas, Provencher et al. 2009). The field players in both sports participate and throw in the overhead motion at similar rates during analogous amounts of game and practice play.

Initial reports within studies focused on proprioception and kinetics (Dover, Kaminski et al. 2003; Werner, Guido et al. 2005) show similar range of motion differences between limbs in softball players, which is well documented in baseball players. However, an evaluation by Whiteley et al (Whiteley, Ginn et al. 2009) found no significant difference between baseball and softball players humeral torsion values. To date, there has not been a study designed to analyze both the range of motion characteristics and humeral torsion of baseball and softball athletes. Therefore, the purpose of this study is to provide normative descriptive data on the shoulder range of motion characteristics and humeral torsion in active softball players, and compare them to the characteristics observed in the baseball players.

Chapter 3

Methods

Populations and Recruitment

Subjects were recruited from a university population of NCAA baseball and softball athletes at The University of North Carolina at Chapel Hill and North Carolina Central University. Subjects were male and female between the ages of 18 and 24 years old.

Subject Inclusion Criterion

Subjects were included in the study if they met the following criteria:

- NCAA athletes who participated in either baseball or softball at least 30 minutes per day for at least 4 days per week.

Subject Exclusion Criterion

Subjects were excluded from the study if they had any of the following conditions:

- Current shoulder or elbow pain that had limited participation
- History of rotator cuff tear within the past year.
- History of neck injury within the past year.
- Recurring subluxations/ dislocations of the glenohumeral joint
- Upper extremity nerve pathology (Cervical Plexus and Accessory Nerve)
- Cervical spine pathology

- Scoliosis

Instrumentation

Digital Inclinometer

A Saunders Digital Inclinometer (The Saunders Group Inc, Chaska, MN) was used to collect range of motion data; as well as, it was paired with the diagnostic ultrasound to measure humeral torsion. The digital inclinometer can measure angles up to 360° and is accurate to 1.0°, as reported by the manufacturer.

Diagnostic Ultrasound

A diagnostic ultrasound (Model: LOGIQe, General Electric), with a 4-cm linear transducer was used to measure humeral torsion. The ultrasound image was used to isolate the bony prominences of the greater and lesser tuberosities and place the proximal humerus in a standardized position.

Research Design

A cross sectional between groups study design was utilized to compare the baseball and softball groups.

Procedures

Research subjects reported to a predetermined testing location on site at both the University of North Carolina and North Carolina Central University for a single testing session. The subjects read and signed an informed consent form. Following an explanation

of the procedures, each subject underwent bilateral testing for shoulder range of motion and humeral torsion. The procedures are detailed below:

Shoulder Range of Motion

Bilateral clinical internal and external rotation was measured passively with a digital inclinometer based upon the recommendation of Norkin and White (Norkin and White 1995). The participant was lying supine on a table with 90 degrees of shoulder abduction and elbow flexion with the forearm towards the ceiling, perpendicular to the plane of the treatment table (defined as 0° of humeral torsion). To maintain frontal plane alignment, a small towel roll was placed under the humerus. Scapular stabilization was provided by the examiner through a posteriorly directed force at the acromion to isolate motion at the glenohumeral joint. The examiner passively rotated the limb to end range in internal rotation (Figure 1, A) and external rotation (Figure 1, B) while aligning the digital inclinometer with the forearm to record the humeral rotation angles, measured as the angle between the forearm and the vertical axis, perpendicular to the treatment table. Strong intrasession (ICC=.976, SEM=1.36°) and intertester (ICC=.929, SEM=2.46°) reliability and precision were demonstrated for internal rotation measurements by the investigators. In addition, strong intrasession (ICC=.988, SEM=1.2°) and intertester (ICC=.911, SEM=2.56°) reliability and precision were demonstrated for external rotation measurements by the investigators (Myers, Oyama et al. 2007).

Horizontal adduction was assessed with the participant lying supine on a table, utilizing the Horizontal Adduction Assessment (HAA) method previously employed by the investigators. The participant's scapula was passively stabilized in full retraction. The

humerus was elevated to 90 degrees of abduction and neutral rotation. The humerus was then passively horizontally adducted while the scapula remained fully retracted. At the end range of motion, the examiner measured the humeral horizontal adduction angle with a digital inclinometer (Figure 2). This value was recorded as the amount of horizontal adduction {Myers, 2007 #17}. The investigators of this study had previously demonstrated strong reliability (ICC = 0.91), precision (SEM = 1.1°) and construct validity utilizing the HAA (Myers, Oyama et al. 2007).

Humeral Torsion

Humeral torsion was assessed using a modification of the indirect ultrasonographic technique originally described by Whiteley et al (Whiteley, Ginn et al. 2006) and Yamamoto et al (Yamamoto, Itoi et al. 2006). With the participant lying supine on a table, the participant's shoulder was passively abducted and the elbow was flexed to 90°. The examiner positioned the ultrasound head on the anterior shoulder with the ultrasound head level to the floor and aligned 90° perpendicular to the long axis of the humerus (verified with a bubble level). The examiner with the ultrasound head instructed the second examiner to move the humerus into internal and external rotation until the bicipital groove of the humerus appeared on the center of the ultrasound image, with the line connecting the apexes of greater and lesser tubercles parallel to the horizontal plane (Figure 3). A grid was applied to the display of the ultrasound unit to aid examiners with positioning of the humeral tubercles. The second examiner then aligned the digital inclinometer firmly with the forearm to record the humeral rotation angle, which was the angle from the horizontal plane in the internal rotation direction. As the ulna extends perpendicular to the elbow epicondylar axis (line connecting the medial and lateral epicondyles) it creates an angle that reflects the angular difference

between the epicondylar axis (distal humerus) and the line perpendicular to the line connecting the apexes of the greater and lesser tubercles, providing the measured humeral torsion. (Figure 2). Strong intrasession (ICC=.96, SEM=2.7°), intersession (ICC=.98, SEM=2.3°), and intertester (ICC=.98, SEM=2.0°) reliability and precision were demonstrated for the ultrasonographic assessment demonstrated by the investigators. This process was repeated three times, and the average of the three trials was recorded as the humeral torsion measurement.

Data Reduction

The clinical internal rotation, clinical external rotation, horizontal adduction, and humeral torsion assessment were entered into Microsoft Excel (version 11.5.2 for Macintosh) for calculation of the dependent variables. Once the means of the three trials for bilateral measurements were computed, the following data was calculated: External rotation gain (ERG), glenohumeral internal rotation deficit (GIRD), total range of motion, total range of motion difference, humeral torsion adjusted external rotation, and humeral torsion adjusted internal rotation. Clinical internal rotation (Figure 4, A) and external rotation (Figure 4, B) were defined as the three trial mean of the angle between the end range of passive internal or external rotation and vertical. Horizontal adduction was defined as the three trial mean of the horizontal adduction angle relative horizontal. Humeral torsion was defined as the three trial mean of the humeral rotation angle when the humerus was placed in an anatomic neutral, standardized position where the humeral tubercles are parallel to the plane of the treatment table (Figure 4, D). ERG was defined as the difference of external rotation (ER) measured in the dominant shoulder and the non-dominant shoulder (= Dominant ER- Non-dominant

ER). GIRD was defined as the difference of internal rotation (IR) measured in the dominant shoulder and the non-dominant shoulder ($= \text{Dominant IR} - \text{Non-dominant IR}$). Total range of motion is calculated as the sum of IR and ER ($= \text{IR} + \text{ER}$) (Figure 4, C). Total range of motion difference was calculated as the difference between dominant limb total range of motion and non-dominant limb total range of motion. Humeral torsion adjusted ER was calculated through the sum of the measured ER and the difference of 90 and the measured humeral torsion ($\text{adjusted ER} = \text{ER} + [90 - \text{HT}]$) (Figure 4, F). Humeral torsion adjusted IR was calculated through the difference of the measured IR and the difference of 90 and the measured humeral torsion ($\text{adjusted IR} = \text{IR} - [90 - \text{HT}]$) (Figure 4, E). Adjusted IR represented a side-to-side difference in extensibility of the posterior shoulder.

Statistical Analysis

Statistical Package for the Social Sciences (SPSS) version 16.0 for Macintosh was used to run the statistical analyses. An one within and one between factor ANOVA was used to assess differences between dominant and non-dominant limbs of the baseball and softball players, for the following dependent variables: clinical internal rotation, clinical external rotation, horizontal adduction, humeral torsion, humeral torsion adjusted internal rotation, humeral torsion adjusted external rotation, and total range of motion. Independent sample t-tests were used to assess the difference between baseball and softball athletes for external rotation gain (ERG), glenohumeral internal rotation deficit (GIRD), total range of motion difference, ERG adjusted for humeral torsion, and GIRD adjusted for humeral torsion. An alpha level of .05 was set for all comparisons for statistical significance, with a bonferroni

corrected level of 0.0125 for post hoc testing of variables that demonstrated a significant interaction.

Chapter 4

Results

Fifty-five baseball players (age = 19.5 ± 1.1 , height = $1.82 \pm .07$ meters, mass = 87.3 ± 11.0 kilograms) and twenty-eight softball players (age = 19.3 ± 1.2 , height = $1.66 \pm .06$ meters, mass = 70.9 ± 9.7 kilograms) were tested in this study (Table 1).

Significant group by limb interaction effects were found for internal rotation (IR) ($F_{(1,81)} = 16.36$; $p < .001$; Figure 5), humeral torsion (HT) ($F_{(1,81)} = 16.13$; $p < .001$; Figure 6), and total ROM ($F_{(1,81)} = 5.36$; $p = .023$; Figure 7). Post hoc tests using bonferroni adjustment were completed for all significant interactions. Internal rotation (Figure 5) was significantly less on dominant limb compared to non-dominant limb in baseball players (mean difference = 11.41° ; $t = -8.12$; $p < .001$), but was not significantly different between dominant and non-dominant limb in softball players (mean difference = 2.71° ; $t = -1.61$; $p = .120$). Dominant limb IR was significantly less in baseball players compared to softball players (mean difference = 14.16° ; $t = -6.25$; $p < .001$), but was not significantly different between non dominant limb in baseball players compared to softball players (mean difference = 5.45° ; $t = -2.04$; $p = .045$).

Humeral torsion (Figure 6) was found to be significantly greater on the dominant limb compared to non-dominant limb in both of baseball players (mean difference = 15.25° ; $t = 11.83$; $p < .001$), and softball players (mean difference = 7.02° ; $t = 5.18$; $p < .001$). Yet, dominant limb HT was significantly greater in baseball players than in softball players (mean

difference = 7.70° ; $t = 3.44$; $p = .001$), while non-dominant limb HT was not significantly different in between baseball players and softball players (mean difference = 0.53° ; $t = -.227$; $p = .821$).

Total ROM (Figure 7) was found to be significantly less on dominant limb compared to the non-dominant limb in both baseball players (mean difference = 7.56° ; $t = -5.83$; $p < .001$) but not in softball players (mean difference = 2.31° ; $t = -1.23$; $p = .231$). Furthermore, baseball players had significantly less total ROM on dominant limb compared to softball players (mean difference = 16.30° ; $t = -5.76$; $p < .001$) while baseball players had significantly less total ROM on non-dominant limb compared to softball players (mean difference = 11.05° ; $t = -3.53$; $p = .001$).

There were no significant interactions in external rotation (ER), horizontal adduction (HA), IR adjusted for HT, or ER adjusted for HT. However, there were limb and group main effects for IR adjusted for HT, and ER adjusted for HT. Both baseball and softball players had increased IR adjusted for HT (mean difference = 4.07° ; $F_{(1, 81)} = 13.88$; $p < .001$), and decreased ER adjusted for HT (mean difference = 9.01° ; $F_{(1, 81)} = 47.73$; $p < .001$) on dominant limb compared to non-dominant limb. Baseball players had less IR adjusted for HT (mean difference = 6.23° ; $F_{(1, 81)} = 6.35$; $p = .014$) and less ER adjusted for HT (mean difference = 7.45° ; $F_{(1, 81)} = 9.29$; $p = .003$) compared to softball players.

Additionally, a limb main effect was present for ER and HA. Both baseball and softball players had increased ER (mean difference = 2.13° ; $F_{(1, 81)} = 4.13$; $p = .046$), and decreased HA (mean difference = 3.201° ; $F_{(1, 81)} = 26.18$; $p < .001$) on dominant limb compared to non-dominant limb.

For clinical measures of shoulder range of motion that accounted for limb, baseball players demonstrated significantly greater GIRD (mean difference = 8.71° ; $t_{(81)} = 4.04$; $p < .001$; Figure 8) and less total ROM difference (mean difference = 5.26° ; $t_{(81)} = 2.33$; $p = .023$; Figure 9) compared to softball players. No differences were present in ERG (mean difference = 3.45° ; $t_{(81)} = 1.65$; $p = .103$). Once adjusted for HT, there was no statistical difference between baseball and softball players' adjusted ERG (mean difference = 4.78 ; $t_{(81)} = -1.83$; $p = .070$) and adjusted GIRD (mean difference = $.47$; $t_{(81)} = .22$; $p = .830$).

Chapter 5

Discussion

The goal of this study was to directly compare range of motion characteristics and humeral torsion of the shoulder in baseball and softball players, utilizing both traditional and an innovative measurement method that accounts for humeral torsion. The most important finding of this study was the dominant shoulder of softball players displayed much less pronounced range of motion adaptations, exhibited by the baseball players in this study and previous studies. Softball players' dominant shoulder had significantly less humeral torsion, and greater internal rotation and total rotation range of motion compared to baseball players, using a traditional range of motion measurement (Bigliani, Codd et al. 1997; Tyler, Nicholas et al. 2000; Altchek and Hobbs 2001; Reagan, Meister et al. 2002; Burkhart, Morgan et al. 2003; Mair, Uhl et al. 2004; Sabick, Torry et al. 2004; Borsa, Wilk et al. 2005; Levine, Brandon et al. 2006; Myers, Laudner et al. 2006; Ruotolo, Price et al. 2006; Chant, Litchfield et al. 2007; Clabbers, Kelly et al. 2007; Lintner, Mayol et al. 2007; McClure, Balaicuis et al. 2007; Myers, Oyama et al. 2007; Borsa, Laudner et al. 2008; Laudner, Sipes et al. 2008; Reinold, Wilk et al. 2008; Myers and Oyama Unpublished). However, once adjusted for humeral torsion, internal rotation and external rotation were greater in the softball players as compared to the baseball players. Similarly, GIRD and bilateral deficits in total ROM were less pronounced in softball players compared to baseball players, yet the differences became

insignificant after accounting for humeral torsion. External rotation, ERG, and horizontal adduction were found to be nearly equivalent between sports.

Although baseball and softball players perform a similar overhead throwing motion that incorporates comparable forces when normalized to body weight and height (Barrentine, Fleisig et al. 1998; Chu, Fleisig et al. 2009), there are many variations between the two groups that may lead to an explanation of group differences. Anthropometrically, the female softball player is generally smaller, in body mass, height, size and muscle mass, with an associated decreased in absolute muscle strength (Wells 1991). Riegger-Krugh & LeVeau (Riegger-Krugh and LeVeau 2002) stated that female athletes generate less muscle torque and power, as well as maximum muscle force output occurs later during muscle contractions. Furthermore, the female growth spurt is generally shorter and occurs earlier than their male counterparts, allowing a longer period of time for the open epiphyseal plates of the male population to be manipulated by humeral torques. A longer period of time to achieve maximum force is supported by Chu et al (Chu, Fleisig et al. 2009), as they found female baseball players took a significantly longer amount of time to complete the throwing motion from foot contact to ball release, than their male baseball counterparts. They indicated that this variable could be a critical difference between genders, leading to decreases in angular velocities and overall torques experienced at the shoulder and elbow. This conclusion is supported by the initial findings of Atwater (Atwater 1970), which found the angular velocity during shoulder internal rotation of the male arm was 1540 deg/sec, while the female arm accelerated at 1036 deg/sec. Chu et al (Chu, Fleisig et al. 2009) found females displayed only 55% of maximum proximal shoulder distraction force to that of males in the overhead throwing motion. These forces were still significantly different once normalized to body

weight, therefore the size and weight of the male arm, typically larger and heavier, is not the only factor leading to increases of force within the male population. The distraction forces experienced at the humerus are counteracted by the rotator cuff creating joint compression. This rotator cuff inserts on the proximal humerus about the epiphyseal plates, and therefore increased tension of this musculature during physical maturation may have a permanent effect on local cortical development. However, the majority of alterations at the proximal humerus have been attributed to rotational torques, and not distraction forces (Sabick, Kim et al. 2005).

The significant differences in humeral torsion between baseball and softball players found in this study is in direct contrast to the conclusions made by Whiteley et al (Whiteley, Ginn et al. 2009). Their study showed no significant difference in mean difference of torsion measurements between dominant and non-dominant limbs of baseball and softball players. Ultrasonography was utilized in both experiments to assess the amount of humeral torsion present in the research groups. The research subjects within our study were all collegiate aged athletes (mean age = 19.3 ± 1.2), who indicated participation in overhead sports throughout adolescence and were solely field players, not pitchers. The work by Whiteley et al had two softball groups; one was still experiencing physical maturation (mean age = 16.1 ± 1.3), and the other was an amateur population (mean age = 46.2 ± 8.2), with no indication of their participation in overhead sports during adolescence, or the position played. As indicated, humeral torsion is developed during physical maturation and does not alter afterwards, therefore the populations used within Whiteley et al's experiment do not represent a population that is highly susceptible to variations in dominant limb humeral torsion, possibly explaining the sizeable difference between their torsion results and the

results found in this study. In addition, Whiteley cited the lack of measured rotational range of motion as a major limitation of their study. The additional measurement of internal and external rotation would provide an avenue to compare soft tissue and osseous adaptations between the study groups.

Previous studies comparing baseball player's dominant limb to their non-dominant limb and to control subjects have established explicit range of motion alterations (Bigliani, Codd et al. 1997; Tyler, Nicholas et al. 2000; Reagan, Meister et al. 2002; Myers, Laudner et al. 2006; Ruotolo, Price et al. 2006; Lintner, Mayol et al. 2007; Myers, Oyama et al. 2007; Myers and Oyama Unpublished). Our results were consistent with this literature, showing decreased internal rotation, horizontal adduction, and increased external rotation between limbs in the baseball players. Total range of motion was also significantly decreased in baseball players' dominant limbs compared to non-dominant limbs. While these results are consistent with previous literature, little research on the same variables has been recorded in softball players (Dover, Kaminski et al. 2003; Werner, Guido et al. 2005). Our results indicated much less pronounced variation between softball players' dominant and non-dominant limbs for internal rotation, external rotation, horizontal adduction, total ROM, GIRD and ERG. These results are consistent with our hypotheses, that softball players will exhibit significantly less adaptation to shoulder range of motion characteristics in their dominant limbs, as compared to baseball players.

Humeral torsion has recently been assessed as a chief contributor to alterations in range of motion characteristics in the shoulder of overhead athletes (Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Reagan, Meister et al. 2002; Whiteley, Ginn et al. 2006; Schwab and Blanch 2009; Myers and Oyama Unpublished). Alterations in humeral torsion

are created through opposing torques acting upon the proximal humerus during the late cocking phase into the acceleration phase of throwing. These opposing torques create a twisting effect upon the long axis of the humerus to increase the amount of humeral torsion over time as this motion is excessively repeated. In our experiment, humeral torsion was again found to be on average 14 degrees greater in the dominant limb of the baseball player, as compared to their non-dominant limb, which is consistent with the literature. The softball athlete also displayed an average increase of 7 degrees in humeral torsion of their dominant limb. These findings support our hypothesis, that bilateral difference in humeral torsion would be less profound in the softball players' dominant limb as compared to the baseball group. Despite the greater amount of humeral torsion found in baseball players' over softball players' dominant limbs, this is the first body of work to document significant humeral torsion adaptations in a population of softball players.

Within our study, we have four variables that are adjusted for humeral torsion. This adjustment has recently been suggested to isolate the total range of motion alterations in the shoulder that are attributed to soft tissue contracture or lengthening, as opposed to the traditional thought that all variations in range of motion were caused by soft tissue differences. (Schwab and Blanch 2009; Myers and Oyama Unpublished). The adjustment for humeral torsion redefines the point of neutral for measuring internal and external rotation to the position where the proximal humerus is placed at a standard position. Once this standard position is established, each subject can have his or her internal and external rotation ranges of motion adjusted for humeral torsion. As mentioned, baseball players have been found to exhibit decreased internal rotation and horizontal adduction, and increased external rotation. While these values have traditionally been attributed to soft tissue

variations, redefining humeral torsion neutral truly isolates the amount and direction of soft tissue discrepancy. If the values of adjusted internal and external rotation between dominant and non-dominant limbs are assessed, a true soft tissue deficit can be found regardless of that deficit's direction. Whether a deficit in soft tissue internal or external rotation is found after adjusting for torsion, without the application of torsion it cannot be attributed to only soft tissue contracture. Therefore, it is possible to segregate the direction and amount of soft tissue manipulation necessary to return a dominant limb towards equilibrium.

We found that once torsion was applied to the humeral rotation range of motion, the between limb differences were much smaller in total degrees, which is consistent with the small amount of research that already exists surrounding humeral torsion adjustments (Schwab and Blanch 2009; Myers and Oyama Unpublished). The development of torsion in the proximal humerus is considered to occur through repeated overhead high velocity movements, such as throwing a baseball or softball, during physical maturation while the highly ineffectual proximal humeral physis is open. Humeral torsion adjusted internal rotation had a smaller mean difference, 4 degrees difference between limbs, than clinical internal rotation. Humeral torsion adjusted external rotation's mean difference was found to be less between limb and sport. Although the interaction of adjusted external rotation was not significant ($p = .07$), it could be said that there was a trend towards an overall effect between the sports and limbs. Conceptually, if both the adjusted internal rotation and external rotation are equal between dominant and non-dominant limbs, the bilateral difference in internal rotation and external rotation is due to torsion effects, not soft tissue transformations. In our experiment, while the adjusted internal rotation was nearly equivalent, the adjusted external rotation was greater in the non-dominant limb, indicating

soft tissue structures were causing a decrease in the available amount of external rotation in the dominant limb. This is contrary to the traditional belief that overhead athletes range of motion adaptation are purely caused by stresses and adaptation of the posterior shoulder musculature and stretching of the anterior joint capsule, directly decreasing internal rotation and increasing external rotation. Therefore, significant decreases in adjusted external rotation between baseball players' dominant and non-dominant limbs is a noteworthy result, and warrants further investigation in the future to ensure the traditional clinical approach of attacking purely internal rotation deficits in baseball players may need altered.

The adjusted measurement for GIRD indicates an average of only 3.8 degrees greater internal rotation in the dominant limb caused by soft tissue adaptations. Adjusted ERG accounted for 11.4 degrees less ERG in the non-dominant limb of baseball players. These results were not found to be significantly greater than the softball player once torsion was accounted, as they displayed 4.3 degrees greater GIRD in their non-dominant limb and 6.6 degrees less ERG. Both groups displayed less ERG once adjusted for humeral torsion, indicating a deficit in the external rotation direction that is attributed to purely soft tissue adaptive changes.

A further analysis of the data within our experiment shows total range of motion difference of 7.6 degrees less in the dominant limb for baseball players, and 2.3 degrees greater in softball players. Theoretically, total range of motion should not be affected by the amount of torsion present, as it is merely a shift in the location of the motion and should be equal between limbs. The significant decrease in total range of motion in the baseball players could be attributed to purely soft tissue adaptations, and addressed through stretching

programs. Whether or not this decrease in total ROM in baseball players is attributed to IR or ER deficits is still up for debate, and warrants further investigation.

The presence of humeral torsion, and its assessment using the ultrasonography method have been firmly established as valid (Whiteley, Ginn et al. 2006; Yamamoto, Itoi et al. 2006; Schwab and Blanch 2009; Myers and Oyama Unpublished). Using the quick assessment of torsion can lead to more precise individualized assessment of shoulder characteristics on a clinical exam. This allows the clinician to truly assess the influences of bony versus soft tissue effects on dominant shoulder changes in both the athletic and general population; thereafter allowing more accurately implemented rehabilitation exercises, specifically the stretching program.

Although the softball players did not exhibit as great an adaptation to their sport in the dominant shoulder, the use of humeral torsion to accurately assess shoulder characteristics should be considered for the softball population. As softball players continue to sustain similar injuries to their baseball counterparts, their treatment techniques must be consistent with evidence-based practice utilized in the rehabilitation of baseball players. While the overall population of softball shoulders has smaller variations in range of motion differences, there still exists the need to implement a throwing arm stretching and strengthening program. The stretching program should be tailored to each individual shoulder. The presence of humeral torsion should be taken into account when prescribing the amount and direction of stretching for the athlete's shoulder. While the current research indicates that torsion must be assessed to have a complete understanding of the true range of motion characteristics, not everyone has access to torsion assessment tools. Therefore, a full assessment of both dominant and non-dominant limb range of motion, in a scapular stabilized

position should be completed to fully compare total range of motion differences, subsequently inferring the amount of decreased motion, whether that be internal or external rotation. It is not possible for the clinician to determine the direction of motion lost without the use of a humeral torsion assessment. However, a baseline assessment of rotation range of motion can provide a foundation for the clinician to refer to at a later date given shoulder pathology. At that time, if the overhead athlete displays deficits in internal and external rotation compared to their baseline measurements, the direction of deficit can be determined, and the appropriate direction for a stretching protocol can be implemented.

Whether male or female, the amount of humeral torsion present is considered static once the athlete has matured. Measuring humeral torsion can be accomplished once, during a preseason evaluation for example, in combination with measurements of the shoulder rotation range of motion and horizontal adduction. Thereafter, humeral torsion can be applied to range of motion measurements, and any variation from these adjusted measures in the future would be purely soft tissue in nature, indicating to the clinician if motion changes are part of the foundation in upper extremity pathology. If an injury is present, and the athlete's range of motion measurements are greatly skewed from their baseline marks, it would indicate which structures may be short and tight, or loose and weak; directly leading to a clinician implementing a specified rehabilitation protocol.

Limitations

The greatest limitation of our research was the total number of softball players enrolled in the study, and lack of control group. While several more softball players were evaluated, their data were not included in the analysis due to their primary roll as a pitcher in

their sport. An evaluation of their playing history revealed they participated as pitchers only in high school during their physical maturation, as well as in college. While kinetic data exists to suggest similar forces are experienced at the shoulder for the baseball and softball pitch (Barrentine, Fleisig et al. 1998; Werner, Guido et al. 2005), their kinematics are so highly variable the data from pitchers in softball was not included in the analysis. In addition, a control group was not used for either the male or female population. While the subjects' non-dominant limb is used as the reference point, a matched control group would give more concrete conclusion stemming from the results. It has been found that control groups in studies of male baseball players' humeral torsion can exhibit up to 6 degrees of humeral torsion bilateral difference on average (Crockett, Gross et al. 2002; Myers and Oyama Unpublished), therefore making the mean difference of 7 degrees of humeral torsion in our softball study group less distinct. In addition, the population studied in this experiment was completely healthy. Therefore, it is not possible to determine at this time if the measurements of ROM and humeral torsion are affected within a group with shoulder or elbow injury.

The research subjects in our study average age 19.4 years. While females have reached physical maturity by the age of 19, several of the males in this study may not have reached physical maturity. This indicates that these baseball players may experience a further alteration in humeral torsion. If these players' epiphyseal plates have not closed, they could experience increased torsion effects during the next few years. In addition, the time frame during which physical maturation is experienced is in general longer for the male population (Riegger-Krugh and LeVeau 2002). A longer growth period in turn creates a greater amount of time during which the epiphyseal plates are open and subject to manipulation through humeral torques.

Future Research

Softball shoulder range of motion and torsion variables were found to be overall much less pronounced than their baseball counterparts. While this study is the first to address softball players range of motion between dominant and non-dominant limbs, we only compared the variables within limb and to baseball players. Further investigation into the presence of shoulder range of motion and torsion adaptations between a softball and control population of females would give a larger insight into the amount of variability the sport of softball actually imparts on the female overhead athlete shoulder. In addition, little research exists that compares the kinematics and kinetics of the overhead softball throw to the baseball throw (Chu, Fleisig et al. 2009). An overall biomechanical analysis of the overhead baseball and softball throw including field players may reveal specific factors that differentiate the two groups of shoulders.

Conclusion

The results of this study demonstrate less pronounced adaptation in range of motion characteristics and humeral torsion in the dominant softball shoulder, as compared to the baseball players in this study and previous literature. Still, humeral torsion was present in the dominant limbs for both baseball and softball players, and was highly influential on the shoulder rotation range of motion variables. From these results, we conclude that softball players do develop variations in range of motion characteristics including humeral torsion, but these variations are much less pronounced than their baseball counterparts. Within both populations, these adaptations are greatly influenced by the amount of torsion present.

Regardless of the sport played, clinicians with access to humeral torsion assessment should implement the measurement into their baseline evaluation, allowing the future adjustments in shoulder range of motion to be pinpointed to a specific source or direction. In a population of physically mature athletes, the value of humeral torsion will give the athlete and clinician a better understanding of how to treat and prevent subsequent pathology.

Chapter 6

Manuscript

INTRODUCTION

Shoulder and elbow pain are common complaints among overhead athletes that are often addressed by sports medicine clinicians, as a result of the repetitive nature of overhead sport. Specifically, repetitive high velocity overhead motions performed by baseball players has been suggested to contribute to a higher susceptibility to shoulder injury (Altchek, 1995; Burkhart, 2003; Burkhart, 2003; Fleisig, 1996; Kibler, 1998; Kibler, 2003; Souza, 1994; Wilk, 2002). While the shoulder of the baseball player has received substantial attention, sports medicine research assessing the shoulder of the softball player is limited, despite the fact that the prevalence of shoulder injuries in softball players parallels that of baseball athletes (Loosli, Requa et al. 1992; Flyger, Button et al. 2006; Wang 2006; Marshall, Hamstra-Wright et al. 2007).

While softball and baseball exhibit differing pitching motions and participation habits (pitching frequency and pitch count), the repetitive motion used in both games is the primary factor placing the upper extremity, particularly the shoulder and elbow, at high risk for overuse injuries (Lyman, Fleisig et al. 2002). In addition to pitchers, the position players in both baseball and softball exhibit high injury patterns to the upper extremity (Barrentine, Fleisig et al. 1998; Powell and Barber-Foss 2000). In an analysis of the NCAA injury Surveillance System (ISS) data from 1988 to 2004, 45% of all time lost from baseball (for

practice and games) due to injury were attributed to upper extremity injuries (Dick, Sauers et al. 2007). More specifically, shoulder injuries accounted for 23% of the injuries during practice and 16% during games for that entire time period. Further analysis of the NCAA ISS data from 1988 to 2004 reveals strikingly similar injury rates for collegiate softball players (Marshall, Hamstra-Wright et al. 2007). One third of all softball injuries were located in the upper extremity. Moreover, a study of only shoulder injuries in high school athletics between 2005-2007 indicated that sprains/strain injuries to the shoulder accounted for 55-52 percent of all injuries for both baseball and softball (Bonza, Fields, Yard, & Dawn Comstock, 2009). The same study also indicated that the overhead throwing motion was twice as likely to be the cause a shoulder injury in the population of softball players (50.2%) than in the baseball players (24.3%), who were not pitchers in both sports. Additionally, the same study found the softball athlete's shoulder had slightly higher rates of injury due to overuse/chronic mechanism than those of baseball players.

The female athlete overall has less mass, height, overall size, muscles mass, limb length, and absolute muscle strength (Wells 1991). Biomechanically, the motions used by baseball and softball pitchers differ greatly; however, the motion exhibited by the field players, the majority of the players on the field, is strikingly similar. To date, research surrounding the overhead athlete's range of motion characteristics at the shoulder has favored baseball players as the research subjects. As mentioned, there is substantial evidence showing alterations in range of motion characteristics of baseball players dominant shoulder as compared to their non-dominant arm, and to non-overhead athletes (Bigliani, Codd et al. 1997; Crockett, Gross et al. 2002; Reagan, Meister et al. 2002; Meister, Day et al. 2005; Levine, Brandon et al. 2006; Myers, Laudner et al. 2006; Ruotolo, Price et al. 2006; Chant,

Litchfield et al. 2007; Lintner, Mayol et al. 2007; Borsa, Laudner et al. 2008; Reinold, Wilk et al. 2008). The general pattern of adaptation in the baseball players shoulder presents as increased external rotation, and decreased internal rotation, horizontal adduction and total range of motion (Altchek, 2001; Bigliani, 1997; Borsa, 2008; Borsa, 2005; Burkhart, 2003; Chant, 2007; Clabbers, 2007; Izumi, 2008; Jobe, 1989; Kibler, 1998; Krahll, 1947; Laudner, 2008; Lephart, 1994; Levine, 2006; Lintner, 2007; Lintner, 2008; Mair, 2004; Meister, 2000; Meister, 2005; Murray, 2001; Myers, 2006; Myers, Unpublished; Myers, 2007; Osbahr, 2002; Park, 2002; Park, 2002; Reinold, 2008; Ruotolo, 2006; Sabick, 2004; Safran, 2001; Tyler, 2000; Werner, 1993; Whiteley, 2009; Wilk, 2002).

Osseous adaptations of the humerus in overhead athlete have a direct influence on range of motion characteristics (Crockett, Gross et al. 2002; Borsa, Wilk et al. 2005), and are referred to as humeral torsion (Crockett, Gross et al. 2002; Borsa, Wilk et al. 2005). Humeral torsion occurs in response to repetitive opposing muscle torques acting upon the humerus during physical maturation as the proximal humeral physis is directly influenced (Sabick, Torry et al. 2004; Chant, Litchfield et al. 2007). As the angle between the axis through the center of the humeral head and the axis of the elbow increases over time, the range of motion characteristics of the players shoulder permanently change. Furthermore, contracture of the posterior capsule and musculature leads to decreased horizontal adduction range of motion, known often as posterior shoulder tightness (PST). In response to the combination of decreased horizontal adduction (Karduna, Williams et al. 1996; Kuhn, Huston et al. 2005) and humeral torsion (Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Reagan, Meister et al. 2002) alterations in glenohumeral range of motion present clinically, most notably through internal rotation. Baseball players have increased torsion, decreased

horizontal adduction, and shifts in their total arc of motion due to the repetitive nature of their sport, specifically during physical maturation.

While a wealth of literature has traditionally attributed these shifts in range of motion to the contracture of the posterior shoulder capsule and musculature (Tyler, Nicholas et al. 2000; Myers, Laudner et al. 2006; McClure, Balaicuis et al. 2007; Laudner, Sipes et al. 2008), recent evidence has suggested that torsion has a greater role in predicting range of motion alterations. A study performed by Myers et al (Myers and Oyama Unpublished) suggests that when glenohumeral rotation range of motion alterations within the dominant limb of overhead athletes is adjusted for humeral torsion, the differences side-to-side, and compared to control subjects, is much less observable. While decreases in internal rotation would be addressed through soft tissue stretching programs, accounting for humeral torsion has indicated that deficits in internal range of motion are mostly osseous and therefore incapable of being manipulated by a clinical stretching program. While internal and external rotation individually are affected by repeated overhead activity and humeral torsion, the total humeral rotation range of motion should not be manipulated by the presence of torsion differences. This allows the measurement of total humeral rotation range of motion to be used as a direct clinical assessment of shoulder adaptive articular changes that may lead to injury.

Injury rates of baseball and softball players, regardless of position, are similar (Loosli, Requa et al. 1992; Maffet, Jobe et al. 1997; Hill, Humphries et al. 2004; Werner, Guido et al. 2005; Werner, Jones et al. 2006; Rojas, Provencher et al. 2009). In addition, the stresses placed on shoulder of both baseball and softball field players have been found to similar (Barrentine, Fleisig et al. 1998; Werner, Guido et al. 2005; Chu, Fleisig et al. 2009;

Miller, Kaminski et al. 2009; Rojas, Provencher et al. 2009). Field position players in softball and baseball complete repetitive overhead throwing in a similar motion that can lead to overuse injuries. The repetitive motion of throwing has been found to cause alterations in range of motion of baseball players during physical maturation (Lyman, Fleisig et al. 2001; Mair, Uhl et al. 2004; Meister, Day et al. 2005), but has not been directly linked to softball players. The female overhead athlete has been found to exhibit alterations in range of motion (Dover, Kaminski et al. 2003; Werner, Guido et al. 2005). However, the alteration is often believed to be not as significant as their male counterparts, and the literature on range of motion characteristics of the softball players is still very limited (Dover, Kaminski et al. 2003; Werner, Guido et al. 2005; Flyger, Button et al. 2006; Whiteley, Ginn et al. 2009). Whiteley et al (Whiteley, Ginn et al. 2009) are the only group to evaluate humeral torsion in softball players, to date. This initial study of humeral torsion in softball players indicated that there was no significant difference in torsion measurement of both adult and adolescent baseball and softball players. In this study, there was no comparison to internal and external rotation range of motion values, or posterior shoulder tightness. The mean difference in dominant limb torsion for both the adult and adolescent population was 1.7 and 0.5 degrees respectively. The population of softball players studied was recruited from an amateur competition for older adults and an adolescent population that had not yet achieved physical maturity.

Further investigation into the presence of these characteristics is needed in the population of softball players. It is the purpose of this study to compare range of motion and humeral torsion characteristics of the overhead baseball and softball athletes.

METHODS

Subjects

Fifty-five baseball players (age = 19.5 ± 1.1 , height = $1.82 \pm .07$ meters, mass = 87.3 ± 11.0 kilograms) and twenty-eight softball players (age = 19.3 ± 1.2 , height = $1.66 \pm .06$ meters, mass = 70.9 ± 9.7 kilograms) were tested in this study (Table 1). Subjects were excluded from the study if they had any current shoulder or elbow pain that had limited participation, a history of rotator cuff tear within the past year, a history of neck injury within the past year, recurring subluxations/ dislocations of the glenohumeral joint, upper extremity nerve pathology (cervical plexus and accessory nerve), cervical spine pathology or scoliosis. Research subjects reported to a predetermined testing location on site for a single testing session. The subjects read and signed an informed consent form. Following an explanation of the procedures, each subject underwent bilateral testing for shoulder range of motion and humeral torsion.

Instrumentation

A Saunders Digital Inclinometer (The Saunders Group Inc, Chaska, MN) was used to collect range of motion data; as well as, it was paired with the diagnostic ultrasound to measure humeral torsion. The digital inclinometer can measure angles up to 360° and is accurate to 1.0° , as reported by the manufacturer.

A diagnostic ultrasound (Model: LOGIQe, General Electric), with a 4-cm linear transducer was used to measure humeral torsion. The ultrasound image was used to isolate the bony prominences of the greater and lesser tuberosities and place the proximal humerus in a standardized position.

Procedures

Bilateral clinical internal and external rotation was measured passively with the participant lying supine on a table with 90 degrees of shoulder abduction and elbow flexion with the forearm towards the ceiling, perpendicular to the plane of the treatment table (defined as 0° of humeral torsion). To maintain frontal plane alignment, a small towel roll was placed under the humerus. Scapular stabilization was provided by the examiner through a posteriorly directed force at the acromion to isolate motion at the glenohumeral joint. The examiner passively rotated the limb to end range in internal rotation (Figure 1, A) and external rotation (Figure 1, B) while aligning the digital inclinometer with the forearm to record the humeral rotation angles, measured as the angle between the forearm and the vertical axis, perpendicular to the treatment table. Strong intrasession (ICC=.976, SEM=1.36°) and intertester (ICC=.929, SEM=2.46°) reliability and precision were demonstrated for internal rotation measurements by the investigators. In addition, strong intrasession (ICC=.988, SEM=1.2°) and intertester (ICC=.911, SEM=2.56°) reliability and precision were demonstrated for external rotation measurements by the investigators (Myers, Oyama et al. 2007).

Horizontal adduction was assessed with the participant lying supine on a table, utilizing the HAA method previously employed by the investigators. The participant's scapula was passively stabilized in full retraction. The humerus was elevated to 90 degrees of abduction and neutral rotation. The humerus was then passively horizontally adducted while the scapula remained fully retracted. At the end range of motion, the examiner measured the humeral horizontal adduction angle with a digital inclinometer (Figure 2). This value was

recorded as the amount of horizontal adduction (Myers, Oyama et al. 2007). The investigators of this study had previously demonstrated strong reliability (ICC = 0.91), precision (SEM = 1.1°) and construct validity utilizing the HAA (Myers, Oyama et al. 2007).

Humeral torsion was assessed with the participant lying supine on a table, the participant's shoulder was passively abducted and the elbow was flexed to 90°. The examiner positioned the ultrasound head on the anterior shoulder with the ultrasound head level to the floor and aligned 90° perpendicular to the long axis of the humerus (verified with a bubble level). The examiner with the ultrasound head instructed the second examiner to move the humerus into internal and external rotation until the bicipital groove of the humerus appeared on the center of the ultrasound image, with the line connecting the apexes of greater and lesser tubercles parallel to the horizontal plane (Figure 3). A grid was applied to the display of the ultrasound unit to aid examiners with positioning of the humeral tubercles. The second examiner then aligned the digital inclinometer firmly with the forearm to record the humeral rotation angle, which was the angle from the horizontal plane in the internal rotation direction. As the ulna extends perpendicular to the elbow epicondylar axis (line connecting the medial and lateral epicondyles) it creates an angle that reflects the angular difference between the epicondylar axis (distal humerus) and the line perpendicular to the line connecting the apexes of the greater and lesser tubercles, providing the measured humeral torsion. (Figure 2). Strong intrasession (ICC=.96, SEM=2.7°), intersession (ICC=.98, SEM=2.3°), and intertester (ICC=.98, SEM=2.0°) reliability and precision were demonstrated for the ultrasonographic assessment demonstrated by the investigators. This process was repeated three times, and the average of the three trials was recorded as the humeral torsion measurement.

Outcome Measures

The clinical internal rotation, clinical external rotation, horizontal adduction, and humeral torsion assessment were entered into Microsoft Excel (version 11.5.2 for Macintosh) for calculation of the dependent variables. Once the means of the three trials for bilateral measurements were computed, the following data was calculated: External rotation gain (ERG), glenohumeral internal rotation deficit (GIRD), total range of motion, total range of motion difference, humeral torsion adjusted external rotation, and humeral torsion adjusted internal rotation. Clinical internal rotation (Figure 4, A) and external rotation (Figure 4, B) were defined as the three trial mean of the angle between the end range of passive internal or external rotation and a starting position where the forearm points superiorly in a perpendicular relationship to the treatment table. Horizontal adduction was defined as the three trial mean of the horizontal adduction angle relative to the plane of the treatment table. Humeral torsion was defined as the three trial mean of the humeral rotation angle when the humerus was placed in an anatomic neutral, standardized position where the humeral tubercles are parallel to the plane of the treatment table (Figure 4, D). ERG was defined as the difference of external rotation (ER) measured in the dominant shoulder and the non-dominant shoulder ($= \text{Dominant ER} - \text{Non-dominant ER}$). GIRD was defined as the difference of internal rotation (IR) measured in the dominant shoulder and the non-dominant shoulder ($= \text{Dominant IR} - \text{Non-dominant IR}$). Total range of motion is calculated as the sum of IR and ER ($= \text{IR} + \text{ER}$) (Figure 4, C). Total range of motion difference was calculated as the difference between dominant limb total range of motion and non-dominant limb total range of motion. Humeral torsion adjusted ER was calculated through the sum of the

measured ER and the difference of 90 and the measured humeral torsion (adjusted $ERG = ER + [90 - HT]$) (Figure 4, F). Humeral torsion adjusted IR was calculated through the difference of the measured IR and the difference of 90 and the measured humeral torsion (adjusted $GIRD = IR - [90 - HT]$) (Figure 1). Adjusted GIRD represented a side-to-side difference in extensibility of the posterior shoulder.

Statistics

Statistical Package for the Social Sciences (SPSS) version 16.0 for Macintosh was used to run the statistical analyses. An one within and one between factor ANOVA was used to assess differences between dominant and non-dominant limbs of the baseball and softball players, for the following dependent variables: clinical internal rotation, clinical external rotation, horizontal adduction, humeral torsion, humeral torsion adjusted internal rotation, humeral torsion adjusted external rotation, and total range of motion. Independent sample t-tests were used to assess the difference between baseball and softball athletes for external rotation gain (ERG), glenohumeral internal rotation deficit (GIRD), total range of motion difference, ERG adjusted for humeral torsion, and GIRD adjusted for humeral torsion. An alpha level of .05 was set for all comparisons for statistical significance, with a bonferroni corrected level of 0.0125 for post hoc testing of variables that demonstrated a significant interaction effect.

Results

Fifty-five baseball players (age = 19.5 ± 1.1 , height = $1.82 \pm .07$ meters, mass = 87.3 ± 11.0 kilograms) and twenty-eight softball players (age = 19.3 ± 1.2 , height = $1.66 \pm .06$ meters, mass = 70.9 ± 9.7 kilograms) were tested in this study (Table 1).

Significant group by limb interaction effects were found for internal rotation (IR) ($F_{(1,81)} = 16.36$; $p < .001$; Figure 5), humeral torsion (HT) ($F_{(1,81)} = 16.13$; $p < .001$; Figure 6), and total ROM ($F_{(1,81)} = 5.36$; $p = .023$; Figure 7). Post hoc tests using bonferroni adjustment were completed for all significant interactions. Internal rotation (Figure 5) was significantly less on dominant limb compared to non-dominant limb in baseball players (mean difference = 11.41° ; $t = -8.12$; $p < .001$), but was not significantly different between dominant and non-dominant limb in softball players (mean difference = 2.71° ; $t = -1.61$; $p = .120$). Dominant limb IR was significantly less baseball players compared to softball players (mean difference = 14.16° ; $t = -6.25$; $p < .001$), but was not significantly different between non dominant limb in baseball players compared to softball players (mean difference = 5.45° ; $t = -2.04$; $p = .045$).

Humeral torsion (Figure 6) was found to be significantly greater on the dominant limb compared to non-dominant limb in both of baseball players (mean difference = 15.25° ; $t = 11.83$; $p < .001$), and softball players (mean difference = 7.02° ; $t = 5.18$; $p < .001$). Yet, dominant limb HT was significantly greater in baseball players than in softball players (mean difference = 7.70° ; $t = 3.44$; $p = .001$), while non-dominant limb HT was not significantly different in baseball players than in softball players (mean difference = 0.53° ; $t = -.227$; $p = .821$).

Total ROM (Figure 7) was found to be significantly less on dominant limb compared to the non-dominant limb in both baseball players (mean difference = 7.56° ; $t = -5.83$; $p < .001$) but not in softball players (mean difference = 2.31° ; $t = -1.23$; $p = .231$). Furthermore,

baseball players had significantly less total ROM on dominant limb compared to softball players (mean difference= 16.30°; $t = -5.76$; $p < .001$) while baseball players had significantly less total ROM on non-dominant limb compared to softball players (mean difference= 11.05°; $t = -3.53$; $p = .001$).

There were no significant interactions in external rotation (ER), horizontal adduction (HA), IR adjusted for HT, or ER adjusted for HT. However, there were limb and group main effects for IR adjusted for HT, and ER adjusted for HT. Both baseball and softball players had increased IR adjusted for HT (mean difference = 4.07°; $F_{(1, 81)} = 13.88$; $p < .001$), and decreased ER adjusted for HT (mean difference = 9.01°; $F_{(1, 81)} = 47.73$; $p < .001$) on dominant limb compared to non-dominant limb. Baseball players had less IR adjusted for HT (mean difference= 6.23°; $F_{(1, 81)} = 6.35$; $p = .014$) and less ER adjusted for HT (mean difference = 7.45°; $F_{(1, 81)} = 9.29$; $p = .003$) compared to softball players.

Additionally, a limb main effect was present for ER and HA. Both baseball and softball players had increased ER (mean difference = 2.13°; $F_{(1, 81)} = 4.13$; $p = .046$), decreased HA (mean difference = 3.201°; $F_{(1, 81)} = 26.18$; $p < .001$) on dominant limb compared to non-dominant limb.

For clinical measures of shoulder range of motion that accounted for limb, baseball players demonstrated significantly greater GIRD (mean difference = 8.71°; $t_{(81)} = 4.04$; $p < .001$; Figure 8) and less total ROM difference (mean difference = 5.26°; $t_{(81)} = 2.33$; $p = .023$; Figure 9) compared to softball players. No differences were present in ERG (mean difference = 3.45°; $t_{(81)} = 1.65$; $p = .103$). Once adjusted for HT, there was no statistical difference between baseball and softball players' adjusted ERG (mean difference = 4.78; $t_{(81)} = -1.83$; $p = .070$) and adjusted GIRD (mean difference = .47; $t_{(81)} = .22$; $p = .830$).

Discussion

The goal of this study was to directly compare range of motion characteristics and humeral torsion of the shoulder in baseball and softball players, utilizing both traditional and an innovative measurement method that accounts for humeral torsion. The most important finding of this study was the dominant shoulder of softball players displayed much less pronounced range of motion adaptations, exhibited by the baseball players in this study and previous studies. Softball players' dominant shoulder had significantly less humeral torsion, and greater internal rotation and total rotation range of motion compared to baseball players, using a traditional range of motion measurement (Bigliani, Codd et al. 1997; Tyler, Nicholas et al. 2000; Altchek and Hobbs 2001; Reagan, Meister et al. 2002; Burkhart, Morgan et al. 2003; Mair, Uhl et al. 2004; Sabick, Torry et al. 2004; Borsa, Wilk et al. 2005; Levine, Brandon et al. 2006; Myers, Laudner et al. 2006; Ruotolo, Price et al. 2006; Chant, Litchfield et al. 2007; Clabbers, Kelly et al. 2007; Lintner, Mayol et al. 2007; McClure, Balaicuis et al. 2007; Myers, Oyama et al. 2007; Borsa, Laudner et al. 2008; Laudner, Sipes et al. 2008; Reinold, Wilk et al. 2008; Myers and Oyam, In Press). However, once adjusted for humeral torsion, internal rotation and external rotation were greater in the softball players as compared to the baseball players. Similarly, GIRD and bilateral deficits in total ROM were less pronounced in softball players compared to baseball players, yet the differences became insignificant after accounting for humeral torsion. External rotation, ERG, and horizontal adduction were found to be nearly equivalent between sports.

Although baseball and softball players perform a similar overhead throwing motion that incorporates comparable forces when normalized to body weight and height (Barrentine,

Fleisig et al. 1998; Chu, Fleisig et al. 2009), there are many variations between the two groups that may lead to an explanation of group differences. Anthropometrically, the female softball player is generally smaller, in body mass, height, size and muscle mass, with an associated decreased in absolute muscle strength (Wells 1991). Riegger-Krugh & LeVeau (Riegger-Krugh and LeVeau 2002) stated that female athletes generate less muscle torque and power, as well as maximum muscle force output occurs later during muscle contractions. Furthermore, the female growth spurt is generally short than their male counterparts, allowing a longer period of time for the open epiphyseal plates of the male population to be manipulated by humeral torques. A longer period of time to achieve maximum force is supported by Chu et al (Chu, Fleisig et al. 2009), as they found female baseball players took a significantly longer amount of time to complete the throwing motion from foot contact to ball release, than their male baseball counterparts. They indicated that this variable could be a critical difference between genders, leading to decreases in angular velocities and overall torques experienced at the shoulder and elbow. This conclusion is supported by the initial findings of Atwater (Atwater 1970), which found the angular velocity during shoulder internal rotation of the male arm was 1540 deg/sec, while the female arm accelerated at 1036 deg/sec. Chu et al (Chu, Fleisig et al. 2009) found females displayed only 55% of maximum proximal shoulder distraction force to that of males in the overhead throwing motion. These forces were still significantly different once normalized to body weight, therefore the size and weight of the male arm, typically larger and heavier, is not the only factor leading to increases of force within the male population. The distraction forces experienced at the humerus are counteracted by the rotator cuff creating joint compression. This rotator cuff inserts on the proximal humerus about the epiphyseal plates, and therefore increased tension

of this musculature during physical maturation may have a permanent effect on local cortical development. However, the majority of alterations at the proximal humerus have been attributed to rotational torques, and not distraction forces (Sabick, Kim et al. 2005).

The significant differences in humeral torsion between baseball and softball players found in this study is in direct contrast to the conclusions made by Whiteley et al (Whiteley, Ginn et al. 2009). Their study showed no significant difference in mean difference of torsion measurements between dominant and non-dominant limbs of baseball and softball players. Ultrasonography was utilized in both experiments to assess the amount of humeral torsion present in the research groups. The research subjects within our study were all collegiate aged athletes (mean age = 19.3 ± 1.2), who indicated participation in overhead sports throughout adolescence and were solely field players, not pitchers. The work by Whiteley et al had two softball groups; one was still experiencing physical maturation (mean age = 16.1 ± 1.3), and the other was an amateur population (mean age = 46.2 ± 8.2), with no indication of their participation in overhead sports during adolescence, or the position played. As indicated, humeral torsion is developed during physical maturation and does not alter afterwards, therefore the populations used within Whiteley et al's experiment do not represent a population that is highly susceptible to variations in dominant limb humeral torsion, possibly explaining the sizeable difference between their torsion results and the results found in this study. In addition, Whiteley cited the lack of measured rotational range of motion as a major limitation of their study. The additional measurement of internal and external rotation would provide an avenue to compare soft tissue and osseous adaptations between the study groups.

Previous studies comparing baseball player's dominant limb to their non-dominant limb and to control subjects have established explicit range of motion alterations (Bigliani, Codd et al. 1997; Tyler, Nicholas et al. 2000; Reagan, Meister et al. 2002; Myers, Laudner et al. 2006; Ruotolo, Price et al. 2006; Lintner, Mayol et al. 2007; Myers, Oyama et al. 2007; Myers and Oyama, In Press). Our results were consistent with this literature, showing decreased internal rotation, horizontal adduction, and increased external rotation between limbs in the baseball players. Total range of motion was also significantly decreased in baseball players' dominant limbs compared to non-dominant limbs. While these results are consistent with previous literature, little research on the same variables has been recorded in softball players (Dover, Kaminski et al. 2003; Werner, Guido et al. 2005). Our results indicated much less pronounced variation between softball players' dominant and non-dominant limbs for internal rotation, external rotation, horizontal adduction, total ROM, GIRD and ERG. These results are consistent with our hypotheses, that softball players will exhibit significantly less adaptation to shoulder range of motion characteristics in their dominant limbs, as compared to baseball players.

Humeral torsion has recently been assessed as a chief contributor to alterations in range of motion characteristics in the shoulder of overhead athletes (Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Reagan, Meister et al. 2002; Whiteley, Ginn et al. 2006; Schwab and Blanch 2009; Myers and Oyama, In Press). Alterations in humeral torsion are created through opposing torques acting upon the proximal humerus during the late cocking phase into the acceleration phase of throwing. These opposing torques create a twisting effect upon the long axis of the humerus to increase the amount of humeral torsion over time as this motion is excessively repeated. In our experiment, humeral torsion was again found

to be on average 14 degrees greater in the dominant limb of the baseball player, as compared to their non-dominant limb, which is consistent with the literature. The softball athlete also displayed an average increase of 7 degrees in humeral torsion of their dominant limb. These findings support our hypothesis, that bilateral difference in humeral torsion would be less profound in the softball players' dominant limb as compared to the baseball group. Despite the greater amount of humeral torsion found in baseball players' over softball players' dominant limbs, this is the first body of work to document significant humeral torsion adaptations in a population of softball players.

Within our study, we have four variables that are adjusted for humeral torsion. This adjustment has recently been suggested to isolate the total range of motion alterations in the shoulder that are attributed to soft tissue contracture or lengthening, as opposed to the traditional thought that all variations in range of motion were caused by soft tissue differences. (Schwab and Blanch 2009; Myers and Oyama, In Press). The adjustment for humeral torsion redefines the point of neutral for measuring internal and external rotation to the position where the proximal humerus is placed at a standard position. Once this standard position is established, each subject can have his or her internal and external rotation ranges of motion adjusted for humeral torsion. As mentioned, baseball players have been found to exhibit decreased internal rotation and horizontal adduction, and increased external rotation. While these values have traditionally been attributed to soft tissue variations, redefining humeral torsion neutral truly isolates the amount and direction of soft tissue discrepancy. If the values of adjusted internal and external rotation between dominant and non-dominant limbs are assessed, a true soft tissue deficit can be found regardless of that deficit's direction. Whether a deficit in soft tissue internal or external rotation is found after adjusting for

torsion, without the application of torsion it cannot be attributed to only soft tissue contracture. Therefore, it is possible to segregate the direction and amount of soft tissue manipulation necessary to return a dominant limb towards equilibrium.

We found that once torsion was applied to the humeral rotation range of motion, the between limb differences were much smaller in total degrees, which is consistent with the small amount of research that already exists surrounding humeral torsion adjustments (Schwab and Blanch 2009; Myers and Oyama Unpublished). The development of torsion in the proximal humerus is considered to occur through repeated overhead high velocity movements, such as throwing a baseball or softball, during physical maturation while the highly ineffectual proximal humeral physis is open. Humeral torsion adjusted internal rotation had a smaller mean difference, 4 degrees difference between limbs, than clinical internal rotation. Humeral torsion adjusted external rotation's mean difference was found to be less between limb and sport. Although the interaction of adjusted external rotation was not significant ($p = .07$), it could be said that there was a trend towards an overall effect between the sports and limbs. Conceptually, if both the adjusted internal rotation and external rotation are equal between dominant and non-dominant limbs, the bilateral difference in internal rotation and external rotation is due to torsion effects, not soft tissue transformations. In our experiment, while the adjusted internal rotation was nearly equivalent, the adjusted external rotation was greater in the non-dominant limb, indicating soft tissue structures were causing a decrease in the available amount of external rotation in the dominant limb. This is contrary to the traditional belief that overhead athletes range of motion adaptation are purely caused by stresses and adaptation of the posterior shoulder musculature and stretching of the anterior joint capsule, directly decreasing internal rotation

and increasing external rotation. Therefore, significant decreases in adjusted external rotation between baseball players' dominant and non-dominant limbs is a noteworthy result, and warrants further investigation in the future to ensure the traditional clinical approach of attacking purely internal rotation deficits in baseball players may need altered.

The adjusted measurement for GIRD indicates an average of only 3.8 degrees greater internal rotation in the dominant limb caused by soft tissue adaptations. Adjusted ERG accounted for 11.4 degrees less ERG in the non-dominant limb of baseball players. These results were not found to be significantly greater than the softball player once torsion was accounted, as they displayed 4.3 degrees greater GIRD in their non-dominant limb and 6.6 degrees less ERG. Both groups displayed less ERG once adjusted for humeral torsion, indicating a deficit in the external rotation direction that is attributed to purely soft tissue adaptive changes.

A further analysis of the data within our experiment shows total range of motion difference of 7.6 degrees less in the dominant limb for baseball players, and 2.3 degrees greater in softball players. Theoretically, total range of motion should not be affected by the amount of torsion present, as it is merely a shift in the location of the motion and should be equal between limbs. The significant decrease in total range of motion in the baseball players could be attributed to purely soft tissue adaptations, and addressed through stretching programs. Whether or not this decrease in total ROM in baseball players is attributed to IR or ER deficits is still up for debate, and warrants further investigation.

The presence of humeral torsion, and its assessment using the ultrasonography method have been firmly established as valid (Whiteley, Ginn et al. 2006; Yamamoto, Itoi et al. 2006; Schwab and Blanch 2009; Myers and Oyama Unpublished). Using the quick

assessment of torsion can lead to more precise individualized assessment of shoulder characteristics on a clinical exam. This allows the clinician to truly assess the influences of bony versus soft tissue effects on dominant shoulder changes in both the athletic and general population; thereafter allowing more accurately implemented rehabilitation exercises, specifically the stretching program.

Although the softball players did not exhibit as great an adaptation to their sport in the dominant shoulder, the use of humeral torsion to accurately assess shoulder characteristics should be considered for the softball population. As softball players continue to sustain similar injuries to their baseball counterparts, their treatment techniques must be consistent with evidence-based practice utilized in the rehabilitation of baseball players. While the overall population of softball shoulders has smaller variations in range of motion differences, there still exists the need to implement a throwing arm stretching and strengthening program. The stretching program should be tailored to each individual shoulder. The presence of humeral torsion should be taken into account when prescribing the amount and direction of stretching for the athlete's shoulder. While the current research indicates that torsion must be assessed to have a complete understanding of the true range of motion characteristics, not everyone has access to torsion assessment tools. Therefore, a full assessment of both dominant and non-dominant limb range of motion, in a scapular stabilized position should be completed to fully compare total range of motion differences, subsequently inferring the amount of decreased motion, whether that be internal or external rotation. It is not possible for the clinician to determine the direction of motion lost without the use of a humeral torsion assessment. However, a baseline assessment of rotation range of motion can provide a foundation for the clinician to refer to at a later date given shoulder

pathology. At that time, if the overhead athlete displays deficits in internal and external rotation compared to their baseline measurements, the direction of deficit can be determined, and the appropriate direction for a stretching protocol can be implemented.

Whether male or female, the amount of humeral torsion present is considered static once the athlete has matured. Measuring humeral torsion can be accomplished once, during a preseason evaluation for example, in combination with measurements of the shoulder rotation range of motion and horizontal adduction. Thereafter, humeral torsion can be applied to range of motion measurements, and any variation from these adjusted measures in the future would be purely soft tissue in nature, indicating to the clinician if motion changes are part of the foundation in upper extremity pathology. If an injury is present, and the athlete's range of motion measurements are greatly skewed from their baseline marks, it would indicate which structures may be short and tight, or loose and weak; directly leading to a clinician implementing a specified rehabilitation protocol.

The greatest limitation of our research was the total number of softball players enrolled in the study, and lack of control group. While several more softball players were evaluated, their data were not included in the analysis due to their primary roll as a pitcher in their sport. An evaluation of their playing history revealed they participated as pitchers only in high school during their physical maturation, as well as in college. While kinetic data exists to suggest similar forces are experienced at the shoulder for the baseball and softball pitch (Barrentine, Fleisig et al. 1998; Werner, Guido et al. 2005), their kinematics are so highly variable the data from pitchers in softball was not included in the analysis. In addition, a control group was not used for either the male or female population. While the subjects' non-dominant limb is used as the reference point, a matched control group would give more

concrete conclusion stemming from the results. It has been found that control groups in studies of male baseball players' humeral torsion can exhibit up to 6 degrees of humeral torsion bilateral difference on average (Crockett, Gross et al. 2002; Myers and Oyama Unpublished), therefore making the mean difference of 7 degrees of humeral torsion in our softball study group less distinct. In addition, the population studied in this experiment was completely healthy. Therefore, it is not possible to determine at this time if the measurements of ROM and humeral torsion are affected within a group with shoulder or elbow injury.

The research subjects in our study average age 19.4 years. While females have reached physical maturity by the age of 19, several of the males in this study may not have reached physical maturity. This indicates that these baseball players may experience a further alteration in humeral torsion. If these players' epiphyseal plates have not closed, they could experience increased torsion effects during the next few years. In addition, the time frame during which physical maturation is experienced is in general longer for the male population (Riegger-Krugh and LeVeau 2002). This longer period of time may allow for a greater overall effect on humeral torsion.

Softball shoulder range of motion and torsion variables were found to be overall much less pronounced than their baseball counterparts. While this study is the first to address softball players range of motion between dominant and non-dominant limbs, we only compared the variables within limb and to baseball players. Further investigation into the presence of shoulder range of motion and torsion adaptations between a softball and control population of females would give a larger insight into the amount of variability the sport of softball actually imparts on the female overhead athlete shoulder. In addition, little research exists that compares the kinematics and kinetics of the overhead softball throw to the

baseball throw (Chu, Fleisig et al. 2009). An overall biomechanical analysis of the overhead baseball and softball throw including field players may reveal specific factors that differentiate the two groups of shoulders.

Conclusion

The results of this study demonstrate less pronounced adaptation in range of motion characteristics and humeral torsion in the dominant softball shoulder, as compared to the baseball players in this study and previous literature. Still, humeral torsion was present in the dominant limbs for both baseball and softball players, and was highly influential on the shoulder rotation range of motion variables. From these results, we conclude that softball players do develop variations in range of motion characteristics including humeral torsion, but these variations are much less pronounced than their baseball counterparts. Within both populations, these adaptations are greatly influenced by the amount of torsion present. Regardless of the sport played, clinicians with access to humeral torsion assessment should implement the measurement into their baseline evaluation, allowing the future adjustments in shoulder range of motion to be pinpointed to a specific source or direction. In a population of physically mature athletes, the value of humeral torsion will give the athlete and clinician a better understanding of how to treat and prevent subsequent pathology.

Figures



Figure 1: (A) Clinical Internal Rotation. (B) Clinical External Rotation



Figure 2: Horizontal Adduction Assessment

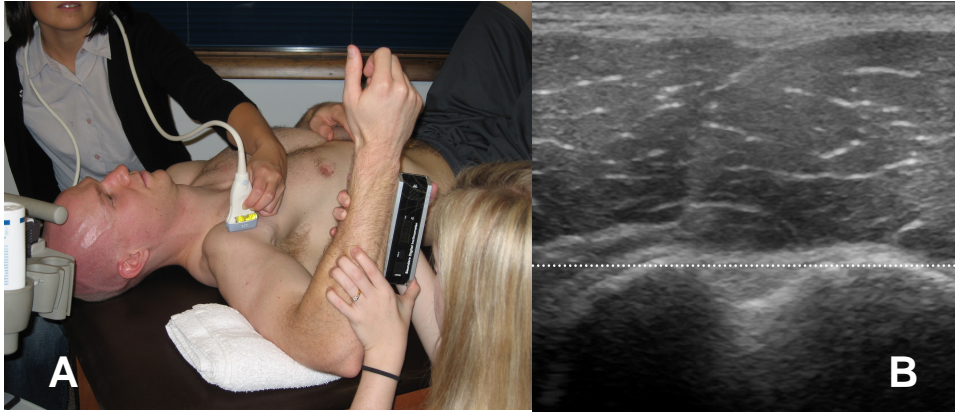


Figure 3: (A) Ultrasonographic assessment of humeral torsion. (B) Ultrasonographic image of the upper humerus where the humeral tubercles are pointing superiorly.

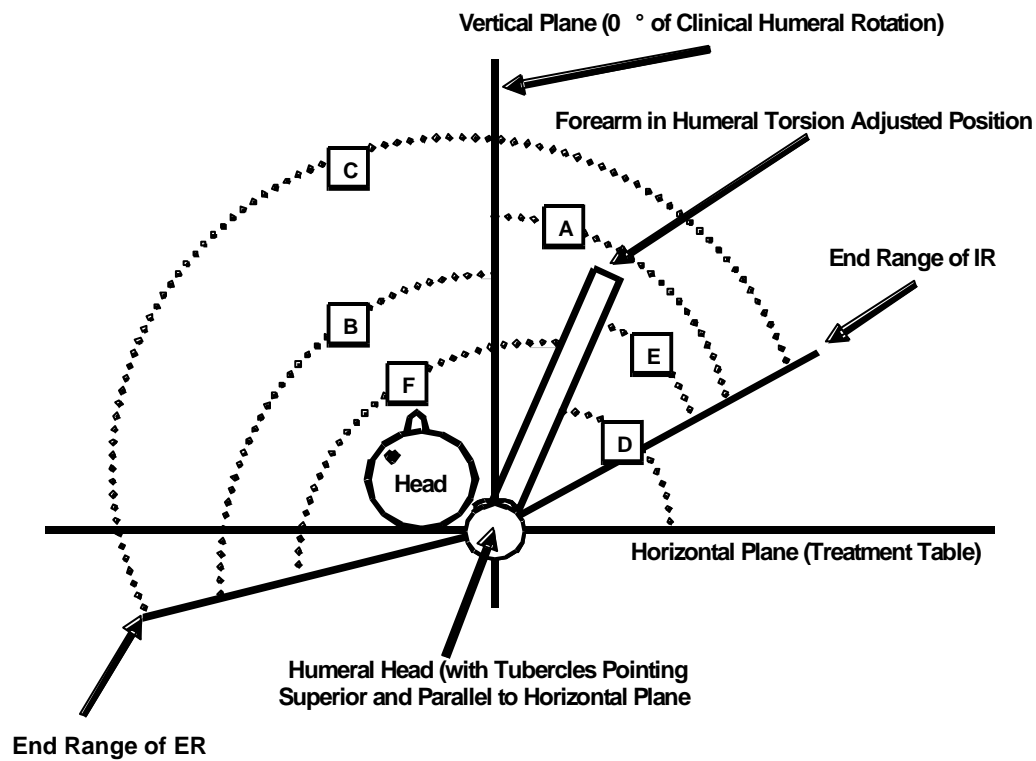


Figure 4: Humeral internal rotation and humeral torsion variables assessed.

- A: Clinical Internal Rotation
- B: Clinical External Rotation
- C: Total Range of Motion
- D: Humeral Torsion
- E: Internal Rotation Corrected for Humeral Torsion
- F: External Rotation Corrected for Humeral Torsion

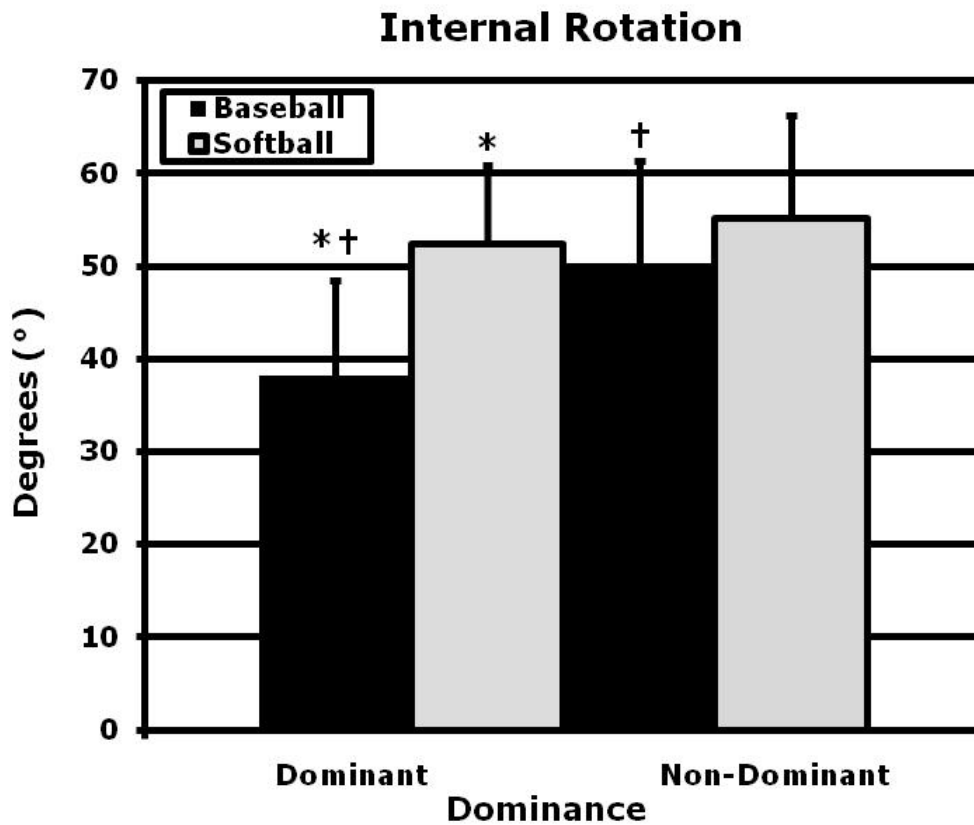


Figure 5: Internal rotation for baseball and softball players' dominant and non-dominant limbs.

* Significant difference (bonferroni corrected $p < .0125$) between baseball and softball players' dominant limbs.

† Significant difference (bonferroni corrected $p < .0125$) between dominant and non-dominant limbs.

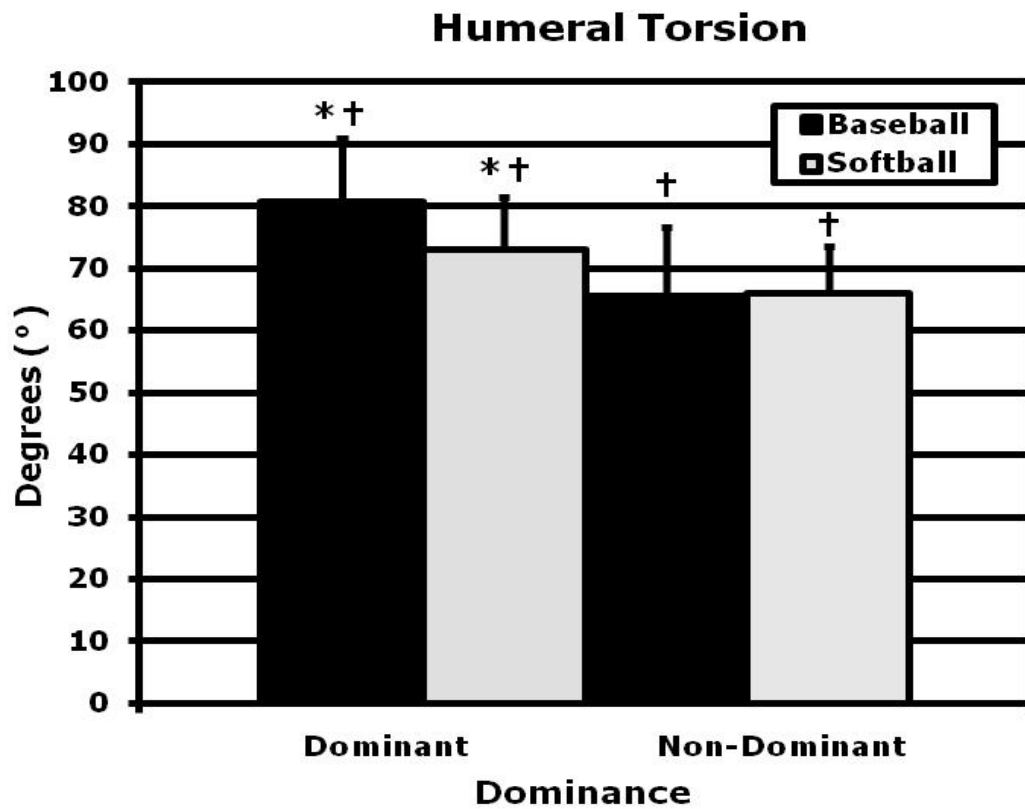


Figure 6: Humeral torsion for baseball and softball players' dominant and non-dominant limbs.

* Significant difference (bonferroni corrected $p < .0125$) between baseball and softball players' dominant limbs.

† Significant difference (bonferroni corrected $p < .0125$) between dominant and non-dominant limbs.

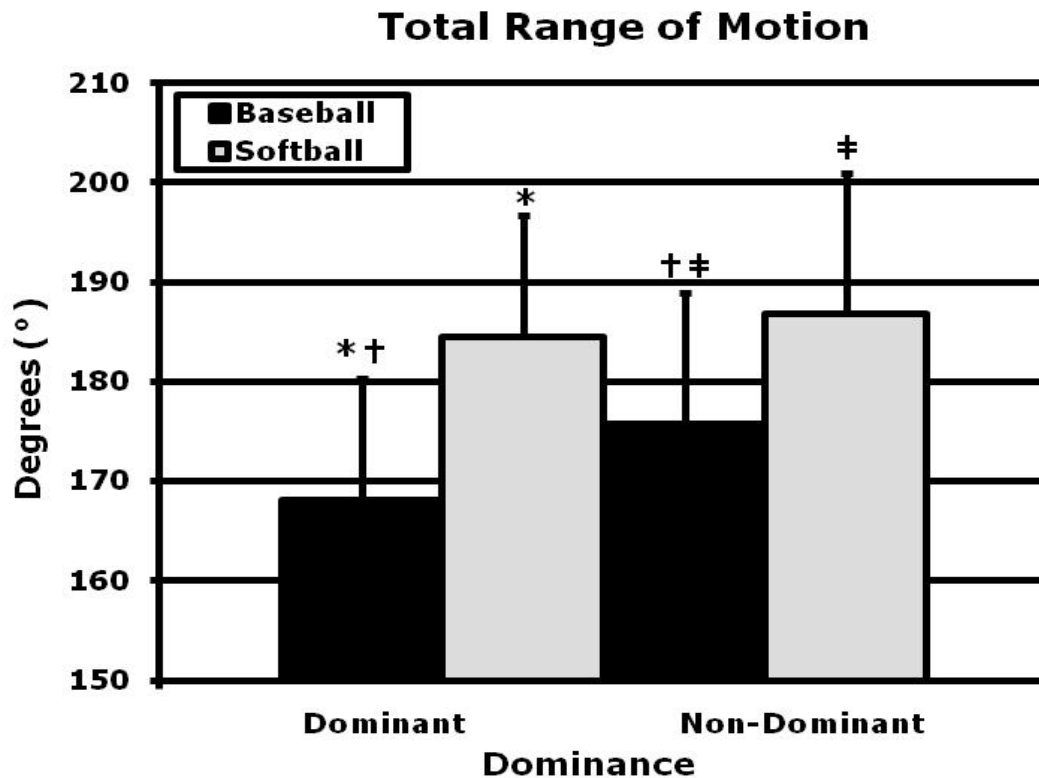


Figure 7: Total range of motion for baseball and softball players' dominant and non-dominant limbs.

* Significant difference (bonferroni corrected $p < .0125$) between baseball and softball players' dominant limbs.

† Significant difference (bonferroni corrected $p < .0125$) between dominant and non-dominant limbs.

‡ Significant difference (bonferroni corrected $p < .0125$) between baseball and softball players' non-dominant limbs.

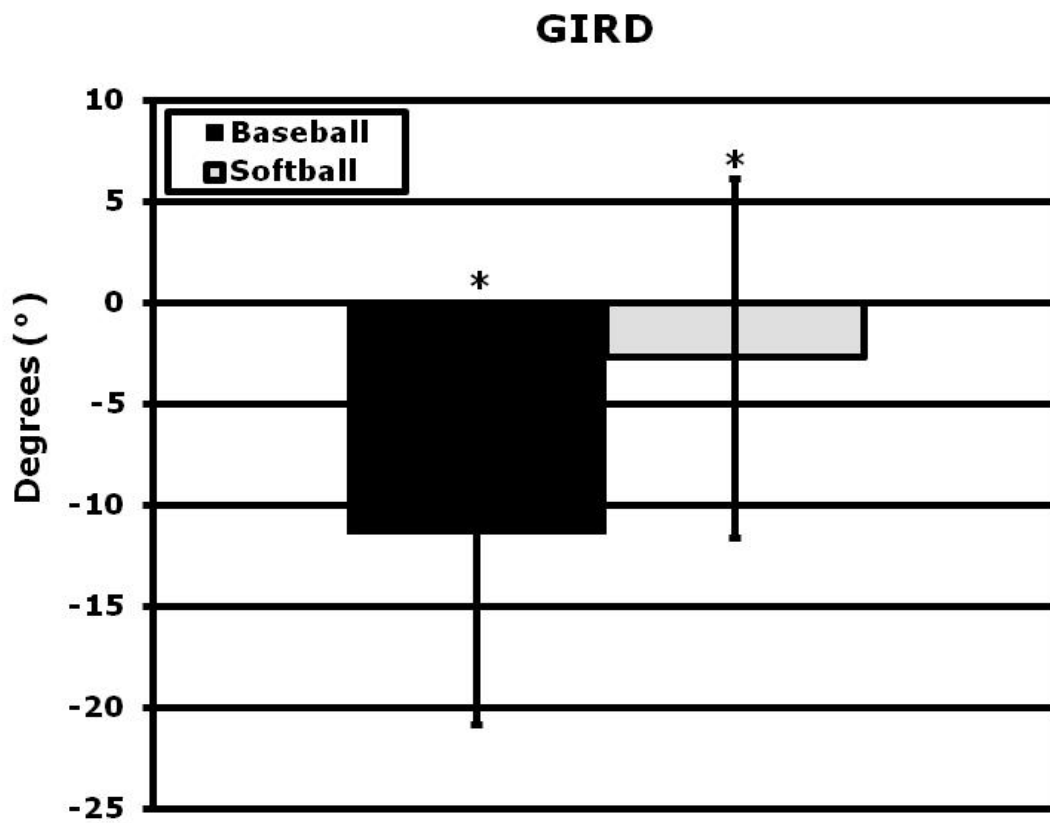


Figure 8: GIRD for baseball and softball players.

. * Significant difference ($p < .05$) between baseball and softball players.

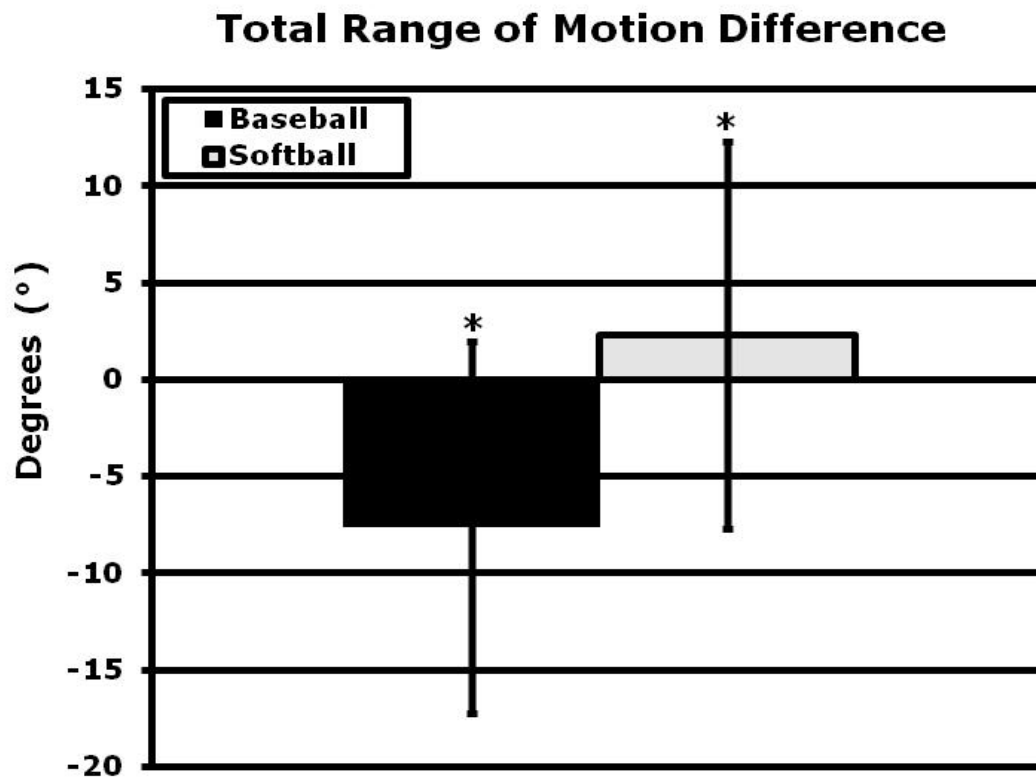


Figure 9: Total range of motion difference for baseball and softball players.
* Significant difference ($p < .05$) between baseball and softball players.

Tables

TABLE 1: Subject demographics

	n	Age	Height (m)	Mass (kg)	Dominant Throwing Arm	
					Right	Left
Baseball Players	55	19.5 ± 1.1	$1.82 \pm .07$	87.3 ± 11.0	41	14
Softball Players	27	19.3 ± 1.2	$1.66 \pm .06$	70.9 ± 9.7	24	3

TABLE 2: Descriptive Statistics

	Baseball Players				Softball Players			
	<u>Dominant</u>		<u>Non-dominant</u>		<u>Dominant</u>		<u>Non-dominant</u>	
	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
Internal Rotation (°)	38.2	10.3	49.6	11.7	52.4	8.6	52.4	8.6
External Rotation (°)	130.0	11.4	126.1	12.1	132.1	10.7	131.7	11.1
Humeral Torsion (°)	80.8	10.2	65.6	11.2	73.1	8.4	66.1	7.4
Horizontal Adduction (°)	98.0	7.0	102.1	6.2	97.1	8.6	99.3	7.0
Total ROM (°)	168.2	12.2	175.8	13.2	184.5	12.2	186.8	14.1
Adjusted IR (°)	29.0	11.0	25.2	11.2	35.5	12.0	31.2	13.4
Adjusted ER (°)	139.2	11.5	150.6	13.1	149.0	11.2	155.6	11.0
GIRD (°)	-11.4	9.4			-2.7	8.9		
ERG (°)	3.9	9.8			0.4	7.1		
Adjusted GIRD (°)	3.8	9.2			4.3	9.9		
Adjusted ERG (°)	-11.4	11.7			-6.6	10.3		
Total ROM Diff (°)	-7.6	9.6			-2.6	10.0		
Humeral Torsion Diff (°)	15.3	9.6			7.0	7.2		

GIRD = Glenohumeral Internal Rotation Deficit; ERG = External Rotation Gain;
ROM = Range Of Motion; IR = Internal Rotation; ER = External Rotation;
Diff = Difference

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