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Establishment of Normative Shoulder Internal Rotation Passive Range of Motion Values in the Sidelying and Semi-sidelying Positions

Alisse Indrelie
St. Catherine University

Shannon Kelly
St. Catherine University

Hugo Klaers
St. Catherine University

Tatia Nawrocki
St. Catherine University

Michael Stelzmler
St. Catherine University

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ESTABLISHMENT OF NORMATIVE SHOULDER INTERNAL ROTATION
PASSIVE RANGE OF MOTION VALUES IN THE SIDELYING AND SEMI-
SIDELYING POSITIONS

by
Alisse Indrelie
Shannon Kelly
Hugo Klaers
Tatia Nawrocki
Michael Stelzmler

Doctor of Physical Therapy Program
Saint Catherine University

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Research Advisor: Professor Cort J. Cieminski, PT, PhD, ATR

ABSTRACT

Background: A common impairment seen in individuals with shoulder pathology is decreased internal rotation (IR), or glenohumeral IR deficit (GIRD). The literature has indicated that there are several different contributing factors to GIRD that include posterior capsule tightness, humeral retroversion, and posterior shoulder muscle stiffness. The supine position is the current standard for measuring IR range of motion (ROM). However, there is a lack of consistency of stabilization of the shoulder during this test. Researchers, therefore, have studied other positions for measuring IR ROM, such as sidelying, which provides a consistent degree of stabilization of the scapula. In the sidelying position, it has been purported that the scapula is stabilized by the subject's own body weight, and is therefore not dependent on the examiner. This sidelying IR ROM position was found to be more reliable when compared to that of the supine IR ROM. Currently, however, there are no reported normative IR ROM values for either the sidelying or semi-sidelying positions for overhead athletes or non-athletes.

Purpose: The purpose of this study was to establish normative values for shoulder IR ROM in the sidelying and semi-sidelying positions for both an overhead athlete and non-athlete group. In addition, these IR ROMs were compared to the standard supine position.

Methods: One hundred fourteen overhead athletes [57 males, mean age 21.8 (\pm 4.9), range 18-47; 57 females, mean age 21.4 (\pm 5.3), range 18-56] and 204 non-athlete subjects [63 males, mean age 36.9 (\pm 25.1), range 18-70; 141 females, mean age 33.4 (\pm 14.4), range 18-89] without shoulder pathology participated in this study. Two measurements of passive IR ROM for the dominant and non-dominant shoulders were

gathered in a supine, semi-sidelying, and sidelying position using a bubble inclinometer. Additional measurements of bilateral passive external rotation ROM were taken in the athlete group. Inter-rater and intra-rater reliability for all six investigators were established prior to data collection.

Results: The sidelying mean for the athletic population was $43.4^{\circ} (\pm 8.3^{\circ})$ for the dominant side and $55.2^{\circ} (\pm 9.8^{\circ})$ for the non-dominant side. There was a significant difference between total arc measurements when measured in supine vs. sidelying. The difference between the two was significantly greater on the dominant side (15.0° difference) compared to non-dominant side (12.4° difference). The mean value for sidelying position for non-overhead athletes was $46.9^{\circ} (\pm 12.4^{\circ})$ for the dominant shoulder and $53.6^{\circ} (\pm 11.9^{\circ})$ for the non-dominant shoulder. Supine and semi-sidelying IR ROM were not significantly different from each other except in the non-dominant shoulder in athletes. Sidelying IR ROM was significantly different from both the supine and semi-sidelying positions.

Conclusion: This study was the first to establish normative IR ROM values other than the standard supine position, namely the semi-sidelying and sidelying positions for both an overhead athlete and non-athlete group. The sidelying position yielded significantly smaller IR ROM values for dominant and non-dominant shoulders within both groups compared to the supine and semi-sidelying positions. Clinicians can use these results when evaluating IR ROM loss in their patients and it is suggested that therapists use the sidelying IR ROM position, due to its improved reliability as an outcome measure.

PROJECT APPROVAL FORM

The undersigned certify that they have read, and recommended approval of the research project entitled

ESTABLISHMENT OF NORMATIVE SHOULDER INTERNAL ROTATION
PASSIVE RANGE OF MOTION VALUES IN THE SIDELYING AND SEMI-
SIDELYING POSITIONS

submitted by
Alisse Indrelie
Shannon Kelly
Hugo Klaers
Tatia Nawrocki
Michael Stelzmilller

in partial fulfillment of the requirements for the Doctor of Physical Therapy Program

Primary Advisor *Cort J. Cieminski*

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TABLE OF CONTENTS

Abstract.....	i
Project Approval Form.....	iii
Acknowledgments.....	iv
Table of Contents.....	v
Chapter I: Introduction.....	1
Shoulder Overview.....	1
Posterior Capsule Tightness.....	2
Humeral Retroversion.....	3
Posterior Shoulder Muscle Stiffness.....	5
Range of Motion.....	6
Typical Methods of Measuring.....	7
Normative Values.....	9
Purposes and Hypotheses.....	9
Chapter II: Literature Review.....	11
Glenohumeral Internal Rotation Deficit.....	11
Glenohumeral Range of Motion.....	12
Posterior Capsule Tightness.....	19
Humeral Retroversion.....	25
Posterior Shoulder Muscle Stiffness.....	32
Posterior Capsulorrhaphy.....	36
Range of Motion for Normal Adults.....	37
Range of Motion and Overhead Athletes.....	40
Range of Motion and Technique Used.....	44
Range of Motion and Age.....	46
Range of Motion and Arm Dominance/Handedness.....	47
Goniometric Measurement.....	48
Goniometer with Scapular Stabilization.....	48
Digital Inclinometer.....	51
Vertebral Level.....	52
Posterior Shoulder Tightness Measurements.....	53
Chapter III: Methods.....	58
Subjects.....	58
Raters.....	58
Instrumentation.....	59
Procedures.....	59
Statistical Analysis.....	61
Chapter IV: Results.....	63
Athlete Group.....	63
Non-Athlete Group.....	65
Chapter V: Discussion.....	67
Athlete Group.....	67
Non-Athlete Group.....	70
Reliability.....	72

Clinical Application.....	74
Limitations & Recommendations for Future Research.....	76
Chapter VI: Conclusion.....	78
References.....	80
Figures.....	85
Figure 1: Bubble Inclinometer	
Figure 2: 45° Bolster	
Figure 3: Supine IR Position	
Figure 4: Sidelying IR Position	
Figure 5: Semi-Sidelying IR Position	
Figure 6: External Rotation Position	
Figure 7: Bar Graph: Mean IR ROM for Athletes	
Figure 8: Bar Graph: Mean IR ROM for Non-Athletes	
Tables.....	90
Table 1: Intra-Rater Reliability ($ICC_{1,1}$).....	90
Table 2: Inter-Rater Reliability ($ICC_{2,k}$).....	90
Table 3: Descriptive Statistics: Athlete Group.....	90
Table 4: Repeated Measures ANOVA: Athlete Group Dominant Shoulder IR ROM.....	91
Table 5: Repeated Measures ANOVA: Athlete Group Non-Dominant Shoulder IR ROM.....	91
Table 6: IR And ER ROM Differences Between Dominant And Non-Dominant Shoulders: Athlete Group.....	91
Table 7: Supine And Sidelying Total Arc: Athlete Group.....	92
Table 8: Difference Between Supine And Sidelying Total Arc: Athlete Group.....	92
Table 9: Total Arc Difference: Athlete Group.....	92
Table 10: Descriptive Statistics: Non-Athlete Group.....	92
Table 11: Repeated Measures ANOVA: Non-Athlete Group Dominant Shoulder IR ROM.....	93
Table 12: Repeated Measures ANOVA: Non-Athlete Group Non-Dominant Shoulder IR ROM.....	93
Table 13: IR ROM Differences Between Dominant And Non-Dominant Shoulders: Non-Athlete Group.....	93
Appendices.....	94
Appendix A: Recruitment Flyer	
Appendix B: Demographics/Shoulder History Form	
Appendix C: Consent Form	
Appendix D: HIPAA Form	
Appendix E: Data Collection Form	

CHAPTER I

INTRODUCTION

The shoulder is a joint that is built for mobility. Within the shoulder complex is the glenohumeral joint, which is comprised of the proximal humerus and humeral head that articulate with the scapula at the glenoid fossa. The articulations of the humerus, scapula, and ribs form the scapulothoracic joint. The glenohumeral joint is surrounded by a ligamentous joint capsule as well as the muscles of the rotator cuff and are responsible for the stabilization of the joint. All gross shoulder motion is accompanied by accessory motion of the scapula moving along the ribs.

The shoulder is a ball-and-socket joint that is capable of performing a variety of motions including flexion, extension, abduction, adduction, internal rotation (IR), and external rotation (ER). Internal rotation occurs with anterior tilting of the scapula, while ER occurs with posterior tilting of the scapula. Posterior tilting of the scapula causes the acromion to move such that the subacromial space is enlarged. This protects the structures running through the subacromial space and allows for greater excursion of the humeral head. In contrast, anterior tilting of the scapula causes a decrease in subacromial space, which could potentially result in impingement of the structures running through that space.

Multiple studies have shown that overhead-throwing athletes demonstrate adaptive changes in their glenohumeral IR and ER range of motion (ROM), namely significantly increased glenohumeral ER and significantly decreased glenohumeral IR in their throwing shoulder.¹⁻¹² The literature has indicated that there are several different

contributing factors to glenohumeral IR deficit (GIRD), which include posterior capsule tightness, humeral retroversion, and posterior shoulder muscle stiffness.^{1,3,4,9,10,13}

Posterior Capsule Tightness

There is a significant amount of literature regarding the effect of posterior capsule tightness on the shoulder. Researchers have looked at healthy cadaver shoulders and have found that in the mid-range of IR ROM, the shoulder capsule is relatively lax and no translation occurs, but as the shoulder is flexed, the humeral head translates anteriorly and as the shoulder is extended, the humeral head translates posteriorly.¹⁴ When the researchers operatively tightened the posterior capsule, they found a significant anterior translation of the humeral head that occurred earlier in shoulder flexion and a small superior translation of the humeral head.¹⁴ There are also findings indicating a significant relationship between posterior shoulder tightness (PST) and IR ROM.¹⁵ Some cadaveric studies indicated that when the posterior capsule is tightened, the anterior glenohumeral translation increases with flexion and ER of the glenohumeral joint, which causes a decrease in IR, therefore creating GIRD.³

There is evidence indicating that athletes with pathologic internal impingement have significantly greater PST.^{1,16} The asymmetrical tightness is hypothesized to cause anterior and superior translation of the humeral head with shoulder flexion, which may contribute to shoulder impingement and GIRD.¹⁷ Additionally, internal impingement has been associated with altered glenohumeral mechanics secondary to PST.³ Throwing athletes with PST and pathologic internal impingement may have adaptive changes to the posterior structures of the shoulder, including both the capsular and rotator cuff muscles.¹

Although altered glenohumeral rotation patterns may be created from repetitive stress of long-term throwing, it does not necessarily compromise the joint's passive restraining quality in professional athletes.¹³ Capsulorrhaphies have been suggested as a surgical treatment for shoulder instability and increased capsular laxity. There is a paucity of evidence support this procedure but there have been studies shown that a selective tightening of the capsule can result in a predictable pattern decreased range of motion.¹⁷

Humeral Retroversion

A review of the current literature on humeral retroversion suggests that an osseous adaptation may contribute to overhead athletes having a difference in ROM values between their dominant and non-dominant shoulders.^{7,8,10,18} This difference comes from a decrease in IR and an increase in ER on the dominant arm as compared to the non-dominant side. It is thought that an increase in humeral retroversion allows the humerus to externally rotate further before the anterior shoulder structure can limit this motion, while this same increase in humeral retroversion leads to a decrease in IR as the humerus is restricted by the posterior capsule sooner.^{8,10} If the loss of IR is not matched with the gains of ER then the subject is said to have GIRD. One study found no difference between the amount of humeral retroversion in the non-dominant shoulder of pitchers compared to the non-dominant shoulder of controls.⁷ Therefore, the increase in humeral retroversion in the dominant shoulder of overhead athletes may be an adaptive response of the shoulder complex in order to protect itself from the high velocities and torque of overhead sports movements.^{7,8}

Specifically in baseball players, Osbahr et al. found that college baseball pitchers had an association between humeral retroversion and an increased ER and decreased IR ROM in the dominant shoulder.¹⁸ In a study performed by Reagan et al, the researchers found mean humeral retroversion in 54 asymptomatic college baseball players to be 10° greater in the dominant arm compared to the non-dominant arm.⁸ The researchers discussed that their values for humeral retroversion were consistent with the normative values that have previously been established. A study by Crockett et al. looked at 25 male professional pitchers and found on average 17° more humeral retroversion in the throwing shoulder as compared to the non-throwing arm which the researchers stated was similar to the findings of another study which examined 51 professional European handball players and found the difference to be 14.4°. ^{7,12} Myers et al. looked at 29 collegiate baseball players compared to 25 college controls that had not partaken in overhead athletics and found the baseball players had more humeral retroversion in their dominant arm compared to the dominant arm of the controls.⁹ The researchers also found the collegiate baseball players had an average of 15° more humeral torsion in the dominant arm compared to the non-dominant arm.⁹ Tokish et al. found an average of 11° more humeral retroversion in the dominant arm of 23 professional baseball pitchers as compared to their non-dominant arm.¹⁹

All of these findings suggest that the dominant arm of overhead athletes has an increased amount of humeral retroversion as compared to the non-dominant side. In addition, this increase in humeral retroversion on the dominant side of overhead athletes is also greater than the dominant retroversion of control subjects who do not participate in

overhead athletics. This increase in humeral retroversion leads to a change in the ROM in that shoulder such that ER ROM is increased and IR ROM is decreased but the total arc of motion seems to be maintained.^{7,8} However, if the loss of IR does not match the gains made in ER then GIRD has occurred.²⁰

Posterior Shoulder Muscle Stiffness

Minimal evidence was found on posterior shoulder muscle stiffness and its relationship to stiff shoulders or a change in shoulder range of motion. This is a newer area of research on the topic of GIRD and thus there have been fewer studies on the subject. Review of the current research suggests that stiffness occurring in the posterior shoulder musculature is correlated with a decrease in shoulder IR ROM.^{21,22} Specifically, Hung et al. found significant correlations between decreased shoulder IR and the posterior deltoid, infraspinatus, and teres minor in 20 subjects with stiff shoulders. The patients with stiff shoulders had less displacement by the Myotonometer than did healthy controls, showing significantly increased stiffness in the posterior musculature.²¹

A case study by Poser and Casonato found that treatment consisting of massage to the infraspinatus and teres minor muscles for three 10-minute sessions resulted in a 20° increase in shoulder IR ROM in a patient that presented with impingement syndrome.²³ It can be assumed that this rapid increase in shoulder IR ROM would not be solely due to the posterior capsule being stretching but also from the posterior shoulder musculature. Reinold et al. studied 67 asymptomatic male professional baseball pitchers in which the researchers measured shoulder IR and ER ROM before, immediately after, and 24 hours post-pitching.²⁴ The researchers found these throwers to have a significant loss of IR

ROM (9.5°) and total motion (10.7°) immediately after a bout of throwing that continued to be present 24 hours later. These findings suggest that an acute bout of throwing can impact the IR ROM of baseball pitchers and suggests it is likely posterior muscular tightening is a factor to consider along with stiffening of the posterior capsule. Reinold et al. suggests this acute change in IR ROM is at least partially due to the eccentric motion of the posterior shoulder muscles during throwing, in combination with changes to bony and capsular structures.²⁴ Therefore, it is important to also take the posterior musculature into consideration when assessing the loss of IR ROM.

Range of Motion

Shoulder ROM in overhead athletes is often influenced by repetitive motion of their sport. Some research supports the theory that asymptomatic overhead athletes have decreased glenohumeral IR with an absolute loss of total arc rotation ROM in their dominant arm.^{6,11,25} Total arc is determined by adding the amount of ER that a player has with the amount of IR. In a typical overhead athlete, the loss of IR should be equal to the gain in ER. A player is said to have GIRD if those amounts are not equal. Other studies indicate that overhead athletes have a decrease in IR but an increase in ER ROM of the dominant arm.^{1,13,20} Additional research suggests that internal impingement causes GIRD in the dominant arm of throwing athletes.^{1,3,16} Internal impingement of the non-dominant arm has been shown to have decreased IR and ER ROM.¹⁶ However, the literature is mixed on whether or not ER ROM in the dominant arm is affected by the internal impingement.

Typical Methods of Measuring

A review of the literature shows a wide variety of methods for measuring glenohumeral IR and PST. The current gold standard for measuring shoulder IR ROM is with the subject in the supine position and arm abducted to 90° with a towel roll under the elbow.^{26,27} The shoulder is then passively internally rotated until the joint's end-range is reached, or until an accessory motion of the scapula occurs. The accessory motion can occur when the scapula begins to anteriorly tip and coracoid process translates into the tester's stabilizing hand. This motion can be blocked by the stabilizing hand to isolate the glenohumeral joint, but the amount of force used to block this motion is subjective and cannot be standardized. Another supine option involves the clinician visually observing for anterior tilt of the scapula or lift-off of the acromion process from the measuring surface. Visualizing the lift off of the spine of the scapula may be a viable option for assessing pure glenohumeral motion (posterior-lateral acromion lifting off of the table), however it is dependent on the patient. If you are unable to easily visualize anterior tipping of the scapula then this is not a reliable option. The supine position and both of the previously mentioned techniques for isolating glenohumeral rotation are subjective, leading to decreased reliability.

Researchers have examined shoulder IR ROM in other positions such as sidelying to try and resolve this lack of consistency with stabilization of the scapula in the supine position. In the sidelying position, it has been purported that the scapula is stabilized and consistent within the subject and is thus not dependent on the amount of stabilization force provided by the examiner leading to a high intra- and inter-rater reliability. The

sidelying IR ROM position was found to be more reliable when compared to that of the supine IR ROM.²⁸

Another method for measuring or obtaining an estimate for functional IR is by assessing the highest vertebral level to which the patient can reach behind their back. The literature suggests the use of vertebral levels consistently shows poor reliability and is not the primary recommendation for clinical measurement of shoulder IR, despite its ease and time saving advantages.²⁹⁻³¹

There are a variety of instruments at the disposal of the clinician for measuring ROM. Digital inclinometers are a good choice for clinical use given proper training, although there is some evidence that it does not offer anything that a standard goniometer wouldn't.³²⁻³⁵ When using goniometers, it does not appear that using a small or large goniometer impacts the reliability of the measurement.

Finally, another aspect of shoulder motion that needs to be considered by clinicians is PST. Typically PST is measured by having the subject lie supine with the test arm abducted to 90° with the elbow flexed to 90° and in neutral rotation. The clinician stabilizes the scapula with one hand on the lateral border and with the other hand passively moves the subject's arm through horizontal adduction. An angle is measured between the midline of the humerus and a line perpendicular to the mat to quantify the amount of PST. Another method of measuring PST is measured with the subject in a sidelying position on the non-involved side with the test arm abducted to 90° with the elbow flexed to 90° and in neutral rotation. While stabilizing the scapula in a retracted position, the tester horizontally adducts the humerus. The test is stopped and the

measurement taken when the motion of the humerus ceases or there is rotation of the humerus.³⁶ Measures of PST generally show good reliability and are easy to perform in the clinic.³⁷ Additionally, there is good correlation between measures of PST and decreased shoulder IR.^{16,36}

Normative Values

The American Academy of Orthopedic Surgeons (AAOS) has stated that the average IR measurement is 70°. ²⁶ The methods with which they determined that value are unclear especially in regards to the presence of scapular stabilization. In many studies, the average IR measurement found is not consistent with the value stated by the AAOS.³⁸⁻⁴¹ Also, in these research studies there has not been consistency among the methods used. Some researchers perform the measurement in the supine position with the scapula stabilized and some do not.^{32,35,38-44} Others performed the measurement in a position other than supine.^{28,45,46} Researchers have also determined that the dominant and non-dominant arms consistently have differing values of IR and it is not recommended to use the opposite arm for measurement of “baseline” or normal ROM for a patient or subject.^{11,40,41,47,48} Other studies have shown that there are different values of shoulder motion between males and females, athletes and non-athletes, and throughout the lifespan.^{13,25,38,39,43,44} None of these studies presented values that were consistent with the value presented by the AAOS.

Purposes and Hypotheses

Since there is research suggesting the sidelying position is more reliable than the supine position for measuring shoulder IR ROM, it is important to establish normative

values for shoulder IR ROM in sidelying. These values could be utilized to make clinical judgments of IR ROM deficits and as an outcome measure to monitor improvements in GIRD resulting from physical therapy interventions. The semi-sidelying position (halfway between supine and sidelying) should also be measured to see if it is also a reliable position for measuring IR. This position would mimic the “sleeper stretch” position commonly used in the orthopedic setting and would be familiar to clinicians. Based on the review of the literature and prior research, there is a lack of normative data for the sidelying and semi-sidelying positions. Establishing normative range of motion values for these positions would benefit current physical therapy practice, as these methods of measuring have been shown to be more reliable than other currently used methods for measuring shoulder IR. Therefore, the primary purposes of this study are to:

- 1) Establish normative values for passive shoulder IR ROM across the adult lifespan in the sidelying and semi-sidelying positions, and
- 2) Determine if there is a significant difference in shoulder IR ROM available depending on the position. A secondary purpose of this study is to establish normative values for shoulder IR ROM in overhead athletes.

The hypotheses of this study are that: 1) There will be different normal values of ROM across different age ranges, between males and females, between overhead athletes and non-overhead athletes, and between a person’s dominant and non-dominant shoulders, and 2) There will be significantly different normal values of ROM between the three testing positions (sidelying, supine, and semi-sidelying), with the supine position yielding the greatest amount of IR.

CHAPTER II

LITERATURE REVIEW

Glenohumeral Internal Rotation Deficit

The shoulder joint is one of the most complex joints of the body and performs movement in all axes of motion. One of the common impairments seen in individuals who regularly participate in overhead activities is a decrease in shoulder IR, which has also been referred to as GIRD. This loss of IR may be beneficial or detrimental to the individual overhead athlete. The research suggests several different factors contributing to GIRD that include bony and/or soft tissue restriction. This section of the literature review focuses on glenohumeral ROM and the restrictions secondary to posterior capsular tightness, humeral retroversion, and posterior shoulder muscle stiffness. Capsulorrhaphy will also be examined with regard to its effects on glenohumeral ROM.

A study by Borich et al. investigated the relationship between GIRD and 3-dimensional scapular angular positioning during active arm movements.⁴ Twenty-three subjects who had recent participation in overhead sports activity within the past five years were put into two groups based on their degree of GIRD. Measurements of glenohumeral IR ROM and scapular position at the end of this range were used to analyze the relationship between GIRD and scapular position using 2-way ANOVA and regression analyses. The group with GIRD had significantly greater scapular anterior tilt across positions in comparison to the control group. Results suggest a significant association between GIRD and scapular position during IR. These results indicate a significant relationship between GIRD and increased anterior tilt. This relationship

supports GIRD as a mechanism for development of excessive scapular anterior tilt, therefore causing an increase in shoulder IR and decreased ER.

Glenohumeral Range of Motion

Multiple studies have indicated that overhead-throwing athletes demonstrate adaptive changes to their glenohumeral internal and external rotation range of motion (ROM), with throwers having significantly increased glenohumeral ER ROM and significantly decreased glenohumeral IR ROM.¹⁻¹² Theories of ER gain and IR loss include microtrauma to static and dynamic restraints of the glenohumeral joint as a result of repetitive overhead throwing, contracture of the posterior or inferior joint capsule, and osseous adaptation of the humerus. Myers et al. examined 11 overhead-throwing athletes with pathologic internal impingement (compared to demographically-matched control throwers that had no history of upper extremity injury) to determine if there was a difference in shoulder IR and ER ROM.¹ The 11 subjects in the experimental group were diagnosed with pathologic internal impingement by an orthopedic surgeon experienced in treating patients with throwing injuries. These subjects also received an MRI arthrogram with gadolinium, combined with a complete history and physical examination. Internal rotation and ER ROM were measured based on methods described in Norkin and White.²⁷ Each subject was measured in a supine position with a goniometer that was secured to the stationary arm. IR loss was calculated by taking the difference between the involved (throwing) limb and the uninvolved limb for IR. Throwers with internal impingement had $42.5^{\circ} (\pm 12.1^{\circ})$ of IR in their involved limb and $62.2^{\circ} (\pm 16.9^{\circ})$ in the uninvolved limb, as compared to throwers without impingement who had $51.1^{\circ} (\pm 14.4^{\circ})$

of IR in their throwing limb and $62.2^\circ (\pm 13.7^\circ)$ in the non-throwing limb. These results showed throwing athletes with pathologic internal impingement had $19.7^\circ (\pm 12.8^\circ)$ of IR loss, which was significantly greater than the controls ($11.1^\circ \pm 9.4^\circ$). There was no significant difference in ER range gains between the groups (impingement group = $8.3^\circ \pm 9.2^\circ$; controls = $5.1^\circ \pm 5.3^\circ$). The difference in GIRD found in the pathologic group was hypothesized by the researchers to be an adaptive change to structures of the posterior shoulder, including both capsular structures and the posterior rotator cuff muscles.

A study by Dwelly et al. studied 48 healthy division I and II athletes during an athletic softball/baseball season to determine changes in ROM over time and to track the frequency of GIRD.²⁰ Passive rotational ROM was measured for each glenohumeral joint using the standard goniometric technique and arm position for measures of maximal IR. The researchers used a visual inspection technique to control for scapulothoracic motion. As the investigator passively moved each athlete's shoulder into IR, measurements were taken when the acromion began to rise or when they felt a firm capsular end-feel. Subjects did not display any significant change in GIRD between pre-fall (dominant: $45.5^\circ \pm 11.1^\circ$; non-dominant: $52.7^\circ \pm 11.8^\circ$), pre-spring (dominant: $47.5^\circ \pm 5.8^\circ$; non-dominant: $52.6^\circ \pm 10.2^\circ$), or post-spring (dominant: $45.8^\circ \pm 10.0^\circ$; non-dominant: $52.2^\circ \pm 11.3^\circ$). However, subjects did have significant gains in ER between pre-fall (dominant: $96.2^\circ \pm 12.7^\circ$; non-dominant: $92.0^\circ \pm 10.0^\circ$), pre-spring (dominant: $104.0^\circ \pm 17.0^\circ$; non-dominant: $101.7^\circ \pm 15.2^\circ$), and post-spring (dominant: $106.9^\circ \pm 19.9^\circ$; non-dominant: $104.4^\circ \pm 17.8^\circ$). Therefore, dominant ER ROM increased by 11° from pre-fall to post-spring along with the total arc of motion increasing by 11° because there was no

significant difference found in IR ROM. The authors hypothesized the increase in ER was due to the demands of throwing, such as the cocking phase requiring maximal ER in order to obtain optimal IR velocity. The researchers suggested their ER and IR mean values found in this study were comparable to those in a study by Myers et al.¹ It should be noted that a small-to-medium effect size of 0.33 was reported even though the findings were significant. There was a decrease in IR between pre and post-spring measurements (23 of 48 athletes), but they were not significant. While this may suggest a trend towards a decrease in IR, the authors noted that their sample size was too small with a power of 0.35. In other words, if the sample had been larger, significance may have been found.

Myers et al. measured the influence of humeral torsion on interpretation of clinical indicators of PST in overhead athletes.⁹ The subjects in this study included 29 healthy intercollegiate baseball players and 25 college-aged control individuals with no history of participation in overhead athletics. Bilateral humeral rotation and humeral horizontal adduction ROM were measured in all subjects with a digital inclinometer in a supine position, with 90° of shoulder abduction and elbow flexion. The scapula was stabilized against the treatment table through a posteriorly-directed force, isolating movement to pure glenohumeral joint motion. In all participants, ultrasonography was also used to measure bilateral humeral torsion. Results demonstrated that there was less IR and total rotation ROM when compared to control participants and the non-dominant limb in both groups. There were significant group limb differences present for IR, total ROM, humeral torsion and humeral horizontal adduction. There was insignificant interaction for ER, but there was significant limb and group main effects present. This

indicated that there are differences in measurements of PST in healthy overhead athletes when compared with control participants, which is consistent with previous studies by Tyler et al. and Ellenbecker et al.^{3,6} These differences seem to be influenced by the amount of humeral torsion present in the shoulder, rather than as a result of soft tissue tightness. However, once the torsion was accounted for and corrected, there were minimal limb differences observed clinically in healthy overhead athletes. These results indicate that humeral rotation ROM that is present after taking into consideration humeral torsion may be attributed to soft tissue flexibility.

Ellenbecker et al. studied active glenohumeral IR and ER ROM in both the dominant and non-dominant arms in 203 elite junior tennis players ages 11-17.6 years.²⁵ They took active IR and ER ROM measurements in the supine position with 90° abduction using a standard goniometer. The scapula was stabilized using a posteriorly-directed force by the tester's hand over the coracoid process and anterior aspect of the acromion. The testers did not permit scapular protraction or elevation to occur. There were 113 male subjects with a mean dominant shoulder IR of 45.4° (\pm 13.6°) and non-dominant of 56.3° (\pm 11.5°). The total rotation mean for the male subjects' dominant shoulder was 149.1° (\pm 18.4°) and 158.2° (\pm 15.9°) for the non-dominant shoulder. There were 90 female subjects with a mean dominant IR of 52.2° (\pm 10.7°) and non-dominant IR of 60.3° (\pm 9.8°). The female total rotation mean for the dominant shoulder was 157.4° (\pm 14.9°) and 164.4° (\pm 13.6°) for the non-dominant shoulder. The findings of this study revealed no significant difference in ER ROM between the dominant and non-dominant arm for males or females. However, there was significantly less IR ROM and less total

rotational range in the dominant arm as compared to the non-dominant arm in both males and females. The decrease in IR in the elite tennis players is hypothesized to occur due to fibrous tissue build-up in the posterior capsule along with posterior rotator cuff muscle tightness. The decrease in total rotational ROM found by the researchers is in agreement with other research done on elite junior tennis players. These findings of a decrease in total rotational ROM led the researchers to suggest stretching of the posterior capsule and musculature to regain the loss of IR for both rehabilitation purposes and for preventative programs.

Kibler et al. investigated passive glenohumeral ROM in 39 members of the US National Tennis Team and correlated these findings with age, years of play, and dominant to non-dominant shoulder differences.¹¹ Internal rotation ROM was measured with the subject in a supine position with the scapula stabilized and arm abducted to 90°. Their findings show that at 90° of abduction, dominant IR and the difference between dominant and non-dominant IR increased with both age and years of tournament play. These findings were not different between males and females. Their findings suggest there is a decrease in IR with more years of play and the loss of motion is an absolute loss due to a decrease in total rotation motion. These findings came from the significant moderate negative correlation found between dominant total rotation and years of play. In other words, the researchers found there was a progressive loss of IR the longer the athlete played tennis and, in addition, their total rotation ROM also decreased. A decrease in IR and a loss in absolute total rotation may lead an athlete to change mechanics to maintain the desired momentum of the racquet and may increase the risk of injury by

implementing glenohumeral translations that may be troublesome. From this gathered data, it is suggested that a corrective training program be utilized to assist in correcting these changes to help decrease the risk of injury due to the biomechanical changes that can occur.

A study by Borsa et al. was conducted to determine side-to-side differences in passive glenohumeral ROM and stiffness in a group of asymptomatic professional baseball pitchers using selected kinematic measures.¹³ Thirty-four subjects participated in this study and had bilateral assessments for passive glenohumeral ROM and stiffness during a single testing session. Glenohumeral ROM was taken in supine with the scapula stabilized, eliminating contribution from the scapulothoracic articulation during measurements. The results indicated significantly less IR and significantly more ER in the throwing shoulder compared to the contralateral shoulder when measured at 90° of humeral abduction. The throwing shoulder had an average of 8.5° less IR than the non-throwing shoulder. However, there were no significant differences between the sides for the total arc of motion, forward elevation, horizontal adduction at neutral rotation, and maximal ER. It was concluded that repetitive stress of long-term throwing in professional baseball pitchers creates altered glenohumeral rotational patterns, but does not compromise the joint's passive restraining quality.

Tyler et al. examined 31 patients with dominant and non-dominant shoulder impingement, which was determined by the patient's history and clinical examination including full passive shoulder flexion motion and a positive Neer's test, and compared them to 33 controls without shoulder abnormalities in order to record changes in ROM.

Internal rotation ROM was assessed passively using a standard goniometer with the shoulder abducted to 90° while the subject was lying in.¹⁶ The examiners did not report if the scapula was stabilized or not during ROM measurements. The researchers found that patients with impingement in their non-dominant arm had decreased IR ($44.58^\circ \pm 5.53^\circ$) and ER ROM ($84.42^\circ \pm 4.64^\circ$) when compared to controls (non-dominant IR = $54.36^\circ \pm 1.37^\circ$; ER = $93.91^\circ \pm 2.02^\circ$). Patients with impingement in their dominant arm had reduced IR ROM ($38.71^\circ \pm 2.80^\circ$) but had no significant loss of ER ROM compared to controls (dominant IR = $47.67^\circ \pm 1.49^\circ$). The researchers suggested the decrease in ER ROM for impingement on the non-dominant shoulder to be due to the decreased demand for use of the non-dominant arm for activities of daily living or that patients seek treatment later, once significant functional limitations occur, than those who have impingement on their dominant shoulder.

A subsequent cohort study by Tyler et al. looked at 22 patients diagnosed with internal impingement by an orthopedic surgeon that had experience in treating shoulder injuries, to assess if decreases in GIRD and/or PST are linked with resolution of impingement symptoms.³ Impingement was diagnosed based on an MRI finding of a posterior-superior glenoid labrum lesion along with a positive relocation test, posterior impingement sign, and posterior glenohumeral joint line tenderness. Researchers found significant GIRD ($35^\circ \pm 19^\circ$) and loss of ER ROM ($23^\circ \pm 35^\circ$) during their initial evaluation compared to the unaffected side. Glenohumeral IR and ER ROM were measured with the subject in supine and at 90° of shoulder abduction and elbow flexion. The scapula was monitored with one hand, using the fingers to palpate the spine of the

scapula and the thumb of that same hand on the coracoid process while the opposite hand moved the arm passively into IR. Treatment included physical therapy three times a week consisting of manual mobilizations and stretching of the posterior shoulder with a prescribed home exercise program. Subjects also filled out the Simple Shoulder Test (SST) during the first and final treatment sessions. GIRD ($9^\circ \pm 12^\circ$) and loss of ER ($9^\circ \pm 21^\circ$) were both significantly improved after the period of physical therapy treatment sessions when compared to the unaffected side.

Posterior Capsule Tightness

A study performed by Harryman et al. examined eight glenohumeral joints in adult cadavers to determine the direction and magnitude of the translations that occur during selected passive motions and to test the hypothesis that glenohumeral movement is a result of locally tight capsular tissue.¹⁴ The cadavers used had stable shoulders, were without ROM restrictions, and had no catches or roughness during passive motion. For a specified motion, the direction of glenohumeral translation was consistent among specimens; however the magnitude of the change was different. When the capsule was tightened, glenohumeral translation was significantly changed and was large. The researchers found that in the mid-range of the arc of motion, the capsule was relatively lax and no translation occurred. However, when flexed beyond 55° the humeral head translated anteriorly. When it was extended past 35° the humeral head translated posteriorly. When the researchers operatively tightened the posterior capsule they found a significant anterior translation of the humeral head earlier in flexion and a small superior translation. In other words, operative tightening of the posterior capsule led to earlier and

greater anterior translation of the humeral head during the IR motion. There were no implications given by the researchers other than stating they were interested in what would occur with tightening of the posterior capsule as this occurs frequently in patients with impingement syndrome. Further research on glenohumeral translation was suggested in order to further understand the mechanisms of motion and stability of the glenohumeral joint.

Myers et al. studied 11 throwing athletes with pathologic internal impingement compared to 11 demographically-matched control throwers with no prior upper extremity history of injury to analyze the contributions of PST and GIRD to internal impingement.¹ The 11 subjects in the experimental group were diagnosed with pathologic internal impingement by an orthopedic surgeon experienced in treating throwing injuries. These subjects also received an MRI arthrogram with gadolinium, combined with a complete history and physical examination. Posterior shoulder tightness was measured by having subjects lie on their non-tested side with a mark placed at the medial epicondyle of the tested arm. From here, the test arm was passively moved into horizontal adduction until either the initiation of scapular movement or until maximum humeral horizontal adduction was achieved. The distance between the mark at the medial epicondyle and the exam table was used to measure horizontal adduction as a proxy for PST. A larger distance between the medial epicondyle and the table represented greater posterior tightness. Posterior shoulder tightness was then calculated as the difference between horizontal adduction of the throwing arm to that of the non-throwing arm. Throwers with impingement had 27.0 cm (\pm 5.9cm) of PST in the involved limb and 22.8 cm (\pm 4.3cm)

in the non-involved limb; where throwers without impingement had 21.1 cm (\pm 6.2cm) of PST in their involved limb and 21.9 cm (\pm 5.9cm) in their uninvolved limb. This study found that throwing athletes with pathologic internal impingement had significantly greater PST, as measured by the difference between involved and uninvolved limb, when compared with the controls (impingement group: -4.2 cm \pm 4.4 cm; controls: -0.9 cm \pm 2.0 cm). The researchers hypothesized that this increase in PST in throwers with pathologic internal impingement to be related to chronic adaptive changes to the posterior structures of the shoulder, including both the joint capsule and the rotator cuff muscles.

Internal impingement has been associated with altered glenohumeral mechanics secondary to PST. Tyler et al. studied 22 males and females with internal impingement as diagnosed by an orthopedic surgeon to see if a reduction in PST after a bout of physical therapy sessions would resolve symptoms in these patients.³ Upon the initial evaluation, GIRD, PST, and ER ROM were documented for all of the patients. Each patient completed a questionnaire called the Simple Shoulder Test (SST), where lower scores on the SST were associated with greater amounts of PST. The surgeon used the relocation test, posterior impingement sign, and posterior glenohumeral joint line tenderness as positive tests for inclusion, along with presence on an MRI of a posterior-superior glenoid labral lesion. Posterior shoulder tightness was measured with the patient in sidelying with the scapula stabilized manually in a retracted position. The subject was then passively lowered from 90° of shoulder abduction and neutral rotation to horizontal adduction until end-range or when the humerus began to internally rotate. The angle was taken along the humerus in reference to the horizontal plane. Subjects then underwent

physical therapy three times per week that consisted of manual mobilization and stretching of the posterior shoulder along with a home exercise program until symptoms resolved and return to full activity or a plateau of progress. Before the treatment, the patients had an SST score of 5 ± 3 , with a maximum score of 12. Posterior shoulder tightness was significantly improved after the bout of physical therapy, with SST scores increasing to 11 ± 1 . Improvements were greater in patients who reported complete resolutions of symptoms as compared to those patients who still reported some residual symptoms. The researchers hypothesized that subjects with more pronounced internal impingement and greater amounts of PST at intake are more likely to have successful outcomes with physical therapy focused on the posterior shoulder than subjects with less marked PST.

Asymmetrical tightness of the posterior capsule is hypothesized to cause anterior and superior translation of the humeral head with shoulder flexion, which may contribute to shoulder impingement. Tyler et al. studied the changes in posterior capsule tightness in patients with dominant and non-dominant shoulder impingement.¹⁶ Diagnosis of shoulder impingement was determined based on patient history and clinical examination, which included full passive shoulder flexion and a positive Neer's impingement sign. Posterior capsule tightness was measured by having the subject in sidelying on the non-test arm with the lateral border of the top (test arm) scapula stabilized in a retracted position. The shoulder was passively horizontally adducted until a capsular end-feel was felt or until the start of humeral rotation. The distance from the exam table to the medial epicondyle of the tested arm was used to indicate the amount of flexibility of the posterior capsule

tissues with a larger distance representing tighter posterior tissues. The current study's procedure is based on the method from the regression analysis of a previous reliability and validation study by Tyler et al. on their method to measure capsular tightness. They concluded a clinician can anticipate about 1 cm of change in posterior capsule tightness for every 4° of IR loss, which correlates well with the findings of Myers et al.¹ The results from this study found that both subjects with impingement in their dominant or non-dominant shoulder had increased posterior capsule tightness (dominant = 39.9 cm ± 1.3 cm; non-dominant = 37.7 cm ± 1.7 cm). Also, posterior capsule tightness in the impingement patients had a significant correlation with the loss of IR ROM. The researchers hypothesized that subjects may avoid positions of IR, as they tend to cause pain due to internal impingement and this leads to posterior capsule tightness. Another hypothesis is that the tight posterior capsule causes the humeral head to migrate forward leading to impingement and pain, and the subject is less likely to move, which results in a decrease in ROM.

Thomas et al. performed a study to determine if the posterior capsule of the dominant shoulder of 24 collegiate baseball pitchers and position players was related to glenohumeral IR and ER ROM.¹⁵ Internal rotation and ER ROM measurements were taken passively with the subject in the supine position and the shoulder abducted to 90°. The results of the study showed that posterior capsule tightness, as measured with an ultrasound transducer while the patient was in a seated position with their forearm resting on their thigh, was greater on the dominant shoulder (2.0 cm ± 0.3 cm) than on the non-dominant shoulder (1.6 cm ± 0.3 cm). A significant negative correlation was discovered

between posterior capsule tightness and IR ROM. This indicated that with increased posterior capsule thickness there is a decrease in IR ROM. Internal rotation may also be limited to some extent by tightness in the posterior rotator cuff, but this was not measured. The researchers stated they are unaware of any current methodology that can measure the posterior rotator cuff musculature. Posterior capsule tightness was significantly correlated with ER and between posterior capsule tightness and scapular upward rotation at 60°, 90°, and 120° of glenohumeral abduction.

Branch et al. studied the relationship between IR and ER of the humerus and the lengths of the anterior and posterior components of the glenohumeral capsuloligamentous complex of six cadaveric shoulders that were stripped of all muscles.⁴⁹ The process includes lengthening different components of the glenohumeral capsuloligamentous complex in 12 combinations, each with a different anterior and posterior component length. The results suggested that the length of the anterior component of the complex had the greatest effect on humeral ER, and the length of the posterior component had the greatest effect on humeral IR. However, there was a limitation of rotation at a number of positions by lengths of both the anterior and posterior components. Clinically, the results provide an understanding of the risk for rotational injury based on the position of the shoulder. One of the implications is that when the glenohumeral joint is in extension both the anterior and the posterior components share in resisting IR and ER. This indicates that in an extended position, excessive rotation of the shoulder can damage both the anterior and posterior components at the same time. However, in flexion, excessive IR will

damage only the posterior components and excessive ER will damage both components. Thus, the risk for rotational injuries is dependent upon the position of the shoulder.

Humeral Retroversion

A study by Chant et al. examined 19 competitive baseball players and six controls to discover if a side-to-side difference in humeral head retroversion is present in baseball players and to see if retroversion is associated with shoulder joint ROM.¹⁰ The researchers found a significant side-to-side difference in humeral head retroversion with a 10.6° greater retroversion in the dominant arm as compared to the non-dominant arm. This side-to-side difference was not noted in the control group (average difference = 2.3°). Greater humeral head retroversion was shown to be associated with more ER ROM and less IR ROM in the throwing arm of throwing athletes. The mean passive ER rom of the throwing arm was 114.0° (± 9.8°) as compared to 104.1° (± 7.4°) for the non-throwing arm, and the mean passive IR for the throwing arm was 57.1° (± 8.7°) compared to 73.5° (± 9.6°) for the non-throwing arm. It should also be mentioned that there was a significant loss in total arc of motion, both passively and actively, for the throwing shoulder compared to the non-throwing shoulder. Passive total arc for the dominant arm was 171.1° (± 12.5°) compared to 177.6° (± 11.0°) for the non-throwing arm, and active total arc for the dominant arm was 151.2° (± 11.8°) compared to 158.0° (± 9.4°) for the non-throwing arm. This study suggests that the side-to-side difference in shoulder ROM in throwing athletes should not be considered as solely a soft tissue problem, but rather the thrower may also have an underlying bony component that should be evaluated.

Reagen et al. also examined humeral retroversion and its relationship to rotation of the glenohumeral joint.⁸ Fifty-four asymptomatic college baseball pitchers and positions players were selected for inclusion in this study. Internal rotation ROM at 0° abduction was performed in a seated position in which the subject reached behind their back to the highest vertebral level possible, and this was converted to a number established by the AAOS.²⁶ The remaining motions of flexion, IR at 90° abduction, and ER at 0° and 90° of abduction were conducted with the patient in supine and the scapula stabilized in a neutral position. The subjects were passively taken to a firm, capsular end-feel for each motion, at which point goniometric measurements were taken using the standard guidelines from the AAOS. Humeral retroversion was measured radiographically with the subject in supine and the humerus positioned in neutral rotation, 90° of flexion, and 20° of abduction with the elbow flexed to 90°. The forearm was kept in a neutral pronation-supination. The findings suggest that an increase in humeral retroversion is significantly correlated with a decrease in glenohumeral IR and an increase in ER on the dominant arm at 90° abduction. This increase in retroversion on the dominant shoulder allows for greater ER of the shoulder during overhead throwing. However, there was no statistical significance between total ROM (full ER ROM in 90° abduction to full IR ROM at 90° abduction) between the dominant and non-dominant shoulder ($159.5^\circ \pm 12.4^\circ$, $157.8^\circ \pm 11.5^\circ$). There was a significant difference between humeral retroversion on the dominant compared to the non-dominant shoulder (mean dominant: $36.6^\circ \pm 9.8^\circ$, mean non-dominant: $26.0^\circ \pm 9.4^\circ$). This difference was

hypothesized to be a result of external forces placed on the proximal humerus while throwing that occur during growth (up to 16 years old).

A study by Crockett et al. utilized 25 professional pitchers and 25 non-throwing subjects to determine if there was a significant bony difference between groups and/or between shoulders of the same subject, as well as if this difference may explain the change in motion of professional pitchers.⁷ The throwing subjects had significantly greater humeral head retroversion (dominant = $40^{\circ} \pm 9.9^{\circ}$; non-dominant = $23^{\circ} \pm 10.4^{\circ}$), ER at 90° abduction (dominant = $128^{\circ} \pm 9.2^{\circ}$; non-dominant = $119^{\circ} \pm 7.2^{\circ}$), and decreased IR (dominant = $62^{\circ} \pm 7.4^{\circ}$; non-dominant = $71^{\circ} \pm 9.3^{\circ}$) of the dominant shoulder as compared to the non-dominant shoulder. The researchers discussed how a throwers' dominant shoulder adapts to throwing by increasing ER ROM and decreasing IR ROM to allow for them to reach the high velocities required for this sport, yet they maintain their total arc of motion. Total motion for the throwers in this study was $189^{\circ} (\pm 12.6^{\circ})$ for the dominant arm and $189^{\circ} (\pm 12.7^{\circ})$ for the non-dominant arm. This shows that there is not a significant difference between shoulders but rather that the dominant shoulder is shifted to greater ER ROM and less IR ROM. The study also found the throwing group had significantly greater ER at 90° (throwers = $128^{\circ} \pm 9.2^{\circ}$; non-throwers = $113^{\circ} \pm 14.6^{\circ}$) and humeral retroversion (throwers = $40^{\circ} \pm 9.9^{\circ}$; non-throwers = $18^{\circ} \pm 12.9^{\circ}$) in the dominant shoulder as compared to the control group. These findings show that this retroversion adaptation occurs in overhead-throwing athletes to allow for the high demands of throwing and is therefore not seen in non-throwers (controls). Another relevant finding is the humeral retroversion of the non-dominant shoulder for the

throwing group ($23^{\circ} \pm 10.4^{\circ}$) was not significantly different from the non-dominant shoulder for the non-throwing group ($19^{\circ} \pm 13.5^{\circ}$).

Osbahr et al. studied 19 male college baseball pitchers to see if radiographs from these pitchers could determine if proximal remodeling of the humerus contributes to rotational asymmetry.¹⁸ The study found a significant difference between the dominant and non-dominant shoulder for ER at 0° ($9.1^{\circ} \pm 5.6^{\circ}$) and 90° abduction ($12.3^{\circ} \pm 6.7^{\circ}$), IR at 90° abduction ($-12.1^{\circ} \pm 8.6^{\circ}$), and humeral retroversion ($10.1^{\circ} \pm 4.7^{\circ}$). For the dominant arm, there was a significant correlation between humeral retroversion and ER ROM at both 0° and 90° abduction. The authors suggest that since these players started throwing at a younger age and continued to throw over many years, their shoulders were able to adapt by changing the rotational symmetry of the shoulder. They go on to discuss how retroversion may be beneficial to a thrower by allowing the thrower greater ER ROM, which in turn allows greater force to be exerted during a throw. The second potential benefit is that with increased retroversion, the anterior soft tissue structures do not have to stretch as much and therefore allow for better stabilization at the glenohumeral joint.

In a study of handball athletes compared to healthy controls, Pieper examined both shoulders of a subject to see if there was a side-to-side difference in humeral retroversion and to see if this difference was a factor in chronic shoulder pathologies in handball athletes.¹² The study included 51 male handball players ages 18-39 who all started participating in competitive handball by the age of 10 and had participated in at least five years of competition. Thirty-eight of the 51 had no prior history of shoulder

problems while the remaining 13 had complaints of chronic shoulder pain. There were 37 healthy male controls ages 20-74 who had not taken part in any unilateral sports or any unilateral manual labor while growing up. Radiographic imaging was used to determine the degree of humeral retroversion present at each shoulder. The handball players without shoulder pain had a significant increase in humeral retroversion by an average of 14.4° in their dominant shoulder compared to their non-dominant shoulders, while handball players with shoulder pain had a non-significant average of 5.2° less humeral retroversion in their dominant shoulders compared to their non-dominant shoulders. The control group showed no significant difference between dominant and non-dominant shoulders. The handball players without chronic shoulder pain had an average of 7.62° more retroversion than the controls for dominant shoulders. This increase in retroversion in the dominant arm allows for an increase in ER, which may be an adaptation during early overhead throwing to protect from anterior instability. Athletes who do not have this adaptation seem to have greater anterior capsule strains and an increased possibility of chronic pain due to anterior laxity.

In a study by Yamamoto et al., the relationship and growth in the dominant and non-dominant shoulders of 66 elementary and junior high school baseball players was determined using ultrasonography to measure the rotation angle of the proximal humerus relative to the elbow (“bicipital-forearm angle”).² The humeral retroversion angle is the angle between the axis of the humeral head and a line passing through the two epicondyles, but could not be directly measured by ultrasonography. Therefore, the bicipital-forearm angle was used, which states that a smaller bicipital-forearm angle

indicates greater humeral retroversion. Each of the subjects received a physical examination and ultrasonography on both shoulders to measure the bicipital-forearm angle. There was a significantly smaller bicipital-forearm angle in dominant shoulders when compared to non-dominant shoulders, which indicated that the retroversion angle was larger in dominant shoulders than non-dominant shoulders. A moderate positive correlation was found between age and bicipital-forearm angle in dominant and non-dominant shoulders. It was concluded that humeral retroversion decreases with age, but with less decrease occurring in the dominant shoulder. The assumption was made that repetitive throwing motion restricts the pathological deterioration process of the humeral head during growth rather than increasing humeral retroversion.

A study published in 2008 by Tokish et al. examined 23 active, asymptomatic professional (Major League Baseball) pitchers.¹⁹ Their purpose was to determine if GIRD was existent in an asymptomatic population of professional baseball pitchers, and to assess if the changes were primarily due to soft tissue or bony adaptations. Two independent orthopedic surgeons measured subjects' glenohumeral ROM, laxity, and GIRD, as well as radiographic measures of humeral retroversion. These measures were compared side-to-side using paired t-tests for continuous data and a Chi-squared test for ordinal data, with a significance set at 0.05. Their results indicated no difference between total arc of motion, laxity, ER at 0°, IR at 0°, elevation, or cross body adduction between dominant and non-dominant arms. There were, however, significant differences noted for ER, IR, and humeral retroversion at 90°, when comparing dominant to non-dominant arms. There was a 19° increase in ER at 90° in dominant versus non-dominant arms

across the whole group; conversely there was a 19° decrease in IR of the dominant arm when compared to the non-dominant side. There was an increase of 11° of humeral retroversion in dominant arms over non-dominant arms. GIRD, which was defined as a loss of IR greater than ER gain or as a loss of IR greater than 25°, was present in 10 of 23 pitchers. This group demonstrated a significant increase in humeral retroversion and correlation with GIRD. The non-GIRD group did not demonstrate an increase or correlation. Tokish et al. concluded that GIRD is a common finding in asymptomatic professional pitchers and is related to humeral retroversion. It was also determined that IR deficits should not be used as the sole screening tool when diagnosing the disabled throwing shoulder.¹⁹

Myers et al. measured the influence of humeral torsion on interpretation of clinical indicators of PST in overhead athletes.⁹ The subjects in this study included twenty-nine healthy intercollegiate baseball players and 25 college-aged control individuals with no history of participation in overhead athletics. Bilateral humeral rotation and humeral horizontal adduction variables were measured with a digital inclinometer aligned with the subject's forearm. In all participants, ultrasonography was also used to measure bilateral humeral torsion. Results demonstrated that there was greater humeral torsion in the dominant arm of the baseball players, and less IR and total rotation ROM compared to control participants and the non-dominant arm in both groups. This indicated that there are differences in measurements of PST in overhead athletes when compared with control participants. These differences seem to be influenced by the amount of humeral torsion present in the shoulder. This study demonstrated that the

dominant arm of overhead athletes had an average of 15° more humeral torsion than their non-dominant arm and about 13° more than those who did not participate in overhead activities.⁹ There were statistically significant relationships between the amount of humeral torsion and measures of PST. These results indicate that clinicians should account for torsion when measuring PST in order to assist in determining appropriate interventions.

Posterior Shoulder Muscle Stiffness

A case report by Poser and Casonato examined a 42-year-old male manual worker who had symptoms consistent with internal impingement that had persisted for 12 weeks.²³ The investigators were interested in seeing if the impingement was occurring secondary to posterior muscle stiffness rather than posterior capsule tightness. The treatment consisted of seven minutes of massage to the infraspinatus and three minutes to the teres minor on alternating days for a week (three treatments), as this was deemed to be a sufficient amount of time in order to observe a change in the two muscles. The massage was conducted with the subject in prone with the arm relaxed in order to treat the muscles and not to affect the capsule. No medications were taken during this time and the subject performed no exercise program. The subject's shoulder IR ROM was measured with an inclinometer. An electronic dynamometer was attached to the wrist of the patient in supine with his arm at 90° of abduction to measure the force utilized by the therapist, which was determined to be the same for the pre and post-treatment measures. The initial examination of IR ROM rendered a measure of 68° and on the last visit the subject was measured at 88° of shoulder IR ROM. The investigators concluded that a

reduction in IR could be due to a contracture in the posterior musculature and not just a restriction of the posterior capsule.

A study by Hung et al. looked at the relationship between stiffness in the posterior shoulder muscles and shoulder rotation in patients with and without shoulder stiffness.²¹ The researchers recruited 20 healthy control subjects along with 20 subjects with stiff shoulders, as described by limited IR ROM of <20% of the contralateral side along with subjective complaints of pain and stiffness in the shoulder region for at least three months. A goniometer was used to measure shoulder IR ROM in supine with the subjects arm abducted to 90° and the lateral border of the scapula stabilized by the researcher's hand. The mean IR ROM of subjects with stiff shoulders was 30.4° (\pm 10.3°) and of subjects with healthy shoulders was 88.3° (\pm 4.6°). Shoulder stiffness was measured with a Myotonometer, a probe that detects displacement when inserted into the muscle and surrounding tissue, with the subject sitting with his or her arm abducted on a pillow. A significant correlation was found between muscle stiffness and shoulder IR ROM in the posterior deltoid, teres minor, and infraspinatus for subjects with stiff shoulders. Upon further analysis the posterior deltoid stiffness was found to account for 51% of the variance in shoulder IR ROM. The researchers discussed that these muscles can contribute to stiffness since all of their actions involve ER so, if tight, could limit IR. It was speculated that the reason for the posterior deltoid accounting for 51% of the variance was that this muscle also includes a shoulder adduction component on top of an external rotation component. The infraspinatus and teres minor, however, only supply an external rotation component. Since muscle stiffness was obtained in shoulder abduction

the posterior deltoid had increased tension placed upon it and, therefore, the posterior deltoid showed a higher correlation with the loss of IR than the other two muscles.

A controlled lab study conducted by Reinold et al. examined the changes in shoulder and elbow passive ROM before a warm-up, within 30 minutes post-completion of a pitching session, and within 24 hours of the initial measurement.²⁴ Sixty-seven asymptomatic professional baseball pitchers participated in the study. Passive IR and ER ROM was measured with the subject in supine with their arm abducted to 90° and 10° of horizontal adduction. Measurements were taken with a bubble inclinometer when the examiner felt the end-feel and/or saw compensatory movements of the shoulder. A significant change in IR ROM and total motion was noted after the pitching session and within 24 hours of the initial practice session. Mean IR ROM before pitching was 54.1° ($\pm 11.4^\circ$), 44.6° ($\pm 11.9^\circ$) within 30 minutes of pitching, and 46.5° ($\pm 10.0^\circ$) within 24 hours of the first measurement. The mean total motion measurement taken before warm-up was 190.6° ($\pm 14.6^\circ$), 179.9° ($\pm 13.7^\circ$) within 30 minutes of finishing pitching session, and 182.9° ($\pm 11.5^\circ$) within 24 hours of the first measurement. There was no significant change noted for ER ROM and no significant change in any motion of the non-dominant shoulder. The researchers stated that this loss of IR ROM and total motion within a pitching session could not be entirely due to bony or capsular adaptations but must have included muscular adaptations to acute throwing. The researchers also discussed that the external rotators of the shoulder go through repetitive eccentric muscle activity during throwing which can lead to adaptive shortening of the soft tissue and, therefore, a reduction in IR ROM. Reinold et al. also discussed other studies that have found

decreases in both upper and lower extremity ROM post repetitive eccentric movements, revealing a correlation eccentric contractions of muscles and loss of ROM in joints due to increased passive tension in muscles.

A study by Borsa et al. was conducted to determine side-to-side differences in passive glenohumeral ROM and stiffness in a group of asymptomatic professional baseball pitchers using selected kinematic measures.¹³ Thirty-four subjects participated in this study and had bilateral assessments for passive glenohumeral ROM and stiffness during a single testing session. An instrumented stress device called the LigMaster was used to measure force-displacement bilaterally by measuring force-induced changes within a joint to determine the stiffness or passive resistance the joint has to forces applied. Shoulders were positioned in 90° of abduction and 90° external rotation, while subjects were in a seated position. Two counter bearings were placed on the spine of the scapula and the coracoid process to limit scapular motion during testing. The researchers found no significant differences for passive joint stiffness between the throwing and contralateral shoulder or between the anterior and posterior directions. There was, however, an overall greater anterior stiffness (16.4 ± 1.6 N/mm) than posterior stiffness (15.2 ± 3.2 N/mm) in both shoulders. It was concluded that repetitive stress of long-term throwing in professional baseball pitchers creates altered glenohumeral rotational patterns, but does not compromise the joint's passive restraining quality.

A study conducted by Yang et al. evaluated the relationships between anterior and posterior shoulder tightness and its association with shoulder kinematics and functional deficits in subjects with stiff shoulders.²² The researchers had 46 patients who had

unilateral stiff shoulders and were assessed via a clinical measurement for shoulder tightness, a three-dimensional electromagnetic tracking device for shoulder ROM, and self-reports of function. Stiff shoulders were defined as having at least 25% loss in ROM as compared to the non-involved shoulder, in at least two separate shoulder motions, along with pain/stiffness lasting at least three months. Posterior and anterior shoulder tightness were measured with an inclinometer placed parallel to the humerus next to the medial epicondyle while the shoulder was passively moved into cross-chest adduction or below-chest abduction while the subject was in supine. The passive movement stopped when there was a firm end-feel, which suggested the end of shoulder tissue flexibility. The angle measured represented the flexibility of the posterior or anterior shoulder tissues where a greater angle represented more flexibility. Findings showed that subjects with dominant stiff shoulders had statistically greater PST ($13.4^{\circ} \pm 9.3^{\circ}$) when compared to the non-dominant shoulder ($10.7^{\circ} \pm 7.6^{\circ}$). There was a significant relationship between IR ROM ($23.3^{\circ} \pm 13.2^{\circ}$) and PST, ER and anterior shoulder tightness, and anterior scapular tipping and anterior shoulder tightness in stiff shoulders. The researchers also found subjects with dominant stiff shoulders had a relationship between PST and functional limitation. It was suggested by the researchers that a stretching program be used for patients with stiff shoulders.

Posterior Capsulorrhaphy

A study by Gerber et al. assessed the effect of capsulorrhaphy on the passive ROM of the glenohumeral joint.¹⁷ The purpose of the study was to simulate localized capsular tightening in order to identify the effects on passive ROM and to identify the

anatomical sites causing specific patterns of capsular stiffness. This study used eight fresh-frozen human cadaveric shoulders with all shoulders having stable and full ROM. Three electronic goniometers, one for each place of motion, were attached to the humerus and the scapula to measure the glenohumeral motion. The measures of motion were taken, one prior to capsular tightening, one with the tightened capsule and one after the capsule was released. The results revealed a decrease in ROM after each shortening. The more inferior the plication occurred, the more of an impact it had on the rotation of the glenohumeral joint. A total posterior-inferior capsulorrhaphy completely eliminated IR in some shoulders. These findings conclude that a posterior capsulorrhaphy could be a contributing factor to GIRD.

Range of Motion for Normal Adults

The review of literature for normative values of shoulder IR revealed a wide range of values with the majority of authors concluding that the normative value for shoulder IR is lower than that recommended by the American Association of Orthopedic Surgeons. Below is a summary of articles investigating normative values of a variety of populations and techniques.

The American Association of Orthopedic Surgeons (AAOS) has determined the average IR of the shoulder complex to be 70°. ²⁶ The AAOS value was put in place to be true for all people regardless of age or gender as well as for both the right and left side. The technique used and recommended is to have the arm abducted 90° from the side of the body with no scapular stabilization. The methods with which they determined this average measurement are not clear.

One study by Boone and Azen measured shoulder IR of 56 males ages 20-54 years old.⁴² They measured IR in the supine position with 90° of shoulder abduction without scapular stabilization based on the recommendation of the AAOS methods. The study found the average IR of males over 20 years old to be 67.1° (\pm 4.1°).

Another study by Gill et al. reviewed 72 patients (35 males and 37 females) ages 20-49.³⁸ This study measured IR in a supine position with 90° shoulder abduction in a supine position, with the examiner applying a posterior force on the anterior shoulder to stabilize the scapula. They found active IR to be 64.6° (\pm 13.0°) and passively to be 64.6° (\pm 13.3°). It was concluded that the population tested had lower IR values compared to the AAOS norms.

A study by McIntosh et al. had 41 participants aged 50+ years.³⁹ All participants must have been independent in all activities of daily living, be community dwelling and have adequate mobility for sit-to-lie transfer. Internal rotation was measured supine with the arm positioned in 90° of abduction with the scapula stabilized by applying a posterior force on the anterior shoulder. The active and passive measurements of this population were lower than the AAOS normative values with active IR measuring 61.6° (\pm 8.2°) and passive IR measuring 66.5° (\pm 8.0°). The authors also noted a significant difference in ROM between genders. The female participants had higher ROM with a mean of 64.6° compared to male participants with a mean of 58.7°.

A study done by Gunal et al. compared IR of 1000 male participants aged 18-22 years with right hand dominance.⁴⁰ They followed AAOS recommendations and measured shoulder IR ROM in a supine position, with the arm abducted to 90°. No

scapular stabilization was applied. They found active IR of the right side to be $95.5^{\circ} (\pm 12.6^{\circ})$ and passively to be $102.2^{\circ} (\pm 6.3^{\circ})$. The measurements showed to vary from the averages given by the AAOS despite the authors stating that they followed the specific written methods of the AAOS directions.

One study by Conte et al. measured the passive IR of non-athlete women who were right hand dominant.⁴¹ The participants of this study ranged from 20 to 29 years old and were not practicing any overhead sports or activities. Internal rotation was measured in a supine position without scapular stabilization. The end point was determined when the scapula began to lift off the table. The average of the right shoulder was $58.5^{\circ} (\pm 10.5^{\circ})$ and the average of the left side was $62.0^{\circ} (\pm 10.4^{\circ})$. The right shoulder presented with a significantly different IR ROM compared to the left shoulder. The authors concluded there is a difference in ROM between dominant and non-dominant shoulders for women and that the measurements they took were lower than the norms proposed by the AAOS.

The study done by Allander et al. looked at the normal ROM of the shoulder with special reference to side and compared two populations.⁴⁶ One part of the study took place in Iceland with 2342 female participants aged 33-60 and the second population from Sweden with 946 male participants and 974 female participants aged 45-70. The examiners used a goniometer and the participant was in a seated position and the examiner did not manually stabilize the scapula. The examiners measured the arc of rotation with the arm at 90° abduction. The authors saw no significant difference between

genders in regards to shoulder rotation but did identify an overall decrease of shoulder rotation with age.

A study by Lunden et al. was completed in 2010 to establish the reliability of the sidelying position for measuring IR.²⁸ This was done using 70 subjects with and without shoulder pathology. The authors found sidelying IR measurements for the entire group ranged from 11° to 69°, with an average value of 39.8° ($\pm 9.5^\circ$) or 39.6° ($\pm 12.3^\circ$) for healthy subjects, depending on the rater. The authors noted that this “normal” value is significantly different than what the AAOS suggests for IR measured in supine (70°).²⁸ It is likely that the sidelying position provides a different degree of stabilization to the scapula to prevent accessory motion, namely anterior tipping, which contributes to the overall passive ROM observed during IR measurement. Therefore, there exists a need for a normal range of values for this position.

Range of Motion and Overhead Athletes

In a study by Baltaci et al, shoulder range of motion in 38 collegiate baseball players with no history of shoulder pathology was examined.⁵⁰ Players were excluded if they had previous trauma or injury to the spine, rib cage, shoulder or scapula or if they displayed signs of impingement or instability. Both dominant shoulder and non-dominant shoulder were measured, using a standard goniometer. Passive IR was measured supine with the arm abducted at 90° and the scapula was stabilized to avoid anterior tipping during the movement. There was a significant difference in the IR measurement when comparing the dominant versus the non-dominant arms of pitchers. For right arm dominant pitchers, the IR was 55.8° ($\pm 7.1^\circ$) while the non-dominant left arm was 69.2°

($\pm 4.8^\circ$). For left arm dominant pitchers, the IR was $62.6^\circ (\pm 3.6^\circ)$ and the non-dominant right arm was $71.6^\circ (\pm 3.4^\circ)$. It was also found that right hand dominant position players had 10° more IR compared to their non-dominant side. All of the pitchers had a significantly increased ER on the dominant arm compared to the non-dominant arm. For right hand dominant pitchers, the difference was 14.9° and for left handed pitchers, the difference was 13° . The position players also had a significant difference of 7.8° in ER between dominant and non-dominant. The authors concluded that there was selective tightening of the posterior capsule with repetitive stress and that comparison between the two sides to identify the normal ROM may not be appropriate.

Borsa et al. investigated the glenohumeral range of motion in professional baseball players.¹³ There were 34 professional baseball pitchers that participated in the study, none of whom had a history of glenohumeral instability or previous shoulder surgeries. They took their measurements in the supine position with the use of a standard goniometer and no external stabilization was applied to the scapula. They found a significant difference between the throwing arms and non-throwing arms with regard to IR. The throwing/dominant arm revealed decreased IR compared to the non-throwing/non-dominant arm. The average IR for throwing arms was $59.7^\circ (\pm 7.0^\circ)$ history of shoulder pathology and for non-throwing arms $68.2^\circ (\pm 8.6^\circ)$. The authors found that pitchers have significantly less IR on their throwing arm compared to the contralateral side.

A study by Brown et al. investigated the upper extremity range of motion in Major League Baseball players.⁵¹ Forty-one professional baseball players were subjects

in this study. Measurements were taken in a supine position without scapular stabilization with a standard goniometer. The results showed a significant difference between the dominant and non-dominant shoulder IR. The results also showed a difference between pitchers and position players but the difference was not significant. Position players demonstrated $85^{\circ} (\pm 11.9^{\circ})$ of IR on their dominant arms and $91^{\circ} (\pm 13.0^{\circ})$ on their non-dominant arm. Pitchers showed $83^{\circ} (\pm 13.9^{\circ})$ on their dominant arms and $98^{\circ} (\pm 13.2^{\circ})$ on their non-dominant arms. The researchers concluded that this significant difference has clinical implications and clinicians need to be aware of these differences when creating a treatment plan for these patients.

A study by Ellenbecker et al. examined whether there was a difference between the dominant and non-dominant extremity in glenohumeral IR and ER ROM in elite tennis players.²⁵ They recruited 203 subjects, ages 11-17 years old, 113 males and 90 females. None of the participants had a history of upper extremity injury. The subjects were measured in supine with arm at 90° of abduction with a standard goniometer. The tester applied stabilization to the scapula. The results were that there was a significant difference between dominant and non-dominant arms. There was a decrease in total range of shoulder rotation on the dominant arm compared to non-dominant. Males showed IR on their dominant side to be 45.4° and 56.3° on their non-dominant side. Females showed IR on their dominant side to be 52.2° and 60.3° on their non-dominant side.

Another study by Ellenbecker et al. studied the glenohumeral joint total range of motion in elite tennis players and baseball pitchers.⁶ They looked at each group individually to compare dominant and non-dominant shoulder rotation as well as

comparing the two groups of upper extremity athletes. There were 163 total participants, 46 baseball pitchers and 117 tennis players. The participants had no history of shoulder injury or previous shoulder surgeries. This study measured active range of motion with the subject supine and the scapula stabilized. The baseball pitchers showed IR of the dominant arm to be $42.4^{\circ} (\pm 15.8^{\circ})$ and on the non-dominant arm to be $52.4^{\circ} (\pm 16.4^{\circ})$. The tennis players had IR on the dominant side to be $45.4^{\circ} (\pm 13.6^{\circ})$ and on the non-dominant arm to be $56.3^{\circ} (\pm 11.5^{\circ})$. Both groups showed significant differences between the dominant shoulder range of motion and the non-dominant shoulder range. The study did not reveal significant differences between the two populations in regards to IR.

A study by Kibler et al. aimed to report the glenohumeral rotation measurements in a specific high use population of tennis players and correlate these measurements with age, years of play and dominant, non-dominant shoulder differences.¹¹ They used 39 volunteers from the US tennis association, (20 males and 19 females) ages 14-21. None of the participants had any current shoulder symptoms. Shoulder range of motion was measured in supine, with the arm abducted to 90° and the scapula stabilized by the examiner. The end point was determined to be right before the scapula protracted off the table. The authors found no significant differences between the genders in regards to IR, but did find significant differences between dominant and non-dominant shoulders. Men were found to have 41.7° of IR on their dominant shoulders and 68.0° on their non-dominant shoulders. Women had 43.3° on their dominant shoulders and 72.8° on their non-dominant shoulders. The researchers also found that the dominant shoulder IR

declined with age and year of play as well as there was increase in the differences between dominant and non-dominant differences with age and years of total play.

The purpose of a study by Reagan et al. was to determine the relationship between the humeral head retroversion and the rotational motion of the glenohumeral joint.⁸ They found 54 male college baseball players who had no history of pathologic laxity, shoulder injury or shoulder surgery. The rotation was measured in the supine position with the scapula stabilized by the examiner. The results showed a significant difference between the dominant and non-dominant shoulders in regards to IR but the total rotational motion of both sides was the same. The dominant shoulders had $43.0^{\circ} (\pm 7.4^{\circ})$ of IR, while the non-dominant shoulders had $51.2^{\circ} (\pm 7.3^{\circ})$.

Range of Motion and Technique Used

A study by McCall et al. measured IR ROM in different anatomical planes of motion on 16 subjects, eight males and eight females, ages 20-32 years old with no history of cervical or shoulder pathology.⁴⁵ Internal rotation was measured in the coronal plane, scapular plane and sagittal plane with 90° of humeral elevation in each plane while the subject was seated. The end point was determined by a computer preset of 4 Nm of force or when the subject reported discomfort. Active and passive measurements were taken. In the coronal plane, measurements were $73^{\circ} (\pm 18^{\circ})$ and $90^{\circ} (\pm 22^{\circ})$ respectively. In the scapular plane, measurements were $65^{\circ} (\pm 11^{\circ})$ actively and $75^{\circ} (\pm 20^{\circ})$ passively. Finally in the sagittal plane, active measurements were $41^{\circ} (\pm 14^{\circ})$ and passively $49^{\circ} (\pm 19^{\circ})$. This study concluded that the plane the measurement was taken in has effect on the

range of motion measurement due to the tightening of the posterior glenohumeral ligaments as the humerus is moved anteriorly.

A recent study by Carcia et al. found normative values for shoulder IR taken in the sidelying position.⁵² They measured 60 college-aged students (28 males and 32 females) and took the passive glenohumeral IR measurement of both the dominant and non-dominant arm using a digital inclinometer. The mean for the dominant arm was 48° ($\pm 12.7^{\circ}$) and 52.7° ($\pm 10.2^{\circ}$) for the non-dominant. The authors concluded that there was a significant difference between the dominant and non-dominant shoulders in healthy, college-aged students. A secondary conclusion was that there was no significant interaction between age and glenohumeral IR.

Another study done by Boon and Smith measured IR and the effect of manual scapular stabilization.³⁵ The participants were 50 high school athletes (18 males and 32 females) aged 12-18 years old. Rotation was measured in supine with 90° abduction with manual scapular stabilization and without manual scapular stabilization. The stabilization was applied by the tester at the subject's coracoid process and clavicle with the heel of the hand. The end point with passive rotation was determined by subject's comfort and capsular end-feel as determined by the tester. The IR with scapular stabilization was 62.8° ($\pm 12.7^{\circ}$) and without scapular stabilization was 89.1° ($\pm 23.0^{\circ}$). The authors concluded that scapular stabilization had an effect on the amount of IR.

One study by Awan et al. compared three techniques for measuring IR of the shoulder.³² They tested IR with scapular stabilization, without scapular stabilization and by visual inspection. Fifty-six high school aged students (32 males and 24 females)

participated in this study. Internal rotation was measured in supine with 90° of glenohumeral abduction. While testing with scapular stabilization and without scapular stabilization, end point was determined by patient comfort or a capsular end-feel noted by the tester. Stabilization was applied at the coracoid process and clavicle with the heel of the tester's hand. For visual inspection, end point was determined by the posterolateral acromion was visualized to rise off the table. The researchers found that IR with scapular stabilization and IR by visual inspection were more accurate in determining glenohumeral movement. Internal rotation with scapular stabilization measured to be 63.2° (\pm 11.8°), IR without scapular stabilization measured to be 91.2° (\pm 15.4°), and IR by visual inspection measured to be 60.6° (\pm 10.9°).

Range of Motion and Age

A study done by Fiebert et al. had 102 participants (71 females and 31 males).⁴³ They were aged 61-93 years with an average age of 76.1 years. The examiners measured their active right shoulder ROM and volunteers were excluded if they had any shoulder dysfunction present. The ROM was measured in supine position with stabilization of the scapula by the examiner. The examiner demonstrated the motion and the participant performed the motion twice with the second measure being recorded. The average IR measurement for females was 65.8° \pm 11.8° and for males the measurement was 58.2° (\pm 12.1°). The authors analyzed the data for age, by decade and found that IR decreased linearly with age. The values found were lower than the values proposed by the AAOS. The authors concluded that the change in ROM for persons over the age of 60 should be taken into consideration when performing clinical testing.

Another study by Walker et al. examined the active joint mobility of volunteers aged 60-84 years.⁴⁴ There were 60 participants (30 females and 30 males) that lived functionally independently. Participants were excluded if they had ROM limitations that interfered with their daily living, a pathological condition or other conditions that would be under constant treatment. Subjects with mild arthritis or similar musculoskeletal conditions were not excluded due to those conditions being common in the age group being tested. The testers used the position described by the AAOS and all motions were measured twice. Internal rotation measured for the males was $59^{\circ} (\pm 16^{\circ})$ and for the females it was $66^{\circ} (\pm 13^{\circ})$. The authors concluded that IR and joint mobility decreased with age and that males have less ROM when compared to females.

Range of Motion and Arm Dominance/Handedness

Two studies examined whether measuring the dominant vs. non-dominant arm made a significant difference in shoulder ROM measurements.^{41,47} In one study, the researchers found statistically significant differences in both ER ROM and IR ROM.⁴¹ External rotation ROM was increased on the dominant side by an average of 4.7° (95% CI = $1.6-7.9^{\circ}$) and IR ROM was decreased on the dominant side by an average of 3.5° (95% CI = $1.6-5.4^{\circ}$). These significant findings were consistent with the findings in a study by Yoshida et al.⁴⁷ A third study using collegiate water-polo players did not show a statistically significant difference between dominant and non-dominant sides for shoulder IR, although there were significant differences for ER and total arc of motion, both of which were greater on the athlete's dominant side.⁴⁸ In a study by Gunal et al., the authors collected data on 1000 male subjects who were right hand dominant.⁴⁰ Internal

rotation ROM was measured for the upper extremities and the passive measurement for the dominant side was $102.2^{\circ} (\pm 6.3^{\circ})$ and on the non-dominant side was $110.4^{\circ} (\pm 5.8^{\circ})$. This was found to be a significant difference between the dominant and non-dominant side. The results of these studies suggest handedness or dominance should be considered when measuring shoulder rotation.

Goniometric Measurement

The review of literature for statistics related to goniometric measurement of shoulder IR shows mixed evidence. Below is a summary of articles pertaining to inter-rater and intra-rater reliability as well as commentary on various patient positions for measuring shoulder IR. The last section describes statistics related to tests and measures of PST.

Goniometer with Scapular Stabilization

One study by Boon and Smith examined manually stabilizing the scapula and its effect on shoulder IR measurement compared to measurement without stabilizing the scapula in asymptomatic high school athletes.³⁵ Two testers used goniometers with a level attached to the stationary arm to ensure accurate measuring. Each subject was positioned supine, with the test arm in 90° abduction. Stabilization of the scapula was achieved by applying anterior-posterior pressure to the coracoid process. Intra-class coefficient (ICC) and standard error of measurement (SEM) values were calculated for inter- and intra-rater reliability. Inter-rater reliability was 0.13 (SEM = 21.5°) for non-stabilized measurement and 0.38 (SEM = 9.99°) for stabilized measurement. Intra-rater reliability was 0.23 (SEM = 20.2°) for non-stabilized and 0.60 (SEM = 8.0°) for

stabilized. Non-stabilized measurement had SEM values ranging from 20.2-21.5° and stabilized measurement had SEM values ranging from 8.03-9.99°. Reliability was poor for all scenarios with the exception of intra-rater reliability with scapular stabilization, and it should be noted that standard error decreases with scapular stabilization.

A study by Lunden et al. was conducted in 2010 to examine the reliability of IR PROM measurements in the supine versus sidelying position.²⁸ The researchers compared the reliability (ICC values) of measuring IR PROM in two positions. The first position involved the subject lying supine with the test arm abducted to 90° and the elbow flexed to 90° and the scapula was manually stabilized by the tester by providing a posterior force through the subject's acromion and coracoid processes. The second test position involved the subject in a fully-sidelying position lying on the test side with the subject's body weight providing scapular stabilization. The subject's arm was then passively internally rotated until a firm end-feel was felt. Seventy subjects were recruited for this study, some healthy (n = 51) whose dominant shoulder was measured, and some with shoulder pathology (n = 19), whose involved shoulder was measured. The ICC values for intra-rater reliability in the supine position ranged from 0.70-0.93 compared to 0.94-0.98 for the sidelying position. Inter-rater reliability was also lower for the supine position, with ICC values ranging from 0.74-0.81 compared to 0.88-0.96 for the sidelying position. The authors concluded that the sidelying position could be a viable option for a more reliable glenohumeral IR measurement due to better stabilization of the scapula via the patient bearing weight on their own scapula.

A second purpose of the authors in Lunden et al. was to calculate the minimal detectable change (MDC) for measurements in each position. In the supine position, the MDC was 2.3° for the healthy group and 4.1° for the shoulder pathology group.²⁸ In the sidelying position, the MDC was 3.0° for the healthy group and 6.1° for the shoulder pathology group. The authors concluded that despite being similar to MDC values for goniometric measurement, the MDC values for the sidelying position were greater than supine and therefore represent greater variability in measurement.

A study by Awan et al. compared non-stabilized vs. stabilized shoulder IR measurement, and also included visual inspection looking for scapular anterior tipping as a third means of determining the end of the patient's range.³² The patient was considered to be at end-range when the posterior-lateral corner of the acromion visibly lifted off from the mat. In this study, subjects were asymptomatic high school athletes, and measurement was taken with a digital inclinometer. Good reliability was reported for all techniques, both stabilized and non-stabilized scapula methods, with inter-rater reliability (ICCs) ranging from 0.50-0.66 and intra-rater reliability ranging from 0.63-0.71. The researchers also found the scapular stabilization method and visual inspection method average range of motion values were smaller and closer to each other. This is suggestive of the non-stabilization method allowing too much scapular motion when measuring shoulder IR. Based on the reliability statistics, a digital inclinometer may be a useful tool for achieving greater reliability. Visual inspection of the acromion lifting off the mat showed good reliability in this study, although with certain patient populations this technique may not be applicable.

Digital Inclinometer

The previous study by Awan et al. used digital inclinometers as opposed to goniometers, and there is a question as to whether this gives added benefits to clinicians.³² A study done by Kolber et al. examined the use of a digital inclinometer compared to standard goniometer for shoulder measurement on 30 asymptomatic participants.⁵³ Intra-rater reliability was calculated using ICCs as well as report of error using SEMs. Intra-rater reliability for IR using a goniometer was 0.95 (95% CI = 0.89-0.98) with a SEM of 2°. Intra-rater reliability for IR using a digital inclinometer was 0.97 (95% CI = 0.93-0.98) with a SEM of 2°. Concurrent reliability of goniometric measurement and inclinometry were calculated using ICCs, and for IR this value was 0.95 (95% CI = 0.89-0.96). This represents excellent agreement between the two measurement techniques.

A study by Thomas et al. examined differences in IR measurement for various scapular positions using a digital inclinometer.¹⁵ Positions included supine with arm in 90° abduction (standard), standing with arm at 60°, 90°, and 120° abduction (scapular upward rotation), and standing at rest, with hands on hips, and 90° abduction with maximum IR (scapular protraction). The authors found significant differences in shoulder IR measurements between high school and collegiate baseball players when the scapula was protracted (hands on hips or 90° abduction with maximum IR) or upwardly rotated (90° or 120° of abduction). It should be noted that positioning of the scapula affects shoulder IR measurement in the advanced throwing athlete. Also of note, prior to the study, Thomas measured test-retest reliability for this device in this population (20 male,

collegiate baseball players who were asymptomatic), and the intra-rater reliability ICC was calculated to be 0.99 for shoulder IR with a SEM of 1.03°.

Vertebral Level

In a study by Wakabayashi et al., the researchers sought to investigate the relationship between IR of the shoulder and the vertebral level reached in the measurement technique of reaching behind the back.²⁹ Electromagnetic tracking software was used to examine the amount of shoulder IR occurring in seven asymptomatic male participants. The researchers concluded that 66% of shoulder IR occurred from the participant's arm at their side position to the level of the sacrum reached by the thumb. Above the sacrum however, elbow flexion, shoulder abduction, and shoulder extension contributed to the vertebral level reach by the participant. It was concluded that three vertebral levels are required to show a significant increase in shoulder IR when measuring above the level of the sacrum. With these anatomical considerations in mind, the following studies describe the reliability of measuring shoulder IR using vertebral levels.

A study by Hayes et al. compared reliability (ICCs and SEMs) of shoulder IR measurement in a patient population with a spectrum of shoulder dysfunctions.³⁰ The measurement methods were visual estimation of vertebral level reached as well as tape measuring the distance from the T1 spinous process. Inter-rater ICCs were 0.26 (95% CI = -0.01-0.69) for visual estimation and 0.39 (95% CI = 0.09-0.77) for measured distance from T1. Intra-rater ICCs were 0.14 (95% CI = -0.11-0.55) for visual estimation and 0.39 (95% CI = 0.08-0.75) for measured distance from T1. The SEM for the visual estimation

technique was two vertebral levels. The SEM for the measured distance from T1 technique was six vertebral levels. The patient/client's reach to the highest vertebral level does not appear to be a reliable technique for measuring shoulder IR, either as a visual estimate or by measuring from a bony landmark.

Another study conducted by Edwards et al. examined use of vertebral level as a potential method for measuring shoulder IR.³¹ A marker was placed on a randomly chosen vertebral level of a subject, and surgeons and physical therapists were asked to correctly identify the level. Radiographs were performed to identify the true vertebral level where the marker was positioned. Inter-rater ICCs ranged from 0.12-0.27 with an average error of 1.02-1.15 levels. Intra-rater ICCs ranged from 0.016-0.82 (mean = 0.44) with an average error of 0.4-2.2 levels (mean = 1.07). This study gives evidence that using vertebral levels is not a reliable measurement technique, despite being a quick and easy measure of shoulder IR. Analysis showed the poorest ratings occurred in the lower thoracic spine when compared to the upper thoracic and lumbar spine. Authors concluded this is most likely due to the proximity bony landmarks in assessing vertebral levels.

Posterior Shoulder Tightness Measurements

A study by Laudner et al. examined measurements of contracture of the posterior glenohumeral joint capsule.³⁷ The measurement involved the patient lying in supine with the test arm abducted to 90° with the elbow flexed to 90° and in neutral rotation. The tester stabilized the scapula with one hand, and with the other passively moved the subject's arm through horizontal adduction. The angle was measured between the midline of the humerus and a line perpendicular to the mat. Twenty four shoulders (12 subjects)

were examined to determine reliability of the measure, followed by 46 shoulders (23 subjects) of professional baseball pitchers. The inter-rater ICC was 0.91 (SEM = 1.71°), while the intra-rater ICC was 0.93 (SEM = 1.64°). The validity of the measure in shoulders with decreased ROM was established by measuring the non-dominant shoulder to the dominant shoulder in the group of professional pitchers. A Pearson correlation coefficient was calculated and showed moderate to good relationship ($r = 0.72$, $p = .001$). This study suggests the method of measuring PST described here is reliable as well as valid for shoulders with decreased ROM in overhead throwing athletes.

A study by Kolber and Hanney examined the reliability and minimal detectable change of measuring PST.⁵³ Posterior shoulder tightness was measured by first positioning the subject in sidelying on the non-test side. The test arm was raised to 90° abduction with the elbow flexed to 90° and neutral rotation. Testers then manually stabilized the scapula by maximally retracting it, after which they asked the subjects to allow them to lower their arm to the table. A digital inclinometer was used to quantify the amount of posterior capsule motion as the arm was passively moved into horizontal adduction. Measurements were taken on 45 asymptomatic non-dominant shoulders. The inter-rater reliability (ICC) for PST was 0.90 (95% CI = 0.82-0.94), the SEM was 4°, and the MDC was 9°. This method of measuring PST appears to be a strongly reliable measure and the authors also provided the MDC for detecting change in patients over time or in response to treatment.

Witwer and Sauers describe another technique for measuring PST in sidelying with the scapula stabilized.⁴⁸ Rather than using an inclinometer, a carpenter's square was

used to measure the distance from the subject's medial epicondyle to the table. Thirty one collegiate water-polo players served as subjects and both shoulders were measured (62 shoulders). The intra-rater ICC was 0.82 (SEM = 0.7 cm), which is lower than other measurement techniques, although still good reliability. However, the researchers did not find a significant difference between dominant and non-dominant shoulders, indicating PST may not be related to shoulder IR deficits in this population. The authors concluded that the lack of finding in this population may be due to the nature of the swim stroke, namely that it requires full ROM.

In two studies by Tyler et al., posterior shoulder capsule tightness was investigated.^{16,36} In the first study, the researchers investigated the reliability and validity of measuring shoulder posterior capsule tightness in sidelying using passive shoulder horizontal adduction with neutral rotation as the measurement method.³⁶ The experimental group participants were 22 asymptomatic male college baseball pitchers and the control group participants were 49 asymptomatic volunteers. The subjects were placed in a sidelying position and the humerus of the upper extremity being measured was passively moved to 90° of abduction with neutral rotation. While stabilizing the scapula in a retracted position, the tester horizontally adducted the humerus. The test was stopped and the measurement taken when the motion of the humerus had ceased or there was rotation of the humerus. The distance from the plinth to the participant's medial epicondyle was the indication of the amount of flexibility in the shoulder posterior capsule. The ICC values for intra-rater reliability for PST were 0.92 and 0.95 and the ICC for inter-rater reliability was 0.80. The researchers also measured the participants

shoulder IR and ER and found that the baseball pitchers had significantly less IR along with greater PST than the non-baseball pitchers.

The second study by Tyler et al. examined the connection between posterior capsule tightness and motion loss in patients with shoulder impingement.¹⁶ Participants were 31 patients with shoulder impingement and 33 participants without shoulder impairments. Shoulder posterior capsule tightness was measured in sidelying and shoulder IR and ER were measured in supine with the scapula manually stabilized. The results of the study demonstrated that patients with impingement in their dominant arm shoulder had statistically significant loss of shoulder IR ROM and greater posterior capsule tightness when compared to control subjects. Patients with impingement in their non-dominant shoulder had statistically significant loss of shoulder IR and ER ROM along with greater posterior capsule tightness compared to control subjects. These two studies suggest a relationship between shoulder posterior capsule tightness and a limitation in glenohumeral range of motion.

Salamh et al. conducted a systematic review of the literature to determine the reliability of measuring PST.⁵⁴ The two methods described in the studies are those described above – one in a sidelying position, one in a supine position. Techniques for quantifying the measure included goniometry, inclinometry, and “linear techniques” (measuring the distance from the medial epicondyle of the elbow to the table). There was a trend towards higher reliability in the goniometric and inclinometry techniques, with inclinometry being the most reliable method. Additionally, there was moderate to good correlations ($r = 0.35-0.88$) between PST and IR measurement, indicating that PST

measurements are a worthwhile aspect of clinical examination in patients with shoulder IR deficits.

CHAPTER III

METHODS

Subjects

This study was approved by the Institutional Review Board of St.Catherine University. Subjects were recruited through a sample of convenience through flyers (Appendix A) placed on the Minneapolis campus of St. Catherine University and through family and friends of investigators in this study. Participants included in this study were over the age of 18 and were excluded from this study if they had a history of shoulder surgery, fracture, or dislocation, had pain that limited their shoulder ROM, were currently participating in a medically-supervised shoulder rehabilitation program, or were unable to lie on their back, on their side, or on the floor. The participants were identified as either athletes or non-athletes based on their demographics form and history of overhead activities (Appendix B). The procedures for the two groups were the same with the exception of an ER measurement being added for the athlete group. Subjects were asked to sign a written consent form (Appendix C) and a HIPAA authorization form (Appendix D) in order to participate in this study.

Raters

All measurements were taken by five Doctor of Physical Therapy (DPT) student investigators from St. Catherine University or their faculty research advisor, who is a professor in the DPT Program. The student investigators in this study were instructed in the correct technique and proper end-feel of shoulder IR ROM using multiple subject positions to ensure consistency among raters. Instruction and training were provided by

an experienced clinician with 25 years of physical therapy experience. Inter-rater and intra-rater reliabilities were determined, using 18 subjects, prior to the beginning of data collection.

Instrumentation

All ROM measurements were taken using a bubble inclinometer that was placed on the subject's distal forearm just proximal to the wrist, on the ventral aspect for ER measurements and on the dorsal aspect for IR measurements (Figure 1). A wooden support (Figure 2), which was fabricated by the investigators, was used to standardize the semi-sidelying position to a midpoint (45°) between the supine and sidelying positions. For this semi-sidelying position, subjects began in sidelying. The patient was positioned two inches away from the base of the angle support, which was aligned with the subject's scapula between the scapular spine and inferior angle. The subject then rolled back until their scapula rested firmly against the support.

Procedures

After providing written consent, each participant was asked to complete a brief questionnaire regarding their demographics (age, gender, date of birth, self-reported height and weight), history of overhead shoulder activities, and any previous shoulder injuries or surgeries. In this questionnaire, arm dominance was determined by asking the participant which arm they would use to throw a ball. There were three different IR ROM testing positions, leading to six different possible testing orders. A number 1-6 was randomly chosen by the participant to determine the order of the IR ROM testing positions. This process ensured randomization between the different positions.

Once the participant was cleared for inclusion in this study and the order of the IR ROM testing conditions was randomized, subjects were asked to lie on the floor in one of three positions: on their back (supine IR ROM condition); on their side (sidelying IR ROM condition); or in a position halfway between the two (semi-sidelying IR ROM condition) (Figures 3-5). For each of these IR ROM conditions the investigator passively abducted the humerus to a visually-estimated 90° , with the elbow flexed to 90° . The investigator then passively rotated the shoulder so that the palm of the hand moved towards the floor into IR. For the supine position, the investigator applied a posterior force to the coracoid and acromion process to limit anterior tilting of the scapula. For the sidelying position and the semi-sidelying position, the stabilizing force came from the participant's body weight so no stabilizing force was applied by the investigator. When the investigator determined the shoulder motion was at its end-range, the inclinometer was placed on the dorsal aspect of the forearm to obtain the ROM value. The measured ROM value was then recorded by the rater on the data collection form (Appendix E). This process was performed twice for each of the three passive IR ROM testing positions. The three shoulder IR ROM test positions were performed first on the dominant shoulder and then on the non-dominant shoulder, using the same order of positions.

If the participant had a history of being an overhead athlete, an additional measurement was taken of passive shoulder ER ROM. For this ER motion the measurements were taken with the participant lying supine on either a table or another firm surface (Figure 6). The arm was passively abducted to 90° and the elbow was flexed to 90° with a towel roll placed beneath the elbow. The investigator passively rotated the

shoulder so that the dorsal aspect of the hand was moving towards the floor into ER. When the investigator had determined to be at the end-range, the inclinometer was placed on the ventral aspect of the forearm and a ROM value was obtained. The process was performed twice for both the dominant and the non-dominant shoulders.

Statistical Analysis

Using the 18 subjects recruited for the reliability portion of this study, intraclass correlation coefficients (ICCs) were calculated to quantify within-subject intra-rater reliability ($ICC_{1,1}$) for each of the six raters. This was calculated for the supine, semi-sidelying, and sidelying IR positions along with ER. Intraclass correlation coefficient values were also used to calculate inter-rater reliability ($ICC_{2,k}$) of the mean for each rater's two measurements taken on each subject in the supine, semi-sidelying, and sidelying positions for IR and ER. Classification of these ICC values was broken down in the following manner: excellent (0.90-0.99), good (0.80-0.89), fair (0.70-0.79), and poor (<0.69).⁵⁵ For both intra-rater and inter-rater reliability, the 95% confidence intervals (CI) were also calculated.

Descriptive statistics (mean and standard deviation) were gathered for each subject in this study. The mean and standard deviations were calculated for age, height, weight, and BMI, along with finding age ranges for athletes and non-athletes respectively.

An analysis of variance (ANOVA) was calculated using the mean IR measurements for athletes and non-athletes on their dominant and non-dominant shoulders across the three IR positions. For ANOVAs that were significant, a post-hoc

analysis was performed using paired t-tests, with Bonferroni multiple comparisons correction applied to these t-tests. Paired t-tests were then performed to compare the means of the three IR positions between dominant and non-dominant shoulders.

In addition, paired t-tests were performed to compare athletes' dominant and non-dominant shoulders using the mean for ER. The mean ER value for athletes dominant and non-dominant shoulders was added to the supine and sidelying IR means to calculate total arc (supine or sidelying IR + ER). Paired t-tests were then used to compare dominant to non-dominant supine total arc, as well as dominant to non-dominant sidelying total arc. Two-sample t-tests were utilized to then compare the dominant supine total arc to the dominant sidelying total arc, as well as comparing the supine to sidelying total arcs on the non-dominant side. Finally, to find the total arc difference (supine total arc – sidelying total arc) a paired t-test was performed to compare the dominant total arc versus the non-dominant total arc. A level of significance was set *a priori* at 0.05 for all statistical analyses performed in this investigation. Number Cruncher Statistical Software (NCSS) was used for all statistical calculations.

CHAPTER IV

RESULTS

Using the $ICC_{1,1}$, ranges for intra-rater reliability across the 6 raters for the three IR ROM positions and ER ROM were as follows (95% confidence intervals in parentheses): 0.78-0.92 (0.70-0.96) for supine; 0.74-0.97 (0.66-0.99) for semi-sidelying; 0.87-0.97 (0.79-0.99) for sidelying; and 0.79-0.95 (0.70-0.98) for ER (ICC values for all individual raters can be seen in Table 1). Utilizing an $ICC_{2,k}$, inter-rater reliability values were as follows, with the 95% confidence intervals in parentheses: 0.84 (0.74-0.91) for supine; 0.81 (0.72-0.90) for semi-sidelying; 0.91 (0.83-0.96) for sidelying; and 0.84 (0.74-0.90) for ER (Table 2). The highest inter-rater reliability was found for the sidelying position (0.91). The 95% confidence intervals were significant at $p < 0.01$ for both intra-rater and inter-rater reliability. The values for inter-rater reliability ranged from good to excellent, while the values for intra-rater reliability ranged from fair to excellent.⁵⁵

Athlete Group

Table 3 displays the descriptive statistics for the athlete group. The data provided includes the mean and standard deviation for age, height, weight, and BMI, as well as age ranges.

Repeated-measures ANOVA's for mean IR ROM across the three IR ROM positions for the athletes' dominant and non-dominant shoulders yielded statistically significant results (Table 4 - Dominant shoulder: $df\ 2/338$, $p < 0.0001$) (Table 5 - Non-dominant shoulder: $df\ 2/332$, $p < 0.0001$). For the dominant shoulder, post-hoc analysis

revealed that the IR ROM for the sidelying position ($43.7^\circ \pm 8.7^\circ$) was significantly lower than the supine ($58.8^\circ \pm 11.3^\circ$) and semi-sidelying ($55.7^\circ \pm 9.5^\circ$) positions (Figure 7). However, the dominant-shoulder IR ROM for the supine and semi-sidelying positions were not significantly different from each other. For the non-dominant shoulder the IR ROM in all three positions were significantly different from each other (supine: $67.6^\circ \pm 11.3^\circ$; semi-sidelying: $63.7^\circ \pm 10.1^\circ$; sidelying: $55.1^\circ \pm 9.8^\circ$) (Figure 7).

Paired t-tests, displayed in Table 6, revealed that there were significant IR ROM differences between the dominant and non-dominant shoulders for the three IR positions in athletes (supine: $9.2^\circ \pm 8.3^\circ$; semi-sidelying: $8.4^\circ \pm 10.3^\circ$; sidelying: $11.8^\circ \pm 10.0^\circ$), with the dominant shoulder having less IR ROM than the non-dominant shoulder in all three positions. The greatest IR ROM difference was noted ($11.8^\circ \pm 10.0^\circ$) for the sidelying position (dominant: $43.4^\circ \pm 8.3^\circ$; non-dominant: $55.2^\circ \pm 9.8^\circ$). Paired t-tests for ER ROM revealed that the athletes' dominant shoulder had significantly greater ER ($118.7^\circ \pm 11.9^\circ$) compared to the non-dominant shoulder ($110.5^\circ \pm 12.9^\circ$).

The supine total arc on the dominant shoulder ($177.2^\circ \pm 18.2^\circ$) in athletes was not significantly different from that on the non-dominant side ($178.4^\circ \pm 19.3^\circ$), however, the sidelying total arc on the dominant side ($162.2^\circ \pm 15.3^\circ$) was statistically different from the non-dominant side ($166.0^\circ \pm 16.6^\circ$) (Table 7). This sidelying total arc side-to-side difference on the dominant shoulder was found to be $3.7^\circ (\pm 12.1^\circ)$. Two-sample t-tests revealed a significant difference between the supine and sidelying total arc for both the dominant (supine total arc: $176.8^\circ \pm 17.9^\circ$; sidelying total arc: $161.8^\circ \pm 15.4^\circ$) and non-dominant (supine total arc: $178.4^\circ \pm 19.3^\circ$; sidelying total arc: $166.0^\circ \pm 16.5^\circ$) shoulder in

athletes (Table 8). This difference was $15.1^{\circ} (\pm 16.7^{\circ})$ for the dominant shoulder and $12.4^{\circ} (\pm 17.9^{\circ})$ for the non-dominant shoulder. A significant difference was found between the total arc difference on the dominant shoulder ($15.0^{\circ} \pm 10.1^{\circ}$) compared to the total arc difference on the non-dominant shoulder ($12.4^{\circ} \pm 10.3^{\circ}$) with $p < 0.001$. This total arc difference was found to be $2.6^{\circ} (\pm 8.4^{\circ})$ (Table 9).

Non-Athlete Group

Table 10 displays the descriptive statistics for the non-athlete group. The data provided includes the mean and standard deviation for age, height, weight, and BMI, as well as age ranges.

Repeated-measures ANOVAs for mean IR ROM across the three IR ROM positions for the non-athletes' dominant and non-dominant shoulders yielded statistically significant results (Table 11 - Dominant shoulder: $df\ 2/572$, $p < 0.0001$) (Table 12 - Non-dominant shoulder: $df\ 2/599$, $p < 0.0001$) (Figure 8). Post-hoc analysis revealed that the IR ROM in the sidelying position for the dominant shoulder ($47.1^{\circ} \pm 12.5^{\circ}$) was significantly lower than the supine ($57.4^{\circ} \pm 8.9^{\circ}$) and semi-sidelying ($56.9^{\circ} \pm 11.6^{\circ}$) positions. The IR ROM in the sidelying position for the non-dominant shoulder ($53.9^{\circ} \pm 11.6^{\circ}$) was also found to be significantly lower from the other two positions (supine: $62.1^{\circ} \pm 9.4^{\circ}$; semi-sidelying: $63.3^{\circ} \pm 12.1^{\circ}$). However, the supine and semi-sidelying positions were not statistically different from one another for either the dominant shoulder.

Paired t-tests, shown in Table 13, display the IR ROM differences between the dominant and non-dominant shoulder for all three IR positions in non-athletes. These

side-to-side differences in all three IR positions were statistically significant (supine: $4.8^{\circ} \pm 9.3^{\circ}$; semi-sidelying: $6.3^{\circ} \pm 12.2^{\circ}$; sidelying: $6.6^{\circ} \pm 10.5^{\circ}$). Again, the greatest difference was noted in the sidelying position (6.6°), however this value is less than the difference found for athletes in the sidelying position (11.8°).

CHAPTER V

DISCUSSION

Athletes

A primary aim of this study was to establish IR ROM normative values in positions other than the traditional supine position. In the current study of 114 overhead athletes, a normative IR ROM value of 43° was noted for the dominant shoulder in the sidelying position. Lunden et al. conducted a study in 2010 to investigate the reliability of measuring IR in the sidelying position.²⁸ They found an average of 40° of IR ROM, which is comparable to the 43° of IR ROM found in this study. The population in Lunden et al. was a combination of non-overhead athletes and overhead athletes and the authors did not divide the groups based on that characteristic. The 40° sidelying IR ROM value noted in Lunden et al. is slightly smaller than the overhead athlete population average (43°) of this study, but still demonstrates that this is a consistent method for measuring shoulder IR ROM.

A main hypothesis of this study was that there would be significant differences between the three testing positions when measuring IR ROM. In general, for overhead athletes, a trend was noted in that IR ROM values were greatest in the supine position, lesser in the semi-sidelying position, and least in the full sidelying position for both the dominant and non-dominant shoulders. For the dominant shoulder, the only statistically significant difference found between mean IR ROM values was in the sidelying position. There was not a statistically significant difference between the supine and semi-sidelying

positions. However, in the non-dominant shoulder of the overhead athletic group, all three measurement positions were significantly different from each other.

The decreased IR ROM in sidelying found in this study compared to the supine and semi-sidelying positions is purported to be due, in part, to increased weight-bearing on the scapula during full sidelying, which is thought to minimize the accessory motion of scapular anterior tilting, and would thus isolate the motion to pure glenohumeral IR ROM. As the arm moves into more horizontal adduction from supine to semi-sidelying to sidelying, the posterior shoulder structures, specifically the posterior glenohumeral joint capsule and the posterior rotator cuff muscles, become taut. The tightness in these structures is thought to lead to the decreased IR ROM observed in the sidelying position. This is in line with previous research that has found that posterior rotator cuff tightness and posterior deltoid tightness can contribute to a decrease in IR ROM.^{16,21,36} In the sidelying position, it is not only the prevention of the scapular anterior tilting that contributes to the decreased range of motion observed, but also the increased stress on the posterior soft tissue structures. In this study, each position tested placed a different amount of weight onto the scapula as well as different stresses on the posterior shoulder structures. It would follow that each position would provide a different amount of internal rotation.

Also in line with previous research, this study found that there is significantly greater ER ROM in an athlete's dominant shoulder ($118.7^{\circ} \pm 11.9^{\circ}$) compared to their non-dominant side ($110.5^{\circ} \pm 12.9^{\circ}$). This is consistent with previous research examining GIRD in overhead athletes.¹⁻¹² In the literature examining GIRD, it is believed that IR

ROM loss is typically offset by gains in ER ROM, primarily as a result of increased humeral retroversion in the overhead athlete.^{7,8} In other words, the total arc of motion is preserved between the dominant and non-dominant shoulders of overhead athletes. In this study, the sidelying total arc for the dominant side ($162.2^{\circ} \pm 15.3^{\circ}$) was significantly different than the non-dominant side ($165.9^{\circ} \pm 16.6^{\circ}$), with a difference of 3.7° . The standard error of the measure (SEM) for sidelying total arc was found to be 2.2° . This demonstrates that the difference between the dominant and non-dominant total arc measured with sidelying IR is not only statistically significant but also clinically significant. However, if total arc was calculated using the supine IR measurement, there was no significant difference between the dominant and non-dominant shoulders. This is important because it illustrates a difference in total arc as a result of using the sidelying IR measurement. Increased humeral retroversion has been proposed as a potential contributing factor for GIRD. However, changing the measurement position (sidelying vs. supine) would not explain changes in total arc of motion due to increased humeral retroversion. Thus, it is possible in overhead athletes that their smaller dominant-side total arc in the sidelying position could be a result of factors other than increased humeral retroversion, namely tightness in the posterior shoulder musculature or posterior capsule.^{14,15,24}

It was determined in this study that regardless of whether a subject was considered an overhead athlete or not, the IR ROM value of a subject's dominant shoulder was significantly less than their non-dominant shoulder, and this was true for all three IR measurement positions. It was noted that the side-to-side differences were

greater for overhead athletes (who had a difference of 11.8°) than for non-overhead athletes (who differed by 6.6°) for the sidelying position. These numbers fall within a range of side-to-side differences that have been presented in the literature.^{6,25,50} In previous studies, the greatest side to side difference found was 15° in professional baseball players.⁵¹ It is hypothesized that the greater IR ROM difference for the overhead athletes is largely explained by increased humeral retroversion specific to this population, which results in less IR on the dominant side.

Non-Athletes

Along with establishing IR ROM normative values in an overhead athlete population, this study also sought to establish normative values in a non-overhead athlete population. In our study of 204 non-overhead athletes, a normative IR ROM value of 47° was noted for the dominant shoulder in the sidelying position. This value is slightly greater than, but comparable to, the average IR ROM value found in Lunden et al. of 40° , demonstrating that measuring IR ROM in a sidelying position in a non-athlete population is a consistent way of measuring shoulder IR ROM.²⁸

Carcia et al. (2013) recently examined sidelying IR norms in healthy college students, and their averages are within 1° of the findings of this study.⁵² The subjects in Carcia et al. included college students with the average age of participants being 21.5 years for males and 20.6 years for females. In the current study, the average age for non-overhead athlete females was 33.4 years and for males was 36.9 years, which demonstrates that this study had a wider age range of participants and is more reflective of a general population. The current study also had a greater number of participants with

204 (63 males, 141 females) non-overhead athletes, while Carcia et al. included 60 subjects (28 males, 32 females). It should be noted that the participants in Carcia et al. were more evenly distributed with regard to gender. The methods in Carcia et al. were comparable to this study in that they used an inclinometer for their measurements and multiple measurements were taken and averaged together for each participant. All of the measurements taken in Carcia et al. were performed on a treatment table and only after the participants had performed three active shoulder stretches. In this study, all measurements were taken on the floor due to convenience and ease in positioning for the SSL position. The subjects were also not asked to perform shoulder stretches prior to the IR measurements being taken. For non-overhead athletes, sidelying shoulder IR measurements on the non-dominant shoulder averaged 53° in Carcia et al., which closely matches the value of 54° found in the current study. For the dominant shoulder, subjects averaged 48° of sidelying shoulder IR in Carcia et al., compared to an average of 47° found in the current study. The consistency between these two studies and that of Lunden et al. should give clinicians confidence in using these now-established IR ROM norms in the sidelying position for non-athletic patients/clients.^{28,52}

When comparing IR ROM values for each position measured in this study in non-overhead athletes, a similar trend to that observed in the overhead athlete population was noted in that IR ROM values were greatest in the supine position, lesser in the semi-sidelying position, and least in the full sidelying position. Similarly to the overhead athlete population, the only statistically significant difference found between mean IR ROM values was in the sidelying position in the non-overhead athlete population. This

held true for both the dominant and non-dominant shoulders of subjects participating in this study.

Also, similar to the overhead athlete group, arm dominance differences in IR ROM were found. The IR ROM value of a subject's dominant shoulder was significantly less than their non-dominant shoulder, and this was true for all three IR positions. These findings add to current knowledge that the sidelying position tends to exaggerate these side-to-side differences. The largest differences between dominant and non-dominant shoulders are observed in the sidelying position. A significant difference between dominant and non-dominant shoulders is a consistent finding in the research.^{6,8,13,25,41,47,50,51}

Reliability

This study determined inter-rater and intra-rater reliability for all three positions prior to data collection. The inter-rater reliability for the supine position was 0.84 and for the sidelying position was 0.91. The intra-rater reliability for the supine position ranged from 0.78-0.92 and for the sidelying position ranged from 0.83-0.96. The reliability values found in this study were similar to those found in Lunden et al., which was the first study to investigate the reliability of the sidelying IR measurement.²⁸ Lunden et al. found the inter-rater reliability for the supine position to range from 0.74-0.81 and for the sidelying position to range from 0.88-0.96. The intra-rater reliability determined by that study ranged between 0.70-0.93 for the supine position and between 0.94-0.98 for the sidelying position. In both of these studies, the sidelying position was found to have

excellent inter- and intra-rater reliability and had superior reliability compared to the supine position.

Other studies have investigated the reliability of the supine IR measurement and have found poor reliability in this position. Boon and Smith determined the reliability of a supine IR measurement with scapular stabilization to be 0.38 for inter-rater reliability and 0.60 for intra-rater reliability, which both are considered to have poor reliability (excellent).³⁵ The primary difficulty in establishing high reliability in the supine position is due to difficulties in finding a consistent end feel. It is subjective based on the rater and there is no clear method of making it completely objective. The sidelying position, on the other hand, has a very clear hard end feel as the scapula is blocked by the subjects' body weight and the testing surface. Another contributing factor could be the increased horizontal adduction of the shoulder, which causes the posterior glenohumeral joint capsule and rotator cuff muscles to become taut, limiting the IR ROM. The sidelying position limits not only the anterior tipping of the scapula, leading to pure glenohumeral ROM, but it also increases the stress on the posterior soft tissues of the shoulder.

In this study, the average IR ROM found in the supine position was 57.4° on the dominant side and 62.1° on the non-dominant side for the non-athlete population. These values are not consistent with the values stated by the AAOS.²⁶ The average IR ROM found for the supine position varied between several studies and many of these investigators also found averages that did not correspond with the AAOS value of 70°.³⁸⁻⁴¹ Internal rotation averages ranged from 58.5° to 102.2°.^{41,42} The IR values in this study fell within the range of values that have been found by previous investigators. The

decreased reliability of the supine method as well as the fact that the AAOS value includes the entire glenohumeral and scapular complex may account for the difference between the findings of these studies and the AAOS normative value. This wide range can also be explained in part by differences in testing methods, the lack of consistency among clinicians in the amount of force applied to block the accessory motion as well as the variability in determining the endpoint of IR ROM as previously stated. The majority of studies that have investigated normative values have used a non-athlete population as their testing subjects. The supine averages (58.8° for the dominant arm and 67.6° for the non-dominant arm) of the athlete population were also below that of the AAOS values. The results found in the current study for the supine position agree with previous studies, all of which do not match to the AAOS recommended value.^{26,38-41}

To our knowledge, the semi-sidelying position has not been investigated in other studies as a way of measuring IR. Thus, there are no stated normative values for semi-sidelying IR that can be used to compare with the results of this study.

Clinical Application

From the results of this study, having these normative IR ROM values allows clinicians to evaluate for potential GIRD or total arc loss in their overhead athletes using the sidelying position. It is advantageous to isolate pure glenohumeral joint motion in order to better identify GIRD in a patient population, and not be confounded by accessory or substitutionary motions that may be occurring. This differential diagnosis may make it easier for clinicians to target problematic structures responsible for GIRD and implement interventions specific to those structures. The benefit of comparing the total arc

measurement in a supine vs. sidelying position is that clinicians can then identify the causative structures responsible for IR ROM loss, whether it be posterior muscle stiffness, posterior capsule tightness, or humeral retroversion. From the results of this study, clinicians can use the SEM of 2.2° for sidelying IR as a way to assess sidelying total arc, and then make clinical judgements as to whether or not posterior shoulder tightness is present. The clinicians can then provide interventions accordingly. In the case of posterior shoulder muscle stiffness and posterior capsule tightness, physical therapists are well-placed to treat such impairments, including interventions such as horizontal adduction (“cross-body”) stretching or posterior capsule (“sleeper”) stretching, respectively.

For the non-overhead athlete presenting to the clinical setting, these new normative values for sidelying IR ROM allow clinicians to assess the amount of IR ROM loss and compare it to a large population based on age, gender, and arm dominance. Other studies have sought to present normative values for the sidelying position due to its clinical usefulness and higher reliability. However, this study expands on the population to develop normative values in order to be of more use to a wider variety of patients.

Clinically it is common practice to use a patient’s non-involved side as a reference for what is their “normal” ROM. However, the literature and this study consistently show significant differences between dominant and non-dominant sides, and therefore, it is recommended to use the sidelying data presented in this study as normative values and discourage the use of a patient’s contralateral or non-involved side as a reference for their normal ROM.

The final recommendation is to use the more reliable sidelying IR ROM measurement as an outcome measure, as opposed to the standard supine position, in order to monitor for improvements in GIRD that result from physical therapy interventions. Whether monitoring for changes in IR ROM on its own or changes in total arc of motion, using the sidelying position provides the clinician with greater confidence and ease of use due to its high reliability and easy administration.

Limitations & Recommendations for Further Research

One limitation of this study is that the subjects comprised a sample of convenience, and they may not accurately represent the general population. The athlete population consisted of primarily college aged athletes thus potentially skewing that data towards a younger population. The non-athlete population provided a greater age range but the number of subjects in each age group was not equal and also had heavy representation of a college age population.

Secondly, the SSL position was intended to provide partial weight-bearing on the subject's scapula for stabilization. Despite an attempt to standardize the position with the 45° wooden bolster, there was variability in the positioning with the use of the bolster. It was difficult to determine if the participant was at the intended position of halfway in between the fully supine and the fully sidelying position. Also in SSL, the end feel was not as firm as the sidelying position and it was challenging to be consistent amongst all the raters as to where the endpoint was for this position.

Finally, it was not easy to ascertain whether a subject should be considered an overhead athlete or non-overhead athlete. Our operational definition of an overhead

athlete was someone who played a competitive overhead sport, such as baseball, volleyball, tennis, or potentially swimming, and who participated at a competitive level in that sport at least two to three times per week within the last five years. For some participants who had a long history of overhead athletics but who were not currently playing, they were also grouped in with the overhead athletic group. Additionally, some of the subjects included in the overhead athlete group did not actually have a history of overhead athletic activity, but rather performed frequent overhead tasks as part of their occupation.

Through the data that was collected in this study, the total arc was calculated for the overhead athletes. However, ER ROM was not gathered for the non-athlete subjects and therefore the total arc could not be calculated for this group. It would be beneficial to have these normative values for a non-athlete population as it can give more information on the soft tissues structures surrounding the shoulder.

Another point of further research would be a validation study that assesses the amount of scapular motion that occurs during IR ROM in the sidelying position. Currently the hypothesis is that the body weight of the subject blocks the anterior tipping that occurs during internal rotation and a 3D kinematics study could aim to confirm this hypothesis.

CHAPTER VI

CONCLUSION

This study was the first to establish normative IR ROM values for the semi-sidelying and sidelying positions in both an overhead athlete and non-athlete group. The sidelying position has shown to be more reliable than the supine position in previous studies.²⁸ This position is beneficial for clinical use as it provides consistent scapular stabilization and can further identify contributing factors to GIRD. The normative values for sidelying IR were significantly smaller when compared to the supine or the semi-sidelying position.

The literature proposes a variety of causes of GIRD, including posterior capsule tightness, humeral retroversion, and posterior shoulder muscle stiffness. The sidelying position can assist in determining the underlying cause of GIRD as it isolates the glenohumeral joint and causes the posterior structures to become taut. Since GIRD is seen primarily in an athletic population, total arc is another beneficial measurement and it is recommended to use the sidelying IR measurement as part of that calculation.

The typical methods of measuring shoulder internal rotation have been well studied in the literature and the sidelying position has shown to be more reliable than the other options including the current gold standard of supine. Across the literature, scapular stabilization has shown to be a favorable option for enhancing reliability and the sidelying position achieves more consistent stabilization as it uses the subject's body weight to block accessory motions of the scapula during internal rotation motion.

There is discrepancy in the literature regarding the normative values as stated by the AAOS as many of the article reviewed did not find a supine average that corresponded the values put forth by the AAOS. In fact, there is a wide range of supine values that were determined by previous studies. The normative values for the sidelying position found in this study was within 3° of values that were put forth by other studies, thus confirming the consistency of the sidelying position. It was also recommended in the literature review and confirmed by the results of this study that the dominant and non-dominant shoulders do not present with the same range of motion and that the contralateral shoulder should not be used as the baseline for that subject. Differences were shown in the literature between athletes and non-athletes in shoulder IR which was also confirmed in this study.

It is suggested to use the sidelying IR ROM position due to its high reliability when measuring for IR ROM loss. This study provides normative values for this position and it is recommended that clinicians use these results when evaluating for IR ROM loss in their patients. Clinicians can also use the sidelying position when determining total arc to further identify the underlying cause of GIRD in their patients.

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FIGURES
BUBBLE INCLINOMETER AND BOLSTER



Figure 1. Bubble Inclinometer

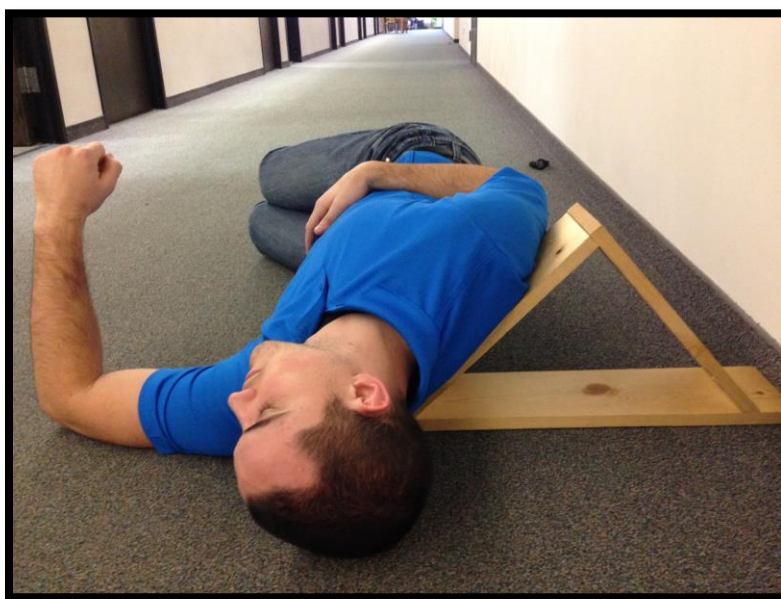


Figure 2. 45° Bolster

TEST POSITIONS

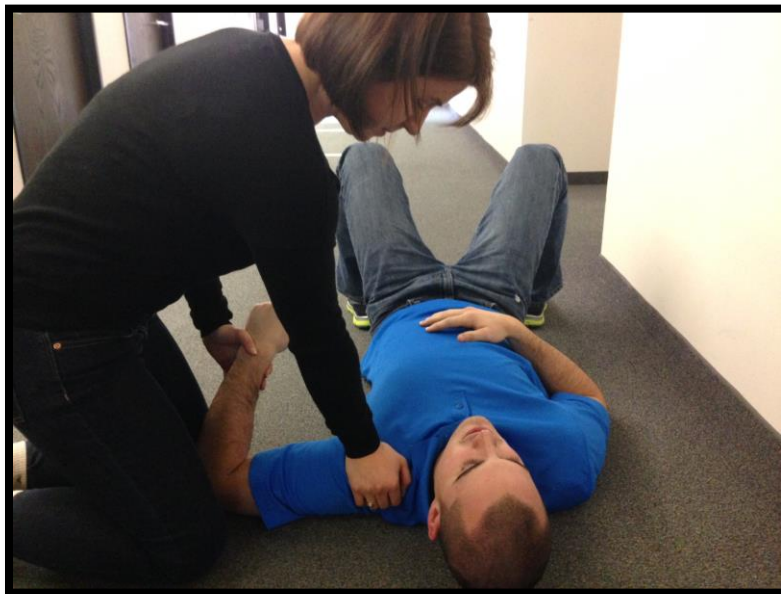


Figure 3. Supine IR Position

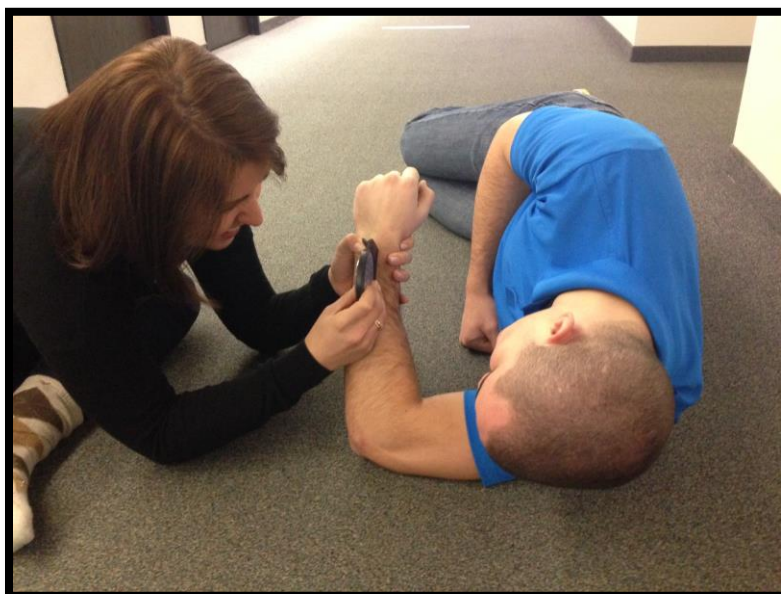


Figure 4. Sidelying IR Position

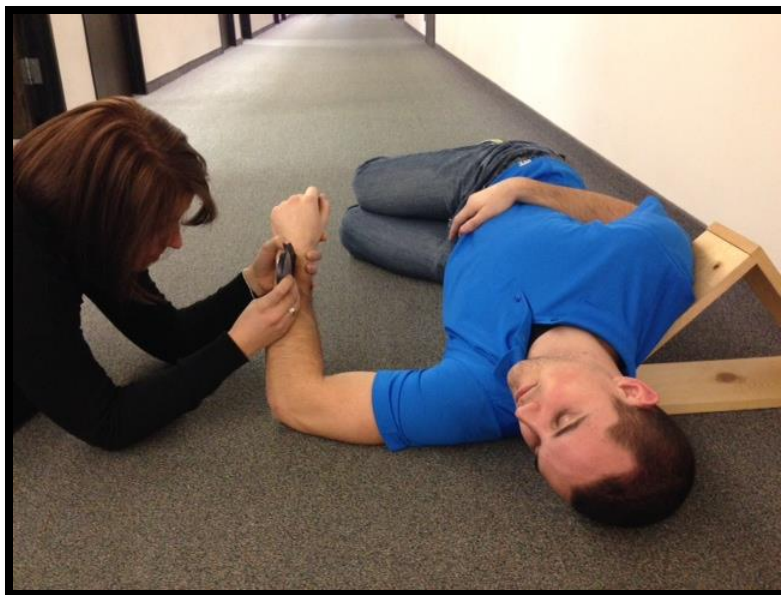


Figure 5. Semi-Sidelying IR Position

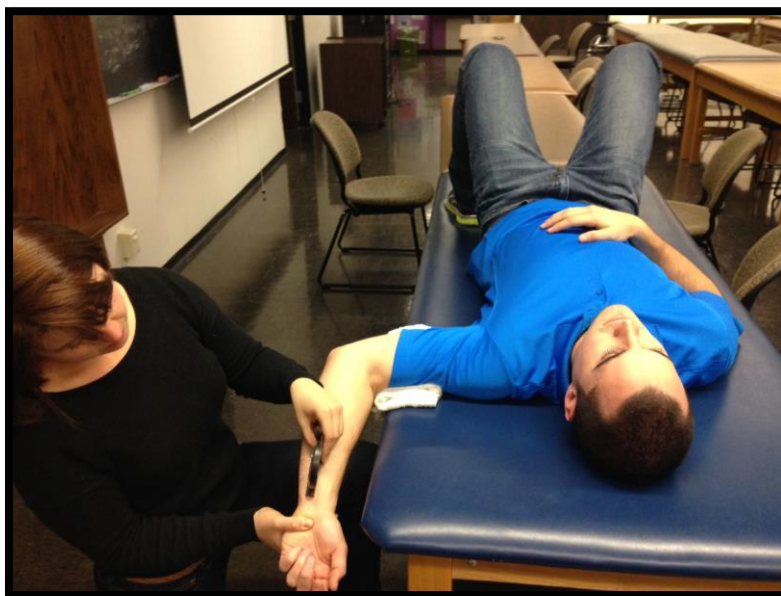


Figure 6. External Rotation Position

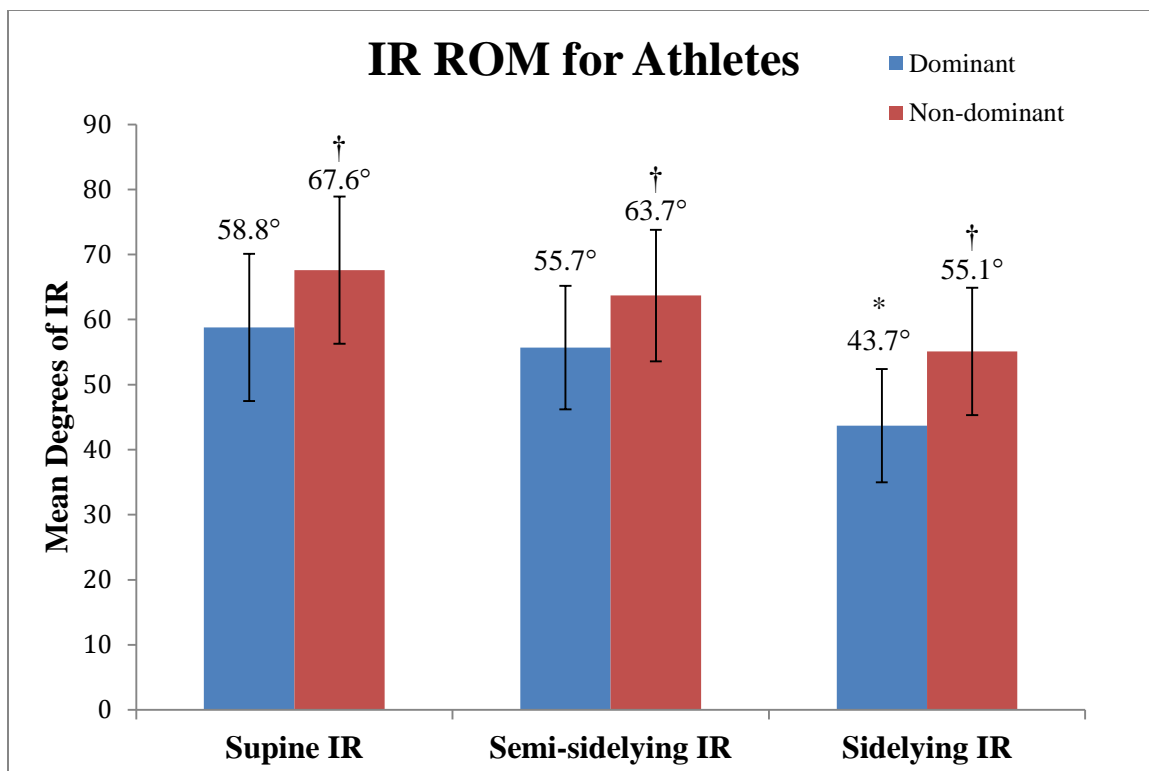


Figure 7. Bar graph representing mean IR ROM across three IR ROM positions for athletes' dominant and non-dominant shoulders. Error bars indicate standard deviation and numbers above error bars represent mean degrees of IR for that position. Asterisk and cross denote significance (* for dominant side comparisons, † for non-dominant side comparisons).

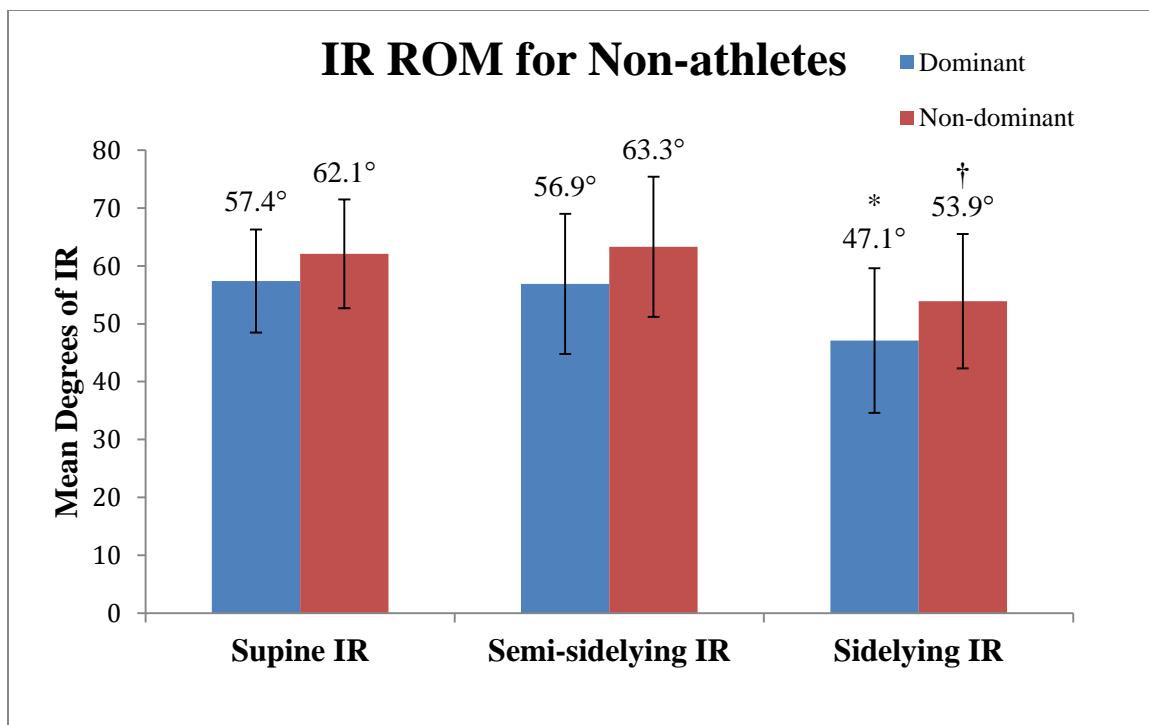


Figure 8. Bar graph representing mean IR ROM across three IR ROM positions for non-athletes' dominant and non-dominant shoulders. Error bars indicate standard deviation and numbers above error bars represent mean degrees of IR for that position. Asterisk denotes significance (* for dominant side comparisons, † for non-dominant side comparisons).

TABLES

Table 1. INTRA-RATER RELIABILITY (ICC_{1,1})

ICC (95% CI)				
	Supine IR	Semi-sidelying IR	Sidelying IR	ER
Ranges	0.78 - 0.92 (0.70 - 0.96)	0.74 - 0.97 (0.66 - 0.99)	0.87 - 0.97 (0.79 - 0.99)	0.79 - 0.95 (0.70 - 0.98)
Rater 1	0.84 - 0.96	0.90 - 0.98	0.92 - 0.99	0.86 - 0.97
Rater 2	0.82 - 0.94	0.87 - 0.97	0.79 - 0.94	0.70 - 0.87
Rater 3	0.81 - 0.93	0.87 - 0.97	0.91 - 0.99	0.88 - 0.98
Rater 4	0.79 - 0.93	0.66 - 0.81	0.86 - 0.97	0.79 - 0.94
Rater 5	0.75 - 0.91	0.89 - 0.99	0.75 - 0.91	0.75 - 0.91
Rater 6	0.70 - 0.88	0.87 - 0.97	0.81 - 0.94	0.81 - 0.94

All significant at $p < 0.01$ IR = IR, CI = confidence intervals, ROM = range of motion, ER = external rotation

Table 2. INTER-RATER RELIABILITY (ICC_{2,k})

ICC (95% CI)				
	Supine IR	Semi-sidelying IR	Sidelying IR	ER
ICC	0.84 (0.74 - 0.91)	0.81 (0.72 - 0.90)	0.91 (0.83 - 0.96)	0.84 (0.74 - 0.90)

All significant at $p < 0.01$ IR = internal rotation, CI = confidence intervals, ROM = range of motion, ER = external rotation

Table 3. DESCRIPTIVE STATISTICS: ATHLETE GROUP

Athletes Descriptive Statistics: Mean \pm Standard Deviation (n = 114)					
	Age	Age Range	Height (in.)	Weight (lbs)	BMI
Male (n = 57)	21.8 \pm 4.9	18-47	71.0 \pm 3.0	184.4 \pm 27.1	25.7 \pm 3.0
Female (n = 57)	21.4 \pm 5.3	18-56	67.5 \pm 3.0	146.0 \pm 18.5	22.5 \pm 2.3

Table 4. REPEATED MEASURES ANOVA: ATHLETE GROUP DOMINANT SHOULDER IR ROM

Source term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
IR condition	2	14280.87	7140.434	72.81	0.000000*	1.000000
S	336	32952.12	98.07178			
Total (Adjusted)	338	47232.99				
Total	339					

* Significance at alpha = 0.05, IR = internal rotation, ROM = range of motion, DF = degrees of freedom

Table 5. REPEATED MEASURES ANOVA: ATHLETE GROUP NON-DOMINANT SHOULDER IR ROM

Source term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
IR condition	2	9095.869	4547.935	41.97	0.000000*	1.000000
S	330	35761.38	108.3678			
Total (Adjusted)	332	44857.24				
Total	333					

* Significance at alpha = 0.05, IR = internal rotation, ROM = range of motion, DF = degrees of freedom

Table 6. IR AND ER ROM DIFFERENCES BETWEEN DOMINANT AND NON-DOMINANT SHOULDERS: ATHLETE GROUP

Differences Between Dominant and Non-dominant IR (n = 110) and ER ROM (n = 107) in Athletes				
	Dominant (° ± SD)	Non-dominant (° ± SD)	Difference (° ± SD)	P-value
Supine IR	58.5 ± 11.3	67.8 ± 11.3	9.2 ± 8.3*	0.0001
Semi-sidelying IR	55.5 ± 9.4	63.9 ± 10.1	8.4 ± 10.3*	0.0001
Sidelying IR	43.4 ± 8.3	55.2 ± 9.8	11.8 ± 10.0*	0.0001
ER	118.7 ± 11.9	110.5 ± 12.9	8.2 ± 10.1*	0.0001

* Represents significance at p < 0.05, IR = IR, ROM = range of motion, SD = standard deviation

Table 7. SUPINE AND SIDELYING TOTAL ARC: ATHLETE GROUP

Difference Between Dominant and Non-dominant Shoulder Supine and Sidelying Total Arc (n = 107)				
	Dominant (° ± SD)	Non-dominant (° ± SD)	Difference (° ± SD)	P-value
Supine Total Arc	177.2 ± 18.2	178.4 ± 19.3	1.1 ± 10.3	0.261
Sidelying Total Arc	162.2 ± 15.3	166.0 ± 16.6	3.7 ± 12.1*	0.002

* Represents significance at $p < 0.05$, SD = standard deviation

Table 8. DIFFERENCE BETWEEN SUPINE AND SIDELYING TOTAL ARC: ATHLETE GROUP

Difference Between Supine and Sidelying Total Arc				
	Supine Total Arc (° ± SD)	Sidelying Total Arc (° ± SD)	Difference (° ± SD)	P-value
Dominant (n = 113)	176.8 ± 17.9	161.8 ± 15.4	15.1 ± 16.7*	0.0001
Non-dominant (n = 108)	178.4 ± 19.3	166.0 ± 16.5	12.4 ± 17.9*	0.0001

* Represents significance at $p < 0.05$, SD = standard deviation

Table 9. TOTAL ARC DIFFERENCE: ATHLETE GROUP

Dominant vs. Non-dominant Total Arc Difference (Supine Total Arc – Sidelying Total Arc)			
	Total Arc Difference (° ± SD)	Difference (° ± SD)	P-value
Dominant	15.0 ± 10.1	2.6 ± 8.4*	0.002
Non-dominant	12.4 ± 10.3		

* Represents significance at $p < 0.05$, SD = standard deviation

Table 10. DESCRIPTIVE STATISTICS: NON-ATHLETE GROUP

Non-athletes Descriptive Statistics: Mean ± Standard Deviation (n = 204)					
	Age	Age Range	Height (in.)	Weight (lbs)	BMI
Male (n = 63)	36.9 ± 15.1	18-70	71.0 ± 2.6	188.2 ± 28.8	26.2 ± 3.7
Female (n = 141)	33.4 ± 14.4	18-89	65.7 ± 2.9	148.6 ± 25.1	24.2 ± 4.1

Table 11. REPEATED MEASURES ANOVA: NON-ATHLETE GROUP DOMINANT SHOULDER IR ROM

Source term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
IR condition	2	12827.04	6413.522	50.14	0.000000*	1.000000
S	570	72916.95	127.9245			
Total (Adjusted)	572	85743.98				
Total	573					

* Significance at alpha = 0.05, IR = internal rotation, ROM = range of motion, DF = degrees of freedom

Table 12. REPEATED MEASURES ANOVA: NON-ATHLETE GROUP NON-DOMINANT SHOULDER IR ROM

Source term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.05)
IR condition	2	10517.47	5258.733	42.63	0.000000*	1.000000
S	597	73639.21	123.3488			
Total (Adjusted)	599	84156.67				
Total	600					

* Significance at alpha = 0.05, IR = internal rotation, ROM = range of motion, DF = degrees of freedom

Table 13. IR ROM DIFFERENCES BETWEEN DOMINANT AND NON-DOMINANT SHOULDERS: NON-ATHLETE GROUP

Differences Between Dominant and Non-dominant IR ROM in Non-Athletes (n = 187)				
	Dominant (° ± SD)	Non-dominant (° ± SD)	Difference (° ± SD)	P-value
Supine IR	57.3 ± 8.9	62.1 ± 9.9	4.8 ± 9.3*	0.0001
Semi-sidelying IR	56.7 ± 12.1	63.0 ± 12.9	6.3 ± 12.2*	0.0001
Sidelying IR	46.9 ± 12.4	53.6 ± 11.9	6.6 ± 10.5*	0.0001

* Represents significance at p < 0.05, IR = IR, ROM = range of motion, SD = standard deviation

APPENDICES

APPENDIX A

RECRUITMENT FLYER

WANTED:
YOUR HEALTHY SHOULDERS!

Who: You and your healthy shoulders

What: Cort Cieminski, a faculty member in the Doctor of Physical Therapy Program at St. Catherine University, along with five physical therapy students, are conducting a research study comparing three methods for measuring shoulder range of motion(s) in individuals without history of shoulder surgery or injury.

When: On your time. 10-15 minute session, no follow-up testing.

Where: St. Kate's campus, or a location convenient for you.

Why: To establish normative values for shoulder IR in a sidelying and semi-sidelying position.

How:

- Provide background information to the investigator (age, weight, height; and history of shoulder surgery or injury, and record of overhead activities).
- Allow a tester to move your arm through an arc of motion while lying on your back, side, and halfway between. Please wear t-shirt or tank top.

If interested please contact:
Cort Cieminski at (651) 690-7884 or
cjieminski@stkate.edu

PARTICIPATION IS VOLUNTARY. IF YOU CALL YOU WILL RECEIVE MORE INFORMATION BEFORE YOU ARE ASKED FOR FULL CONSENT.

APPENDIX B

DEMOGRAPHICS/SHOULDER HISTORY FORM

Subject ID# _____

GENERAL INFORMATION
Shoulder Questionnaire

Age (years) _____

Height (inches) _____

Weight (pounds) _____

Date of Birth ____/____/____

Sex: M / F

Which arm do you use to throw a ball? L/R

Have you played competitive or recreational sports within the last 5 years? Y/N

If yes: which sport(s)? _____

What level of competition? _____

How often? (per week) _____

For how long? (years & months) _____

Have you ever injured your shoulder(s)? Y/N

If yes, what type of injury:

Shoulder dislocation Y/N L/R

Labral tear Y/N L/R

AC or SC joint instability Y/N L/R

what if any stabilization was performed? _____

what if any displacement was noted? _____

Fracture: collarbone (clavicle) Y/N L/R

upper arm (humerus) Y/N L/R

shoulder blade (scapula) Y/N L/R

shoulder tendonitis Y/N L/R

shoulder impingement Y/N L/R

rotator cuff tear Y/N L/R

shoulder bursitis Y/N L/R

shoulder strain Y/N L/R

Other:

Have you ever had surgery on your shoulder(s)? Y/N L/R

If yes, describe: _____

Are you currently experiencing pain in your shoulder(s) during motion? Y/N L/R

If yes, describe: _____

- Are you currently receiving any treatment for your shoulder(s)? Y/N L/R
If yes, describe: _____
- Have you ever received any treatment for your shoulder(s)? Y/N L/R
If yes, describe: _____
- Are you currently able to lie on either side comfortably? Y/N L/R
If no, describe: _____
- Are you currently able to lie on your back? Y/N
If no, describe: _____

APPENDIX C

CONSENT FORM

ESTABLISHMENT OF NORMATIVE SHOULDER INTERNAL ROTATION PASSIVE RANGE OF MOTION VALUES IN THE SIDELYING AND SEMI- SIDELYING POSITION

RESEARCH INFORMATION AND CONSENT FORM

Introduction:

You are invited to participate in a research study to establish normative values for shoulder IR in a sidelying and semi-sidelying position. This study is being conducted by Dr. Cort Cieminski, faculty member in the Doctor of Physical Therapy (DPT) Program at St. Catherine University, along with five 2nd year DPT students: Alisse Indrelie, Shannon Kelly, Hugo Klaers, Tatia Nawrocki and Michael Stelzmler. Participants must be 18 years of age or older. You will be excluded from participation in the study if you: have a history of previous shoulder surgery, fracture, or dislocation; have current pain that limits your shoulder range of motion; are currently participating in shoulder rehabilitation; or are unable to lie in supine or sidelying position. Please read this form and ask questions before you decide whether to participate in the study.

Background Information:

Shoulder pain is a fairly common orthopedic condition that is often associated with decreased shoulder range of motion. There is currently a method of measuring shoulder range of motion that involves a clinician using one hand to stabilize the shoulder while using their other hand to take a measurement. Some evidence, however, exists for a method of measuring shoulder range of motion that does not involve stabilization by the clinician. This study will compare the reliability of shoulder range of motion measurements using these different methods and the study will attempt to establish normal values for the non-stabilization method, as well examine any differences present in an athletic population. Approximately 250 people are expected to participate in this research.

Procedures:

If you agree to participate in this study, you will be asked to do the following:

1. **Shoulder questionnaire:** The researcher will give you a brief questionnaire asking about your history of overhead shoulder activities and any previous shoulder problems or surgeries.
2. **Shoulder range of motion:** A measuring device (bubble inclinometer) will be secured to the back of your forearm. Then you will be asked to lie on the floor in one of three positions in a random order; on your back, on your side, or in a position halfway between. If you are unable to get into the position on the floor, you will be asked to lie on a table or other firm surface. The examiner will then

measure your dominant side shoulder IR motion two times. Dominance will be determined by asking which arm you use to throw a ball. This will be repeated in the other two positions on this side, followed by taking these measurements on the non-dominant side.

For the overhead athlete subjects, the above procedure will be used with the addition of a measurement of external rotation in each position on both shoulders.

Risks and Benefits:

You may experience temporary minor muscle soreness after completing the shoulder motions. The use of ice packs, gentle stretching and/or possible rest from activity for a brief period of time after your testing session will minimize potential soreness. There are no direct benefits to you for participating in this research.

Confidentiality:

Any information obtained in connection with this research study that could identify you will be kept confidential. In any written reports or publications, no one will be identified or identifiable and only group data will be presented.

We will keep the research results in a password protected computer and in a locked file cabinet in the Women's Health and Integrative Research Center on the St. Paul campus of St. Catherine University and only the researcher(s) named in this form will have access to the records while we work on this project. We will finish analyzing the data by December 2013. We will then destroy all original reports and identifying information that can be linked back to you.

Voluntary nature of the study:

Participation in this research study is voluntary. Your decision whether or not to participate will not affect your future relations with St. Catherine University in any way. If you decide to participate, you are free to stop at any time without affecting these relationships, and no further data will be collected.

New Information:

If during the course of this research study we learn about new findings that might influence your willingness to continue participating in the study, we will inform you of these findings.

Contacts and questions:

If you have any questions, please feel free to contact me, Cort Cieminski, at (651) 690-7884. You may ask questions now, or if you have any additional questions later, I will be happy to answer them. If you have other questions or concerns regarding the study and would like to talk to someone other than the researcher(s), you may also contact John Schmitt, PhD, Chair of the St. Catherine University Institutional Review Board, at (651) 690-7739.

You may keep a copy of this form for your records.

Statement of Consent:

You are making a decision whether or not to participate. Your signature indicates that you have read this information and your questions have been answered. Even after signing this form, please know that you may withdraw from the study at any time and no further data will be collected.

I consent to participate in the study.

Signature of Participant Date

Signature of Researcher Date

APPENDIX D

HIPAA FORM

HIPAA AUTHORIZATION TO USE AND DISCLOSE

INDIVIDUAL HEALTH INFORMATION FOR RESEARCH PURPOSES

1 **Purpose.** As a research participant, I authorize Cort Cieminski to use and disclose my individual health information for the purpose of conducting the research project entitled ESTABLISHMENT OF NORMATIVE SHOULDER INTERNAL ROTATION PASSIVE RANGE OF MOTION VALUES IN THE SIDELYING AND SEMI-SIDELYING POSITION.

2 **Individual Health Information to be Used or Disclosed.** My individual health information that may be used or disclosed to conduct this research includes demographic information.

3 **Parties who may disclose my Individual Health Information.** The principal investigator and co-investigators may obtain individual health information from:

Hospitals: ___None_____

Clinics: _None_____

Other Providers: __None_____

Health Plan: _None_____

and from hospitals, clinics, health care providers, and health plans that provide my health care during the study.

4 **Parties Who May Receive or Use My Individual Health Information.** The individual health information disclosed by parties listed in item 3 and information disclosed by me during the course of the research may be received and used by Cort Cieminski.

5 **Right to Refuse to Sign This Authorization.** I do not have to sign this Authorization. If I decide not to sign the Authorization, I may not be allowed to participate in this study or receive any benefits that are provided through this study. However, my decision not to sign this Authorization will not affect any

other treatment, payment, or relationship with St. Catherine University, health care plans or health care providers.

- 6 **Right to Revoke.** I can change my mind and withdraw this Authorization at any time by sending a written notice to Cort Cieminski, St. Catherine University, 601 25th Avenue South, Minneapolis, MN 55454, to inform the researcher of my decision. If I withdraw this Authorization, the researcher may only use and disclose the protected health information already collected for this research study. No further health information about me will be collected by or disclosed to the researcher for this study.
- 7 **Potential for Re-disclosure.** My individual health information disclosed under this Authorization may be subject to re-disclosure outside the research study and no longer protected. For example, researchers in other studies could use my individual health information collected for this study without contacting me if they get approval from an Institutional Review Board (IRB) and agree to keep my information confidential.

7A. There are other laws that may require my individual health information to be disclosed for public purposes. Examples include potential disclosures if required for mandated reporting of abuse or neglect, judicial proceedings, health oversight activities and public health measures.

This authorization does not have an expiration date.

I am the research participant or personal representative authorized to act on behalf of the participant.

I have read this information, and will receive a copy of this Authorization form after it has been signed.

Signature of research participant or research participant's personal representative

Date

Printed name of research participant or research participant's personal representative

Description of personal representative's authority to act on behalf of the research participant

APPENDIX E
DATA COLLECTION FORM

Subject ID #:

Randomization Input Form

Option 1: Supine Semi-Side lying Side lying	Option 2: Supine Side lying Semi-Side lying	Option 3: Side lying Semi-Side lying Supine	Option 4: Side lying Supine Semi-Side lying	Option 5: Semi-Side lying Supine Side lying	Option 6: Semi-Side lying Side lying Supine
---------------------------------------------------------	---------------------------------------------------------	---------------------------------------------------------	---------------------------------------------------------	---------------------------------------------------------	---------------------------------------------------------

Dominant Shoulder		
Position 1:		
Position 2:		
Position 3:		
External Rotation:		

Non-Dominant Shoulder		
Position 1:		
Position 2:		
Position 3:		
External Rotation:		