USING ROTATIONAL RESISTANCE MEASURES TO THOROUGHLY ASSESS SHOULDER FLEXIBILITY IN BASEBALL PITCHERS: IMPLICATIONS FOR THROWING ARM ADAPTATIONS AND INJURIES

By

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Throwing arm injuries are extremely prevalent in baseball pitchers. The flexibility of the throwing shoulder is thought to be relevant to the incidences of throwing arm injuries and injury mechanisms. Previous flexibility studies have assessed a single shoulder variable: the range of motion (ROM). In this study, a custom device was built to measure shoulder flexibility and a new and more thorough manner. The device assesses the amount of torque (or effort) required to passively rotate the shoulder. This novel analysis provides a measure of how stiff or loose the shoulder is as it is rotated to the end ROM. The two shoulder motions that are considered the most relevant to injury were analyzed (internal rotation and external rotation). Two major findings were revealed in this study. First, for both ER and IR the end ROM and stiffness of the shoulder are not related. This means that two pitchers can have similar ROM but drastically different shoulder stiffness. This data suggests that both ROM and stiffness are required to describe the flexibility of the pitching shoulder. Second, pitching alters the flexibility of the throwing shoulder. This was discovered by comparing the flexibility of the throwing shoulder to that of the non-throwing shoulder. Variables that were significantly different bilaterally were the ROM, the resistance onset angle (angle where the soft tissue begins to stretch), and shoulder

stiffness. These bilateral differences were large (20–40%). The magnitude and direction of these bilateral differences are likely relevant to throwing arm injuries. We recommend the incorporation of this new shoulder analysis into clinical and rehabilitation settings and believe future research should strive to better understand the relevance of shoulder flexibility to throwing arm injuries.

CHAPTER 1
INTRODUCTION TO STUDY

General Introduction

Evolving the ability to throw was crucial to the existence and advancement of our species (Darlington et al., 1975; Young et al., 2003). Although the importance of throwing to daily survival has diminished, its pervasiveness remains. Hundreds of thousands of individuals around the world participate in recreational and organized athletics that involve throwing or throwing-like motions (Fleisig et al., 1996; Conte et al., 2001; Escamilla et al., 2001; Janda, 2003).

Athletes that regularly throw or use throwing-like motions are referred to as overhead athletes (Baltaci et al., 2004; Borsa et al., 2005). Example overhead actions include the baseball pitch, football pass, javelin throw, volleyball spike, and tennis serve. Regularly performing overhead actions places great demands on the dominant arm (Zheng et al., 2004; Mullaney et al., 2005). Detailed, long term injury surveillance studies have yet to be completed however; injuries to the dominant shoulder and elbow are prevalent and often severe, especially in baseball pitchers (Fleisig et al., 1995).

Currently, Major League Baseball disabled list reports provide the most thorough description of injury prevalence in baseball pitchers (Conte et al., 2001). Over 11 seasons (1989-1999), each team, on average, had players miss 640.6 days per season. Pitchers accounted for over half of these missed days. The majority of injuries were to the shoulder (27.8%) and elbow (22.0%). The knee was a distant third at 7.3%. These findings are not unique to professionals; high throwing arm injury rates are seen throughout all levels of play (Hang et al., 2004; Sabick et al., 2004; Olsen et al., 2006).

Throwing arm injuries are related to repeated exposure to extreme biomechanics. Throwing arm joint velocities, forces, and torques are approximately 25–40% greater than other

overhead actions, like the football pass (Fleisig et al., 1996), and they are thought to load elbow and shoulder tissues at or near capacity (Fleisig et al., 1995). Also, the throwing arm is subjected to these loads many times and very often. Starting pitchers throw 100+ pitches every 4–6 days and relief pitchers commonly throw 15+ pitches on consecutive days (Mullaney et al., 2005). Finally, the seasons are long, up to 8 months in the professional leagues, with games almost every day.

A plethora of throwing arm injuries has been documented. Most injuries are "overuse" in nature meaning they gradually develop over the course of a season or career (Zheng et al., 2004). Pitching overuse injuries develop in one of two ways. First, repetitive loading may weaken or alter a bony or soft tissue to the point where the pitcher suffers laxity, dysfunction, pain, or a severe tear. Common examples include gradual stretching of the anterior passive constraints (Kvitne et al., 1993), humeral epiphyseal plate injuries (Sabick et al., 2004), and the gradual weakening (and perhaps eventual tearing) of the ulnar collateral ligament (Safran et al., 2005) or rotator cuff muscles (Mazoué et al., 2006). Second, repetitive loading may lead to throwing arm mal-adaptations. For example, the posterior capsule may excessively tighten (Burkhart et al., 2003) or the scapular positioning may become altered in a detrimental way (Myers et al., 2005). These alterations may lead to clinical problems like shoulder impingement.

Baseball pitchers have now been intensely studied for approximately 30 years. The understanding of the pitching motion and demands on the throwing arm has improved dramatically (Feltner et al., 1986; Matsuo et al., 2006). Ability to diagnose injuries and help injured pitchers has also improved dramatically (Nakagawa et al., 2005; Koh et al., 2006; Song et al., 2006). Interestingly, injuries remain prevalent.

Fortunately, progress is being made in three areas. The first is pitching behavior. The number of pitches thrown, types of pitches thrown, and tendency to throw with pain appear to be relevant to injuries, especially in youth (Lyman et al., 2001; Olsen et al., 2006). Second, the relevance of pitching mechanics to injuries is being discovered (Wight et al., 2004; Matsuo et al., 2006). Last, researchers are beginning to better understand the mechanical characteristics of the pitching arm, specifically the shoulder. These three general topics all provide great potential to reduce injuries because they are relevant to injuries and can be controlled by players/coaches or manipulated through interventions. This project will focus on the last factor: better understanding the mechanical characteristics of the throwing shoulder.

Shoulder Mobility and Stability

Biomechanical studies have revealed the essential requirements of the pitching shoulder. First, the shoulder must be mobile, especially in external rotation. During the arm cocking phase, pitchers externally rotate the shoulder as far as possible to help generate throwing velocity (Feltner et al., 1986). The magnitude of shoulder rotation is crucial to success. High velocity pitchers are able to achieve 175–180° of shoulder ER (Zheng et al., 2004). This is approximately 10–15° more than low velocity pitchers (Matsuo et al., 2001; Murray et al., 2001). The second essential requirement is shoulder stability. The shoulder must remain stable enough to prevent injuries as it is externally rotated to 175°, rapidly internally rotated to over 7000°/s (Dillman et al., 1993), and exposed to a distraction force during the follow through phase that is near or beyond the pitchers body weight (Fleisig et al., 1996).

Many have stressed the importance of understanding the delicate balance between shoulder mobility and stability (Wilk et al., 2002; Ellenbecker et al., 2002; Crockett et al., 2002). Developing a better understanding of shoulder mobility and stability is important for three reasons. First, it is thought to influence to how vulnerable to injury the shoulder is. Second, it

may influence how vulnerable to injury the elbow is; shoulder mobility and stability may influence the throwing arm movements that place stress upon and injure the elbow joint (Feltner et al., 1986; Fleisig et al., 1995). Third, there is potential to improve or optimize the mobility and stability of the shoulder since strength (Treiber et al., 1998), proprioception (Safran et al., 2001), and flexibility (Kibler et al., 2003) can be altered via interventions.

Assessing Shoulder Mobility and Stability

Ideally, shoulder mobility and stability would be assessed during the pitch. But the ability to do this is limited. The only kinetic analysis available is inverse dynamics and the ability to assess the kinematics of the humeral head has yet to be established. Therefore, the most productive way to study shoulder mobility and stability is to examine the shoulder in a controlled clinical setting. Topics relevant to shoulder mobility and stability that have been assessed in this manner include strength (Noffal et al., 2003), motor control (Safran et al., 2001), glenohumeral translation (Borsa et al., 2005) and stiffness (Borsa et al., 2006), scapular mobility (Downar et al., 2005) and shoulder ROM (Ellenbecker et al., 2002). The most important, popular, and useful shoulder examination thus far has proven to be the shoulder internal rotation (IR) and external rotation (ER) ROM examination. This project will focus on improving the shoulder IR/ER examination to better understanding throwing shoulder flexibility, how pitching alters the throwing shoulder, and throwing arm injuries.

Specific Aims

The relevance of the IR/ER motion was discovered when researchers revealed it to be drastically altered by pitching (Brown et al., 1988; Baltaci et al., 2001). In most pitchers, this motion is shifted back (towards ER) approximately 10°. Thus, the pitcher gains 10° of ER and loses 10° of IR. This “motion shift” is thought to be a positive adaptation that allows the pitcher to externally rotate the shoulder to an extreme ROM during the pitch (Crockett et al., 2002;

Baltaci et al., 2004). The IR/ER motions and motion shift are relevant to throwing arm injuries. Pitchers with limited IR often have throwing arm problems including shoulder impingement and SLAP lesions (Burkhart et al., 2003; Myers et al., 2006). The loss of IR motion is commonly referred to as glenohumeral internal rotation defecit or GIRD (Myers et al., 2006). GIRD is considered excessive when it is approximately 20° or more. Relationships between the ER motion and injuries are not as well established. However, excessive ER motion, whether it be natural or developed from pitching, may be relevant to shoulder problems including instability (Crockett et al., 2002; Kuhn et al., 2000).

The relevance of osseous and soft tissues to the IR/ER motions and motion shifts has been addressed. Osseous tissues have been studied directly via CT scans (Crockett et al., 2002) and radiographs (Osbahr et al., 2002; Reagan et al., 2002). The amount of "twist" or retroversion in the proximal humeral physis appears to contribute to the IR/ER motions. Retroversion is also relevant to the shifted motion. In most pitchers, the throwing arm humerus is retroverted towards ER 5–20° more than the non-throwing arm. But retroversion does not fully explain the IR/ER ROMs or the motion shift. Correlations with ER are conflicting among studies and correlations with IR are non-significant or weak (Osbahr et al., 2002; Reagan et al., 2002). The lack of ability of retroversion to explain the IR/ER motions and motion shift suggests that soft tissues may be important. This idea is not new: over 20 years ago Pappas et al., (1985) suggested that the IR/ER motion shift results from the stretching of anterior shoulder soft tissues and tightening of posterior shoulder soft tissues. Surgical interventions have qualitatively verified this hypothesis for injured pitchers; excessive laxity to the anterior capsule and/or excessive thickening of the posterior capsule and rotator cuff muscles has been observed (Burkhart et al., 2003; Myers et al., 2006). However, surgical interventions cannot be used to examine the shoulder soft tissues in the

vast majority of pitchers. A non-invasive, measure of the soft tissue's looseness or stiffness is needed to help better understand the IR/ER motion and the mechanisms of the motion shifts.

This gap in the literature will be addressed by examining the IR/ER passive motion in a novel, more extensive manner. A new flexibility measure, called rotational resistance, will be assessed along with the traditional ROM measures. Rotational resistance is measured as the torque (N·m) required to internally and externally rotate the shoulder to the end ROM. This measure provides information regarding how "stiff" or "loose" the shoulder is as it is rotated and is thought to reflect the passive resistance to motion provided by the soft tissues as they stretch. The rotational resistance of the shoulder has been reliably measured for clinical purposes once, but it has never been measured in baseball pitchers (Novotny et al., 2000).

The ultimate goal for this line of research is to use rotational resistance and ROM measures to assess shoulder flexibility and determine its relevance to incidence of throwing arm injuries, injury prevention, injury mechanisms, and injury rehabilitation. In this project, three studies have been designed to help make progress towards those goals. The objective of the first study is to examine important relationships among various flexibility measures. A priority will be determining how to best measure shoulder IR/ER passive flexibility for research purposes. The general hypothesis is that rotational resistance is needed to sufficiently evaluate shoulder flexibility. The objective of the second study is to determine the relevance of rotational resistance to the shifted motion. The general hypothesis is that shoulder rotational resistance is altered by pitching and is related to the magnitude of the motions shifts. The objective of the third study is to determine if incidences of throwing arm injuries vary among groups of pitchers that have drastically different shoulder flexibility. The general hypothesis is that pitchers that have extremely flexible or extremely inflexible shoulders will have higher incidences of

throwing arm injuries than pitchers with moderately flexible shoulders. After completing these studies, it may be possible to determine 1) the best way to assess the IR/ER motion, 2) if a pitcher has a flexible or inflexible throwing shoulder, 3) if pitchers with GIRD do in fact have thickened posterior soft tissues, 4) if shoulder soft tissues are altered by pitching, and 5) if shoulder rotational resistance influences the magnitude of the motion change, 6) if shoulder rotational resistance is related to throwing arm injury incidence.

The first general hypothesis will be addressed with two specific aims:

Specific Aim 1a was to determine if ROM and rotational resistance are both necessary to assess shoulder IR/ER flexibility. Previous shoulder passive IR/ER studies are limited to one flexibility measure: the end ROM. This limited analysis may lead to false conclusions about a pitcher's flexibility. For example, it is possible for two pitchers to have similar ROM, yet drastically different rotational resistance. Preliminary shoulder ER pilot data from 26 tennis players revealed multiple instances where players had similar ROM but a two-fold difference for rotational resistance (Wight et al., 2006). The player with half the rotational resistance is clearly more flexible. Measuring rotational resistance will help to properly make these distinctions. We hypothesize that rotational resistance variables and the end ROM will be independent. This finding would suggest that measures of both ROM and rotational resistance are needed to make conclusions about shoulder IR or ER flexibility.

Specific Aim 1b was to determine if high rotational resistance groups have significantly different ROM compared to low rotational resistance groups. Two basic measures will be used to thoroughly assess shoulder rotational resistance. First, is the resistance onset angle (ROA). This represents the angle where soft tissues begin to stretch. Second, the stiffness will be assessed. This represents how "tight" or "loose" the shoulder is. These measures will be used to create a

high rotational resistance group and low rotational resistance group. The low group will have two flexible characteristics: a late ROA and low rotational resistance. The high group will have two inflexible characteristics: an early ROA and high rotational resistance. We hypothesize that the low rotational resistance groups will have significantly greater ROMs compared to the high rotational resistance groups. This finding would suggest that the ROA and stiffness should be considered together when analyzing flexibility.

The second general hypothesis will be addressed with three specific aims: Specific Aim 2a was to determine if pitching alters the soft tissue of the throwing shoulder. Previous researchers have suggested that pitching attenuates the anterior shoulder soft tissues and tightens the posterior shoulder soft tissues (Pappas et al., 1985). This hypothesis will be tested by comparing the stiffness of the throwing shoulder to the stiffness of the non-throwing shoulder. Bilateral differences are assumed to be alterations to the soft tissues of the pitching shoulder. We hypothesize that the throwing arm IR stiffness will be significantly greater and the ER stiffness to be significantly less stiff than the non-throwing shoulder. These findings would suggest that pitching alters the soft tissues of the shoulder. No alterations to stiffness would suggest that humeral retroversion is the primary factor responsible for the motion shifts.

Specific Aim 2b was to determine if the magnitude of the motion shift is related to the magnitude of the stiffness change. The average pitcher has a 10° motion shift for both ER and IR. But the range is quite variable; some pitchers have virtually no motion shift while others exceed 20°. Limited and/or excessive motion shifts are associated with throwing arm injuries (Burkhart et al., 2003; Myers et al., 2006). Therefore, determining the factors that influence the magnitude of the motion shift is crucial. We hypothesize that the motion shift will increase as alterations to stiffness in the throwing shoulder increases. This finding would suggest that the

motion change is dependent on the extent of the attenuation or tightening of the soft tissues. This test will only be run if bilateral differences in stiffness are found in the previous aim.

Specific Aim 2c was to determine if the rotational resistance of the non-throwing shoulder is related to the magnitude of the motion shift. It is possible that the magnitude of the motion shift is related to the original or "pre-altered" tightness or looseness of the soft tissue. The rotational resistance of the non-throwing arm will be used as a control to represent the pre-altered rotational resistance. We hypothesize that the magnitude of the motion shift will increase with the stiffness of the non-throwing arm. If significant, this finding would help to identify individuals that may be at risk of injury.

The third general hypothesis will be addressed with one specific aim: Specific Aim 3 was to determine if incidence of throwing arm injuries are different among rotational resistance groups. Previous studies have revealed associations between shoulder ROM and throwing arm injuries (Burkhart et al., 2003; Myers et al., 2006). The general consensus is that limited IR motion and/or excessive ER motion likely makes the throwing arm susceptible to injury (Crockett et al., 2002; Kuhn et al., 2000). An analogous hypothesis will be tested with respect to rotational resistance. We hypothesize that pitchers will low ER rotational resistance (i.e., extremely flexible) and pitchers will high IR rotational resistance (i.e., extremely inflexible) will have higher incidences of throwing arm injuries than their peers. This preliminary analysis is considered valuable because it may reveal general injury incidence trends and may help to better identify pitchers at risk of injury.

This study is believed to be innovative because it will be the first to 1) thoroughly assess shoulder IR/ER flexibility in pitchers, 2) directly test if the flexibility of soft tissues are altered by pitching, 3) explore the magnitude of the motion shift, 4) explore whether flexibility is

relevant to the motion shift, and 5) explore the relevance of rational resistance to incidences of throwing arm injuries. Long term benefits are also expected. This study may stimulate the incorporation of rotational resistance into shoulder IR/ER examinations and help to determine the most parsimonious way to examine the motion. Results from this study may help athletics trainers, orthopedic surgeons, and sports medicine clinicians better analyze the shoulder IR/ER passive motion to diagnose injuries, assess throwing arm adaptations, assess throwing, stretching, and/or exercise interventions, and assess rehabilitation outcomes. This study is also expected to stimulate future research. Researchers may be able to use findings and methods from this study to help better determine the relevance of flexibility to the incidence of throwing arm injuries and injury mechanisms.

CHAPTER 2
REVIEW OF THE LITERATURE

The purpose of this literature review is to demonstrate that measurement of the rotational resistance of the shoulder IR/ER passive motion is needed. Focus will be placed on the general methods used to assess the passive mechanical properties of the throwing shoulder thus far, the general findings from those studies, and the gaps in the literature. Throughout the review, shoulder anatomy and injuries will be addressed. A review of shoulder anatomy and example pitching injuries are included as an appendix (Appendix A).

Analyzing the Shoulder IR/ER Passive Motion

Traditional measurement of the IR/ER motion is relatively simple. The investigator internally or externally rotates the shoulder to the end ROM and then measures the angle using a plastic or digital goniometer. Novotny et al., (2000) showed that it is possible to measure the motion more extensively. A custom device was used to quantify rotational resistance. Methodological considerations relevant to collecting ROM and rotational resistance will be discussed.

Important Methodological Considerations

When analyzing the IR/ER motion, three important methodological decisions must be made: whether motion will be passive or active, the positioning of the arm, and whether to stabilize the scapula.

Passive vs. Active

During a passive collection, the participant is instructed to remain totally relaxed and the joint is rotated to the “end feel” as determined by patient comfort and capsular end feel (Awan et al., 2002). During active measurement, the athlete uses the shoulder external rotators and/or shoulder internal rotators to actively rotate the joint as far as possible. Measurements are then

taken as the athlete maintains the end ROM (Ellenbecker et al., 2002). Both methods are commonly used clinically (Boon et al., 2000). The majority of overhead athlete studies have used the passive method (Baltaci et al., 2004). In this study, collections will be passive because rotational resistance cannot be collected actively.

Arm position

Nearly all IR/ER studies have assessed shoulder motion with the participant lying supine on a training table with the arm in the standard throwing relevant position. This arm position is 90° of shoulder adduction, 90° of elbow flexion, and neutral shoulder horizontal ab/adduction meaning the upper arm points lateral (Awan et al., 2002; Ellenbecker et al., 2002; Meister et al., 2005). Alterations in adduction have a drastic influence on the ROM. For 19 pitchers, Osbahr et al., (2002) revealed that the ER end ROM at 90° of shoulder adduction to exceed the 0° adduction position (126.8° vs. 90.1°, respectively, $p<0.05$). The influence of horizontal adduction has not been tested directly. However, Borsa et al., (2005) made a slight alteration to the standard position to place the upper arm in the plane of the scapula (approximately 15° anterior to the coronal plane). This adjustment appeared to have minimal effects on the IR and ER end ROMs; Borsa's findings were comparable to those of other investigators (Table 2-2). In this study, the arm will be assessed in the standard throwing relevant position.

Scapular stabilization

The scapula if often stabilized by manually applying an anterior force to the anterior shoulder. This helps to isolate glenohumeral motion (Boon et al., 2000; Awan et al., 2002). Boon found scapular stabilization to significantly reduce ($p < 0.05$) end ROMs in 50 high school athletes. The eROM reduced approximately 9°. The IR end ROM was reduced far more, approximately 26°. Nearly all researchers have stabilized the scapula when analyzing overhead

athletes. The scapula will be stabilized for this project to isolate glenohumeral motion and to allow for comparison of results to previous research.

Novotny's Approach

Novotny successfully evaluated the rotational resistance of the shoulder. A load cell was used to quantify the torque required to passively internally and externally rotate the shoulder. Angular displacement was continually collected using an electromagnetic motion system. A similar approach will be used in this study; however, angular displacement will be monitored with a potentiometer. There are two other differences between Novotny's approach and the approach used in this study. The first is participant positioning. Novotny had the participant seated with the arm abducted 45° from the side of the body. Participants in this study will lay supine and have the arm in the previously mentioned throwing relevant position. This will allow for better comparison of results to those in the literature. Second, Novotny ceased shoulder rotation once a pre-set torque was achieved (4 N·m). This pre-set torque limited the ROM such that participants were unable to obtain the end ROM. In this study, the shoulder will be rotated to the true end ROM (since the end ROM is a variable of interest).

Reliability of Traditional Measures

Using a goniometer to measure the end ROM is subjective by nature. The investigator must align the device with the participant's arm. The investigator must also maintain the alignment of the participant's upper arm. Not surprisingly, inter and intra-tester reliability scores are often low and variable. Boon et al., (2000) summarized reliability for 9 shoulder ROM studies. Five of the 9 studies had ICC score below 0.60. This craft appears to be highly dependent on the skill of the investigator. Variability may also be related to the accuracy of the device, which is ±1° (Awan et al., 2002), and the ability to line up the device with the forearm.

Using a custom device that secures the arm and uses an electrogoniometer to continuously measure the ROM can improve the accuracy and objectivity of measurement. Not surprisingly, custom devices have produced good to excellent reliability: Novotny had no significant differences between same-day or cross-day measures and the device that will be used in this project produced inter and intra-tester ICC values ranging from 0.79–0.95 for all ROM and rotational resistance measures (Grover et al., 2006).

The Shifted Motion

Shoulder IR/ER passive motion in baseball pitchers became a "hot topic" when bilateral differences were discovered (Brown et al., 1988; Baltaci et al., 2001). Average bilateral differences were calculated for six recent studies that measured pitchers (Table 2-1). The throwing arm had 8.5° more ER and 11.6° less IR and than the non-throwing arm. These findings contrast control groups (Crockett et al., 2002) in which non-throwers have no, or very limited bilateral differences.

The increased ER and decreased IR are commonly referred to as external rotation gain, or ERG, and glenohumeral internal rotation deficit, or GIRD (Myers et al., 2006). For most pitchers, the ERG is quite similar to GIRD. Wilk et al., (2002) used the phrase "total motion concept" to describe this phenomenon since the total motion of the throwing arm changes little.

Other Shoulder Motions

Other passive shoulder motions (extension, abduction, horizontal adduction) have no significant or minimal (1–2°) bilateral differences (Meister et al., 2005; Reagan et al., 2002; Baltaci et al., 2001; Baltaci et al., 2004). This makes the IR/ER motion unique and likely the most relevant to throwing arm injuries.

Table 2-1. Summary of shoulder IR/ER range of motion studies for overhead athletes.

Author	Year	Participants	ER dominant	ER non-dominant	IR dominant	IR non-dominant	Total ROM dominant	Total ROM non-dominant	Active (A) Passive (P)
Borsa	2006	34 professional baseball pitchers	135.5 (9.5)	130.4 (10.7)	59.7 (7.0)	68.2 (8.6)	195.2 (12.1)	198.6 (26.6)	P
Levine	2006	98 amateur baseball players	109 (12.1)	94 (6.9)	38 (9.5)	54 (12.3)	147	148	P
Myers	2006	11 baseball with impingement	125.8 (13.1)	117.5 (16.7)	42.5 (12.1)	62.2 (16.9)	168.3	179.7	P
Myers	2006	11 baseball controls	121.1 (8.7)	116.0 (10.3)	51.1 (14.4)	62.2 (13.7)	172.2	178.2	Pe
Ruotolo	2006	37 college baseball players	117.6	108.8	23.7	32.6	140.7	141.6	A
Borsa	2005	43 professional baseball pitchers	134.8 (10.2)	125.8 (8.7)	68.6 (9.2)	78.3 (10.6)	203.4 (9.7)	204.1 (9.7)	P
Downer	2005	27 pros (20 were pitchers)	108.9 (9.0)	101.9 (5.9)	56.6 (12.5)	68.6 (12.6)	165.5 (14.4)	170.4 (10.5)	P
Baltaci	2004	20 professional baseball	126.5 (10.8)	115.9 (10.6)	59.2 (6.9)	70.3 (5.8)	185.7 (12.7)	186.4 (11.1)	P
Baltaci	2004	20 controls	98.5 (6.8)	97.3 (9.5)	74.4 (9.2)	83.1 (9.1)	172.2 (12.4)	180.1 (9.2)	P
Schmidt-Wiethoff	2004	27 professional tennis players	89.1 (13.7)	81.2 (10.2)	43.8 (11.0)	60.8 (7.4)	132.9 (15.0)	142.0 (11.9)	P
Schmidt-Wiethoff	2004	20 controls	85.4 (7.6)	84.0 (7.3)	61.6 (8.1)	59.3 (8.3)	146.9 (8.7)	143.3 (7.5)	P
Sethi	2004	37 pro and college pitchers	110 (14)	104 (14)	68 (16)	82 (11)	178 (23)	186 (15)	P
Sethi	2004	19 position players	100 (11)	100 (12)	69 (11)	75 (10)	169 (10)	174 (10)	P
Crockett	2002	25 professional pitchers	128 (9.2)	119 (7.2)	62 (7.4)	71 (9.3)	189 (12.6)	189 (12.7)	P
Crockett	2002	25 non-throwing controls	113 (14.6)	112 (13.9)	65(8.9)	69 (7.1)	179(17.7)	181(15.3)	P
Ellenbecker	2002	46 professional pitchers	103.2 (9.1)	94.5	42.4	52.4	145.7	146.9	A
Ellenbecker	2002	117 elite junior tennis players	103.7 (10.9)	101.8	45.4	56.3	149.1	158.2	A
Osbahr	2002	19 college pitchers	126.8(12.0)	114.5(9.1)	79.3(13.3)	91.4(13.6)	206.1	205.9	P
Reagan	2002	54 college baseball players	116.3 (11.4)	106.6 (11.2)	43.0 (7.4)	51.2 (7.3)	159.5 (12.4)	157.8 (11.5)	P
Baltaci	2001	15 college pitchers	131.5 (11.5)	116.6 (11.3)	55.8 (7.1)	69.2 (4.8)	187.3	185.8	P
Baltaci	2001	23 position players	122.4 (10.9)	114.6	58.2 (7.1)	68.7 (6.8)	180.6	183.3	P
		Means for pitchers	124.8	116.3	61.8	72.9	186.4	189.0	

Sport Specific Findings

Ellenbecker attempted to determine if there are IR and ER ROM differences between tennis players and baseball pitchers. The 46 professional baseball (22.6 ± 2.0 years) pitchers were compared to 117 elite junior tennis players (16.4 ± 1.6 years). Identical methods were used to assess the athletes. Both groups lost approximately 10° of IR in the dominant arm.

Interestingly, the baseball pitchers had a significant ER bilateral difference (8.7°) but the tennis players did not. This may be related to the more extreme biomechanics of the baseball pitch during the arm-cocking phase (Feltner et al., 1986; Elliot et al., 2003). Pitchers also show significantly greater bilateral differences than non-pitching baseball players (Baltaci et al., 2001; Sethi et al., 2004).

Age and the Motion Shift

Levine examined 298 youth baseball players (age 8–28 years) with hopes of establishing the onset of the motion shift. Participants were divided into three age groups based on skeletal growth: immature group (n = 100, 8–12 years), period of maximal growth (n = 100, 13–14 years), and at or near skeletal maturity (n = 98, 15-28 years). ER and IR bilateral differences were minimal in the youngest group (4°) and then increased significantly with age. By age 13-14 years the ER bilateral difference was 10° and the IR bilateral differences 9°. Bilateral differences further increased in the oldest group to 15° in ER and 16° in IR.

Meister reported that IR and ER bilateral differences remain relatively constant from 8–12 years of age. Throughout these 4 years, bilateral differences were significant, but minimal (ER = approximately 3–5°, IR = 2–4°). At 13 years of age, both ER and IR began to reduce dramatically. From age 8 to 16 years, ER reduced in the dominant shoulder and non-dominant shoulder by 20.5° and 23.3°, respectively. IR also reduced significantly from age 8 to 16 years, but the dominant arm showed a more dramatic reduction (17.7°) compared to the non-dominant (9.1°). These reductions in ER and IR resulted in significant total range of motion loss of 32.5°. Interestingly, the total range of motion was never different in the dominant and non-dominant shoulders. The IR and ER motions appear to be dynamic in children and adolescents. The shifted motion appears to develop as other changes related to physical maturity become established. It remains unclear if these changes result from osseous change, soft tissue, or both.

Biomechanics of the Baseball Pitch

The biomechanics of the baseball pitch are thought to be extreme enough to alter the tissues of the throwing arm. Feltner et al., (1986) presented the first thorough kinematic and kinetic analysis of the baseball pitch. Eight college pitchers were analyzed. For each pitcher, 3 maximum effort pitches were captured with 2 LOCAM cameras at 200 frames per second. The following injury relevant biomechanics were reported:

- The most extreme motion was reported to be shoulder external rotation. The shoulder was externally rotated over 170° to develop high throwing velocity (Figure 2-1).
- The average time from the instant the stride foot contacted the mound to ball release was just 283 milliseconds. In addition, arm acceleration (instant of shoulder maximum ER to ball release) was only 32 milliseconds.
- At the approximate instant of ball release, shoulder internal rotation angular velocity peaked at 6100°/s ± 1700°/s.
- Torques required to externally rotate and accelerate the arm were high. Peak values were reported to be 110 N·m (horizontal adduction), 70N·m (abduction) and 90 N·m (internal rotation). The highest shoulder load was the shoulder distraction force (Figure 2-2) attempting to dislodge the humeral head at ball release. It was near, or even beyond the pitcher's body weight (860 N).

Figure 2-1. Shoulder ER during the baseball pitch. Repeated exposure to extreme ER during the pitch is thought to increase the shoulder passive ER motion.

Figure 2-2. Follow-through phase of the pitch. Shoulder loads are extremely high at the instant of ball release. The shoulder distraction force is near or beyond the pitcher's body weight. The shoulder posterior soft tissues are thought to develop tightness from repeated exposure to the follow-through loads. Posterior tightness is thought to decrease the shoulder IR passive motion.

Similarly extreme pitching biomechanics have been reported by others (Fleisig et al., 1995; Werner at al., 2001; Wight et al., 2004; Zheng et al., 2004). These biomechanics are thought to be responsible for altering the tissues of the throwing arm that cause the IR/ER motion shift (Baltaci et al., 2001; Osbahr et al., 2002).

Alterations to the Throwing Arm

Strong evidence exists to show that osseous change occurs in the form of humeral retroversion. However, the extent of the contribution to the IR/ER shifted motion remains unclear. Alterations to soft tissues have been verified surgically in injured pitchers (Burkhart et al., 2003). However, it remains unclear if soft tissue alterations significantly contribute to the shifted motion in asymptomatic pitchers. Changes to soft tissue are not as obvious since they have not been tested directly. Osseous and soft tissue studies will now be discussed.

Humeral retroversion

Humeral retroversion refers to the amount of axial "twist" in the bone. Three studies have explored retroversion in baseball pitchers (Table 2-2). Crockett completed the most thorough

study: pitchers and a control group of non-throwers were examined. Non-throwers had approximately 20° of retroversion in each humerus (the bone is retroverted towards ER). Pitchers had a 17° bilateral difference. The throwing arm had 40° of retroversion. The difference between controls and pitchers suggests that retroversion developed from pitching.

Table 2-2. Humeral retroversion in baseball pitchers.

Author	Participants	Retroversion dominant	Retroversion non-dominant	Bilateral difference	Method
Reagan et al., 2002	54 college baseball players	36.6 (9.8)	26.0 (9.4)	10.6	x-ray
Osbahr et al., 2002	19 college pitchers	33.2 (11.4)	23.1 (9.1)	10.1	x-ray
Crockett et al., 2002	25 professional pitchers	40 (9.9)	23 (10.4)	17	Multiple CT scans
Crockett et al., 2002	25 non-throwing controls	18 (12.9)	19 (13.5)	-1	Multiple CT scans

Crockett postulated that humeral retroversion is a protective adaptation that allows the pitcher to more effectively externally rotate the shoulder. Retroversion is thought to occur from repeated exposure to the biomechanics of the cocking phase of the pitch (Osbahr et al., 2002; Reagan et al., 2002). Large forces and torques associated with externally rotating the shoulder and rapidly internally rotating the shoulder are thought to alter the proximal physis in a way that leads to excessive retroversion. The humerus is thought to be particulary susceptible to being retroverted during adolescence, before bones have fully matured.

Retroversion does not fully explain the shifted IR/ER motion. Both Osbahr and Reagan tested whether the amount of retroversion was related to the shifted motion. For ER, Osbahr found a strong relationship ($R^2 = 0.71$, $p < 0.05$) in 19 college pitchers, but Reagan found a weaker relationship ($R^2 = 0.21$, $p < 0.05$) in 25 college pitchers. Relationships with IR were weak

and non-significant. The amount of variation explained is conflicting for ER and weak for IR. This suggests that soft tissue alterations likely contribute to the shifted motion.

Soft Tissue Theories

For years, researchers have theorized that alterations to the soft tissues of the shoulder contribute to the motion shift. The large follow-through loads are thought to place heavy loads upon the posterior soft tissues. Over time, the posterior capsule is thought to develop tightness that contributes to the loss of internal rotation (Pappas et al., 1985). This has been surgically verified in injured players that suffer from severe internal rotation loss (Burkhart et al., 2003). Asymptomatic pitchers may suffer similar posterior tissue tightness, but to a lesser degree. Increases in ER have been attributed to the attenuation of anterior soft tissues over time (Jobe et al., 1991). Attenuation may occur from the accumulation of microtrauma associated with the arm cocking phase of pitching (Baltaci et al., 2001).

Horizontal Adduction Tightness Tests

Tyler et al., (2000) developed a horizontal adduction test that, in theory, tests for tightness of the posterior capsule and/or rotator cuff muscles. Tightness is identified when the dominant shoulder passive horizontal adduction end ROM is significantly farther from the treatment table than the non-dominant arm. Downar et al., (2005) reported no significant bilateral difference between the dominant (30.2 cm ± 4.6 cm) and non-dominant arms (28.0 cm ± 4.8 cm) in a group of healthy professional baseball players (N = 27, 20 of which were pitchers). Myers similarly reported no bilateral differences in a group of 11 competitive asymptomatic baseball players (dominant = 21.1 cm ± 6.2 cm, non-dominant = 21.9 cm ± 6.2 cm). However, a significant deficit occurred in a group of 11 baseball players suffering from pathologic internal impingement in the throwing shoulder (throwing arm = -4.2 cm ± 4.4, non-throwing arm = 2.8 cm ± 4.4). This

test suggests these pitchers suffer from posterior tightness, however, the measure is considered limited because it is subjective by nature and only assesses ROM.

Active IR

Active IR is another theoretical test of posterior shoulder tightness that was recommended by the Amerian Academy of Orthopedic Surgeons and the Shoulder and Elbow Surgeons (Baltaci et al., 2001; Baltaci et al., 2004). For the active IR test, the participant places the posterior surface of the hand on the back and reaches vertically. The goal is to reach the highest vertebral level possible. Active internal rotation is measured as the vertical distance the thumb rests from spinous process T5. Two different groups of college baseball pitchers (N = 38 and N = 54) had significant bilateral differences of 7 cm and 10 cm, respectively (Baltaci et al., 2001; Baltaci et al., 2004). This measure suggests pitchers have posterior tightness but the measure is again considered limited because it only assesses ROM.

Glenohumeral Stiffness

Borsa et al., (2006) and Crawford et al., (2006) measured glenohumeral stiffness which is a reflection of the static structures resisting humeral head displacement from the glenoid cavity. Using a Ligmaster device, a 15-dN force is applied to the proximal humerus with the shoulder at 90° of abduction and 60° of ER. The force displacement curve is divided into two distinct regions: the initial slope and the final slope. The final slope was used to model the passive joint stiffness. The ICCs ranged from poor to excellent depending on side and direction. No bilateral differences were found. The main effect for direction was significant; anterior joint stiffness was significantly greater than posterior joint stiffness (16.4 ± 1.6 N/mm vs. 15.2 ± 3.2 N/mm, respectively). Pitching does not appear to compromise the joint's passive restraining quality but it may alter the rotational resistance.

Glenohumeral Translation

Glenohumeral translation of the shoulder is a measure of the mobility of the humeral head. Glenohumeral translation has been measured bilaterally as well (Borsa et al., 2005; Sethi et al., 2004). Borsa again applied a 15-dN anterior or posterior force to the proximal humerus. A portable ultrasound scanner was used to dynamically track the translation of the humeral head in relation to the scapula. No bilateral differences were found. No significant relationships were found between rotational and translational ROM. There was less than a millimeter of difference between sides for anterior/posterior translation. Sethi measured laxity in 56 college and professional baseball players (19 baseball position players, 37 pitchers). Electromagnetic sensors were placed under the thumb of the examiner over the bicipital groove region of the athlete's humerus. The investigator applied a manual force to produce anterior and posterior translation. Five percent (1/19) of the position players had significant bilateral translation difference greater than 3 mm. Fifty nine percent of college pitchers (10/17) and 60% of professional pitchers (12/20) had significant bilateral differences greater than 3 mm. Correlation revealed a significant moderate positive relationship ($r^2 = 0.20$) between bilateral ER differences and translation in all players. Translational measures do not appear to be strongly related to the IR/ER passive ROM shift in baseball pitchers.

Conclusions

These studies have demonstrated the importance of assessing the passive mechanical properties of the pitching shoulder. They have established the importance of the IR/ER motion and revealed that a thorough assessment, using rotational resistance measures, is warranted. Finally, these studies have identified appropriate methodological considerations that will guide data collection and analysis in this project.

CHAPTER 3
MATERIALS AND METHODS

Participants

Thirty elite baseball pitchers participated in the study (age = 22.1 ± 3.3 years; height = 1.89 ± 0.06 m; mass = 93.2 ± 6.6 kg). Thirteen were pitchers from the University of Florida team and 17 were professional minor league pitchers from the Cincinnati Reds. To participate, pitchers had to be at least 18 years of age, active with their team at the time of testing, and injury free at the time of testing (currently pitching at 100% effort). Individuals that had throwing arm surgery within the past year were excluded.

Equipment

Novotny et al., (2000) demonstrated that it is possible to reliably analyze the rotational resistance of the shoulder throughout the IR/ER passive motion using a custom device. However, Novotny's device was not specific to overhead athletes: the arm was abducted only 45°. Grover et al., (2006) developed a similar device to analyze overhead athletes. The arm was analyzed in a throwing relevant position with the shoulder abducted 90° and elbow flexed 90° (Ellenbecker et al., 2002; Borsa et al., 2006; Myers et al., 2006). Inter and intra-rater reliability was extensively tested on 22 participants and found to be good to excellent for all IR and ER rotational resistance and ROM measures (ICCs = 0.79–0.95). This device and associated methods were used in the current study. The device is called the rotational resistance device (RR device).

The RR device was built to internally and externally rotate the shoulder in an objective, controlled, and safe manner. More specifically, rotational resistance (torque required to passively rotate the arm) and angular displacement are continuously monitored as the shoulder is slowly rotated to the end ROM. A detailed description of the RR device is included (Figure 3-1).

Figure 3-1. RR device designed for measuring overhead athletes. The pitchers laid supine on an athletic training table. The arm rotation assembly was attached to an aluminum pipe (#1) that could be adjusted by inserting a metal pin into holes that were drilled in 1 cm increments. The bottom of the aluminum pipe was secured to a plywood platform. The arm rotation assembly consisted of a wheel-chair wheel, an arm support (#2), and a wrist mount (#3). A cable (#4) runs around the rim of the wheel. The arm is rotated by slowly pulling on the free end of the cable. The cable goes through a pulley (#5) that is mounted to the top of a 50-pound load cell (SBO-50, Transducer Techniques, Temecula, CA). A potentiometer (#6) was mounted to the wheel to continuously monitor angular displacement (Clarostat 73JB100). Analog data from the load cell and potentiometer were collected using an amplifier (#7) (BioAmp 215 Bridged Amplifier, Biocomunication Electronics, Madison, WI), a laptop (HP Pavilion 7020, Palo Alto, CA), and an 11-bit USB-based data acquisition device (#8) (miniLAB 1008, Measurement Computing, Middelboro, MA). Data were recorded at a rate of 100 Hz using LabVIEW software version 7.1 (Austin, TX).

For this project, several improvements were made to the RR device and data collection procedure:

- The participant layed supine on an athletic training table when analyzed, instead of sitting in a reclined chair. This helped to better control and maintain the orientation of the torso, provided the opportunity to stabilize the scapula, and allowed for better comparison of results to studies in the literature (nearly all relevant studies have examined overhead athletes in the supine position).

- One rotation complex measured the right arm and a second measured the left arm. This allowed the participant to remain nearly stationary throughout the data collection. Only one slight position adjustment occurred. After the first shoulder was examined the participant slid laterally approximately 20 cm to have the second shoulder analyzed. Previously, with only one rotation complex, the participant had to stand up and turn around to have the second shoulder assessed. Minimal position adjustment is crucial for accurate bilateral comparisons.

- A new, more optimal 50 lb (222.5 N) load cell (SBO-50, Transducer Techniques, Temecula, CA) replaced the previously used 150 lb (667.5 N) load cell. This provided a higher resolution signal that requires less amplification. Two high quality wheel chair wheels replaced the single bicycle wheel. These new wheels allowed for a better wrist mounts and more optimal potentiometer attachments. Finally, a new and improved cable and pulley was installed, and new potentiometers were used.

Arm Position

IR/ER measures were again collected with the arm in the following throwing relevant position: 90° of shoulder abduction and 90° of elbow flexion. The lateral edge of the acromion process was lined up with the edge of the training table. The RR device was adjusted such that the upper arm was in a neutral position (parallel with the floor). The center of the wheel on the rotation assembly was lined up with the long axis of the upper arm.

Scapular Stabilization

The scapula was stabilized (Figure 3-1) by applying a manual antero-posterior force to the subject's coracoid process and clavicle (Boon et al., 2000; Awon et al., 2002). This helped to islolate glenohumeral motion. The applied force was kept low enough to ensure that the participant felt no discomfort.

Data Collection

A schematic of the five step data collection process is included (Figure 3-2).

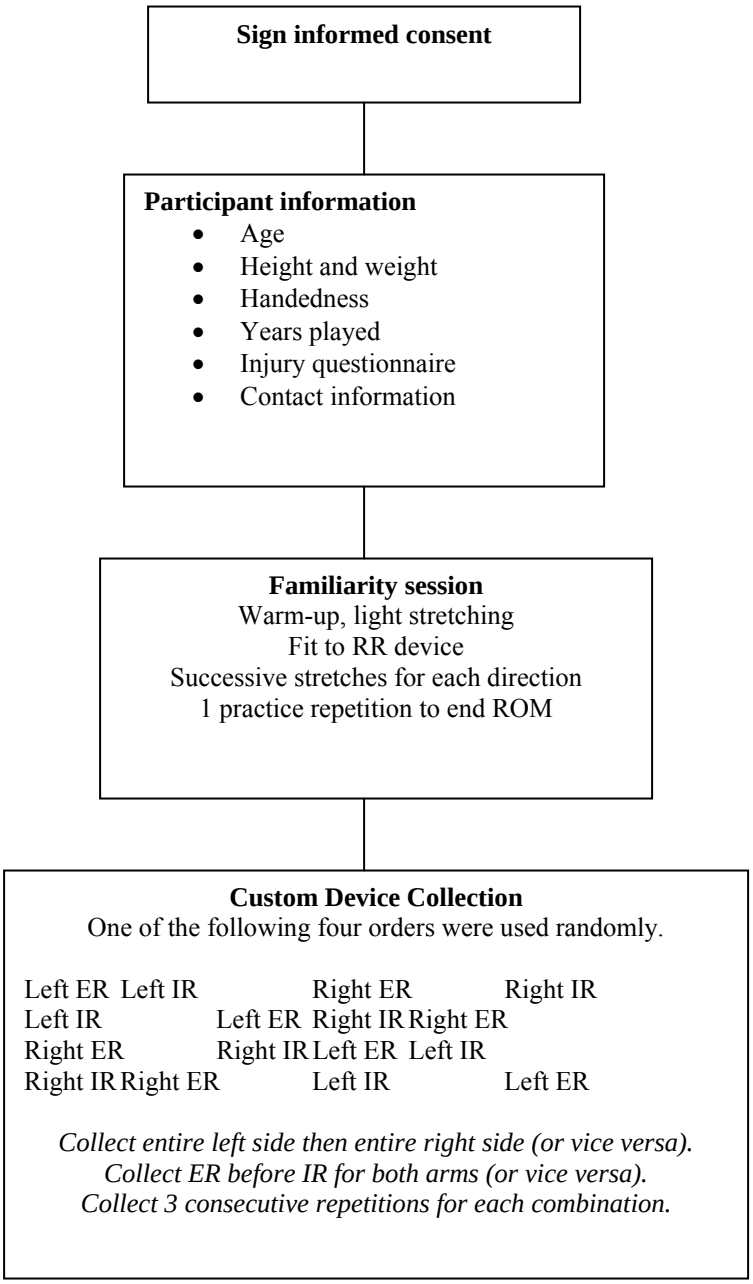


Figure 3-2. Schematic of data collection.

Prior to the data collection, each participant signed an informed consent that was approved by the University of Florida Institutional Review Board. An brief throwing arm injury questionnaire was then filled out (Appendix D). Height and weight were recorded by one

investigator. Age, handedness, years played, and contact information were recorded on a data collection sheet. Another investigator, who performed the shoulder analysis data collections, remained blind to the handedness of the participant until after the collection. Each pitcher participated in a brief familiarization period just prior to the data collection. The purpose was to familiarize the participant with the RR device, instructions, protocol, and their end ROMs (for both arms, IR and ER). For a brief warm-up, participants actively internally and externally rotated each shoulder five consecutive repetitions, or as much as necessary, to feel warmed-up.

The end ROM test was described to the participant. He was told that: 1) this examination is similar to a "sit-and-reach test", 2) the end ROM should be slightly uncomfortable but not painful, and 3) the end ROM should be able to be repeated three consecutive times. Both arms were appropriately fit in the device according to the previously described guidelines.

Two successive stretches were performed on each arm, for both IR and ER. For the first stretch, the participant was instructed to actively rotate the arm until a light stretch was felt. The participant then completely relaxed the shoulder and the investigator held the stretch for 3 seconds. The arm was then slowly returned to the neutral position (forearm pointing anterior to the chest) by the investigator. The participant was instructed to keep the shoulder completely relaxed (passive) for the second stretch. The second stretch was moderately farther (approximately 5–10° beyond the first stretch) and again held for 3 seconds before being returned to the neutral position. Next, the investigator slowly rotated the participant's shoulder to the end ROM. Rotation ceased when a firm endpoint was felt by the investigator (Borsa et al., 2006) or when the subject said "stop", whichever came first. The arm was then returned to the neutral position by the investigator.

RR Device Collection

For each arm, and each direction (IR and ER), three consecutive repetitions were collected to the end ROM. To prevent any unwanted torso movement, IR and ER were collected consecutively for each arm. The order of IR and ER was randomized for the first arm. The second arm followed the same order as the first arm (for optimal bilateral comparison). The arm was rotated very slowly. Pilot data revealed the average angular velocity to be approximately 2 °/sec for 27 previous participants. Rotation was kept this slow to eliminate any possible confounding effects associated with rotating the shoulder quickly.

Data Reduction

Reduce To Best-Fit Line

Custom programs, written in LabVIEW software, were used to reduce the displacement and force data from the potentiometer and load cell, respectively. Force was converted to torque by multiplying by the moment arm of the rotation complex (the distance from the center of the wheel to the wrist support was 0.26 m). Since the arm was rotated manually, the velocity of the rotation was slightly variable. To correct for any minor differences in velocity, all ROM values (and their associated torque) were averaged in 1/2° degree increments. The average torque data was then graphed against angular displacement.

Qualitative analysis revealed the torque to be relatively stable and below 5 N·m in the laxity zone (Figure 3-3). The torque sharply increased and became linear once approximately 5 N·m of torque was achieved. This sharp increase occurred approximately 25º before the end ROM. The first step to modeling the data was fitting each repetition with a best-fit line from the angle where 7 N·m of torque was achieved to the end ROM. R^2 values for each best-fit line were then checked. If R^2 was lower than 0.95, the data was refit with best-fit lines starting at 5 Nm and 6 Nm. The best-fit line with the highest R^2 value was then identified and used to model the data.

Seven N·m was used for 81% of the repetitions. The R^2 for the best-fit lines were high. For ER, the R^2 values were ≥ 0.93 for all repetitions. For IR, the R^2 values were lower for 4 repetitions (0.83–0.87) but very high (≥ 0.92) for the remaining majority of the repetitions.

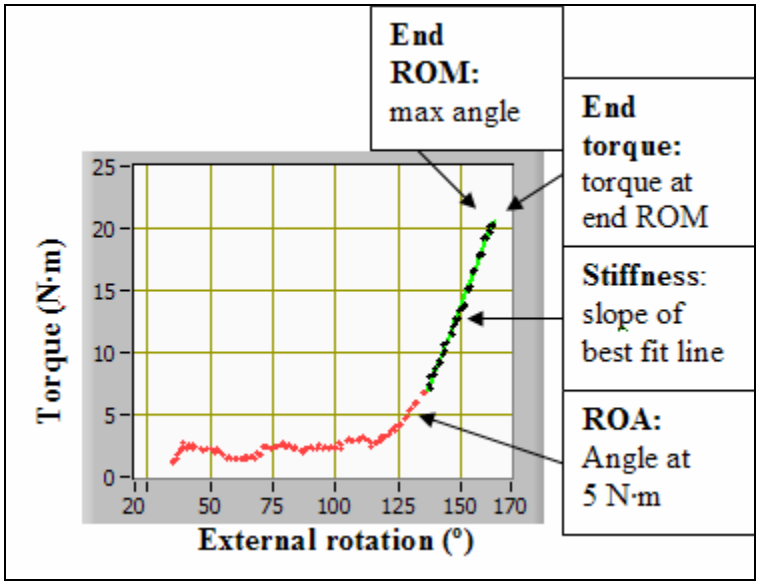


Figure 3-3. Example torque-displacement data for an ER repetition. These data were collected with the RR device and reduced using a custom program written in LabVIEW software. The experimental data and best-fit modeled data (green) are shown for one repetition of shoulder ER. Velocity is controlled for by averaging data into 1/2° slots.. Passive rotational stiffness is defined as the slope of the best-fit line and the ROA is the angle where 5 N·m of torque is first achieved. The end ROM and end torque (torque at the end ROM) were also calculated from the best-fit line.

Variables of Interest

For both arms and both directions (IR and ER), five flexibility variables were calculated. Bilateral differences were also calculated for each variable as the difference between the pitching arm and non-pitching arm (Osbahr et al., 2002)..

- The ROA is defined as the angle on the best fit line where 5 N·m of torque is achieved. The ROA is a measure of the angle where the shoulder soft tissues begin to provide substantial resistance to motion due to stretching.
- Stiffness is defined as the slope of the best-fit line. Stiffness is a measure of how tight or loose the shoulder is when it is passively rotated.
- The end ROM is defined as the farthest degree achieved on the best-fit line.

- The end torque is defined as the torque at the end ROM. It is calculated from the best-fit line.
- The resistance zone is the total displacement from the ROA to the end ROM. It is calculated by subtracting the ROA from the end ROM.

Repeated measures ANOVA were used to determine if subjects became more flexible across repetitions 1, 2, and 3. No differences among the repetitions were expected because all pitchers participated in the warm-up session. However, significant main effects were detected and follow-up tests (dependent T-tests with Bonferroni adjustments) revealed significant differences between the first and second repetitions for the ROA and stiffness suggesting that the shoulder did become more flexible (Table 3-1). Since the mechanical properties were altered between repetitions 1 and 2, data from the first repetition were not used; data from repetitions 2 and 3 were averaged for all flexibility variables.

Table 3-1. Means and SD of flexibility variables for repetitions 1, 2, and 3*

	ROA (°)			Stiffness (N·m/°)			End ROM (°)			End Torque (N·m)		
	1	2	3	1	2	3	1	2	3	1	2	**3**
D_ER	122.2 (11.6)	126.4 (13.2)	127.5 (12.5)	0.49 (0.10)	0.57 (0.12)	0.57 (0.11)	147.8 (12.2)	149.4 (12.3)	150.4 (11.8)	17.4 (3.7)	17.9 (3.2)	17.9 (3.1)
	1-2 1-3	2-1	3-1	1-2 1-3	2-1	3-1	1-2 1-3	2-1 2-3	3-1 3-2			
D_IR	60.2 (7.7)	62.9 (8.1)	63.7 (8.9)	0.46 (0.12)	0.53 (0.14)	0.54 (0.17)	80.5 (10.9)	81.8 (11.4)	83.7 (12.0)	14.5 (4.2)	15.1 (4.1)	15.8 (4.5)
	1-2 1-3	2-1	3-1	1-2 1-3	2-1	3-1	1-2 1-3	2-1 2-3	3-1 3-2	1-2 1-3	2-1 2-3	3-1 3-2

*Signficant differences are show in the boxes below the means and standard deviations. For example, 1-2 means a significant difference between repetitions 1 and 2. For both ER and IR, the mechanical properties of the shoulder (ROA and stiffness) were not different between reps 2 and 3. This suggests that the subjects were successfully warmed-up by rep 2. Interestingly, ROM increased each consecutive repetition despite no change in mechanical properties between reps 2 and 3.

Definition of Rotational Resistance Groups

The two rotational resistance variables (ROA and rotational stiffness) were used to categorize pitchers as having high, low, or moderate rotational resistance (Figure 3-4). This was performed for both ER and IR. The average ROA and average rotational stiffness were used to define groups. The low rotational resistance group had two flexible characteristics: an above

average ROA and below average rotational stiffness. The high rotational resistance group had two inflexible characteristics: a below average ROA and above average rotational stiffness. The moderate group had one flexible characteristic and one inflexible characteristic: a below average ROA and below average rotational stiffness or an above average ROA and above average rotational stiffness.

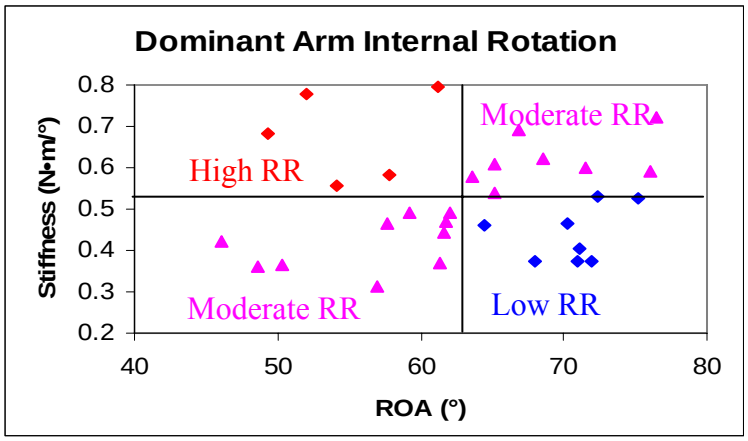


Figure 3-4. Defining groups based on rotational resistance variables. The resistance onset angle (ROA) and rotational stiffness were used to categorize pitchers as into low, moderate, and high rotational resistance groups. The vertical and horizontal lines are the average ROA and rotational stiffness, respectively.

Angle Conventions

Standard shoulder IR/ER angle conventions were used (Ellenbecker et al., 2002; Borsa et al., 2006; Myers et al., 2006). Zero degrees means the forearm is pointed anterior to the pitcher's chest. Ninety degrees of ER means the forearm is pointed superior, towards the head. Ninety degrees of IR means the forearm is pointed inferior, towards the feet.

Data Analysis

General Analysis

For most statistical tests, a conventional level of significance was used (α=0.05). When multiple T-tests were performed within a specific aim, a Bonferroni correction was used to

reduce the chance of committing a type I error. Descriptive statistics (mean and standard deviation) were calculated for all variables of interest.

Analysis of Specific Aims

Specific Aim 1a was to determine if ROM and rotational resistance are both necessary to assess shoulder IR/ER flexibility. Pearson correlations were used to determine if significant relationships exist among the following three flexibility variables: ROA, rotational stiffness, and end ROM. These tests were performed for both ER and IR of the throwing arm.

Table 3-2. Statistical analyses for aim 1a.

Test	Arm	Direction	Variables
Pearson	Throwing	ER	ROA and stiffness
Pearson	Throwing	IR	ROA and stiffness
Pearson	Throwing	ER	ROA and ROM
Pearson	Throwing	IR	ROA and ROM
Pearson	Throwing	ER	stiffness and ROM
Pearson	Throwing	IR	stiffness and ROM

Specific Aim 1b was to determine if high rotational resistance groups have significantly different ROM compared to low rotational resistance groups. Independent T-tests were used to determine if the high and low rotational resistance groups have significantly different end ROMs and/or resistance zones (α=0.05/2). These tests were completed for the throwing shoulder for both directions (IR and ER).

Table 3-3. Statistical analyses for aim 1b.

Test	Arm	Direction	Variables
Independent T-test	Throwing	ER	ROM
Independent T-test	Throwing	IR	ROM
Independent T-test	Throwing	ER	RZ
Independent T-test	Throwing	IR	RZ

Specific Aim 2a was to determine if pitching alters the soft tissue of the throwing shoulder. For both ER and IR, independent T-tests were performed to determine if the rotational resistance variables (ROA and stiffness) of the throwing shoulder are significantly different from the non-throwing shoulder (α=0.05/2).

Table 3-4. Statistical analyses for aim 2a.

Test	Arm	Direction	Variables
Independent T-test	Bilateral comparison	ER	stiffness
Independent T-test	Bilateral comparison	ER	ROA
Independent T-test	Bilateral comparison	IR	stiffness
Independent T-test	Bilateral comparison	IR	ROA

Specific Aim 2b was to determine if the magnitude of the motion shift is related to the magnitude of the stiffness change. For both ER and IR, Pearson correlations were used to determine if the ROM bilateral differences were significantly predicted by the rotational stiffness and ROA bilateral differences.

Table 3-5. Statistical analyses for aim 2b.

Test	Arm	Direction	Variables
Pearson	Bilateral difference	ER	Stiffness bilateral difference and ROM bilateral difference
Pearson	Bilateral difference	ER	ROA bilateral difference and ROM bilateral difference
Pearson	Bilateral difference	IR	Stiffness bilateral difference and ROM bilateral difference
Pearson	Bilateral difference	IR	ROA bilateral difference and ROM bilateral difference

Specific Aim 2c was to determine if the rotational resistance of the non-throwing shoulder is related to the magnitude of the motion shift. For both ER and IR, Pearson correlations were used to determine if the ROA and/or rotational stiffness of the non-throwing arm significantly predicts the motion shift (bilateral ROM difference) of the throwing arm. Independent T-tests were also used to determine if the low rotational resistance groups and high rotational resistance groups (based on the non-throwing arm) have significantly different motion shifts (α=0.05/2).

Table 3-6. Statistical analyses for aim 2c.

Test	Arm	Direction	Variables
Pearson	Both	ER	Non-throwing arm stiffness and throwing arm ROM bilateral difference
Pearson	Both	ER	Non-throwing arm ROA and throwing arm ROM bilateral difference
Pearson	Both	IR	Non-throwing arm stiffness and throwing arm ROM bilateral difference
Pearson	Both	IR	Non-throwing arm ROA and throwing arm ROM bilateral difference
Independent T-test	Throwing	ER	ROM bilateral difference
Independent T-test	Throwing	IR	ROM bilateral difference

Specific Aim 3 was to determine if incidences of throwing arm injuries are different among rotational resistance groups. Incidence of injury was compared among the previously described groups (the low, moderate, and high rotational resistance pitchers from aim 1b). Chi-square analysis was used to determine if significant differences in frequencies throwing arm injuries occurred. This test was performed for both IR and ER (α=0.05/2). A questionnaire was developed and used to determine incidences of throwing arm injuries over the past year (Appendix D).

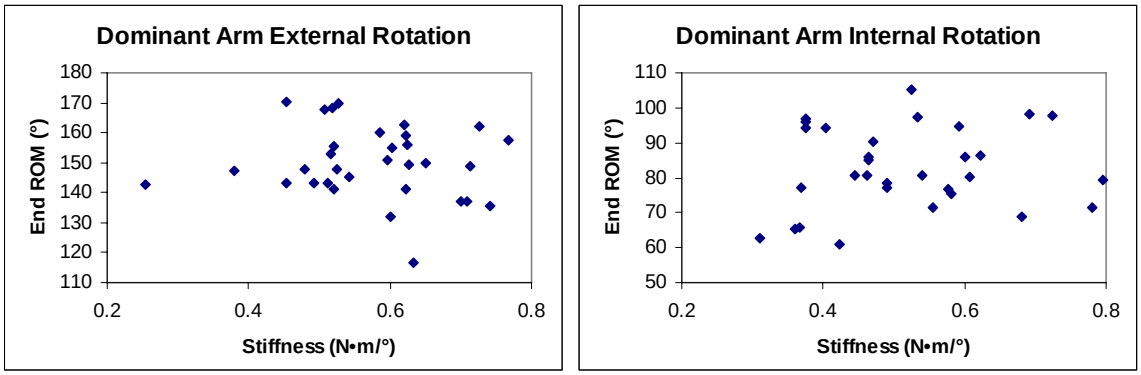
Table 3-7. Chi-square contingency table for aim 3.

	Low RR	Moderate RR	High RR
Injured			
Healthy			

CHAPTER 4
RESULTS

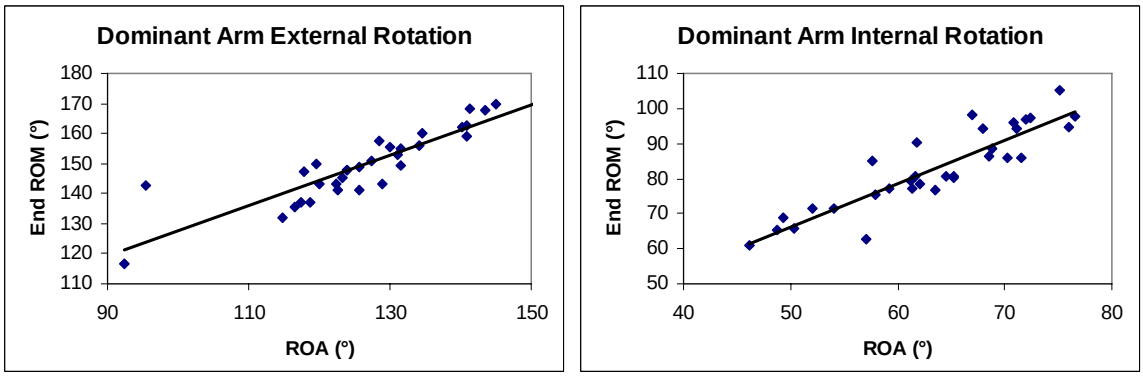
Specific Aim 1a

To determine if end ROM and rotational stiffness are both needed to assess shoulder IR/ER passive flexibility. For both ER and IR, Pearson correlation analysis revealed no significant relationship between stiffness and end ROM in the throwing shoulder (Figure 4-1). The ROA and end ROM were positively correlated for both ER and IR (Figure 4-2). For ER, the ROA occurred 23.0° ± 5.9° before the end ROM. For IR, the ROA occurred 19.4° ± 5.6° before the end ROM.



r = 0.11, R^2=0.01, p=0.55 r = 0.15, R^2=0.02, p=0.42

Figure 4-1. Stiffness versus end ROM for the throwing shoulder. As hypothesized, stiffness and end ROM were not related for both ER and IR.

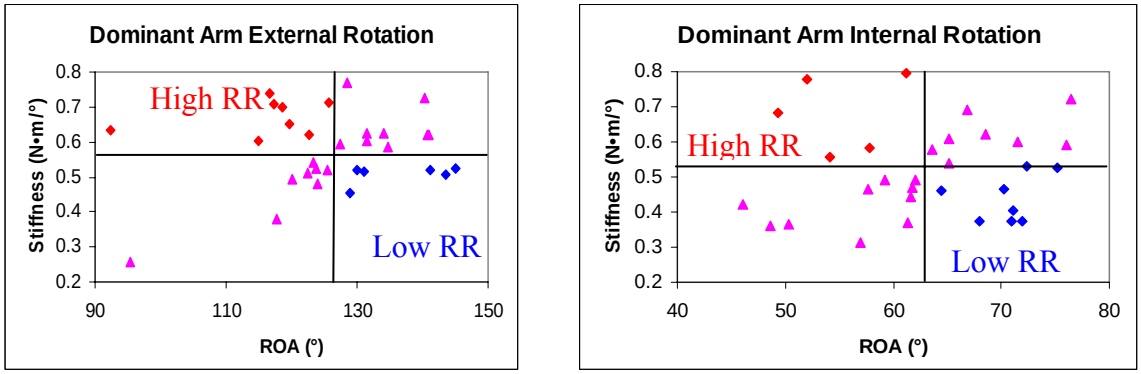


r = 0.89, R^2=0.79, p<0.001* r = 0.90, R^2=0.80, p<0.001*

Figure 4-2. ROA versus end ROM for ER and IR of the throwing shoulder.

Specific Aim 1b

To determine if high rotational resistance groups have a significantly different end ROM compared to low rotational resistance groups. As expected, comparable numbers of pitchers were in the high and low rotational resistance groups (Figure 4-3). For IR, 5 pitchers had high rotational resistance (ROA = 54.9 ± 4.7°; stiffness = 0.68 ± 0.11 N·m/°) and 7 pitchers had low rotational resistance (ROA = 70.5 ± 3.2°; stiffness = 0.43 ± 0.07 N·m/°). For ER, 8 pitchers had high rotational resistance (ROA = 116.0 ± 10.1°; stiffness = 0.67 ± 0.05 N·m/°) and 7 pitchers had low rotational resistance (ROA = 138.8 ± 8.8°; stiffness = 0.50 ± 0.03 N·m/°).



r = 0.15, R^2=0.01, p=0.61 r = 0.09, R^2=0.02, p=0.42

Figure 4-3. Formation of high and low rotational resistance (RR) groups for ER and IR. Vertical lines are at the mean ROA and horizontal lines are drawn at the mean stiffness. High RR pitchers have a below average ROA and above average stiffness. Low RR pitchers have an above average ROA and below average stiffness.

As hypothesized, the high rotational resistance groups had significantly limited ROM compared to the low rotational resistance groups for both IR and ER (Table 4-1). The difference was approximately 20° for both IR and ER. The resistance zones (difference between end ROM and ROA) were not significantly different between the high and low rotational resistance groups. However, the 5° difference between the low and high IR groups approached significance (p=0.06).

Table 4-1. ROM and resistance zones for the high and low rotational resistance groups.

	High rotational resistance group	Low rotational resistance group	p-value
IR end ROM	73.2° (4.1°)	93.8° (7.6°)	p<0.001*
ER end ROM	137.3° (10.5°)	161.1° (10.6°)	p=0.001*
IR resistance zone	18.3° (0.9°)	23.3° (5.0°)	p=0.06
ER resistance zone	21.3° (4.4°)	22.3° (4.4°)	p=0.66

Specific Aim 2a

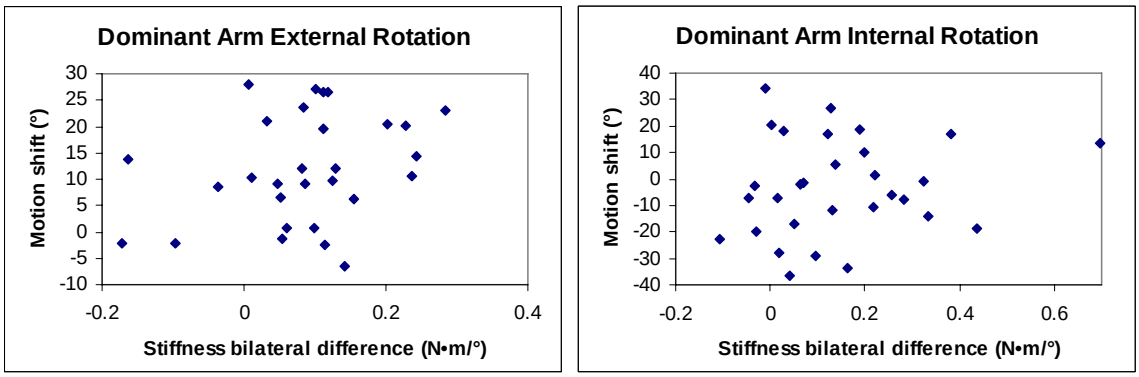
To determine if pitching alters the soft tissues of the throwing shoulder. The dominant shoulder had significantly greater ER stiffness (approximately 20%) than the non-dominant shoulder (Table 4-2). This finding did not support the original hypothesis; the dominant shoulder was expected to be less stiff than the non-dominant shoulder. For IR, the dominant shoulder was significantly stiffer (approximately 39%) than the non-dominant shoulder, as expected. The dominant shoulder had a significantly later ROA than the non-dominant shoulder (approximately 10°) for ER. For IR, the ROA bilateral difference approached significance (p=0.03); the dominant arm had an earlier ROA than the non-dominant shoulder (approximately 5°). Significant bilateral differences were revealed for the ER end ROM: the dominant shoulder had approximately 12° more motion. The dominant shoulder had a limited IR end ROM compared to the non-dominant, but the difference was not significant. The dominant shoulder required significantly more torque (approximately 22%) to be externally rotated to end ROM. The dominant shoulder also had a significantly larger ER resistance zone (approximately 20%).

Table 4-2. Bilateral comparison of flexibility variables for ER and IR.

	Pitching shoulder	Non-pitching shoulder	p-value
ER ROA	127.4° (13.0°)	118.1° (10.7°)	p<0.01*
ER stiffness	0.57 N·m/° (0.11 N·m/°)	0.48 N·m/° (0.09 N·m/°)	p<0.01*
ER ROM	150.6° (12.1°)	137.9° (10.8°)	p<0.001*
ER resistance zone	23.1° (6.0°)	19.2° (17.2°)	p<0.025*
ER torque at end ROM	17.9 N·m (3.1 N·m)	14.7 N·m (3.0 N·m)	p<0.01*
IR ROA	62.7° (8.3°)	67.9° (9.7°)	p=0.03
IR stiffness	0.54 N·m/° (0.16 N·m/°)	0.39 N·m/° (0.07 N·m/°)	p<0.001*
IR ROM	81.9° (11.3°)	85.1° (14.0°)	p=0.34
IR resistance zone	19.2° (5.3°)	17.2° (8.2°)	p=0.27
IR torque at end ROM	15.2, 4.3	11.8, 3.7	p<0.001*

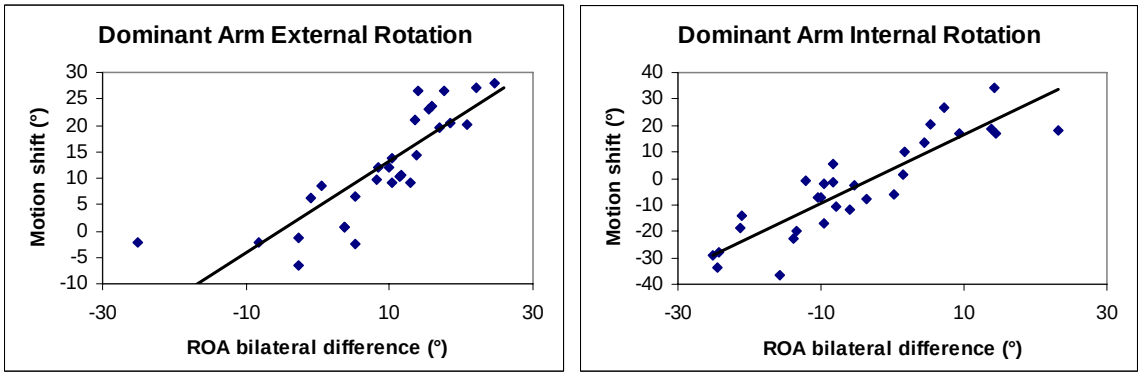
Specific Aim 2b

To determine if the magnitude of the motion shift is related to the magnitude of the stiffness change. Bilateral stiffness differences did not predict the IR and ER motion shifts as hypothesized (Figure 4-4). However, bilateral ROA differences significantly predicted the motion shifts for ER and IR (Figure 4-5). Pearson correlation analysis revealed strong positive correlations between the motion shifts and their respective bilateral ROA differences.



r = 0.34, R^2=0.11, p=0.07 r = 0.14, R^2=0.02, p=0.46

Figure 4-4. Bilateral stiffness difference versus the motion shift for the dominant shoulder. For both ER and IR, the motion shift is not predicted by the bilateral stiffness difference.

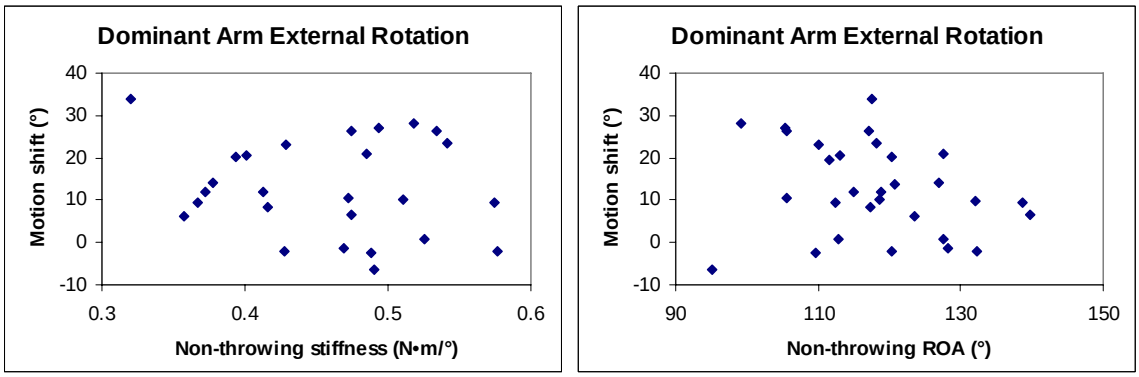


r = 0.85, R^2=0.72, p<0.001* r = 0.89, R^2=0.79, p<0.001*

Figure 4-5. Dominant shoulder ROA bilateral differences versus the motion shift. Pearson correlation analysis revealed strong positive correlations for ER and IR.

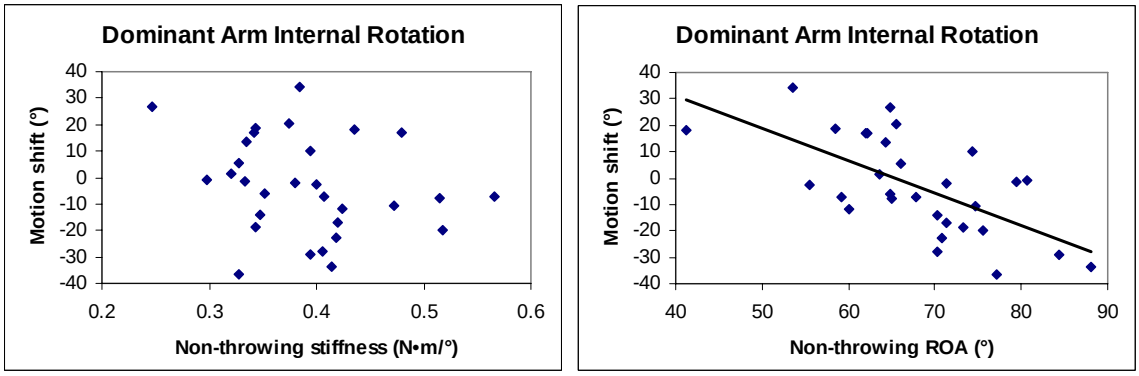
Specific Aim 2c

To determine if the rotational resistance of the non-throwing shoulder is related to the magnitude of the motion shift. Non-dominant shoulder rotational resistance variables did not predict the motion shift for ER (Figure 4-6). However, for IR, the non-dominant ROA was significantly negatively correlated to the motion shift (Figure 4-7). Non-dominant IR stiffness was not related to the motion shift.



r = 0.16, R^2=0.02, p=0.40 r = 0.24, R^2=0.06, p=0.18

Figure 4-6. Non-dominant ER rotational resistance measures versus the ER motion shift. ROA and stiffness did not predict the motion shift.



r = 0.25, R^2=0.06, p=0.19 r = 0.65, R^2=0.41, p<0.001*

Figure 4-7. Non-dominant IR rotational resistance measures versus the IR motion shift. Stiffness did not predict the motion shift but the ROA was a significant moderate predictor.

Low and high rotational resistance groups were formed for the non-dominant arm (Figure 4-8). For IR, 6 pitchers had high rotational resistance (ROA= 57.2 ± 8.4°; stiffness = 0.55 ± 0.08 N·m/°) and 6 pitchers had low rotational resistance (ROA= 75.3 ± 4.3°; stiffness = 0.34 ± 0.03 N·m/°). For ER, 8 pitchers had high rotational resistance (ROA=106.5 ± 6.5°; stiffness = 0.55 ± 0.08 N·m/°) and 8 pitchers had low rotational resistance (ROA=127.1 ± 8.2°; stiffness = 0.40 ± 0.05 N·m/°).

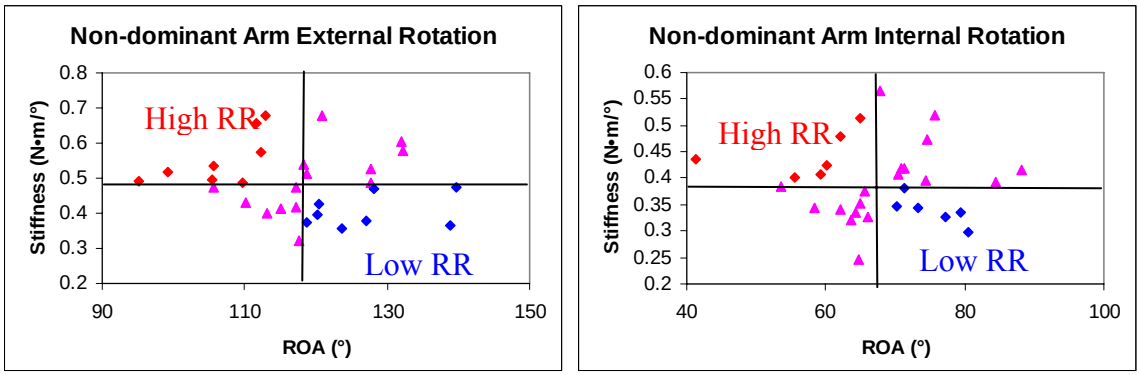


Figure 4-8. High and low rotational resistance groups for the non-dominant ER and IR.

For both IR and ER, the high rotational resistance groups were hypothesized to have significantly greater motion shifts than the low rotational resistance groups. However, no significant differences were revealed (Table 4-3).

Table 4-3. Mean motion shifts for non-dominant shoulder rotational resistance groups.

	High rotational resistance group	Low rotational resistance group	p-value
ER motion shift	12.8° (14.3°)	8.1° (7.6°)	p=0.43
IR motion shift	0.9° (13.2°)	-12.3°(14.2°)	p=0.13

Specific Aim 3

To determine if incidence of throwing arm injuries are different among rotational resistance groups. Throwing arm injuries were prevalent in this group of elite pitchers. Fourteen

of the 30 pitchers had a throwing arm injury that made them unable to pitch for at least one week of practice or games over the past year. Six (43%) were elbow injuries and 8 (57%) were shoulder injuries. The injured pitchers missed an average of 10.5 ± 16.7 weeks over the previous year. Ten of the 14 (71%) injured pitchers visited a physician for their injury. A summary of the self-reported injuries are included (Table 4-4). The injured pitchers were dispersed among the low, moderate, and high rotational resistance groups for both ER (Figure 4-10) and IR (Figure 4-11). Chi-square analysis revealed no significant differences in incidence of injury among the groups for both ER (p=0.90) and IR (p=0.41).

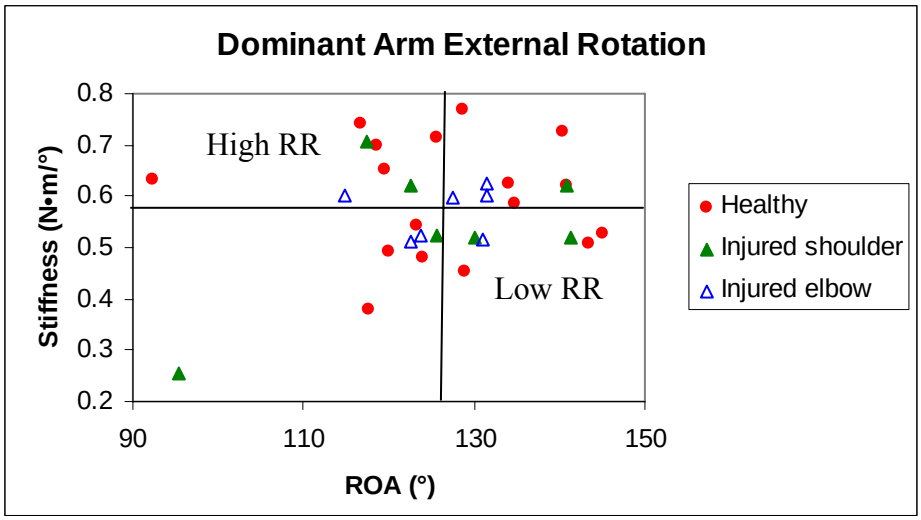


Figure 4-9. Prevalence of shoulder and elbow injuries with respect to ER passive flexibility. A vertical line is drawn at the mean ROA and a horizontal line is drawn at the mean stiffness. Shoulder and elbow injuries were dispersed among the low, moderate, and high rotational resistance groups for ER.

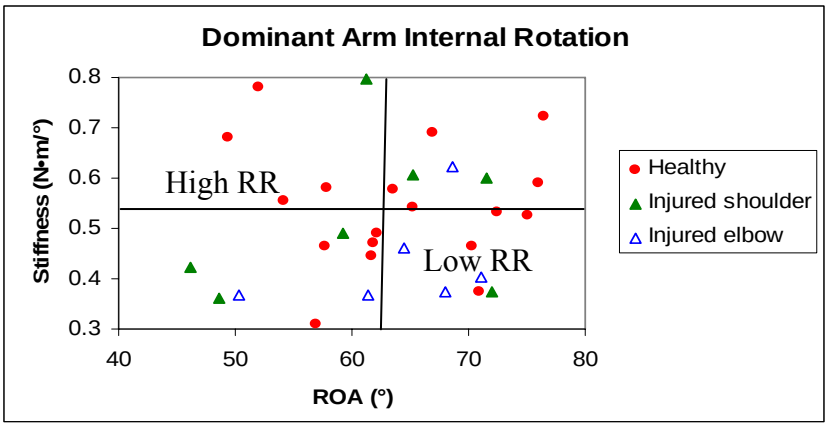


Figure 4-10. Prevalence of shoulder and elbow injuries with respect to IR passive flexibility. A vertical line is drawn at the mean ROA and a horizontal line is drawn at the mean stiffness. Shoulder and elbow injuries were dispersed among the low, moderate, and high rotational resistance groups.

Table 4-4. Summary of self-reported throwing arm injuries.

Elbow (E) or Shoulder (S)	Self-reported injury	Was a physician seen?	Time missed	College (C) or Professional (P)
S	Lateral shoulder pain	No	2 weeks	C
S	Posterior shoulder tightness	Yes	3 weeks	C
S	Shoulder bursitis	Yes	10 days	P
S	Partial tear of supraspinatus	Yes	10 days	P
S	Subluxation which caused bicep tendonitis	No (worked with athletic trainers)	1 month	P
S	Proximal tricep tendon pain	Yes	1 month	P
E	Distal bicep tendon pain	Yes	1 week	C
E	UCL torn 2 years ago	Yes	2 weeks	C
E	UCL partially torn 2 years ago	Yes	6 months	C
E	Recently recovered from UCL that was torn 2 years ago	Yes	11 months	C
E	Medial elbow pain	No	2 weeks	C
E	Recently recovered from a stitch put in UCL (1 year ago)	Yes	11 months	P
E	Tore UCL 2 years ago	Yes	1 month	P
E	Medial elbow pain	No	1 week	P

CHAPTER 5
DISCUSSION

This discussion is composed of four sections. First, this sub-population of pitchers is addressed. Second, descriptive statistics are highlighted to reveal important general findings. Focus is placed upon the variability of rotational resistance and injury rates in this group of pitchers. Third, the specific research aims are addressed individually. Fourth, a summary of the relevance of this study is provided by sharing general conclusions, practical applications, and future research recommendations. When appropriate, relations between results from this study and those in the literature are discussed. However, the ability to do so is limited since this is the first analysis of shoulder rotational resistance in overhead athletes. Therefore, the majority of the discussion is focused on the interpretation and meaning of the results and future research.

Description of Pitchers

This first analysis of rotational resistance was performed on a relatively homogenous group of pitchers. All pitchers were elite (University of Florida or professional minor league pitchers) and the majority were young (22.1 ± 3.3 years), tall (1.89 ± 0.06 m) and had large body mass (93.2 ± 6.6 kg).

Methods in this study were designed to be similar to those used in studies that analyzed similar groups of elite pitchers (Borsa et al., 2005, Borsa et al., 2006, and Crockett et al., 2002). During analysis, the pitchers laid supine on an athletic training table, the scapula was stabilized, and the elbow remained flexed at 90°. Interestingly, mean ER and IR ROM values in this study are 5-15° greater than those previously reported for similar groups of pitchers. Two factors may have contributed to this discrepancy. First, ROM values are highly dependent on the analyzer(s) and/or the group of pitchers so variation can be expected (Table 2-2 for a review). Second, when assessing the motion manually, it may be difficult for a single analyst, or uncomfortable for the

participant, to hold the shoulder at the end ROM while measures are being taken. In this study the shoulder did not have to be held at the end ROM; the shoulder was rotated to the end ROM and then immediately taken back to the neutral position. Future studies could explore this issue by having the same analyst assess shoulders manually and with a custom device.

This data set is considered to be a good representation of elite pitchers since the ROM values are relatively close to those reported in the previously mentioned studies. Also, the ER and IR bilateral differences in this study were comparable to those of Borsa and Crockett: the dominant shoulder had greater ER (13°) and limited IR (4°) compared to the non-dominant arm.

Important General Findings

One analysis of shoulder IR and ER stiffness was completed seven years ago (Novotny et al., 2000) on a healthy, non-throwing population (N=10). Some methods used by Novotny drastically differed from those used in this study. For example, Novotny ceased shoulder rotation at 5 N·m of torque, therefore, only a fraction of the total shoulder ROM was analyzed (139.4º ± 40.5º). In the current study, the entire shoulder ROM was analyzed; torque was applied as necessary to achieve the end ROM for both IR and ER. We found the true total ROM to be 232.5º which was nearly 100º greater than the total ROM reported by Novotny. Rotating the shoulder to the end ROM required over three times as much torque for ER (17.9 N·m) and IR (15.2 N·m).

Pitchers in this study had far greater shoulder stiffness than the non-throwers studied by Novotny. For ER, the stiffness was approximately 11 times greater (0.05 N·m/º vs. 0.57 N·m/º) and for IR the stiffness was approximately 3 times greater (0.17 N·m/º vs. 0.54 N·m/º). These large differences may be related to the arm positions analyzed. Novotny assessed the shoulder with the arm close to the torso (shoulder abducted 45º) while we assessed the shoulder with the arm in a throwing-relevant position (shoulder abducted 90º). It is possible that in the 90º

abducted position the shoulder soft tissues are stretched more than the 45º abducted. This discrepancy may help to explain the stiffness differences between the studies. Future studies should compare shoulder stiffness at various shoulder position to clarify. Methods used to calculate stiffness also varied between the two studies. Novotny analyzed shoulder stiffness from the angle where 1 Nm of torque was applied to the angle where 5 Nm of torque was applied. We analyzed shoulder stiffness from the angle where 5 N·m of torque was applied to the end ROM. Presumably, Novotny analyzed the shoulder as the soft tissues began to stretch while we analyzed the shoulder as the soft tissues approached their maximum stretch. This discrepancy may also contribute to the different stiffness values between the studies. Future studies shoulder compare throwers and non-throwers at various shoulder positions to better understand the unique characteristics of the throwing shoulder.

Magnitude of Rotational Resistance

A potential contribution of this line of research is determining the relevance of passive soft tissue stretching to joint moments during various activities. Silder et al., (2007) addressed this issue for the hip. The hip joint was passively extended to the end ROM (15º) in 20 healthy young adults. The torque generated by the stretching of hip soft tissues was approximately 20 N·m. This passive torque was approximately 50% of the hip flexor moment reported at toe-off during gait. Silder concluded that "passive mechanisms may contribute substantially to the hip flexor moment seen during normal gait".

The torque required to passively externally rotate the dominant shoulder to the end ROM was high (17 N·m) and relatively similar to the passive hip flexor moment reported by Silder (20 N·m). It seems reasonable to conclude that pitchers likely overcome more than 17 N·m of passive torque when externally rotating the shoulder during the pitch because the pitching end ROM (180º) exceeds the passive end ROM by approximately 50º (Zheng et al., 2004). Regardless, the

magnitude of the passive external rotation torque reported in this study suggests that externally rotating shoulder during the pitch is challenging and it may help to explain why pitchers rotate the torso at such high velocities during the arm-cocking phase of the pitch (Matsuo et al., 2001). Interestingly, the passive ER shoulder torque in this study is approximately 33% of the maximum internal rotation torque reported for the arm cocking phase of the pitch (Zheng et al., 2004). This finding suggests that shoulder passive mechanisms may greatly contribute to the shoulder moments generated during the pitch and therefore may be relevant to throwing arm injuries and performance. Future studies should assess whether the shoulder ER passive properties influence pitching kinematics and kinetics used to externally rotate the shoulder during the pitch. Future studies should also attempt to determine if shoulder passive ER properties are related to pitching performance.

The torque required to passively internally rotate the shoulder in this study was also high (approximately 14 N·m). Interestingly, during the pitch, shoulder IR is ceased at 0° (Zheng et al., 2004) which is well short of the passive end ROM (81°). The IR rotational resistance is therefore not likely directly relevant to the IR motion during the pitch. Instead, it is likely indirectly relevant to other shoulder motions during the follow-through such as distraction, adduction, and horizontal adduction. The relevance of IR rotational resistance to kinematics and kinetics of the follow-through phase should also be assessed.

High Variability in Rotational Resistance Among Subjects

This apparently homogenous group of pitchers had drastically different rotational resistance. For example, the angle where the soft tissues first provided substantial resistance (the ROA) varied drastically. Nine pitchers had an IR ROA less than 120° while 6 exceeded 140°. Similar patterns were revealed for ER. The stiffness of the dominant shoulder was also highly variable. Seven pitchers had extremely low ER stiffness (< 0.4 N·m/°) while 6 pitchers exceeded

0.7 N·m/°. This finding revealed that some pitchers have “stiff” shoulders while others have “loose” shoulders. Similar patterns were found for IR stiffness. This drastic variation may help to better identify pitchers at risk of injury.

Prevalence of Throwing Arm Injuries

Fourteen of the 30 pitchers had a throwing arm injury serious enough to cause at least one week of missed practice or games (Table 4-5). This data further illustrates the high incidence of throwing arm injuries in baseball pitchers and is considered valuable since very few studies have addressed this issue.

Specific Aims

Aim 1a

Aim 1a to determine if ROM and rotational stiffness are both necessary to assess shoulder IR/ER flexibility. A major goal of this project was to determine if stiffness is a useful measure that can help to better assess shoulder flexibility in baseball pitchers. Stiffness, in this study, is a measure of how “tight” or “loose” the shoulder is as it is rotated to the end ROM. This is the first study to measure rotational stiffness in baseball pitchers. Results from aim 1a suggest that stiffness does indeed provide new and important information about the flexibility of the throwing shoulder. The most important finding may be that ROM and stiffness are not related, as hypothesized. This means that two players can have similar ROM but drastically different stiffness (or vice versa). Extreme examples were revealed for both IR and ER. For example, two pitchers with similarly low IR stiffness (approximately 0.45 N·m/º) had IR end ROMs that differed by 30º (Figure 4-1). Large ROM discrepancies (≥30º) were also found among pitchers with similar stiffness at moderate and high levels (approximately 0.6 N·m/º and 0.7 N·m/º, respectively). Similar patterns occurred for ER. These findings suggest that the addition of

rotational stiffness is valuable because it can help to better assess shoulder flexibility (as opposed to analyzing ROM alone).

Previous studies have addressed how tight or loose the pitching shoulder is in a static situation. Borsa et al., (2005) accomplished this by applying a 15-dN anterior or posterior force to the proximal humerus and measuring how far the humeral head translated. Interestingly, the amount of humeral humeral head translation did not predict the end ROM for IR or ER. From this study and Borsa et al., (2006), it is quite clear that rotation and translation measures of shoulder looseness or tightness measures do not predict the absolute ROM. What remains unclear is if rotational or translation stiffness can be altered (via stretching, exercise, or throwing interventions) and if alterations to stiffness influence the end ROM. For example, resistance training may increase rotational or translational stiffness (which may decrease the ROM) and/or stretching interventions may decrease stiffness (which may increase the ROM).

The ROA was also analyzed for the first time in this study. The ROA is a measure of the angle where the soft tissues begin to provide substantial resistance to stretching. The ROA was highly variable among pitchers; for both ER and IR the ROA range exceeded 30º. The ROA is also relevant to study because it determines the beginning of the resistance zone. The resistance zone represents the portion of the motion (ER or IR) where the soft tissue is providing resistance because it is being stretched. The resistance zone begins at the ROA and ends at the end ROM. For IR, the resistance zone was 19.4 ± 5.6º. For ER, the resistance zone was 23.9 ± 5.9º. Interestingly, the ROA strongly predicts the end ROM for both IR and ER. This strong correlation suggests that most pitchers have a resistance zone of similar size. To simplify, an analyst can expect approximately 20º of passive motion once the soft tissue begins to provide substantial resistance from stretching. Future research should focus on the relevance of the

resistance zone to throwing arm injuries. Pitchers who have abnormal resistance zones (limited or excessive) may be more susceptible to injuries than pitchers with average resistance zones.

Aim 1b

To determine if high rotational resistance groups have significantly different ROM compared to low rotational resistance groups. A major focus of this study was identifying and further analyzing pitchers that had high rotational resistance and low rotational resistance. Pitchers with high rotational resistance were defined as those that had two inflexible characteristics: an early ROA and a stiff shoulder. Pitchers with low rotational resistance were defined as those that had two flexible characteristics: a late ROA and loose shoulder. As hypothesized, pitchers with low rotational resistance had significantly greater ROMs compared to pitchers with high rotational resistance. For ER, the low rotational resistance group had a ROM approximately 24º greater than the high rotational resistance group. For IR, the low rotational resistance group had a ROM approximately 20º greater than the high rotational resistance group. The data suggest that pitchers with high rotational resistance are "inflexible" and that pitchers with low rotational resistance are "flexible".

High rotational resistance pitchers were expected to have limited resistance zones since they have stiff shoulders. Interestingly, there was no difference between stiff and loose pitchers; the resistance zone was between 18-23º for all groups. Stiffness had no apparent affect on the motion acquired. But stiffness did demonstrate kinetic relevance. Stiff shoulders appear to require more applied torque to achieve the end ROM. For example, the stiff shoulders of the high rotational resistance group required approximately 20% more applied torque to achieve the ER end ROM than the loose shoulders of the low rotational resistance group. This difference approached significance ($p = 0.05$). The differences in these passive mechanical properties

among pitchers should be further explored because they may make some pitchers more susceptible to throwing arm injuries than others.

Aim 2a

To determine if pitching alters the soft tissue of the throwing shoulder. Results for aim 2a demonstrate that the passive ER and IR flexibility of the throwing shoulder is indeed different from that of the non-throwing shoulder. Previous researchers have hypothesized that the anterior soft tissues of the shoulder become more flexible from repeatedly exposure to extreme external rotation during pitching (Pappas et al., 1985). Unexpected results were revealed; the passive ER rotational stiffness of the throwing shoulder was significantly greater (20%) than the non-throwing shoulder. This finding is important because it demonstrates that the soft tissues of the throwing shoulder are different from that of the non-throwing shoulder. Future studies should strive to better understanding the relevance of this difference between the throwing and non-throwing shoulder as it may help to better identify players at risk for injury and improve injury rehabilitation.

The meaning and limitations of the passive rotational resistance measures are important to address. It is possible that the increased ER stiffness of the throwing shoulder results from the tightening of anterior shoulder soft tissues. However, other potential hypotheses exist because the passive torque collected in this study is a measure of the collective resistance of the shoulder. For example, the stiffness increase may result from hypertrophy of the throwing shoulder internal rotators. Hypertrophy may be associated with the increased internal rotation strength of the throwing arm reported in professional pitchers; Ellenbecker et al., (1997) revealed that the throwing arm produced significantly greater internal rotation isokineitc torques than the non-throwing arm. Future research should attempt to better understand why the ER stiffness is greater

in the throwing shoulder. Examining stiffness bilaterally in non-throwers would help to reveal if pitchers develop increased ER stiffness or if the dominant shoulder is "naturally" stiffer.

The ROA is a measure of the angle where the soft tissue begins providing substantial resistance to rotation (due to stretching). ER ROA analysis revealed the throwing shoulder soft tissues to provide substantial resistance 9º later than the non-throwing shoulder. Both bony and/or soft tissue alterations to the throwing arm may be responsible for this "shift". A bony alteration that may contribute to the 9º ROA shift is humeral retroversion. Three studies have shown the pitching arm humerus to be retroverted ("twisted" along its axis) 11-17º back towards ER. Pitching is thought to cause retroversion because non-throwers have no bilateral difference. Future studies should address the relationship between humeral retroversion and the increased ROA of the throwing shoulder.

The ROA "shift" is also important to study because it may influence the resistance zone. In this study, the throwing shoulder ER resistance zone was 4º larger than the non-throwing shoulder. This difference occurred because the ROA bilateral difference was less than the ROM bilateral difference (Figure 5-1).

The importance of the size of the resistance zone, alterations to the resistance zone, and mechanisms should be addressed. Finally, it is important to note that a significantly higher torque was applied to externally rotate the torque to the end ROM. It is unclear if this is due to differences in the passive mechanical properties of the throwing and non-throwing shoulders or differences in discomfort as the end ROM is approached.

Previous studies have examined posterior shoulder tightness indirectly using bilateral ROM tests. Significant bilateral differences have been reported for tests including passive IR (Borsa et al., 2005), active IR (Ellenbecker et al., 2002), horizontal adduction (Myers et al.,

2006), and reaching to the highest vertebra behind the back (Baltaci et al., 2001). Passive IR was the only ROM measure analyzed in this study. Previous passive IR ROM studies on comparable groups of pitchers have reported the throwing shoulder to have an internal rotation deficit of approximately 10º. As stated previously, this group of pitchers did not have a significant internal rotation deficit. Therefore, if this group of pitchers would have been analyzed with ROM alone, no evidence of posterior tightness would have been revealed. Interestingly, the preliminary rotational resistance analysis did find evidence for posterior tightness, despite the lack of a IR deficit. The throwing shoulder was 38% stiffer than the non-throwing shoulder the earlier ROA (5º) approached significance ($p = 0.03$), and 29% more torque was required to internally rotate the throwing shoulder to the end ROM (with no differences in the size of the resistance zone). It is important to repeat a similar analysis in pitchers with a significant IR deficit (approximately 10º) like the aforementioned studies. Doing so would help to determine if rotational resistance bilateral differences increase even more in pitchers with a large deficit. Also, future studies should be completed on a population of pitchers with shoulder impingement since they are known to suffer from severe IR deficits (Myers et al., 2006). Finally, the relationship between IR rotational resistance and humeral retroversion should be explored. Previous studies have revealed no relationship or a weak relationship between humeral retroversion and the IR loss (Osbahr et al., 2002; Reagan et al., 2002). Exploring relationships between humeral retroversion and IR rotational resistance may help to better understand if humeral retroversion at least partially contributes to this loss of IR motion. This is important because limited IR motion is associated with throwing arm injuries including SLAP lesions (Burkhart et al., 2003) and shoulder impingement (Myers et al., 2006).

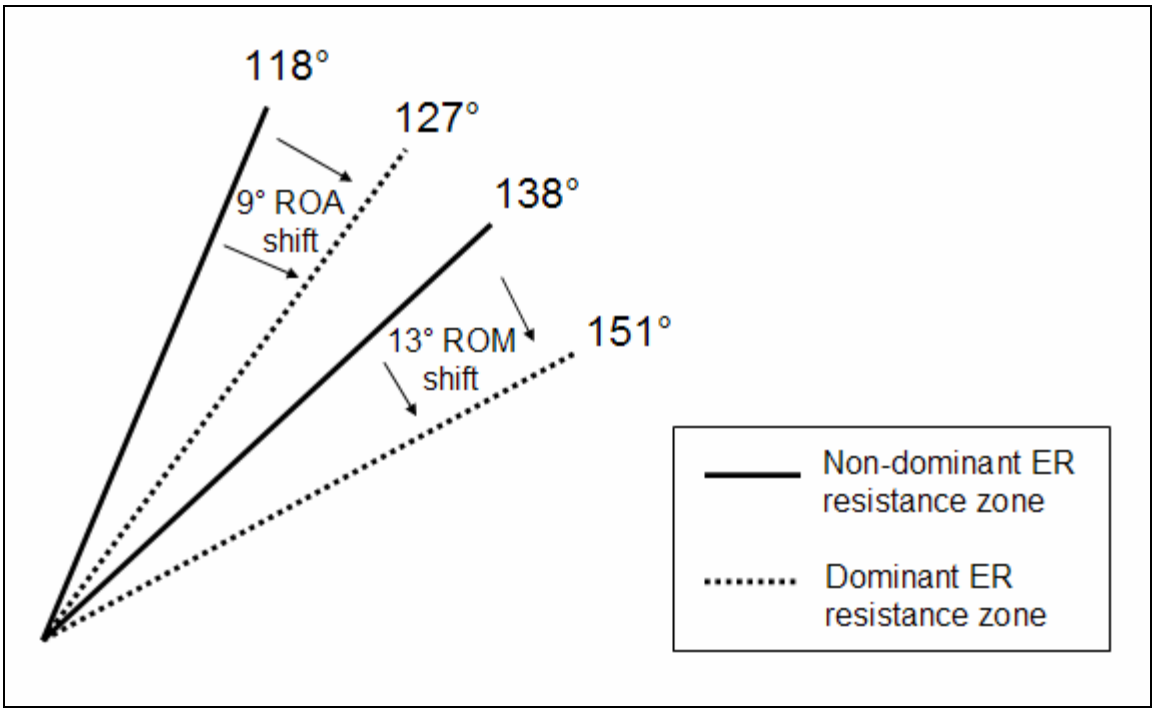


Figure 5-1. The ROA and ROM shifts for external rotation. The ROM shift is 4º larger than the ROA shift for ER. This discrepancy increases the ER resistance zone for the throwing shoulder.

Aim 2b

Aim 2b was to determine if the magnitude of the motion shift is related to the magnitude of the stiffness change. The ER motion shift was hypothesized to be associated with a decrease in ER stiffness and the IR motion shift was also hypothesized be associated with an increase in IR stiffness. Neither motion was significantly correlated with their respective stiffness bilateral difference. It is still possible that alterations to soft tissues contribute to the motion shift; the passive mechanical properties of soft tissue structures (such as rotator cuff muscles or the capsule) may play an important role. But the passive rotational stiffness measure, which is a reflection of all soft tissues, clearly did not predict the motion change in this study.

The magnitude of ER and IR motion shifts were strongly related to their respective ROA bilateral differences. For most pitchers, the ROM bilateral difference was similar to the ROA bilateral difference (both the direction and magnitude). It is important to note that this trend

remained even for the pitchers that had unexpected motion shifts (i.e., loss of ER or gain in IR). These strong correlations between 1) the absolute ROA and the end ROM and 2) the ROA bilateral differences and their respective motion shifts suggest important interaction between these two variables. Analyzing these two variables in unison may help to identify pitchers who are particularly susceptible to throwing arm injuries. This idea has previously been used for ROM analysis. Pitchers with "unbalanced" motion shifts (IR deficit is 10º more than the ER gain) are thought to be particularly susceptible to injury or showing signs of injury (Wilk et al., 2002). Bilateral differences may be good indicators of pitching arm health. For example, having a ROA shift and motion shift of similar magnitude may be a sign of throwing arm health or having drastically different ROA and ROM shifts may be cause for concern. Future research should explore these topics.

Aim 2c

Aim 2c was to determine if the rotational resistance of the non-throwing shoulder is related to the magnitude of the motion shift. For aim 2c the non-throwing shoulder served as a control and was assumed to represent the pre-altered pitching shoulder. For ER, pitchers with stiff non-throwing shoulders and/or an early ROA were hypothesized to have the greatest motion shifts (they were thought to have great potential to "loosen-up"). For IR, pitchers with stiff non-throwing shoulders were hypothesized to have a minimal motion shift (since they were already "tight"). One significant correlation related to these hypotheses was revealed: for IR, a moderate negative correlation was revealed between the non-throwing ROA and the IR motion shift. Interestingly, pitchers that had an early non-throwing ROA gained IR motion. This gain in IR may be important and has yet to be discussed in the literature. This IR finding suggests that pitchers that start with a "tight" shoulder become "looser". Pitchers with an average IR ROA had no or a minimal motion shift. Pitchers with a late IR ROA had the greatest loss of motion; they

started out extremely loose and became tighter. As previously stated, this correlation is moderate, but it is considered important because it is preliminary evidence that helps to explain the IR motion shift. This aim also further highlights the potential for using the ROA as an indicator of pitching health.

Aim 2c should be repeated on a population of adolescent pitchers. This would be useful because two studies have shown that ER and IR motion shifts become established in pitchers as young as 12-14 years (Meister et al., 2005). The non-dominant rotational resistance measures should also be correlated to humeral retroversion. This analysis may help to determine which pitchers have significant bony alterations.

Aim 3

Aim 3 was to determine if incidence of throwing arm injuries are different among rotational resistance groups. The purpose of this preliminary injury analysis was to determine if any general trends existed. Therefore, the number of pitchers analyzed was limited (N=30), the analysis was retrospective in nature, all injuries were analyzed collectively, and the severity and location of injury were not considered. The primary goal was to determine if the majority of injured pitchers belonged to a specific rotational resistance group. Chi-square analysis revealed no significant differences for the ER or IR groups. Interestingly, both healthy and injured pitchers were dispersed quite evenly. This finding is important because it reveals that no obvious injury trends exist.

With no obvious trends revealed, additional steps should now be taken to more thoroughly analyze the relevance of rotational resistance measures to throwing arm injuries. First, rotational resistance bilateral differences should be assessed in a similar fashion. It is possible that alterations to rotational resistance are more important than absolute rotational resistance. Second, greater numbers of pitchers should be analyzed. Injuries were very prevalent in this group of

pitchers, but analyzing additional pitchers would help to improve statistical power and the strength of conclusions. Third, pitchers should be followed prospectively. It is possible that rotational resistance changed after the throwing arm was injured. Last, each type of injury should be analyzed individually. In this study, all injuries were analyzed collectively.

Analyzing injuries individually is important because injuries may be "direction specific". Medial elbow injuries can be used to illustrate this point. The medial elbow is critically loaded as the shoulder is maximally externally rotated at the end of the arm cocking phase of the pitch. The ER rotational resistance is likely relevant at this point in the pitch since the anterior soft tissues are being stretched maximally (Fleisig et al., 1995). The IR rotational resistance is likely not relevant at this point in the pitch since posterior shoulder soft tissues are not being stretched. Therefore, it seems appropriate to focus attention on ER rotational resistance when analyzing elbow injuries.

Interestingly, a high number of pitchers suffered medial elbow injuries in this study (n=7). Qualitative analysis revealed findings to support the relevance of ER rotational resistance to this specific injury. The ER rotational resistance of these 7 pitchers was relatively similar. The ROA measures were within 15º and their stiffness was within 11 N·m/º. This contrasts the disparate findings for IR (the "irrelevant" direction). For IR, the ROA range was greater (7º) and the stiffness range was approximately twice as large. Analyzing larger numbers of specific injuries in this manner could help to identify the direction (IR vs. ER).and group (low, moderate, or high rotational resistance) of greatest concern for each type of injury.

Summary

General Conclusions

- Throwing arm injuries are prevalent and severe in elite baseball pitchers. Forty-seven percent of the pitchers in this study had a serious throwing arm injury that made them unable to participate in practice or a game (for a week or more) during the previous year.

- The torque required to passively rotate the shoulder to the end ROM was 14 N·m for internal rotation and 17 N·m for external rotation. These large passive torques may be extremely relevant to shoulder and elbow loads generated during the pitch that cause throwing arm injuries.

- Shoulder internal and external rotation passive flexibility was highly variable in this relatively homogenous group of elite pitchers. For both IR and ER, the resistance onset angle range exceeded 30º and some pitchers shoulders were twice as stiff as others.

- Aim 1a showed that ROM and stiffness were not correlated. This finding suggests that both measures are needed to make clear conclusions about shoulder flexibility.

- Aim 1a also showed that the resistance onset angle strongly predicted the end ROM. For both ER and IR, the end ROM occurred approximately 20º beyond the resistance onset angle. This was true for pitchers that had a limited ROM and pitchers that had an excessive ROM.

- Aim 1b classified pitchers as having low, moderate, or high rotational resistance. As expected, low rotational resistance pitchers had a significantly greater ROM than high rotational resistance pitchers. The difference was approximately 20º for ER and IR.

- Aim 2a addressed bilateral differences. Results provide strong evidence to suggest that pitching alters the soft tissues of the throwing shoulder. The throwing shoulder was 20% stiffer for ER and 40% stiffer for IR. The ROA was 10º later for ER and 5º earlier for IR.

- Aim 2b addressed the magnitude of the motion shifts. Bilateral stiffness differences did not predict the motion shifts but the ROA shifted similarly to the ROM for ER and IR (the direction and magnitudes of the bilateral differences were similar).

- Aim 2c used the non-throwing shoulder as a model of the original (or pre-altered) flexibility of the throwing arm. The non-throwing ROA predicted the IR motion shift. This finding helps to identify who is having motion shifts and why. Pitchers with an early ROA gained motion, pitchers with an average ROA had no motion shift, and pitchers with a late ROA lost motion.

- Aim 3 was a preliminary retrospective injury analysis that compared incidence of throwing arm injuries among a low, moderate, and high rotational resistance groups. No general trends were revealed. Future efforts should focus on analyzing larger groups of pitchers and groups of pitchers with similar injuries (rather than assessing all throwing arm injuries collectively).

Practical application and recommendations

- Rotational resistance should be developed to analyze the shoulder in clinical and rehabilitation settings. Athletic trainers, orthopedic surgeons, and sports medicine clinicians should consistently monitor the passive ER and IR flexibility of both shoulders in overhead athletes.

- Measures and methods from this study may help to better guide and assess exercise and rehabilitation interventions in overhead athletics.

Future Research

- Determine the relevance of rotational resistance to throwing arm loads during the pitch.
- Determine the relevance of rotational resistance to pitching performance (pitching accuracy and pitching velocity).
- Examine the relationships between rotational resistance the humeral retroversion to better understand the motion shift and causes of the motion shift.
- Analyze rotational resistance in adolescent populations when the motion shifts first become established.
- Perform longitudinal studies to monitor relationships between rotational resistance and throwing arm injuries prospectively.
- Determine the relevance of rotational resistance bilateral differences to incidence of throwing arm injuries.
- Analyze the relevance of rotational resistance to specific throwing arm injuries.
- Determine influence of stretching and resistance training interventions on rotational resistance.
- Assess rotational resistance in baseball position players and other overhead athletes.
- Determine influence of warm-up and fatigue on rotational resistance.
- Determine influence of specific soft tissues on rotational resistance by completing cadaver studies.

In conclusion, this study demonstrated the importance of assessing shoulder passive IR and ER rotational resistance in baseball pitchers. The most important novel finding may be that rotational stiffness and end ROM are not related. This finding suggests that both measures are required to thoroughly assess IR or ER passive flexibility of the throwing shoulder. This study also demonstrated that rotational resistance varies dramatically bilaterally and that rotational resistance is relevant to the motion shift. We believe that rotational resistance shoulder assessments could help athletic trainers, orthopedic surgeons, and sports medicine clinicians to prevent, diagnose, and rehabilitate throwing arm injuries; we recommend the assimilation of

shoulder rotational resistance assessments into practice. Future research should continue to focus on determining the relevance of rotational resistance measures to incidences of throwing arm injuries and injury prevention. We believe throwing arm injuries may be reduced by focusing on injury mechanisms, the motion shifts, and throwing arm interventions. Injury mechanism research should focus on examining associations between rotational resistance and the throwing arm loads experienced during the pitch. Motion shift research should explore the relationship between rotational resistance and humeral retroversion. Finally, throwing arm intervention research should focus on the influence of stretching interventions and resistance training interventions on rotational resistance.

APPENDIX A
SHOULDER ANATOMY AND EXAMPLE INJURIES

Articulations of the Shoulder Joint

The shoulder complex has four articulations: acromioclavicular, sternoclavicular, scapulothoracic, and glenohumeral. Pitching researchers are most concerned with the glenohumeral joint due to the high incidence of injuries (Baltaci et al., 2001). The glenohumeral joint is a ball and socket joint. Pitchers are able to achieve a tremendous shoulder ROM during the pitch because the socket, or glenoid, is extremely shallow (Pink et al., 1995). "Little League Shoulder" is a common bony injury in adolescents (Fleming et al., 2004). Young pitchers suffer from little league shoulder when the growth plate, or physis, at the proximal end of the humerus gradually separates. This injury is known to occur in pitchers age 11-16 years (Carson et al., 1998). Little league shoulder is thought to develop from repeated exposure to external rotation torque at the end of the arm-cocking phase of the pitch (Sabick et al., 2004).

Soft Tissue Stabilizers

The shallow nature of the glenoid forces the soft tissues of the shoulder to be the primary stabilizers. Shoulder soft tissues are categorized as "static stabilizers" or "dynamic stabilizers" (Donatelli, 2004). The static stabilizers are the cartilages and ligaments that surround the joint. The two main static stabilizers, the labrum and capsule, are commonly injured in baseball pitchers. Many dynamic stabilizers, or muscles, also surround the joint. Primary attention is give to the rotator cuff muscles due to their important role in providing shoulder stability and their high susceptibility to injury.

The labrum

The labrum is a ring of fibrous tissue that surrounds the glenoid. The labrum helps to provide stability by forming a "socket" for the humeral head. It also serves as an attachment site

for ligaments and tendons. The labrum helps to secure the humeral head by forming a ring around the glenoid. The biceps tendon attaches to the superior labrum. “SLAP lesions” are injuries to the labrum that baseball pitchers suffer from (Park et al., 2002). SLAP stands for “superior labrum anterior to posterior” and is used to describe tears to the labrum. There are four basic types of SLAP lesions that baseball pitchers suffer from. SLAP lesions may be caused by impingement or large bicep tendon forces that act to “peel” the labrum off the glenoid during the arm cocking and/or arm deceleration phase of the pitch (Park et al., 2002).

The capsule

The capsule completely surrounds the humeral head and provides stability near the limits of motion. At the scapular end it attaches along the rim of the glenoid, just beyond the labrum. At the humeral end it attaches along the anatomical neck. Capsular thickenings occur on the anterior, middle, and inferior surfaces. The role of the capsule as a stabilizer varies with the arm position and the shoulder biomechanics. The capsule remains lax in most shoulder positions (Jobe, 1995). It becomes tense, and an important stabilizer, at extreme shoulder positions. The anterior capsule can become attenuated from repeated exposure to extreme ER and the posterior capsule can become tightened from repeated exposure to the follow through loads. These problems are thought to be highly preventable (Jobe, 1995) and often addressed with surgical interventions. The “capsular shift” surgical intervention is used to eliminate excessive anterior instability (Glousman et al., 1995). Another procedure, thermal capsulorrhaphy, can similarly eliminate excessive instability by shrinking the capsule with a heated probe (Enad et al., 2004).

The rotator cuff muscles

Four rotator cuff muscles originate from the scapula (Figure A-10). The rotator cuff tendons blend with the capsule as they approach the humeral tuberosities. The rotator cuff

muscles are important stabilizers since the capsule is lax at most arm positions (Jobe 1995). Primary roles include stabilizing the humeral head within the glenoid, precisely positioning the humeral head within the glenoid, and rotating the humerus (Yocum et al., 1995). Tears to the rotator cuff are common (Mazoué et al., 2006). Rotator cuff muscles are greatly responsible for decelerating the arm after ball release. Tears are thought to be associated repeated exposure to the large distraction force at ball release that is equal to or greater than the pitchers body weight (Fleisig et al., 1995). Tears occur most commonly in the posterior half of surprspinatus and superior half of infraspinatus (Mazoué et al., 2006). This serious injury requires surgical intervention. Rotator cuff tendons also commonly get impinged between the glenoid and humeral head.

APPENDIX B
APPROVED IRB

1. TITLE OF PROTOCOL:

Shoulder Internal and External Rotational Stiffness in Baseball Pitchers

2. PRINCIPAL INVESTIGATOR(s): (Name, degree, title, dept., address, phone #, e-mail & fax)

Jeff T. Wight, B.S., M.S., PHD candidate, Department of Applied Physiology & Kinesiology, PO Box 118206, 150 Florida Gym, 392-0584 ext. 1400, jwight@ufl.edu, 392-5262 (fax)

Guy B. Grover, B.S., M.S. candidate, Department of Applied Physiology & Kinesiology, PO Box 118206, 152 Florida Gym, 392-9575 ext. 1401, ggrover@ufl.edu, 392-5262 (fax)

3. SUPERVISOR (IF PI IS STUDENT): (Name, campus address, phone #, e-mail & fax)

Mark D. Tillman, Ph.D., Assistant Professor, Department of Applied Physiology & Kinesiology, PO Box 118205, 118 Florida Gym, 392-0584 ext.1237, mtillman@hhp.ufl.edu, 392-5262 (fax)

4. DATES OF PROPOSED PROTOCOL:

October 15, 2006 to October 15, 2007

5. SOURCE OF FUNDING FOR THE PROTOCOL:
(As indicated to the Office of Research, Technology and Graduate Education)

None.

6. SCIENTIFIC PURPOSE OF THE INVESTIGATION:

The purposes of this study are to 1) measure the passive flexibility characteristics of the shoulder in internal/external rotation in baseball pitchers, 2) determine if relationships exist among various passive internal and external rotation variables, and 3) determine if bilateral differences exist in passive flexibility characteristics of the shoulder.

7. DESCRIBE THE RESEARCH METHODOLOGY IN NON-TECHNICAL LANGUAGE: The UFIRB needs to know what will be done with or to the research participant(s).

Protocol and methods. Bilateral shoulder flexibility measurements will be taken with the participant lying supine on an athletic training table. The upper arm will be secured to a rotational device with the elbow bent at 90º. To prevent shoulder and scapular movement, the investigator will push lightly on the participant's anterior shoulder. The whole arm will be internally and externally rotated to the end range of motion. The end range of motion will be determined by the participant. The participant will say "stop" when he believes that further rotation of the arm would become uncomfortable. The participant will be instructed to keep the upper body muscles relaxed (no musclular effort) while the measures are taken. Surface electromyography (Konigsburg Instruments, inc., Pasadena, CA) will be used to monitor the shoulder area muscle activity. Both the force required to rotate the arm and the resulting displacement will be recorded into a laptop computer via a load cell (Tansducer Techniques, Temecula, CA) in line with the force applicator and an electrogoniometer (Model 536 Precision Potentiometer), respectively.

There will be a 20 minute Familiarization Session and a 20 minute Data Collection Session (total of 40 minutes). These two sessions may be performed on the same day or different days (depending on convenience).

Familiarization Session.
First, the participant will read (and sign) the informed consent. The custom device will then be adjusted to properly fit the participant the arm support will be lowered or raised as necessary). The device settings will be recorded (to use in the Data Collection Session). The participant will then be familiarized with the protocol using five sub-maximal repetitions (both internally and externally, for both the right and left arm). The shoulder will be rotated very slowly for all repetitions. The first rotation will cease when the subject first feels a light stretch in the shoulder. That stretch will then be held for approximately five seconds. The only difference in the next four repetitions will be the magnitude of the rotation; each rotation will be slightly further than the previous (but all will be short of the end range of motion). Finally, the subject's shoulder will be rotated once to the comfortable end range of motion.

Next, three simple shoulder range of motion measures will be taken on each shoulder. First, the participant will be asked to reach the highest vertebra possible behind his back. Second, maximum passive adduction will be measured with the subject lying on his side. Third, the internal and external end range of motion will be measured with a plastic goniometer.

Data collection session. The device will be adjusted to the proper settings (recorded in the Familiarization Session). EMG electrodes will be placed over the shoulder area muscles. Five consecutive repetitions (to the comfortable passive end range of motion) will be collected for shoulder internal and external rotation for both shoulders. There will

be two consecutive collections: once with the shoulder stabilized by the investigator and once without.

8. POTENTIAL BENEFITS AND ANTICIPATED RISKS: (If risk of physical, psychological or economic harm may be involved, describe the steps taken to protect participant.)

The anticipated risks associated with this study would be no more than those associated with self stretching of the shoulder under normal conditions. To avoid muscle injury due to overexertion, the subjects will be required not to engage in strenuous exercise during the day of the test and to warm-up properly before the testing session. In the unlikely event that an injury does occur, a certified athletic trainer will be present at the collection, or on call, to provide treatment.

9. **DESCRIBE HOW PARTICIPANT(S) WILL BE RECRUITED, THE NUMBER AND AGE OF THE PARTICIPANTS, AND PROPOSED COMPENSATION (if any):**

Sixty-five male baseball pitchers (age 18-40 years) will be recruited from college and professional teams in Florida. No compensation will be provided by the investigators.

10. **DESCRIBE THE INFORMED CONSENT PROCESS. INCLUDE A COPY OF THE INFORMED CONSENT DOCUMENT (if applicable).**

Written informed consent (see attached) will be obtained from each participant prior to his participation.

Please use attachments sparingly.

_____ _____

Principal Investigator's Signature Co-Principal Investigator's Signature

_____

Supervisor's Signature

I approve this protocol for submission to the UFIRB:

_____

Dept. Chair/Center Director Date

APPENDIX C
APPROVED INFORMED CONSENT

INFORMED CONSENT AGREEMENT

PROJECT TITLE: Shoulder Internal and External Rotational Stiffness in Baseball Pitchers

INVESTIGATORS: Jeff T. Wight and Guy B. Grover

Please read this consent agreement carefully before you decide to participate in this study

PURPOSE OF THIS PROJECT:

The purpose of this study is to measure the passive internal and external rotation flexibility characteristics of both shoulders in baseball pitchers.

WHAT YOU WILL BE ASKED TO DO:

The flexibility tests will be conducted with you lying on an athletic training table. Small sensors (EMG electrodes) will be place over your shoulder area muscles to monitor muscle activity. We will ask you to hold your arm in a throwing position (elbow bent at 90°). We will then secure your arm to a wheel that can rotate. During the test, one investigator will lightly push against the front of your shoulder to prevent unwanted movement. The other investigator will slowly rotate your arm internally (moving the forearm downward) or externally (moving the forearm upward). You will be asked to keep your shoulder totally relaxed during the testing. You will also be asked to say "stop" when you believe that further rotation of the arm would become uncomfortable. Both the force required to rotate the arm and the resulting displacement will be recorded.

The Familiarization Period We want to make sure that you are comfortable with our flexibility measuring protocol. To do this we will perform six practice repetitions for each arm (for internal and external rotation). During these practice repetitions we will ask you to completely relax your shoulder. During the first repetition, we will cease rotation when you first feel a light stretch in your shoulder. We will hold that stretch for approximately five seconds. Four more stretches will be performed, and each time we will rotate your arm a little farther. After the five stretches have been completed, we will rotate your arm to the comfortable end range of motion twice. The first time, we will use a device that we built to measure your shoulder. The second time, we will use a simple plastic goniometer to measure your shoulder.

The data collection.

We will start with two simple shoulder measures. First, you will be asked to place your hand behind your back and reach the highest vertebra possible. Second, we will measure how far you can reach across your body.

Next, we will collect five consecutive repetitions to the passive end range of motion. We will do this for both shoulders and both directions (internal and external rotation). For each repetition you will be asked to say "stop" when you achieve your comfortable end range of motion. Throughout the collections, we would like you to remain still and relaxed. We will complete this test twice.

TIME REQUIRED:

Approximately 40 minutes. Familiarization and testing sessions may occur on consecutive days.

RISKS AND BENEFITS:

The anticipated risks associated with this study would be no more than those associated with self stretching of the shoulder under normal conditions. In the unlikely event that an injury does occur, a certified athletic trainer will be present at the collection, or on call, to provide treatment.

There is no direct benefit to you for participating in this study. However, the findings of this study may help us to better understand performance and injuries in overhand athletics.

COMPENSATION:

No compensation will be provided by the investigators.

CONFIDENTIALITY:

Your identity will be kept confidential to the extent provided by law. The records of your participation will be kept confidentially. Only the investigators of this study will have access to your records and data files. Video recordings will be destroyed when the study is completed. Your name will not be used in any report.

VOLUNTARY PARTICIPATION:

Your participation in this study is completely voluntary. All data collection will be performed by graduate research assistants.

RIGHT TO WITHDRAW:

You have the right to withdraw from the study at anytime without penalty.

WHOM TO CONTACT IF YOU HAVE QUESTIONS ABOUT THIS STUDY:

Jeff T. Wight, M.S., Ph.D. candidate, 150 Florida Gym, 392-0584 ext. 1400, jwight@ufl.edu
Guy B. Grover, B.S., 152 Florida Gym, 392-9575 ext. 1401, ggrover@ufl.edu
Mark D. Tillman, Ph.D., 118 Florida Gym, 392-0584 ext.1237, mtillman@hhp.ufl.edu

WHOM TO CONTACT ABOUT YOUR RIGHTS AS A RESEARCH PARTICIPANT IN THE STUDY:

UFIRB Office, Box 112250, University of Florida, Gainesville, FL 32611-2250; Tel.:392-0433.

AGREEMENT:

I, _____, have read the procedure described above and I voluntarily
(participant's name)
agree to participate in the procedure. I also understand that I will receive a copy of this form upon request.

Participant:_____ Date: _____
Principal Investigator:_____ Date: _____

APPENDIX D
THROWING ARM INJURY QUESTIONNAIRE

This questionnaire will ask you about the frequency and location of throwing arm injuries over the past year.

Please feel free to ask questions.

GENERAL INFORMATION

DATE_____
TEAM_____

NAME_____ Right-handed or Left-handed

Height_____ Weight _____

In the past year, were you a starting pitcher or relief pitcher?

How many years have you pitched competitively?

1. In the past year, did you suffer from any throwing arm injuries/pain that made you unable to fully participate in throwing activities during practice, unable to practice at all, or unable to compete in a game?

YES Please answer questions 1a-1d below. **NO** Please move on to #2.

1a. In the past year, how many days/weeks were you unable to participate in throwing activities during practice, unable practice at all, or unable to compete in a game because of throwing arm injuries/pain?

_____ days _____ weeks

1b. When did the symptoms begin?

1c. Circle the general area of the throwing arm where the injury/pain occurred.

Shoulder **Elbow** **Both** **Other_____**

1c. Circle any specific location(s) of the shoulder and/or elbow where the injury/pain occurred.

Shoulder: **anterior, posterior, superior, lateral**

Elbow: **medial, lateral, internal, anterior, posterior**

1d. Did you see a physician about your throwing arm injury/pain?

YES What was your doctor's diagnosis?_____ **NO**

2. Currently, are you experiencing any throwing arm pain during practice and/or games?

YES Please answer questions 2a-2d below. **NO** Thank you for your time.

2a. Circle the general area of the injury/pain.

Shoulder **Elbow** **Both** **Other_____**

2b. Circle any specific location(s) of injury/pain on the shoulder and/or elbow.

Shoulder: **anterior, posterior, superior, lateral**

Elbow: **medial, lateral, internal, anterior, posterior**

2c. Is the pain severe enough to negatively influence your pitching performance (velocity or control)?
YES **NO**

2d. Do you feel that you have altered your pitching mechanics because of the pain?

YES **NO**

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BIOGRAPHICAL SKETCH

Jeffrey T. Wight was born in Grand Rapids, Michigan in 1977. He was raised in Plover, Wisconsin and graduated from Stevens Point Area Senior High in 1995. Jeff has enjoyed participating in athletics, the outdoors, and fishing throughout his life. His undergraduate studies were completed at the University of Wisconsin-Madison where he received a Bachelor of Science in Zoology and completed extensive studies in mathematics.

After receiving his bachelor's degree, Jeff worked for the Center for Limnology at the University of Wisconsin. Jeff married Erin Largo in the summer of 2001 and they began graduate studies at the University of Delaware in the Department of Health, Exercise Science, and Nutrition in August of 2001. Two years later, Jeff graduated from the University of Delaware with his Master of Science in Exercise Science. He completed and published a thesis titled "*Influence of pelvis rotation styles on overall baseball pitching kinematics and kinetics*" under the supervision and guidance of his advisor, Dr. James Richards. Jeff was also a volunteer baseball coach at the high-school and college level for 8 years during his undergraduate years and time in Delaware.

He and his wife started their doctoral studies at the University of Florida in the College of Health and Human Performance in August of 2003. During his years of graduate studies, Jeff taught a total of nine different courses at the University of Delaware, University of Florida, and Stetson University. He also gave many guest lectures at the University of Florida in a variety of courses: In addition to teaching, Jeff has been actively involved with research projects during his doctoral studies at the University of Florida. He was an investigator on awarded grants, published in peer-reviewed journals, and presented research at various national conferences. Jeff

is a member of professional organizations including the *American Society of Biomechanics* and the *American College of Sports Medicine*.

Jeff was active and involved with the University and College throughout his doctoral tenure. Jeff and his wife were selected as recipients of the College of Health and Human Performance German Scholarship Exchange Program to the University of Darmstadt in Darmstadt, Germany, where they gave a joint research presentation. He has also been actively involved with the College's informal co-ed Ultimate Frisbee league and has enjoyed learning about Florida's natural ecosystems by kayaking many waters from the Florida Keys to Cedar Key with his wife.

Jeff and his wife are graduating with their doctorates from the University of Florida, College of Health and Human Performance, in the summer of 2007. They will also welcome their first child into the world in June of 2007.