University of Alberta

Glenohumeral Internal Rotation Deficits in the Overhead Varsity Level Athlete

By

Judith Carol Chepeha

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Rehabilitation Science

Faculty of Rehabilitation Medicine

Fall 2011
Edmonton, Alberta

DEDICATION

This work is dedicated to the many patients and students I have been honored to work with over the past 22 years. You have inspired me and provided me with some of the most important lessons I have learned as a Physical Therapist.

ABSTRACT

Objectives: The objectives of this project were to determine whether shoulder internal rotation (IR), external rotation (ER) and horizontal adduction (HAd) range of motion (ROM) 1) could be reliably measured and 2) used to detect clinically meaningful differences between varsity level, overhead athletes and non-competitive University students. Thirdly, a randomized clinical trial was used to determine if a common shoulder stretch (i.e. sleeper stretch) was effective in increasing IR- and HAd-ROM limitations in overhead athletes.

Methods: Study I - Thirty men and women (47 shoulders) between 22 and 51 years, underwent standard goniometric assessment of IR and ER in 90˚ of abduction and HAd. Two therapists performed blinded assessments to determine the standard error of measurement (SEM) and minimal detectable change (MDC) values for intra- and inter-rater shoulder ROM. Study II – Shoulder rotation and HAd-ROM values were compared between 66 overhead varsity athletes and 30 non-competitive university students. Independent t-tests determined whether shoulder ROM differences were statistically significant and beyond the SEM and MDC established in Study 1. Study III - Thirty-seven overhead athletes, identified with an internal rotation deficit ≥ 15° were randomized into a stretch or control group. Independent t-tests determined whether significant differences existed between the 2 study groups' IR- and HAd-ROM after 8-weeks and 2-way repeated measures ANOVA tests were used to investigate the rate of change in IR- and HAd-ROM over the 8-week evaluation.

Results: SEM values were ≤ 10˚ for all shoulder motions (IR, ER and HAd) in both within and between therapist comparisons. IR, ER and HAd-ROM were statistically and clinically different between the overhead athletes and non-competitive students; the greatest difference was in IR-ROM. Sub-group analyses amongst athletes found volleyball players had the greatest alteration of normal shoulder ROM. Significant increases in IR-ROM were detected at 4-weeks with further improvement at 8-weeks in the stretch group compared to the control group.

Conclusions: Posterior shoulder flexibility can be reliably measured and is significantly different between overhead athletes and non-competitive university students. An 8-week stretch program in varsity-level overhead athletes identified as having an IR loss of ≥ 15° can successfully increase shoulder movement.

ACKNOWLEDGEMENTS

I would like to extend my gratitude to my committee members, Dr. Carolyn Emery, Dr. Sharon Warren, Dr. David Sheps and Dr. Lauren Beaupre for their assistance in the completion of this thesis and their thoughtful comments.

Very sincere thanks to my supervisor, Dr. David Magee, for inspiring me and supporting me throughout this long journey. I am honored to have been able to complete both my Masters' and Doctorate studies under your guidance.

Finally, I would like to thank my parents for providing me with so many opportunities in life and for continuing to support and encourage me in my career and my life. And lastly, my most heartfelt thanks to Paul, Nicholas and Megan who endured this process alongside of me. I am forever grateful for your patience, understanding and love.

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LIST OF ABBREVIATIONS AND TERMS

The following terms and abbreviations will be used throughout the description of this project:

GERG: Glenohumeral External Rotation Gain

A term used to describe the gain in degrees of glenohumeral external rotation of the dominant shoulder compared with the non-dominant shoulder.

GIRD: Glenohumeral Internal Rotational Deficit

A term used to describe the loss in degrees of glenohumeral internal rotation of the dominant shoulder compared with the non-dominant shoulder.

ICC: Intra-class Correlation Coefficient

IGHL: Inferior Glenohumeral Ligament

MDC: Minimal Detectable Change

The smallest difference in a measurement that has been defined, in some way, to be clinically meaningful. [34]

MGHL: Middle Glenohumeral Ligament

Mobilization Effect

The effect produced in soft tissue in response to repeated joint movements.

Overhead Athlete: An athlete who participates in a sporting activity that involves repetitive shoulder and arm positions. (E.g. baseball, volleyball, swimming and tennis)

PST: Posterior Shoulder Tightness

A term used to describe the amount of tightness in the posterior shoulder. It is commonly represented as the difference in degrees between glenohumeral horizontal adduction of the dominant shoulder compared with the non-dominant shoulder.

ROM: Range of Motion

Rotator Interval: The space between the superior border of the subscapularis and the supraspinatus. The interval includes the region of the superior glenohumeral ligament, middle glenohumeral ligament and the coracohumeral ligament.

SEM: Standard Error of Measurement

A measure of absolute reliability that represents the standard deviation of measurement errors. [32]

SGHL: Superior Glenohumeral Ligament

SLAP: Superior Labral Anterior to Posterior Lesion

TRA: Total Rotation Arc

Described by Wilk[36] as the range of motion produced from both internal and external rotation; normal is approximately 90° internal rotation and 90° external rotation.

Chapter 1 INTRODUCTION

1.1 Statement of the Problem

Shoulder-related disability is reported to be as high as 26% in the general population.[1,2] Epidemiological studies indicate that 22% to 68% of people with shoulder problems continue to experience persistent symptoms for up to one year after the onset of shoulder pain.[3-5] Several factors contribute to this high rate including the repetitive nature of many shoulder activities, weak supporting musculature, muscle imbalances, and a general tendency to overuse this region.[1,6-8] The shoulder girdle itself plays a role in the development of injuries as it is designed primarily for mobility, often at the sacrifice of stability. Not surprisingly, incidence is even greater amongst athletes and workers involved in predominantly overhead activities.[1,5] The positions and movement patterns required to perform many of these overhead activities are often very demanding and if executed without proper flexibility, strength and skill, can lead to significant injury. The ramifications of a shoulder injury in a population that requires their shoulder for their occupation and/or their source of health and well-being are considerable.

In the past decade, research has been conducted in regards to pathoanatomy, mechanisms of injury, examination, differential diagnoses, and treatment of shoulder injuries in the overhead athlete population.[6-11] More is being learned about how forces placed upon the shoulder can lead to injury and more importantly, how clinicians can detect key signs and symptoms associated with these injuries and in turn, prevent them from occurring or plan for appropriate treatment. One particular area of focus is the change in rotational range of motion (ROM) noted in the shoulder of an overhead athlete. Intimately associated with this change in ROM is the posterior shoulder, specifically the posterior capsule, believed to play a major role in altering this shoulder rotation motion.

Changes in the posterior capsule of the shoulder have been noted by both researchers and clinicians, using arthroscopy and diagnostic tools such as magnetic resonance imaging (MRI).[12-16] It is postulated that the change in the posterior capsule occurs in response to the substantial forces that occur during the overhead throwing motion, specifically the cocking and follow through phases of throwing. The resulting repetitive microtrauma is believed to cause the posteroinferior capsule and posterior band of the inferior glenohumeral ligament (IGHL) to thicken and contract. As a result, it appears that throwers demonstrate adaptive changes in glenohumeral rotation, namely an increase or gain in glenohumeral external rotation, referred to as *GERG* (**G**lenohumeral **E**xternal **R**otation **G**ain) and a decrease or deficit in glenohumeral internal rotation, referred to as *GIRD* (**G**lenohumeral **I**nternal **R**otation **D**eficit).

Stretching of the anterior glenohumeral capsule is considered a necessary adaptation that results in increased external rotation at the point of late cocking and early acceleration of the throwing motion and aids in higher throwing velocities. Many authors believe that a consequence of these increased forces is tightening through the development of a contracture of the posterior capsule which can limit the amount of internal rotation available at the shoulder.[6,7,12,14,18-23] More recently, researchers have questioned this theory suggesting that the rotational changes are due to skeletal changes in the amount of humeral retroversion present at the shoulder joint.[24-29] Whatever the cause, the alteration in ROM is understood to become problematic when the amount of internal rotation *loss* exceeds the *gain* in external rotation.[6-8,18,19,30,31] At this point, the posterior portion of the superior labrum and the articular side of the posterior rotator cuff are placed in contact with the osseous glenoid setting up a myriad of possible pathologies likely related to impingement. Burkhart and colleagues[6] observed that a tight posterior capsule combined with a stretched anterior capsule was associated with abrasion-like injury in the posterior superior labrum and rotator cuff of throwers. Further, these structural changes in the posterior capsule can potentially create shear stresses in the posterior supraspinatus and infraspinatus tendons, resulting in partial thickness cuff tears at the articular surface. This shearing effect has been said to produce an excessive twist of the long biceps tendon, which may predispose to a "peel-back" tear of the posterior superior labrum.

Findings such as these have led authors and clinicians to pay particular notice of this apparent relationship between shoulder injuries, reduced internal rotation ROM and posterior shoulder tightness. Certain shoulder conditions have been linked to this altered rotational motion and as a result, increased emphasis is being placed within rehabilitation programs to assess and treat contributing factors, in particular immobility of the posterior shoulder structures.

As clinicians, it is imperative to have a thorough understanding of the relationship between clinical signs and resultant pathologies. Research suggests a strong association between deficits in internal rotation, posterior shoulder tightness and possible internal impingement and labral pathology at the shoulder[2,5-11,14,17-19]. Many shoulder protocols suggest close monitoring of these movements, especially in the overhead athlete, and advocate stretching programs for the posterior capsule, the main structure believed to limit internal rotation[11,18,30]. Although strong clinical evidence supports the benefits and positive outcomes gained from addressing internal rotation deficits in shoulder patients[5,6-8,11], further research is required to answer some of the basic questions surrounding this interesting topic.

1.2 Objectives of Study

The overall goal of this project was to determine if there were differences in glenohumeral joint internal rotation (IR), external rotation (ER) and posterior shoulder flexibility between two distinct populations; varsity level, overhead athletes and University students not involved in competitive sporting activities. If differences were found, this study tried to determine if a particular posterior shoulder stretching program was effective in improving these limitations. Three individual, but related research questions were examined to meet this study's objective and are described in detail in Section 1.3.

1.3 Project Studies

The 3 studies within this project were as follows:

1. Alterations in IR and ER-ROM have been associated with changes in posterior capsule tightness and linked to certain pathologies at the shoulder, particularly in the overhead athlete. Confidence in assessing these shoulder motions is therefore important in the detection of abnormalities as well as for monitoring a treatment's effectiveness. Thus, the first study determined the standard error of measurement (SEM) and minimal detectable change (MDC) associated with measuring IR, ER and horizontal adduction (HAd) at the glenohumeral joint both within and between evaluators. Very few studies have addressed the reliability of measuring these measures and only one study has been found to date, that addressed rotation in an "abducted to 90 degree" position.

The SEM indicates whether a real change in status has occurred in patients in excess of what one might expect as a result of measurement error. It provides a measure of the magnitude of the error associated with the measurement. The MDC provides information about whether a statistically significant difference is in excess of the measurement error and if it is also a clinically meaningful change in the amount of motion. These parameters are relevant to both clinicians and researchers to allow reliable quantification of ROM of the shoulder and "true" change in the movement.[32-35]

2. The second study investigated whether or not differences in shoulder rotational ROM and posterior shoulder flexibility existed between two groups of individuals: (1) Varsity athletes involved in overhead sports and (2) University students not involved in competitive sports. This phase established discriminant validity by determining the difference in glenohumeral rotation ROM and posterior shoulder tightness in two study groups where a difference was expected. In addition, possible patterns or relationships amongst athletes participating in different overhead sports were examined; a currently unexplored area of study.

3. The third study consisted of a randomized, controlled study to determine if an 8-week posterior shoulder stretching program increased IR- ROM and posterior shoulder flexibility of the shoulder. Subjects for this third phase were overhead athletes identified as having a glenohumeral IR deficit.

Ultimately, the information obtained from these three studies will potentially help clinicians determine how to best detect and subsequently manage patients who present with a reduced shoulder rotation ROM and concurrent tight posterior shoulder.

1.4 Clinical Relevance

This study provided important, clinical information to those involved with the care of athletes and patients participating in repetitive, overhead work/sport. Current research indicates that individuals involved in these activities develop altered glenohumeral rotation ROM with a tendency towards greater ER and reduced IR. This appears to be a normal adaptive process that only becomes problematic when the IR deficit is not accounted for by an increase in ER, reducing the total rotation arc. Discussion has been generated about the clinical ramifications of having a true deficit in IR.[6-8,11,19,37-39]

The majority of information regarding this topic arises from studies of baseball pitchers and to a lesser degree, those athletes involved in overhead sports such as tennis, volleyball and swimming.[21,22,30,31,36] Much less is known about the relationship of these altered rotational patterns within specific populations of athletes, non-athletes and individuals with *and without* symptomatic shoulders. Knowing what shoulder rotation ROM and posterior shoulder flexibility values are clinically important for different patient populations, could potentially provide clinicians with a frame of reference for monitoring and preventing early signs of shoulder pathology.

Individuals who have an IR deficit appear to be at a greater risk of developing shoulder pathologies such as impingement and instability. Stretching of the posterior structures of the shoulder can lower the risk of developing these pathologies.[6-8,11,16,17,40-44] Despite this evidence; very few studies have investigated the effectiveness of posterior shoulder stretching in affected populations. This study examined whether a common technique used to stretch the posterior structures of the shoulder was effective in imparting a change in a population of overhead athletes determined to have posterior shoulder tightness.

The clinical relevance of this proposed study's findings may extend well beyond the overhead athlete population. Individuals involved in repetitive, overhead arm positions related to their occupation and/or daily life often are affected by the same types of stresses and abnormal loads as athletes; as a result they are also susceptible to shoulder pathology and resultant dysfunction. The information gained from this study, regarding how to best measure, interpret and treat glenohumeral rotational ROM abnormalities, should assist clinicians faced with this clinical problem. The most important contribution may be early prevention through monitoring and management of individuals at risk of developing shoulder pathologies due to IR deficits of the shoulder.

1.5 Delimitations and Limitations of the Project

Study I

Delimitations:

- The main delimitation associated with this study was goniometric measurement of shoulder motion; a clinical measure found to have considerable variability in reliability testing. The following steps were taken to minimize the delimitations associated with this:

- The evaluators were two registered physical therapists with 15 and 22 years of experience assessing and treating patients with musculoskeletal conditions. The same research assistant was responsible for goniometer placement, reading and recording all shoulder measurements during the test sessions. The evaluators and research assistant participated in two formal training sessions to review and practice the test protocol including patient positioning, stabilization, goniometer placement and end-range determination.
- The same goniometer was used throughout the entire study. A bubble level was attached to one of the goniometer arms and a calibration test was performed at the beginning of each test session.
- Study participants participated in warm-up exercises (see Appendix A) prior to the test session in order to reduce the risk of a mobilization effect from repeated movements during the assessment. Measures were randomized according to side and shoulder movement tested.
- Movements were assessed with subjects in supine lying. This position is believed to allow for support of the trunk, greater relaxation of the participant and better stabilization of the shoulder girdle.

  - Examiner bias was addressed by covering the goniometer with white paper prior to the test session. This ensured that the assessor was blind to the measurement values during the test session, but allowed the research assistant to view and read the values on the dial. The recorded ROM values were not made available to the assessor and the research assistant did not provide feedback during the testing sessions.

Limitations:

- This study defined one unit of analysis as being equal to one shoulder. Therefore, if both shoulders of the potential subject met the criteria, then both shoulders were assessed and represented 2 units of analyses. A sensitivity of analysis was carried out to address the concern regarding the assumption of independence in considering an individual shoulder as the study sample unit rather than the individual.
- This study utilized 2 physical therapists with over 15 years of experience in assessing and treating orthopedic patients to determine subject positioning, landmarking, stabilization and end-feel determination. The results may therefore not be generalizable to novice physical therapists or other health care professionals.
- The testing procedure used in this study utilized 2 individuals; therefore the results may not be generalizable to measurement situations involving one person.

Study II

Delimitations:

- The delimitation associated with this study was the use of goniometric measurement techniques for evaluating shoulder ROM. All subjects in Study II were examined by one assessor (the author) and goniometric measurements were obtained by the same research assistant who was trained and participated in Study I. The test protocols and steps taken to minimize measurement error were exactly the same as previously stated in Study I.

Limitations:

- Study II's results may not be generalizable beyond varsity level overhead athletes involved in volleyball, swimming and tennis and non-competitive University students between the ages of 18 and 25 years, without shoulder pathology.
- The "overhead athlete" group consisted of males and females involved in volleyball, swimming and tennis. The results of this study may not be generalizable to athletes involved in other overhead sports. Research has demonstrated that athletes involved in the overhead sports included in this study possess similar patterns of rotational alterations seen in the baseball pitcher; however the specific amount of IR loss is reported to vary slightly from sport to sport.[20,30,31,45-49] This study compared the shoulder ROM results of the "overhead athlete"

group with the “non-competitive” group as well as examined the results within and between the individual overhead sports.

Study III

Delimitations:

- The delimitation associated with Study III was the use of goniometric measurement techniques for evaluating shoulder ROM. All subjects in Study II were examined by one assessor (the author) and goniometric measurements were obtained by the same research assistant who was trained and participated in Studies I and II. The test protocols and steps taken to minimize measurement error were exactly the same as previously stated in Study I.
- Study III involved ROM testing at 0, 4 and 8-weeks time. The examiner was not blinded to which group subjects were in during the testing however all ROM measurements were read, recorded and kept with the research assistant until the completion of the study.
- The stretch chosen for use in this study; the “sleeper stretch”, represents one of the most commonly prescribed exercises to stretch the posterior shoulder structures.[7,8,11,43,44] However, its effectiveness has not been well studied other than one randomized controlled trial[43] which found it to be effective. In addition, the objective of the stretch, originally proposed for the posterior capsule, may also impart a

lengthening effect on the posterior shoulder musculature. Although an important consideration in the explanation of the study's results, this was not viewed as a limitation of the study as the measured outcomes were change in IR- and HAd-ROM, representing the available motion of all soft tissue at the shoulder joint.

Limitations:

- Similar to Study II, the results of this study may lack generalizability beyond the participating population (i.e. type and level of overhead athlete being studied).
- The results of this study may not be generalizable beyond the specific intervention (i.e. sleeper stretch) and treatment parameters (i.e. dosage) investigated.
- Subjects in the experimental group were instructed to perform the sleeper stretch for a period of 8 weeks. Compliance may have been a limitation of the study. The following steps were taken to maximize compliance:
    - The author of this study discussed the importance of this study with the involved teams' coaches and trainers and stressed the role of compliance.
    - Study participants performing the stretch were taught the technique by the author and provided with written and illustrated instructions on how to properly do the stretch.

- Study participants in the stretch group were given a log book and encouraged to track their compliance with the stretch.
- All varsity teams at the University of Alberta have a designated athletic trainer who works closely with them. This person reminded and monitored his/her athletes' performance of the stretch exercises.
- The author met and encouraged the athletes to keep stretching every week.

1.6 Ethical Considerations

All subjects involved in the studies that make up this project were required to read the respective study's information letter (see Appendix B) and sign a consent form (see Appendix C).

All data collected and records kept on study participants remained confidential; participants were identified by a unique study ID number.

The potential benefits of this research project were believed to far outweigh any potential risks. Only glenohumeral IR, ER and HAd-ROM were measured. Passive measures of motion were performed with subjects in a supine position; therefore possible side effects from the tissue being stretched might have been mild muscle soreness and stiffness. To reduce the risk of this possibility, all subjects completed a warm up of active shoulder ROM exercises prior to being tested. Subjects were advised that they were free to withdraw from participation in these studies at any time without prejudice.

Chapter 2 REVIEW OF THE LITERATURE

Research related to this topic was broad. To fully understand its evolution, one must have a thorough understanding of the underlying anatomy and biomechanics of the glenohumeral joint, the pathomechanics of the overhead athlete's shoulder and the research related to the adaptive glenohumeral joint rotational patterns noted in these individuals. Although literature related to this topic dates back to the early 1990's, there is considerable, current debate surrounding the theories and implications of these observed changes. As well, there is a lack of agreement regarding the best method of detecting and managing rotational deficits in the overhead athlete.

The literature review will therefore be divided into six broad categories: (1) Glenohumeral Joint Anatomy, (2) Pathomechanics of the Overhead Athlete's Shoulder, (3) Glenohumeral Joint Rotation – Alterations and Theories, (4) Pathologies Associated with Posterior Shoulder Tightness, (5) Glenohumeral Joint Rotation and Posterior Shoulder Assessment, and (6) Treatment of Posterior Shoulder Tightness.

2.1 Glenohumeral Joint Anatomy

To properly understand the anatomy of the glenohumeral joint, one must consider the entire shoulder girdle, which consists of 3 bones: the scapula, the clavicle and the humerus. These bones are linked to each other and to the body by four joints: the glenohumeral joint, the acromioclavicular joint, the sternoclavicular joint and the scapulothoracic “articulation”. The combined effect of these four articulations is a high degree of mobility, which allows the arm and hand great functional capacity but also makes the shoulder particularly vulnerable to injury, because stability is sacrificed for mobility.

The glenohumeral joint has an almost global ROM because the glenoid cavity is a shallow socket approximately one third to one fourth the size of the humeral head.[50-52] To compensate for the shallow depth, the glenoid labrum, which attaches tightly to the bottom half of the glenoid and loosely to the top half, increases the glenoid depth approximately two times, adding to the glenohumeral stability.[52-54] Normally, when the humeral head is moved through its large ranges of motion, only a small amount of translation or excursion occurs between the humeral head and the glenoid.[15,20] If this translation is altered as a result of disruption to any of the supporting tissue, normal joint mechanics are affected and injury is probable.

The primary stabilization of the glenohumeral joint comes from the static function of the capsulolabral complex, labrum and bony geometry. Secondary stabilization is provided by the dynamic and coordinated contraction of the rotator cuff and deltoid muscles. [51,52,55] The integrity of the capsule and maintenance of the normal glenohumeral relationship depend on the reinforcement of the capsule by ligaments and the attachment of muscle tendons of the rotator cuff mechanism.

2.1.1 Posterior Capsule – Anatomy

The capsule of the glenohumeral joint is large and has twice the surface area of the humeral head. It is lined with synovium and extends from the glenoid neck to the anatomic neck and proximal shaft of the humerus.[13,51,55] This attachment can, in some instances, extend to include the labrum and the coracoid process superiorly (via the coracohumeral ligament) and the anterior or posterior body of the scapula (via the anterior and posterior recesses)[13,51-55]. The biceps tendon and intertubercular groove of the humerus may also be included within the attachment site of the shoulder capsule.

Three sections make up the capsule of the glenohumeral joint: the anterior capsule, the axillary pouch and the posterior capsule. The anterior capsule includes the superior, middle and inferior regions plus the rotator interval, while the axillary pouch describes the capsule between the anterior and posterior bands of the inferior glenohumeral ligament (IGHL). The posterior capsule extends from the posterior capsulolabral complex and from the posterior origin of the biceps tendon to the inferior aspect of the glenoid. At the inferior aspect of the shoulder joint is the IGHL complex. This complex is bounded by an anterior and posterior band that acts like a hammock to support the humeral head with the arm in abduction.[56, 57] It is often difficult to isolate the posterior band of the IGHL complex either visibly in cadaveric specimens or through palpation. [13]

Until recently, information regarding the glenohumeral joint capsule has focused on the anterior portion.[58, 59] The posterior capsule, described as thin, translucent and relatively featureless, has become a tissue of increased interest in the past decade as dysfunction in the posterior capsule has been shown to be associated with a characteristic loss of internal rotation as well as some shoulder pathologies.

Any discussion of the glenohumeral joint capsule must include a description of its most important thickenings; the glenohumeral joint ligaments. These ligaments generally are thick, organized collagen bundles that lie in the outer layer of the capsule and are distinguished according to their relationship to the joint.

Superior Glenohumeral Ligament (SGHL)

The SGHL is a relatively constant structure with three common variations for its glenoid attachment site; (1) a shared origin with the biceps tendon, (2) on the labrum just anterior to the biceps tendon, or (3) with the origin of the middle glenohumeral ligament. It inserts into the fovea capitis and lies just superior to the lesser tuberosity.[50,55,60] DePalma[61] reported that the SGHL was present 97% of the time. Subsequent anatomic studies have been much less consistent, reporting its appearance between 26% and 90% of the time.[50,59,60] Its size and integrity are quite variable, existing as a thin wisp of capsular tissue to as thick as the patello-femoral ligament.[50,60] Recent biomechanical studies[53, 60,62] report that it does not contribute significantly to the static glenohumeral joint stability as selective transection did not affect either anterior or posterior translation in the abducted shoulder. Its contribution to stability is believed to be best demonstrated with the arm at the side, lending support to the role of keeping the humeral head suspended.

Middle Glenohumeral Ligament (MGHL)

The MGHL shows the greatest variation in size of the glenohumeral ligaments and is not present as frequently as the other glenohumeral ligaments. DePalma et al.[61] described it as a well-formed, distinct structure in 68, poorly defined in 16, and absent in 12 of 96 shoulders. A similar investigation[63] found that it was absent in approximately 27% of the specimens studied. This ligament is described as either quite thin or as thick as the biceps tendon.[62,63] When present, it arises most often from the labrum immediately below the SGHL or from the adjacent neck of the glenoid. It inserts into the humerus just medial to the lesser tuberosity, underneath the tendon of the subscapularis. In some instances, the MGHL has been shown to have no attachment site other than the anterior portion of the anterior capsule. Its contribution to static stability is reportedly variable. In cases where it is rather thick, it has been shown to act as an important secondary restraint to anterior translation if the anterior portion of the inferior glenohumeral ligament is damaged.

Inferior Glenohumeral Ligament (IGHL)

The IGHL is a hammock-like structure that originates from the glenoid and inserts into the anatomic neck of the humerus. It consists of an anterior band, a posterior band, and an axillary pouch that lies in between; collectively referred to as the IGHL complex.[56,57,64] The anterior and posterior bands are most clearly defined when the arm is abducted. When external rotation is added to abduction, the anterior band fans out to support the humeral head, and the posterior band becomes cord-like.[63,64] Conversely, with internal rotation, the posterior band fans out to support the head, and the anterior band becomes cord-like. The origins of the anterior band and posterior band on the glenoid are often described in terms of the face of a clock. A recent anatomic study[63] demonstrated that the anterior band of each specimen originated from areas ranging from 2:00 to 4:00, and the posterior band attached in between the area defined as 7:00 to 9:00. The IGHL is thicker than the anterior capsule, which in turn is thicker than the posterior capsule.

Bey and colleagues[13] specifically examined the structural and biomechanical properties of the posterior capsule in hopes of quantifying regional variations in the tissue. They compared this data to the anterior band of the IGHL, hypothesizing that the material properties of the posterior capsule would be significantly inferior. They discovered that all 4 regions (superior, middle, and inferior posterior capsule and anterior band of the IGHL) when placed under load failed at the glenoid insertion, 3 at the humeral insertion (superior, middle posterior capsule and anterior band of IGHL) and 2 regions failed at their mid-substance (superior posterior capsule and anterior band IGHL). In conclusion, the authors suggested that relatively few differences existed between the 3 regions of the posterior capsule and the anterior band of the IGHL. This study suggests that the posterior capsule may have a higher degree of fiber alignment and strength than previously believed and therefore may have a greater role in passive stability at the glenohumeral joint.

2.1.2 Posterior Capsule – Biomechanics

The posterior capsule blends with the tendinous portion of the posterior aspect of the rotator cuff and limits posterior translation when the arm is forward flexed, adducted and internally rotated[13-16,56]. In addition, the posterior capsule becomes taut in various positions of flexion and IR and can act to limit excessive flexion and IR.

Through experimental tightening of the shoulder capsule, Harryman et al.[15] and Gerber et al. [58] demonstrated that the humeral head translated in the opposite direction to the capsular tightening. Harryman et al. referred to this as the capsular constraint mechanism and suggested that injury resulting in this mechanism may lead to instability, articular damage and symptoms of shoulder impingement. Using seven cadaveric specimens, they confirmed that tightening of the posterior capsule resulted in limited internal rotation, cross-body (HAd) movement and flexion of the shoulder. As well, they were able to show that posterior capsule tightening resulted in a significant increase in anterior translation of the center of the humeral head during both shoulder flexion and cross-body movement. Tightening of the posterior capsule also resulted in significant superior translation of the humeral head during flexion. These changes to the joint arthrokinematics lead to the humeral head and bursal side of the rotator cuff being forced against the undersurface of the coracoacromial arch, potentially causing compression of the cuff as the humeral head cannot remain centered in the glenoid.[50]

Gerber and his research group[58] performed a similar study by plicating the posterior capsule and reported a significant resultant limitation in IR-ROM in their specimens. IR was limited at 0° of abduction by 21.5° (48.2%), at 45° of abduction by 27.2° (69.7%), and at 90° of abduction by 21° (68.2%).

Burkhart et al.[6] used electromagnetic sensors to track the amount of translation before and after posteroinferior capsular plication in cadaveric shoulders. Prior studies measured glenohumeral translation with a tightened posterior capsule while the arm was forward flexed. Burkhart's group was interested in the translational motion in the same environment (i.e. tight posterior capsule), but with the shoulder moving into a functional throwing position of 90° of abduction and 90° of ER. Their results revealed that following posteroinferior capsular plication, the humeral head shifted approximately 4.4 mm posterosuperiorly on the glenoid.

A similar study was conducted by Clabbers et al.[23] to study the effects of posterior capsule tightness on humeral head position in a simulated late cocking model. They used eight fresh frozen shoulders and a 3-dimensional infrared motion sensor to measure the humeral head to glenoid relationship before and after suture plication of the posterior capsule. Their results showed that surgical imbrication of the posterior capsule produced a non-significant statistical trend to posterior and superior migration of the humeral head in the simulated late cocking position. The authors reported that their study lacked adequate power related to the large measurement variance.

The glenohumeral joint is an unstable joint that relies heavily on the integrity of the capsuloligamentous tissue and neuromuscular components. Disruption or alteration of any of these structures often leads to resultant joint instability and painful impingement. Individuals involved in repetitive overhead activities place these structures under additional stress and are therefore at greater risk of developing injuries.

2.2 Pathomechanics of the Overhead Athlete's Shoulder

The shoulder of an athlete who participates in an overhead or overhand sporting activity faces numerous challenges. The degree of mobility required often exceeds normal limits and movement occurs in combination with high speeds, precise neuromuscular control, coordination and high repetitions. This apparent contradiction of activities leaves the athlete's shoulder extremely vulnerable to injury. Thus, considerable attention has been directed at how to optimize athletic performance while simultaneously preserving a healthy, well-functioning shoulder girdle.[6-8,11,17,36,40]

The overhead throwing motion is a highly skilled movement, performed in extreme joint positions and extreme velocities. Athletes involved in these activities require balanced flexibility, strength, coordination and neuromuscular control of their shoulder girdle as well as their entire kinetic chain. Research has shown that athletes involved in sports such as tennis, swimming and volleyball share many of the characteristics noted in the throwing athlete, most notably the repetitive overhead rotation motion and the adaptive tissue changes that result from this[7,8,19,21,30,48]. Knowing the biomechanics and the extraordinary demands placed on the shoulder joint in this population will help clinicians in developing injury prevention and sport-specific treatment programs.

The majority of research related to the overhead athlete has been performed on baseball pitchers who throw overhand. Although certain comparisons between pitchers and other overhead athletes appear to be reasonable, recent studies have highlighted subtle differences in motions and tissue demands amongst other overhead sports. [7,19,21,31,46,47,49]

Baseball, tennis and handball players all require repetitive overhead motions that are discontinuous and ballistic in nature. In these activities, the arm is forcefully propelled forward from maximal or near maximal ER through to IR and requires the posterior rotator cuff musculature to act eccentrically in order to decelerate or “brake” the arm as it internally rotates and horizontally adducts across the body.[6,7,36,65,66]

The football throw is similar to the throwing motion seen in baseball; however the increased weight of the ball (0.42kg versus 0.14 kg for the baseball) affects the arm position and stresses the shoulder differently.[67,68] To compensate for the heavier football, the muscle activation pattern required, results in greater stress being placed on the biceps tendon and pectoralis major muscle as well as the rotator cuff muscles.

Kelly et al.[69] identified four sequential phases of the football throw based on his work and found that these 4 phases closely paralleled the six phases of the baseball throw. In the same study, Kelly et al. also defined two distinct muscle groups used in the football throw. The first group he classified as the stabilizers (i.e. supraspinatus, infraspinatus, anterior, middle and posterior deltoid and biceps) as they demonstrated relatively static levels of activity throughout the entire throw. This finding was similar to reports of muscle activity in the baseball throw. The second group was classified as the accelerator muscles (i.e. subscapularis, pectoralis major, and latissimus dorsi) as they were responsible for the majority of the force imparted into the football throw.

According to Fleisig et al.,[67] one of the main differences between the baseball pitch and the football pass is that during arm deceleration, pitchers produce greater forces and torque in the shoulder and elbow as well as higher overall arm speeds. In addition, the accelerator muscle groups measured in baseball[70] demonstrate considerably more activity than those muscles in football.

Conversely, an activity such as freestyle swimming requires a more continuous and repetitive bilateral overhead motion, while submerged in water, where the arms are used to propel the body forward during the “pull through” phase. During the corresponding “recovery” phase, the arm is lifted out of the water and brought over the body as the body rolls in preparation for hand entry and the next stroke cycle. This type of activity produces less stress and eccentric loading to the joint; however, the continuous nature of the freestyle technique permits less opportunity for muscular recovery and a greater risk of fatigue-induced microtrauma to the joint.[71-73]

Water polo represents a unique combination of both forceful throwing and swimming. Therefore, the forces imparted upon the shoulders of water-polo players include the forceful unilateral stresses observed in overhead throwing as well as the more continuous bilateral forces observed in swimmers.[74]

In volleyball, the majority of the force transmitted during an overhand spike originates from the torso. The scapula serves as a "funnel" for the transfer of kinetic energy to the shoulder and arm and provides a stable base of support so that the upper limb can be correctly positioned in space during the overhead skills.[47,48,75] Because the glenohumeral joint is inherently unstable, the dynamic stabilizers of the scapula and the humeral head are essential to maintaining the functional integrity of the shoulder joint and to allow successful execution of an overhead serve and spike in volleyball.

2.2.1 Shoulder Injuries in Overhead Athletes

The overhead athlete's shoulders must be adequately mobile to perform overhead activity, while also providing enough stability to allow and execute a motion without the shoulder "giving way" or subluxating. The "thrower's paradox", a phenomenon described by Wilk and Arrigo,[76] refers to this inherent contradiction. The loss of this fine balance between mobility and stability is believed to be the main contributing factor to the development of shoulder injuries in the overhead athlete population.

The shoulder is one of the most commonly injured regions among overhead athletes.[77-79] Several studies have determined the incidence of shoulder injury in various sports.[77-84] This information is essential for the identification of prognostic features and the development of preventative strategies and appropriate rehabilitation programs.

A recent study conducted by Bonza et al.[77] in the United States found that shoulder injuries were the fifth most common injury among high school athletes. This study's population consisted of high school athletes participating in nine sports: football, soccer, basketball, baseball and wrestling for boys and soccer, volleyball, basketball and softball for girls. They recorded 805 shoulder injuries, resulting in an injury rate of 2.27 per 10 000 athlete-exposures. An exposure was defined as one athlete participating in one practice or game situation. Shoulder injuries were found to occur more often in competition than practice and were highest in contact sports such as football, wrestling and baseball where high-speed collisions and falls are common. The incidence of chronic, overuse injuries was also reportedly high in sports that require repetitive, overhead motions such as volleyball and baseball. Common shoulder injuries included sprains/strains (39.6%), dislocations/separations (23.7%), contusions (11.5%), and fractures (6.6%).

Hootman et al.[82] undertook a similar project that summarized 16 years of National Collegiate Athletic Association (NCAA) injury surveillance data for 15 sports. Their cohort included 182 000 injuries and slightly more than 1 million exposure records, where an exposure was defined as one athlete participating in one practice or game situation. Similar to Bonza and associate's findings,[77] injury rates were significantly higher in games versus practices, and football produced the highest injury rate in the sports evaluated. The incidence of injury to the upper extremity was reversed with 18.3% reported in games and 21.4% reported in practices. The type of injuries recorded in the upper extremity tended towards chronic, overuse-type injuries, which are more commonly reported during practice situations.

Swenson et al.[85] studied the pattern of recurrent or chronic injuries to determine if there were sport and gender differences. Of the 13 755 injuries recorded, 1445 (10.5%) were classified as recurrent injuries. Overall, football players had the highest rate of recurrent injury. Recurrent shoulder injuries comprised 12.0% of reported injuries and consisted primarily of tendinitis' and muscle strains. Of interest, 45.5% of all of these recurrent shoulder injuries required corrective surgery. The authors highlighted the need for both better prevention of initial shoulder injuries and improved management of shoulder injuries to prevent re-injury or increased injury severity.

Epidemiological data from collegiate baseball players reveals that shoulder injuries, specifically rotator cuff pathology, account for the majority of injuries and time lost from the sport. Approximately 70% of these reported injuries occur in pitchers.[86] High school baseball players generate similar injury incidence values reporting an injury rate of 1.26 injuries per 1000 athletic exposures over a two season period of time.[78] The shoulder was the most commonly injured body site (18%) with the most common diagnoses being muscle and tendon strains and joint instability injuries. Measures in this athletic population have reported arm velocities of greater than 7000°/sec, rotational torques greater than 70 Nm with shear forces at 1000 N or higher.[78,87] With these tremendous forces placed repetitively on the shoulder, it is easy to understand why the region is commonly injured.[87]

Burkhart and his research group re-introduced the term “dead arm” to refer to “a pathologic shoulder condition in which the thrower is unable to throw with his pre-injury velocity and control because of a combination of pain and subjective unease in the shoulder” (page 126)[88]. This term implies more of a syndrome that affects the throwing athlete’s shoulder, consisting of a cluster of signs and symptoms originating from more than one source of pathology.

From their research on collegiate and masters’ level swimmers, Stocker and associates[84] reported that approximately one half of competitive swimmers would experience shoulder pain severe enough to prevent them from swimming for 3 weeks or more at some point in their swimming career. Other studies have reported prevalence rates of shoulder pain in swimmers ranging up to 80%.[72,73,84,89,90]

Pink et al.[45] compared the rate of reported shoulder problems in various sports and noted that 66% of swimmers complain of shoulder problems, compared to 57% of professional pitchers, 44% of collegiate volleyball players and 29% of collegiate javelin throwers. The high numbers of shoulder revolutions, the extreme ROM required for the revolutions and the generalized state of joint laxity in swimmers have been cited as common causal factors for injury in this population. Elite swimmers regularly train 10 – 12 months of the year, practicing 1 – 2 times per day, 5 – 7 days per week. Daily distance may vary between 7315 –

18 288 m per day. This translates into 16 000 shoulder revolutions per day with the majority of revolutions being done repetitively without rest or recovery.

The incidence of injury in tennis is not well reported; however the literature does demonstrate that the most common types of injury in young tennis players are microtrauma-related overuse injuries, most often affecting the upper extremity (20 – 45%).[22,79,83,91] The repetitive nature of high-velocity arm acceleration and deceleration coupled with the precise control required of the racquet are believed to be the main reasons for this high incidence. Rotator cuff inflammation is one of the most common injuries reported in tennis players, often secondary to instability of the glenohumeral joint in young players and as a result of repetitive impingement in the older athlete.

Shoulder pain represents the third most common injury amongst both female and male volleyball athletes and the second most common overuse related condition, accounting for 8 – 20% of all volleyball injuries.[75,80,92-96] From sixteen years of NCAA injury surveillance data on women's volleyball, Agel et al.[80] reported that approximately 20% of all game and practice injuries involved the upper extremity. The most commonly reported injury in the upper extremity was shoulder "muscle-tendon strains", followed by subluxation and chronic tendinitis. Repetitive overhead swinging was cited as the primary cause of the majority of these injuries.

An earlier study by Bahr and Reeser[93] noted that shoulder (10%) and lower back (19%) problems were 2 of the most common overuse injuries reported by professional male and female beach volleyball athletes. This finding highlighted the fact that despite volleyball having a relatively low overall rate of injury compared to other overhead sports, almost 40% of the athletes reported some type of overuse injury requiring medical attention.

Similarly, in a single season prospective cohort study of volleyball injuries, Verhagen and associates[94] reported the shoulder as one of the most common sites of overuse injuries. On average, 6.5 weeks of lost training and/or competition time were reported per season, the longest mean absence from sports participation compared with other time-loss injuries. Despite these and earlier findings, very little is known about the epidemiology of shoulder pain among volleyball players.

Reeser et al.[95] recently presented a review on some of the suspected risk factors and potential strategies for preventing common volleyball related injuries. Most volleyball shoulder problems appear to result from the stresses caused by frequent spiking and jump serving, both of which include extreme shoulder external rotation similar to throwing and racquet sports. In beach volleyball, where there are only two players on each team, it can be presumed that these forces will occur even more frequently. The volleyball athlete is estimated to perform greater than 40 000 spikes in a season. [95,96] The resultant load depends on the mechanics of the arm swing and the distribution of overhead swings between practice and competition.

Although the kinetics of the volleyball spike have not been reported, it is clear that the shoulder girdle is exposed to tremendous cumulative loads as a result of repetitive spiking and serving. In 1996, Kugler[97] identified clinical findings commonly seen in the dominant shoulder girdles of elite volleyball attackers, including depression and lateralization of the dominant scapula relative to the non-dominant side. Adaptation of scapular positioning is similar to that reported amongst other overhead athletes and has been called the “SICK scapula” (**S**capular malposition, **I**nferior medial border prominence, **C**oracoid pain and malposition and scapular dys**K**inesis).[6] It is associated with shoulder conditions such as rotator cuff pathology and functional instability and in the volleyball player, has been considered as a possible contributing etiology for suprascapular neuropathy, a common mononeuropathy occurring in up to 45% of elite volleyball players.[47,48,75,95,96]

Additional risk factors for the development of shoulder injury among volleyball players have not been thoroughly investigated. Factors of interest include extrinsic ones such as the trajectory and weight of the ball, a particular concern especially in beach volleyball where the environmental conditions can play an important role. Intrinsically different styles of spikes and strength ratios between isokinetic eccentric external rotation and concentric internal rotation are other potential risk factors under evaluation.

In summary, it is clear that the overhead athlete is at risk of injury as a result of the intense demands of the sporting activity as well as the inherent anatomical limitations of the shoulder girdle. Epidemiological studies have shown the shoulder to have an approximate 20% rate of injury when a range of sports involving the upper and lower body were considered. In those sports identified as having a predominantly upper extremity component, this rate of injury increases significantly. Information detailing the specific types of shoulder pathology commonly seen is more limited. Of interest to the present study is the high proportion of injuries that fall into the recurrent or overuse injury category; a pattern consistent with the characteristics associated with the overhead athlete's shoulder. Although the majority of studies have been done on the shoulder of the male baseball pitchers, there is enough evidence from sports such as volleyball, tennis and swimming to suggest that these athletes are also at risk of developing shoulder injuries as a result of their sport. Thus, the present study evaluated athletes who participate in a variety of overhead sports.

2.3 Glenohumeral Joint Rotation – Alterations and Theories

Previous sections have discussed the delicate balance of mobility and stability required at the shoulder for overhead activities such as sport. Alterations in this mobility have been reported in overhead athletes and are believed to develop secondary to adaptive structural joint changes that occur as a result of the extreme physiological demands of the activity itself.[6,7,17-19,23,25,27,98,99] Authors are currently divided as to whether these mobility changes arise from soft-tissue or osseous adaptations within and around the shoulder.[6,17,19,23,25-28,98-106] Theories include the presence of subtle microtrauma to the static and dynamic restraints of the glenohumeral joint from repetitive overhead throwing motions,[104-109] contracture of the posteroinferior joint capsule,[6,38,98-103,110,111] and osseous adaptation of the humerus.[24-29,112]

2.3.1 The Alterations

When examined, the shoulder of an overhead-throwing athlete has been shown to demonstrate a particular pattern of rotation. Compared to the non-dominant limb, the throwing or dominant arm, at 90 degrees of abduction, presents with an increase in ER and a decrease in IR. Verna[37] was the first to discuss the relationship between IR deficits and shoulder pathology, however Burkhart et al [6] first coined the terms GIRD and GERG in 2003, to represent these clinical findings. Glenohumeral IR deficit (GIRD) is defined as the loss, in degrees, of IR of the dominant or throwing arm compared with the non-dominant arm. Glenohumeral ER gain (GERG) is the increase, in degrees, in external rotation of the dominant or throwing shoulder compared with the non-dominant shoulder. Although the individual components of shoulder rotation change, the amount of total humeral rotation ROM available in the throwing arm often remains the same as the non-involved arm. Wilk et al.[36] called this the total arc of motion and described it as the full ROM (approximately 180°) from maximum ER to maximum IR (See Figure 2.1). The alteration in the ratio of ER to IR is believed to be a natural and seemingly necessary adaptation that develops in overhead athletes in order to accommodate positions such as the wind up in throwing or overhead spike in volleyball. It does not appear to become problematic unless the amount of glenohumeral IR loss exceeds the compensatory gain in ER.[6,36] In these instances, the loss of IR, without an increase in ER leads to an overall reduction in the total humeral rotation ROM.

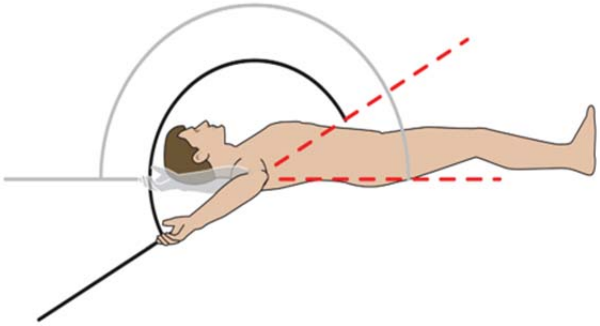


Figure 2.1 – Total Rotation Arc
External Rotation (ER) + Internal Rotation (IR)

Several authors have studied groups of overhead athletes to identify this altered pattern of glenohumeral rotation ROM.[7,8,11,12,18-21,25-28,113-122] Most studies have examined the baseball pitcher's shoulder producing results that are then generalized to other overhand athletes. Few studies have specifically examined shoulder rotational ROM in sports such as tennis, team handball, swimming and water polo.

2.3.1a Baseball Players – Symptomatic

As previously mentioned, Verna[37] was one of the earliest researchers to document the relationship between IR deficit and shoulder pathology. He followed 39 professional pitchers over the course of their regular season and found that at spring training, all of the pitchers had at least 35° of an IR deficit on their throwing arm. (See Table 2.1) Sixty percent of this group of pitchers developed shoulder problems requiring them to stop pitching during the course of their season. No explanation was provided as to why 40% of this group of pitchers did not develop shoulder problems.

Other authors[6-8,10,17,22,38,88,102,109,123] have investigated the relationship between IR deficits and shoulder pathology. Both Kibler[123] and Burkhart et al.[6] examined the characteristics of baseball pitchers with symptomatic type II SLAP lesions and reported average GIRD values of 33° and 53° respectively. Myers et al.[17] compared baseball players with and without pathologic internal impingement and noted that players with impingement had an average GIRD of 19° compared to an average of 11° in the non-impingement group of players. In addition, impingement players demonstrated increased posterior shoulder tightness when compared to the non-impingement group. Neither of these researchers compared their athletes shoulder ROM findings to non-athletic subjects with and without pathology.

Table 2.1: Summary Table of GIRD/GERG Values

Author/Yr	**Study Sample**	**Study Results**	**Study Findings**
Verna (1991)	Descriptive Study 39 Professional Pitchers	Average 35° GIRD (spring training)	60% of these developed shoulder problems requiring them to stop pitching
Kibler (2006)	Prospective study 38 arthroscopically proven symptomatic type II SLAP	GIRD average 33° (range: 26-58°) ($p<0.001$)	Found average GIRD of 33° in athletes with type II SLAP lesions
Burkhart et al (2003)	Cross-sectional study 1) 124 baseball pitchers/symptom type II SLAP 2) 19 asymptomatic pitchers	1) Average GIRD of 53° (range: 25 - 80°) ($p<0.001$) 2) 13° preseason - 16° postseason	GIRD of 25° or greater significant – risk factor for SLAP lesion

Myers et al (2006)	Case control study 11 male competitive baseball players with internal impingement and 11 baseball players without impingement	Players with impingement = GIRD 19° /without = 11˚ (p=.03) ↑ posterior shld tightness impingement group (p=.03) No difference in ER gain (p=.16)	Significant difference found between the 2 groups IR & PST
Baltaci et al (2001)	Prospective study design 38 collegiate baseball players	GERG range:13° - 15° GIRD range:11°- 14° (p<0.05) No difference in HAd-ROM (p>0.05)	Pitchers had highest change in ROM compared to position players
Reinold et al (2008)	Controlled laboratory study 67 asymptomatic professional baseball players	Significant ↓ in dominant shld IR (-9.5°), total rotation motion (-10.7°) and elbow extension (-3.2°) immediately after (p<0.001) and still at 24 hours later	Examined acute effects of pitching on shld &elbow ROM Acute musculo-tendinous changes produced high eccentric muscle activity & adaptive changes in rotation ROM
Nakamizo et al (2008)	Cross-sectional study 25 male little league pitchers	10/25 pitchers had GIRD between 5 and 30° / ER measures not significantly different (p=0.461) between throwing and non-throwing arms	Suggested that GIRD may occur prior to development of GERG in young baseball players
Trakis et al (2008)	Controlled laboratory study 23 adolescent pitchers	IR deficit = 13° (p<.001) ER gain = 11°(p<.001) No difference in total ROM between arms (2˚±7˚ loss, p=.14)	Throwing related pain in adolescent pitchers may benefit from selective posterior shoulder strengthening and stretching
Borsa et al (2005)	Descriptive laboratory study 43 asymptomatic professional baseball players	No significant difference in translation between throwing & non throwing shoulders Both shoulders posterior translation (5.38±2.7mm) greater (p<.001) than anterior translation (2.81±1.6mm) ER ↑ (p<.001)and IR ↓ (p<.001) on throwing shoulder	No correlation between GH joint translation and rotational ROM changes in their subjects

Fitzpatrick et al (2005)	Descriptive laboratory study Cadaveric model of thrower's shoulder	Increased ER (18.2° +/- 6.5°) with anterior capsular sretching (p<.0001) Decreased IR (8.8° +/- 7.4°) with posterior contracture (p=.005)	Measured rotational ROM and relative GH positioning as the joint was moved from neutral to maximum ER
Huffman et al (2006)	Controlled laboratory study 8 cadaveric shoulders	16% increase in ER (p<.001) post ER stretching Humeral head apex shifted posteriorly at 135˚ (p=.039) and 150˚ (p=.049)	Posterior capsule tightness alters humeral head position most during deceleration and follow-through phases of throw
Kibler et al (1996)	39 members of US National Tennis Team	165.3° vs. 178.7° total rotation (men – dominant to non-dominant side) (p<0.05) 168.9° vs. 193.5° total rotation (women – dominant to non-dominant side) Significant differences between age and years of play and total rotation loss (p<0.05)	Effect of age and years of tournament play in their analysis
Vad et al (2003)	Cross-sectional study 100 male professional tennis players divided into symptomatic and asymptomatic groups	Symptomatic = GIRD of 15.2° / 7.2 cm difference in side-to-side horizontal adduction (p<0.05) Asymptomatic = GIRD of 7.5° / 2.3 cm difference in side-to-side horizontal adduction (p<0.05)	Statistically significant correlations were found between hip IR deficits and LBP and shoulder IR deficits and shoulder pain Authors support theory of soft tissue capsular contracture as a cause of limited shoulder ROM
Schmidt-Wiethoff et al (2004)	Cross-sectional study 27 male professional tennis players and 20 male controls	Tennis players' ER gain average = 7.9° (p<0.01) Tennis players' IR deficit average = 17° (p<0.01) Control groups dominant to non-dominant arm values within 3° Tennis players' total rotation ROM reduced on dominant shoulder (10˚) vs. controls (3˚)	Dominant arm had significantly <IR and > ER than non-dominant arm

Bak & Magnusson (1997)	Cross sectional study 15 elite swimmers (painful & painfree shoulder groups)	IR ↓ in painful shlds compared with painfree swimmers ($p=0.14$) No significant difference between ER-ROM found	Changes in shoulder ROM due to physiologic adaptation to repetitive stress of the anterior labrum and posterior capsule
Beach et al (1992)	Cross-sectional design 32 college level swimmers	ER gain = 1° ($p>0.05$) IR deficit = 4° ($p>0.05$)	Swimmers might have tight posterior shoulder structures No correlation ($p>0.001$) between shld flexibility, strength ratios and pain
Wang et al (2000)	Cross-sectional design 10 male elite level volleyball players	IR deficit = 18° ($p<0.001$) ER gain = <5° ($p=0.473$)	Significant difference between IR ROM but not ER ROM (6/10 athletes reported shld pain, only 3 receiving treatment)
Lajtai et al (2009)	Cross-sectional study 84 professional (male and female) beach volleyball players	Average GIRD = 5° ($p<0.001$) Average GERG = 4° ($p<0.001$)	Atrophy of infraspinatus muscle in 30% of dominant shoulder
Ellenbeker et al (2002)	163 professional baseball pitchers and elite tennis players	ER ↑ and IR ↓ in dominant arm of both groups of athletes Total rotation ROM not significantly different in baseball pitcher's shoulder (145.7 vs. 146.9) ($p>0.05$) Total rotation ROM significantly different in tennis players' dominant arm (149.1 vs. 158.2) ($p<0.05$)	Compared rotation ROM values in baseball pitchers and elite tennis players – total rotation ROM different in tennis players only
Torres and Gomes (2009)	Cross-sectional study 54 asymptomatic male subjects: tennis players (n=21), swimmers (n=20) and controls (n=13)	Tennis GIRD = 23.9° ($p<0.001$) Swim GIRD=12.0° ($p<0.001$) Controls GIRD = 4.9° ($p=0.035$)	Tennis players exhibited the greatest deficit of internal rotation
Baltaci & Tunay (2004)	Cross-sectional Design 80 healthy male professional athletes: baseball (n=20), basketball (n=20), volleyball (n=20), handball (n=20), controls (n=20)	Baseball GIRD = 11.1° Basketball GIRD = 4.1° Volleyball GIRD = 5.7° Handball GIRD = 4.2° Controls GIRD = 8.7°	ROM of IR on dominant side baseball players significantly smaller than basketball, handball, volleyball players and controls ($p<0.01$)

2.3.1b Baseball Players – Asymptomatic

Glenohumeral rotational ROM changes have also been studied in the asymptomatic baseball player.[6,114,116, 117, 119,124] Burkhart et al[6] and Baltaci et al[117] reported GIRD values ranging from 11° to 16° and ER gains of between 13° and 15°. Baltaci et al[49] analyzed their results according to position and found that the greatest rotation changes occurred within the pitching group. Burkhart and his colleagues[6] noted a worsening in their asymptomatic players' GIRD values as the season progressed from pre- to postseason. Similar to previous reports, these findings represent professional level baseball players only and are provided without comparison to non-athletic controls or different types and/or levels of athletes.

Reinold et al.[116] examined the acute effects of baseball pitching on shoulder and elbow range of motion in 67 asymptomatic professional baseball pitchers. They measured their subjects before, immediately after, and 24 hours after pitching and found a significant decrease in shoulder IR (-9.5°), total rotation motion (-10.7°) and elbow extension (-3.2°) occurred immediately following activity which remained 24 hours after pitching. They suggested from these results that perhaps an additional explanation for the adaptations seen in throwers' rotation ROM was the acute musculotendinous changes produced from the high level of eccentric muscle activity that took place during the pitching motion.

Nakamizo et al[119] studied the rotation ROM pattern of 25 asymptomatic male little league pitchers. They were interested in knowing if the changes documented for older overhead athletes were present in a group of young athletes who had been pitching for an average of only 2.5 years. Their results showed 20 out of the 25 young pitchers as demonstrating an IR deficit of between 5° and 30°. Of interest however, was the fact that this group's ER-ROM measurements were not significantly different when comparing throwing to non-throwing arms. The authors suggested from these results that GIRD might occur prior to the development of GERG in young baseball pitchers. The reportedly large range of IR-ROM deficit (5° to 30°) including the variance of these values was not addressed in this study.

In 2008, Trakis and associates[124] investigated the rotation ROM of the dominant arm of adolescent pitchers as well as the strength of key posterior shoulder muscles (i.e. lower trapezius, middle trapezius, rhomboids, latissimus dorsi, supraspinatus, internal and external rotators). Additionally, they evaluated whether these measures differed in pitchers with and without a history of throwing related shoulder and elbow pain. Range of motion measures were consistent with previous reports: reduced IR (13°) and increased ER (11°) on the dominant arm with no significant difference in total rotation ROM between arms. Athletes had greater strength on the dominant side in their lower and middle trapezius, latissimus dorsi, and internal and external rotators. No significant difference between dominant and non-dominant sides was found in the rhomboid and the supraspinatus muscle groups. Strength of the external rotators was 67% of the internal rotators on the dominant side versus 72% on the non-dominant side.

In comparing pitchers with and without a history of throwing related shoulder pain, the group with pain exhibited lower muscle strength in the middle trapezius and supraspinatus and greater strength in the internal rotators.[124] These results led the authors to conclude that throwing-related pain in adolescent pitchers might be due to weakness in the posterior shoulder musculature and selective posterior shoulder strengthening might be indicated for injury prevention and rehabilitative programs directed to this population.

In 2005, Borsa and associates[114] compared glenohumeral joint translation and rotational ROM measurements in the throwing and non-throwing shoulders of 43 asymptomatic professional baseball pitchers. Their results revealed no significant difference in joint translation between the subjects' throwing and non-throwing shoulders with both shoulders having significantly greater posterior than anterior translation. IR and ER measures were similar to previous authors' findings[7,8,11,12,18-21,25-28,113-122] that found ER to be increased and IR reduced on the athlete's throwing shoulder. The authors were unable to conclude that glenohumeral joint translation was correlated to the changes in rotational ROM in their cohort of professional baseball pitchers. This study raised the question of whether the reduction in IR-ROM observed was entirely the result of posterior capsule tightness or perhaps partly due to other posterior shoulder tissues such as the rotator cuff. One would expect that if IR was reduced as a result of capsular tightening, there would be decreased posterior translation, not increased as was reported in Borsa et al.'s study. This study included subjects with asymptomatic shoulders only therefore the results may not be generalizable to athletes with pathology. In addition the study used only 1 force level (15 dN or 34 lb) and shoulder position (90˚ of abduction in the scapular plane and 60˚ of external rotation) for assessment. As a result, the authors were not certain whether the capsular end point was obtained for each subject or how much subject positioning affected humeral translation.

2.3.1c Cadaveric Studies

In 2005, Fitzpatrick and his group[12] developed 2 novel cadaveric models that simulated the capsuloligamentous changes seen in a thrower's shoulder. They measured rotational ROM and relative glenohumeral positioning as the joint was moved from neutral to maximum ER. Both of their models showed an increased humeral ER (18.2° +/- 6.5°) and decreased IR (8.8° +/- 7.4°) as well as an increased humeral shift inferiorly after the anterior capsule was put on stretch. With the addition of posterior capsule plication, the humeral head shifted superiorly.

Huffman et al.[20] undertook a similar study the following year using a cadaveric model of a thrower's shoulder to quantify the kinematic changes present. By applying a 44 N compressive force to the thrower's shoulder in a simulated late-cocking and follow through position, they were able to measure a 16% increase in ER that remained increased even after posterior-inferior capsular plication. At maximum ER, the humeral head apex was noted to shift posteriorly in the stretched and plicated states when compared to the intact state. The authors concluded that significant changes in glenohumeral ROM did occur in the late-cocking and follow through phases of throwing and that posterior capsule tightness altered the humeral head position most significantly during the deceleration and follow-through phases of this motion. The best method by which to simulate posterior capsular contracture has not been determined therefore the cadaveric representation of the events that lead to contracture are theoretical at best.

2.3.1d Tennis Players

Kibler et al.[30] studied the glenohumeral rotational ROM in 39 members of the US National Tennis Team noting specifically the effect of age and years of tournament play in their analysis. Their results echoed those of colleagues studying the baseball pitcher's shoulder, finding IR deficits and ER gains. This loss of IR was an absolute loss of motion because the total rotation also decreased. Values were 165.3° total rotation (men - dominant side) versus 178.7° (men – nondominant side) and 168.9° total rotation (women – dominant side) versus 193.5° (women – nondominant side). The difference between male and female players was not found to be statistically significant, but led the authors to conclude that female athletes, despite having greater intrinsic flexibility, could demonstrate the same degree of deficit in response to musculoskeletal demands. Analysis according to age and years of tournament play indicated significant statistical differences between age and years of tournament play and the amount of total rotation loss.

Vad et al.[22] investigated the correlation between hip IR deficits and low back pain and shoulder IR deficits and shoulder pain in 100 professional male tennis players. Their results revealed that players with shoulder pain had significantly less shoulder IR than players without shoulder pain (15.2° versus 7.5°) as well as greater posterior shoulder tightness as determined by HAd-ROM values (7.2 cm difference side-to-side in the painful shoulder group versus 2.3 cm difference in the painfree shoulder group). The authors theorized that the reductions in IR-ROM were the result of microtrauma and scar formation leading to capsular contracture.

Schmidt-Wiethoff et al.[118] compared glenohumeral joint IR and ER-ROM in 27 male professional tennis players and compared these results to a control group (n = 20) not involved in overhead sporting activities. Their results were similar to earlier studies with the tennis player group demonstrating an average increase in ER of 7.9° and an average decrease in IR of 17°. The rotation measures of the control group's dominant and non-dominant arms were on average within 3°. The tennis players' dominant arm total rotation ROM was also significantly reduced in comparison to the non-dominant arm and to the controls.

2.3.1e Swimmers

Bak and Magnusson[46] evaluated the differences in shoulder strength and ROM between painful and pain-free shoulders in elite swimmers and found that both groups of swimmers exhibited increased ER-ROM and reduced IR-ROM compared with normal values. These values did not differ significantly between the pain-free and painful shoulders leading the authors to believe that the changes in shoulder ROM might be explained by a physiologic adaptation to repetitive stress of the anterior labrum and posterior capsule.

Beach et al.[122] compared shoulder ROM values between swimmers and non-swimmers. They found that swimmers exhibited greater degrees of ER and abduction (10° and 40° respectively) when compared to non-swimmers. IR values were notably less (40°) in the swimmer group as well. These authors concluded from the findings that some swimmers may have tight posterior shoulder structures that can produce anteriorly directed forces on to the humeral head.

2.3.1f Volleyball Players

Wang and associates[48] evaluated the differences in strength and mobility of the dominant and non-dominant shoulders of 10 male elite level volleyball players and reported a significant difference in IR-ROM between the two sides. No significant difference was found between the dominant and non-dominant external rotation values. Subjects in this study also completed questionnaires related to pain. The results indicated that six of the ten players reported a shoulder pain problem, but only three of them were receiving treatment. This finding supports the theory that athletes participating in repetitive overhead sporting activities frequently do so in the presence of pain. The study proposed herein will examine this belief by obtaining information from all participants regarding their shoulder's present and past level of pain and function. Relationships between this information and ROM measures will be examined.

Lajtai et al.[75] conducted a similar study on 84 professional beach volleyball players to determine the prevalence of a variety of clinical and diagnostic features. Amongst these was active ER and IR in 90° of abduction. Their results yielded only minimal differences between the two shoulders (4° difference in ER and 5° difference in IR); however it should be noted that these measurements were taken actively, in contrast to most studies that measured passive overhead rotation ROM. This study also reported a high proportion of players played with significantly higher reported pain levels in their hitting versus non-hitting arm.

2.3.1g Combined Athlete Studies

A few articles have compared the shoulder rotation ROM between different groups of overhead athletes. Ellenbecker and associates[31] studied the IR and ER-ROM values in baseball pitchers and elite tennis players to compare the total arc of rotational ROM between each subject's dominant and non-dominant arms. Their results revealed greater ER and reduced IR in the dominant arm of both groups of athletes. However, the total average rotation ROM was found to be not significantly different ($p>0.05$) in the baseball pitchers' shoulders (146° versus 147°), but was significantly different ($p<0.001$) in the elite tennis players' dominant arm (149° versus 158°).

Torres and Gomes[21] compared the glenohumeral IR-ROM in asymptomatic tennis players and swimmers and compared these findings to a group of controls. They found that the mean GIRD in tennis players was 23.9°, compared to 12° in swimmers and 4.9° in matched controls. Significant differences were found between the dominant and non-dominant shoulders in all groups, but this difference was almost twice as large in the tennis player group compared to the swimmers and control group.

Baltaci and Tunay[49] measured the isokinetic performance and shoulder mobility in male professional basketball, volleyball, handball and baseball players to determine if significant differences existed between the dominant and non-dominant extremity in these athletes when compared to controls. This appears to be the only study that compared the ROM values across such a diverse group of overhead athletes. Their results showed that there was a significant reduction in IR-ROM on the baseball players' dominant shoulder when compared to all other athlete groups and controls. ER and HAd measures were not statistically different between the two sides in athletes and controls.

The above section establishes quite conclusively that a characteristic pattern of rotation exists in the dominant or throwing arm of the overhead athlete. The majority of studies on this topic involve professional, male, baseball pitchers with a much smaller proportion consisting of male and female athletes involved in other overhead sports such as tennis, swimming and volleyball. Although sample size in most studies was ample, only a very few studies included control groups or accounted for possible confounding variables such as years of play or position. In addition, the method by which IR- and ER-ROM was measured was inconsistently reported and rarely included details such as the type of ROM measured (active or passive) and/or whether scapular stabilization was maintained. Authors have measured shoulder rotation ROM and tried to determine what relationship the ROM changes have with shoulder pain and pathologies such as internal impingement and SLAP lesions. Further study regarding additional relationships between shoulder rotation ROM alterations and other clinical examination findings are warranted.

The proposed study attempted to build on previous work and examined a group of overhead athletes to determine if they exhibited the characteristic pattern of increased ER and decreased IR when compared to control subjects not involved in competitive overhead sports. In addition, flexibility of the posterior shoulder was measured as this value has been suggested to represent tightness in all of the posterior shoulder structures, not just the posterior capsule. The majority of studies related to this topic have used professional male baseball players. The present study recruited male and female varsity level athletes participating in a variety of overhead sports to determine, in addition to the primary question, whether typical patterns or characteristics existed within and between male and female athletes and among different types of sports.

2.3.2 Theories for Glenohumeral Joint Alterations

Alterations in glenohumeral joint rotation in the overhead athlete are well reported: increased ER and decreased IR in the dominant arm. Researchers agree that these changes develop as a result of the inherent demands of the overhead activity. There is, however, a current debate as to whether this altered rotational pattern arises from soft-tissue or osseous adaptations within and around the shoulder. [6,17,19,23,25-28,98-106] Some believe that it is from reactive scarring or contracture of the periscapular soft-tissue structures, namely the posterior capsule and/or posterior rotator cuff musculature.[6,38,98-103,104,109-111] Others suggest that the altered rotation occurs as a result of adaptive changes in the proximal humerus anatomy. [24-29,112] Finally, a third group of researchers advocate the changes are due to a combination of both the osseous and soft-tissue features of the overhead athlete's shoulder.[7,19]

2.3.2a Acquired Laxity Theory

The theory of acquired anterior hyperlaxity in overhead athletes describes a gradual elongation of the anterior capsule-ligamentous restraints producing a lax and mechanically unstable shoulder. Most throwers exhibit some degree of laxity of the glenohumeral joint in order to achieve the necessary ROM for their sport, referred to as "thrower's laxity" by Wilk et al.[76] This paper has outlined the most common increase in shoulder ROM: ER with the arm at 90 degrees of abduction. Reports of this laxity have extended past the throwing athlete and include elite level swimmers who possess inherently lax shoulders that may acquire further capsular laxity as a result of the extreme physical demands placed on the shoulder during swimming.[45,46,71] Subacromial impingement in swimmers is thought to develop as a result of capsular laxity, but these two conditions have never been empirically linked.

Jobe and associates[104-108] in the late 1980s and early 1990s first described subtle shoulder instability as the primary pathology in overhead throwers leading to the increased ER at 90° of abduction. They noted the anterior instability in the dominant shoulder of throwers during subacromial decompression surgeries for chronic impingement related symptoms. These patients ended up having poor functional outcomes from these procedures leading Jobe to conclude that it was the acquired laxity at the origin of the problem.

Despite widespread acceptance in the sports medicine community, no definitive study in humans using objective, quantitative measures of glenohumeral joint translation has confirmed the theory of acquired hyperlaxity in the overhead-throwing athlete. In fact, recent studies[18,114] have reported contradictory findings to Jobe's work through measuring glenohumeral joint laxity in the throwing versus non-throwing shoulder. These studies revealed greater posterior laxity relative to anterior laxity in the throwing shoulder and no association between measurements of joint laxity and alterations in IR and ER-ROM. Some pitchers in these studies who exhibited extremely diminished glenohumeral joint IR-ROM were found to have significant posterior capsule laxity, leading these authors to question both the acquired anterior laxity theory and the posterior capsular tightness theory. They suggested that the changes in glenohumeral motion seen in pitchers might be due to other factors.

2.3.2b Soft-tissue Theory

Pappas et al.[98] in 1985 were the first to suggest that posterior shoulder immobility occurred as a result of repetitive microtrauma leading to the development of fibrotic scar tissue within the posterior capsule. Contracture of the posterior joint structures has been proposed as a major contributor to the deficits seen in IR in the overhead throwing athlete.[6,17,98-102] At present, it is unclear which posterior shoulder tissues actually undergo contracture. Most literature implicates either the posterior capsule or posterior cuff musculature as the culprit, theorizing that a tight posterior-inferior capsule or rotator cuff musculature results in glenohumeral arthrokinematic alterations leading to secondary damage to joint structures.

The major proponents of this theory are Burkhart and Morgan[100] who first described the role that posterior capsule tightness played in the development of SLAP lesions in the late 1990s. This “peel-back” mechanism theory described how an acquired contracture of the posterior capsule resulted in a posterior-superior shift in the humeral head during the late-cocking throwing phase. The twisting of the biceps in this position and the tension from the humeral shift, tractions the posterior-superior labrum, eventually pulling it away from the superior glenoid. They believe that this process leads to the development of a Type II posterior SLAP lesion, causing an anterior “pseudolaxity” that was not the result of anterior-inferior capsular stretching.

There is considerable evidence to support the theory that posterior shoulder immobility develops in response to long-term overhead activity.[6-8,11,14,16-23,100-102,110,111,148] Athletes involved in these sports present clinically as having less than normal ranges of IR and an overall reduction in total rotation of the dominant or throwing arm. Several authors have used HAd-ROM, with scapular stabilization as a method of quantifying posterior shoulder tightness and have noted a significant relationship between IR deficits and posterior shoulder immobility in this population.[98,110,111,126-130] However, the question regarding which structures (posterior capsule or posterior rotator cuff) cause the motion restriction remains.

Despite the debate, there does appear to be a general acceptance that posterior shoulder immobility, no matter what the source, may be a contributing factor in the development of shoulder pathologies such as internal impingement and labral lesions. This support comes from studies that have observed posterior capsule contracture during surgical interventions in throwers with type II SLAP lesions.[6,14,16,37,123]

2.3.2c Osseous Theory

Recent evidence has attributed the altered mobility pattern seen in the overhead athlete to adaptive changes in the bony architecture of the glenohumeral joint.[24-29,112] These authors theorize that the opposing muscle forces applied to the humeral head during repetitive overhead throwing result in osseous adaptations of the proximal growth plate rather than the periarticular soft tissue structures surrounding the glenohumeral joint.[25,27] This adaptation results in increased humeral retroversion, which presents clinically as increased ER-ROM.

Researchers promoting the theory of osseous adaptations challenge the claims that deficits in IR deficit and gains in ER occur only as a result of soft-tissue changes. They argue that ROM is determined by both bony architecture and soft tissue (i.e. capsular and musculotendionous) extensibility and that present measuring techniques cannot discriminate between the two types of tissues.

Humeral torsion (also known as retrotorsion or retroversion) describes the amount of twisting about the longitudinal axis of the humerus. It is calculated by measuring the direction that the humeral head faces in relation to the distal epicondylar axis of the humerus. The more posteriorly the humeral head faces with respect to the distal epicondyles, the greater the humeral retrotorsion. When measuring shoulder rotation range in supine, subjects with greater humeral retrotorsion will display an apparent increase in shoulder ER range, as the neutral rotation position will be shifted toward ER.

Recent research has reported substantial variation occurs in the amount of humeral torsion in different races, age groups and in individuals involved in overhead sporting activities.[25,29] Computed tomography (CT) and X-ray investigations of subjects involved in baseball and handball have demonstrated that there is an increase in humeral retrotorsion on the dominant side of these athletes.

Crockett et al.[25] studied the role of humeral head retroversion in relation to increased glenohumeral ER. They looked at glenohumeral joint ROM and laxity along with glenoid version in the dominant versus non-dominant shoulders of 25 professional pitchers and compared these results with 25 non-throwing subjects. Computed tomography was used to measure the glenoid version. Subjects in the throwing group demonstrated a significant increase in the dominant versus the non-dominant shoulder in humeral head retroversion, glenoid retroversion, ER at

90° and ER in the scapular plane. IR was also decreased. There were no significant differences noted between shoulders in the non-throwing group.

Chant et al.[26] used computed tomography (CT) scans to compare the angle of humeral head version in 19 competitive baseball players and 6 control subjects. They found that the baseball players had statistically significant side-to-side differences in humeral head version, with an average of 10.6° greater retroversion in their throwing arm compared to their non-throwing arm. This same difference was not recorded in the control group. In addition, the authors noted that greater humeral head retroversion was strongly associated with the altered rotation pattern of increased ER and decreased IR.

Similar studies by Reagan et al.[27] and Osbahr et al.[28] investigated the relationship between humeral retroversion and rotational motion of the GH joint in baseball players. Their results supported Crockett's work in concluding that a pattern of increased ER and decreased IR in the dominant extremity was found to exist in combination with humeral retroversion. Osbahr et al. [28] concluded that even though there was an aspect of IR deficit caused by soft tissue, the major culprit was retroversion of the humerus.

Whiteley et al.[112] investigated the reliability of two methods of measuring humeral torsion; direct palpation and indirect ultrasound measurement. They found the inter-tester reliability was excellent for the ultrasound visualization method of measuring humeral torsion, while the palpation method yielded poor inter-tester reliability results. In addition, humeral torsion differed between throwers and non-throwers and there was a considerable side-to-side variation found in both populations with the throwers demonstrating significantly greater humeral retrotorsion in their throwing arm. In light of these findings as well as the work of others,[24-29] the authors suggested that the contribution of humeral torsion to total shoulder rotation ROM should be established in order to make valid clinical decisions regarding the treatment of shoulder dysfunction.

2.3.2d Combination of Osseous & Posterior Shoulder Tightness Theory

In the past few years, there has been growing acceptance amongst authors and clinicians that the unique rotational ROM pattern observed in the athlete's shoulder, specifically an increase in ER and decrease in IR, is the result of many factors. All agree that the demands of the sport itself plays an essential role in the development of this adapted motion, but recently, the debate surrounding which anatomical structures are most responsible has given way to the belief that it is most likely a combination of osseous and soft-tissue changes.

A recent article by Wilk et al.[7] supported this belief, suggesting that the loss of IR in overhead athletes is likely to be the result of a combination of osseous adaptations and posterior muscle tightness. They cited a study that looked at the correlation of ROM and glenohumeral translation in professional baseball pitchers[114] and found that most of the throwers in the cited study had significant posterior laxity, not stiffness, when evaluated. Therefore, they recommended performing posterior-lateral joint mobilization glide techniques to mobilize the posterior capsule if it was shown on clinical examination to be excessively hypomobile. They did, however, suggest that to improve IR motion, athletes perform two commonly described stretches; the sleeper stretch and supine HAd stretch. They believed that these stretches were addressing the reduced flexibility of the posterior musculature that might become tight from the intense muscle contraction during the deceleration phase of throwing.

Poser and Casonato[131] used a 42 year old male manual worker with sub-acromial impingement to investigate the question surrounding which posterior shoulder structures were responsible for limiting glenohumeral IR. They believed that the limitations might be caused by a contracture of the infraspinatus and teres minor muscles and therefore treated these muscles specifically with soft-tissue massage techniques. Their results supported their hypothesis demonstrating a 20° increase in IR-ROM over 3 treatment sessions. It is difficult to make generalizations based on the response of a single, non athletic case, but it raises an important question about which soft tissues are at fault with an IR deficit as well as which treatment interventions are most effective and appropriate.

The opinion of Wilk et al.[7] and Poser and Casonato[131] appear to be reasonable in trying to make sense of the cause of altered shoulder rotation characteristics of the overhead athlete. Glenohumeral IR deficit is considered to be the loss of IR compared with the opposite side and is attributable to both bony and posterior shoulder soft tissue (i.e. capsular and musculotendionous) changes. If the loss of IR equals the gain of ER, the total rotation arc has been maintained and this change can be attributed to both osseous and soft tissue changes. This appears to be a normal physiologic adaptation that occurs in response to the demands of the activity and occurs without consequence. If the loss of IR exceeds the gain in ER and the total rotation arc of motion is also decreased, these changes are attributed to soft tissue changes of the posterior shoulder structures and are considered pathologic.[7]

2.4 Pathologies Associated with Reduced Glenohumeral Internal Rotation

In the overhead athlete, a reduction in IR-ROM coupled with an overall reduction of total rotation can potentially set a sequence of events in motion that leads to injury and eventual shoulder pathology.[6-8,10,11,17,18,22,99-102,109,113,122,124,137,138] The posterior shoulder structures, specifically the posterior capsule, have been implicated as the main culprits. The following section will provide an overview of the specific shoulder pathologies believed to be associated with this phenomenon.

2.4.1 Posterior Capsule Contracture

Although contracture of the posterior capsule is rarely defined as a pathology, it warrants discussion as an important deviant of normal anatomy because of the central role it may play in the development of shoulder pathology in overhead athletes. In fact, Burkhart et al.[6], suggest that contracture of the posteroinferior capsule is the *essential lesion* that sets the sequence of events in motion and potentially leads to pathology in the thrower's shoulder. The forces placed upon the posteroinferior capsule during repetitive overhead activities are thought to be the primary cause of contracture and thickening of this portion of the glenohumeral joint capsule.[6,14,16,99-102,142-144] Specifically, the arm moving from an abducted and maximally externally rotated position to maximal IR and HAd is cited as a primary cause of the stress to the posterior capsule as this final position, known as the follow-through phase in throwing, places the inferoposterior portion of the capsule on its greatest stretch.[6-8,12,18,19,23,38,65,145]

In addition to the stretch mechanism, the posterior capsule is exposed to a deceleration force as the arm internally rotates and horizontally adducts across the body during the throwing motion. After ball release, the arm moves ahead of the body and exerts a large distraction force of approximately 750 N (approximately 80% of the pitcher's weight), that acts on the posteroinferior capsule as well as other posterior shoulder soft tissue.[6-8,65,66,68] Because the shoulder is internally rotated during follow-through, the inferior portion of the posterior capsule is rotated into a more posterior-central position where it more directly resists the distraction force of follow-through. The reactive force of the shoulder musculature produces a compressive load to resist this distraction force. The shoulder capsule is then subjected to repetitive high loads that cannot be completely resisted by muscle forces. This repetitive tensile loading of the posteroinferior capsule is suggested to cause the capsular hypertrophy and resultant contracture, commonly seen in the throwing athlete.[13,14,16]

Burkhart et al.[6] reported in their review of surgical observations that throwers who exhibited glenohumeral IR deficits showed a severely contracted and thickened posteroinferior recess in the posterior band of the IGHL.

Ticker et al.[16] reported similar results, discovering thickened posterior capsule tissue in patients diagnosed with limited IR in conjunction with subacromial impingement. In addition to these arthroscopic findings, cadaveric research has demonstrated altered humeral migration on the glenoid or loss of humeral IR in cadaveric models with a plicated posterior capsule.[15, 58] The shift of glenohumeral contact point (from a tight posteroinferior capsule) results in increased clearance of the greater tuberosity, which then allows hyperexternal rotation of the humerus and a delayed contact point of internal impingement. The contact point is frequently shifted to the extent that rotation takes the humerus all the way around to the posteroinferior quadrant of the glenoid before contact is made. Pathomechanically, this change in glenohumeral arthrokinematics may compromise the posterosuperior rotator cuff, bicipital insertion, and labrum and result in the development of subacromial impingement, pathologic internal impingement, and/or superior labral anterior posterior (SLAP) lesions in individuals involved in overhead sport/activities.[6-8,14-17,23,37,38,68,88,100-102,109-111]

Other overhead activities, such as the front crawl in swimming, involve a more continuous motion of the arm with less powerful deceleration forces. The increased number of revolutions and shortened muscular recovery time is believed to result in additional stress and microtrauma being placed on surrounding structures, placing the posterior capsule at greater risk of trauma.[19] Similar observations have been made in tennis players.[30, 31, 40,41] It is logical to assume that the findings noted in these athletes offer insight into other overhead athletes involved in similar movement patterns as well as individuals involved in repetitive, overhead manual labor. Further research is required to determine to what extent these generalizations can be made.

2.4.2 Glenohumeral Joint Internal Impingement

Walch[109] first described internal impingement in 1992 while studying a group of tennis players. He discovered through arthroscopy that partial, articular-sided rotator cuff tears were a direct result of what he called "internal impingement". This impingement occurs through contact between the articular surface of the rotator cuff and greater tuberosity and the posterior and superior glenoid rim and labrum. This impingement is said to occur when the joint is in 90° of abduction and maximal ER, a position common in many overhead sport and work activities. In throwing, the excessive anterior translation of the humeral head combined with the excessive glenohumeral joint external rotation, is believed to predispose the rotator cuff to impinge against the glenoid labrum. Burkhart and Morgan[6,88,100-102,131] as well as other authors [14,17,37,40,41] felt that a tight posterior capsule in this abducted and externally rotated position led to abnormal humeral head translations that could narrow the subacromial space and contribute to pathologic internal impingement.

Others have studied the clinical features of patients identified as having pathologic internal impingement in an effort to establish key predictors and causal links. [132-138] Myers et al.[17] conducted a study that compared the IR-ROM and posterior shoulder tightness of 11 throwing athletes with pathologic internal impingement to 11 matched controls. The throwing athletes with impingement demonstrated statistically significant glenohumeral IR deficits and posterior shoulder tightness compared to the control subjects. No significant differences were found in comparing the 2 groups' ER values indicating that the symptomatic throwers had a true rotation loss of motion.

2.4.3 Subacromial Shoulder Impingement

Athletes participating in sports that require repetitive overhead motions such as baseball, volleyball, swimming and tennis are also identified as being at high risk of developing subacromial shoulder impingement secondary to repetitive placement of the shoulder in vulnerable positions coupled with high forces and extreme loads. [42,68,104,146,147] Several factors have been cited as potential contributors to the development of this condition, including inflammation and/or degeneration of the rotator cuff tendons and bursa, weakness or dysfunction of the rotator cuff and/or scapulothoracic muscles, posterior glenohumeral joint capsule tightness, poor posture and bony or soft tissue abnormalities of the borders of the subacromial outlet.[146,147]

Ticker et al.[16] studied a group of 9 patients identified as having a painful loss of internal rotation associated with subacromial impingement syndrome to determine whether the posterior capsule had physiologic changes. All of the patients underwent arthroscopy and were observed to have a thickened posterior capsule.

2.4.4 SLAP Lesions

The term *SLAP* describes a lesion of the glenoid labrum, specifically a fraying and stripping of the superior aspect of the labrum, as well as the biceps tendon and biceps-labral anchor. Andrews and colleagues[139] were the first to describe this lesion in 1985 through arthroscopic findings in a group of throwing athletes with shoulder dysfunction. Snyder et al.[148] later coined the term and subsequent work has classified the types of SLAP lesions into 4 main types with 3 variations.[149] The overhead athlete is most often associated with a type 2 SLAP lesion.

Patients who are diagnosed as having a type 2 SLAP lesion generally fall into 2 categories: overhead athletes with a history of repetitive overhead activity and no history of trauma and individuals with a history of trauma. Several studies have attempted to define the pathophysiology of the SLAP lesion, but this topic is still under debate.[6,38,99-102,148-153] Clinicians and researchers do agree that it is a commonly seen pathology in overhead athletes and workers and as previously mentioned, some authors[6,11,17,38,88,99-102,110,111,151,153] believe that contracture of the posterior capsule is a main causal factor in the development of this pathology.

Grossman et al.[38] performed rotational, humeral shift and translation tests on ten cadaveric shoulders that represented 3 simulated shoulder models: 1) completely intact, 2) stretched anterior capsule and 3) posterior capsule contracture. They found that a posterior capsule contracture leads to a posterosuperior shift of the glenohumeral contact point, placing increased stress on the posterosuperior labrum. This shift in contact point allows increased ER motion as the greater tuberosity now has more glenoid clearance. With excessive ER, the long head of the biceps started to pull on the superior labrum from a posterior direction setting up a sequence of events that Burkhart and Morgan[6,100-102] referred to as the 'peel-back' mechanism. The altered force vector of the biceps caused the superior labrum to avulse from the glenoid, resulting in a SLAP lesion. This study supported claims by Burkhart and others that suggested altered rotation of the glenohumeral joint, in particular, reduced IR, causes the process that can lead to a superior labral lesion.

2.4.5 Scapulothoracic Alterations

Altered scapulothoracic kinematics has been strongly linked to shoulder conditions such as impingement, rotator cuff tendinopathy, rotator cuff tears, glenohumeral instability, adhesive capsulitis and stiff shoulders.[132,137] In addition to altered muscle activation patterns, soft tissue tightness of muscles or structures that can restrict normal scapular motions during arm elevation has been identified as a potential mechanism for the development of the scapulothoracic alterations seen in patients. The two most commonly reported are shortening of the pectoralis minor muscle and posterior shoulder tightness. It is believed that posterior tightness alters the scapular kinematics by passively "pulling" the scapula laterally over the thorax, particularly during humeral IR in elevated arm positions.[154]

A study by Borich et al.[39] investigated the relationship between glenohumeral IR-ROM deficit and 3-dimensional scapular angular positioning during active arm movements in subjects involved in overhead sports activity. They discovered that the athletes who had an IR deficit also had a significantly greater scapular anterior tilt (9.2° difference) across different overhead positions, when compared to their control group. They concluded that a significant relationship did exist between glenohumeral IR deficit and abnormal scapular positioning, particularly increased anterior tilt and suggested that this relationship identified a possible mechanism for the development of common shoulder pathologies such as instability and impingement. These studies suggest that tightness of the posterior shoulder (largely dominated by the posterior capsule) may play an important role in the development of scapulothoracic dysfunction, which ultimately may affect the integrity of the glenohumeral joint and lead to injury. What these studies have not determined are the causal factors of the observed scapulothoracic alterations. In other words, is it posterior shoulder tightness that leads to an altered scapular position or an altered scapular position, as a result of scapular muscle weakness, that leads to tightness of the posterior shoulder structures?

2.5 Glenohumeral Joint Rotation and Posterior Shoulder Tightness – Measurement

2.5.1 Measurement of Joint Range of Motion

Range of motion testing is commonly utilized in the assessment of the shoulder girdle. As the glenohumeral joint has large mobility, ROM is a parameter that is very often affected in the presence of shoulder pathology. Glenohumeral joint rotation has been discussed extensively as an important clinical feature that changes in the overhead athlete. Although agreement is lacking regarding the specific cause and consequence of altered ROM, there is consensus that ROM should be monitored closely. In this study, measures of passive IR and ER at 90° of abduction were obtained. The following section presents an overview of reliability and validity studies that measured rotation ROM at the shoulder. The second part will discuss methods described to measure posterior capsule or posterior shoulder tightness.

2.5.2 Overview of Rotation ROM Studies

The most common method used to measure glenohumeral joint ROM is goniometry. A wide range of results of the intra- and inter-rater reliability of this measurement technique have been reported.[155-169] A surprisingly small amount of this research has looked specifically at goniometry in the upper extremity; of these, only one presented reliability data on glenohumeral IR and ER in a 90° abducted position.[169]

Bovens et al.[156] reported from their study that it was difficult to show either an improvement or worsening of joint motion of less than 5° to 10° for most joints measured by the same tester. Although their study did not investigate overhead rotation of the shoulder, it highlighted the importance of reporting the amount of motion change (in degrees) necessary for clinicians to believe that the change is, in fact real, and not simply what one might expect as a result of measurement error. This value, known as the standard error of measurement (SEM), is not consistently reported within the literature related to ROM reliability.

Hayes et al.[159] assessed the inter-rater and intra-rater reliability of five different methods for assessing six different shoulder movements: visual estimation, goniometry, still photography, "stand and reach" and hand behind back. The participating orthopedic surgeon saw subjects within a two year time period. Goniometry results for active flexion, abduction and external rotation (0° of abduction) demonstrated fair – good reliability (Rho = 0.64 – 0.69 inter-rater and 0.53 – 0.65 intra-rater) and were closest to the values reported for visual estimation of ROM. Still photography yielded slightly better reliability values and the "hand behind back" method produced the lowest reliability measures. Standard error of measure scores for goniometry varied 14° – 25° for inter-rater trials and 14° – 23° for intra-rater trials.

Reliability of shoulder ROM measures has also been evaluated according to test position. Sabari et al.[161] found that measures of intra-rater reliability were stronger for shoulder flexion and abduction, than other movements, regardless of whether assessments were made in the supine or sitting positions. (ICC = 0.95 to ICC = 0.97). They did acknowledge that testing in a sitting position was potentially more difficult to do and required vigilance by the examiner to prevent compensatory movements of the pelvis and spine.

MacDermid et al.[160] conducted a study on the intra- and inter-tester reliability of goniometric measurement of passive lateral shoulder rotation. Their subjects consisted of 34 patients with a variety of different shoulder pathologies. Measures of lateral rotation were taken with subjects supine and the arm abducted approximately 20° – 30°. ICCs and the associated 95% confidence intervals were calculated as well as repeated-measures ANOVA and SEM. Intra-therapist ICCs (0.88 and 0.93) and inter-therapist ICCs (0.85 and 0.80) were high and SEMs indicated that differences of approximately 5° to 7° could be attributable to measurement errors when the same therapist repeats a measurement. A somewhat greater error could be expected between different therapists.

Other studies have looked at measuring the reliability of shoulder ROM with different instruments such as an inclinometer.[157,158] Inter- and intra-rater reliability measures were calculated for flexion, abduction, IR and ER in neutral and in varying degrees of abduction. De Winter's group[157] found their inter-observer agreement to be poor, concluding that differences in ROM of less than 20° – 25° could not be distinguished from measurement error. Green and her research team [158] found that both intra-observer and inter-observer agreement was greater for shoulder flexion and abduction when compared to the other glenohumeral movements. Agreement was greater for ER measured in neutral (ICC = 0.88) than ER measured in abduction (ICC = 0.70). Inter-observer agreement for IR in 45° of abduction was only modest (ICC = 0.47).

Muir et al.[169] evaluated the intra-rater, inter-rater reliability and measurement error in 15 active and passive shoulder ROM measurements. Thirty-four shoulders were assessed: 11 pathologic and 23 non-pathologic. The group's hypothesis testing evaluated whether intra- and inter- rater values could achieve a reliability of ICC>0.70, a value considered acceptable as a clinically meaningful measurement tool according to Streiner and Norman.[170] The SEM and MCD were calculated for each movement as these values express agreement in the same units as the original measurement and indicate the amount of change needed to exceed the error of the measurement itself. In comparing the normal and the pathology groups, these researchers found similarities in the movements that achieved the criterion level of reliability with comparable magnitudes for point estimates and 95% confidence intervals, SEM and MCD. This was a significant finding as it demonstrated that the reliability of goniometric measurements was not adversely affected by the presence of pathology.

Similar to earlier research, the intra-rater reliability values in Muir's[169] study achieved greater criterion levels of reliability than inter-rater values for both passive and active range of motion. Of particular interest to the present study were the findings related to IR and ER at 90° of abduction. IR at 90° was performed actively, which is different than the passive method being proposed for use in the present study. Intra- and inter-rater reliability findings for this study, including the SEM and MCD for each measure, can be found in Table 2.2.

Table 2.2 – Reliability, Standard Error of Measurement (SEM) and Minimal Clinical Difference (MCD) Values of Internal Rotation (IR) and External Rotation (ER) at 90° Abduction

Movement	Intra-rater reliability	SEM_{intra}	MCD single rater	Inter-rater reliability	SEM_{inter}	MCD two raters
Active IR 90° abd. *Normal	0.87 (0.73, 1)	4	11	0.62 (0.47, 1)	6	18
Passive ER 90° abd. *Normal	0.86 (0.64, 1)	5	13	0.49 (0.35,1)	9	24
Active IR 90° abd. *Pathology	0.69 (0.32,1)	5	14	0.39 (0.24,1)	7	20
Passive ER 90° abd. *Pathology	0.95 (0.90, 1)	4	12	0.89 (0.82, 1)	7	18

*From Muir SW, Luciak-Corea C, Beaupre L: Evaluating Change in Clinical Status: Reliability and Measures of Agreement for the Assessment of Glenohumeral Range of Motion, NAJSPT,Vol.5(3),2010

Research on the reliability of measuring glenohumeral joint rotation specifically, was sparse. Authors who included rotation did so with the arm in an adducted position. Only 1 article[169] examined reliability measures of both IR and ER at 90° of abduction; a position of function in sport, overhead work and several activities in daily life. Other inconsistencies were noted in the descriptions of the motion being measured including the position in which the subject was measured (supine vs. sitting vs. standing), the type of range measured (passive vs. active) and whether stabilization was provided during the test.[157-161,166-168]

2.5.3 Measurement of GIRD

Various methods for measuring GIRD have been described in the literature with variations primarily in patient positioning and whether or not the scapula is stabilized.[165] None of these articles have investigated the SEM or MDC associated with GIRD or GERG values.

The most common technique for measuring GIRD, and the method used in the present study, is described with the patient supine with his/her affected arm supported by the table and abducted to 90° at the GH joint and 90° at the elbow. (Figure 2.2) The test is done by moving the arm passively into IR while stabilizing the scapula. When scapular movement is first detected or an end feel at the glenohumeral joint is reached, the degrees of motion are determined using a handheld goniometer. Some authors have suggested that a goniometer with a leveling bubble be used, orienting 1 arm of the goniometer parallel to the ground.[165] Other methods describe placing the patient in side lying, on the affected shoulder, and then performing the 2 rotations, or with the patient standing with the arm abducted to 90°. In the latter position, scapular motion can be easily detected, but difficulty holding the arm in this position can make the measurement troublesome.

Figure 2.2 – Measurement of Internal Rotation with arm at 90º Abduction

Authors have investigated the effect of scapular stabilization on the accuracy of rotational ROM measures.[166-168] Not surprisingly, results from these studies have found the amount of rotation recorded when the scapula was stabilized was significantly less than when there was no stabilization. In addition, reliability coefficients produced variable results with the intra- and inter-reliability results yielding good, comparable results for both the stabilized and non-stabilized external rotation measures (ICCs from 0.58 – 0.84) In contrast, the internal rotation intra- and inter-rater reliability values were poor for the non-stabilized motion (ICCs of 0.23 and 0.13 respectively), but improved substantially when the scapula was stabilized (ICCs ranging from 0.38 to 0.65).

This study used goniometric measurement of IR and ER at 90° of abduction as one of its main outcome measures. Most reliability studies have reported ICCs associated with ROM measurement, but this value does not provide quantification of the magnitude of error associated with the measure. Therefore, phase one of this study reported the ICCs as well as the SEM and MDC associated with the shoulder motions analyzed.

Because this study was interested in overhead shoulder rotation in the overhead athlete, these motions were examined with the shoulder positioned at 90° of abduction reflecting the functional position and the test position used in all related research.

2.5.4 Posterior Shoulder Tightness – Measurement

Tightness and/or contracture of the posterior shoulder structures is one of the main theories postulated as a source leading to a reduction in IR in the overhead athlete's shoulder.[6-8,11,14,16-23,100-102,110,111,148] As earlier stated, there are conflicting opinions regarding which posterior shoulder structures are responsible for this loss of motion: the posterior capsule, posterior musculotendinous structures or both. Different techniques have been proposed to measure the flexibility of the posterior shoulder structures, although the most effective method has not been conclusively established.

The technique most commonly used to represent this immobility is the previously described passive IR at 90° of abduction. More recently, authors[6-8,13,15,99-102] have conceded that measuring IR-ROM as suggested above may not distinguish tightness in the posterior capsule from tightness in the posterior musculature. As a result, authors[110,111,126-128] have proposed different measurement techniques that they believe differentiate the 2 structures from one another. These methods utilize horizontal adduction ROM and vary primarily in patient positioning and method of scapular stabilization.

Clinicians may be inclined to simply measure shoulder IR motion as the best indicator of posterior shoulder contracture. However, because of the possible contribution of the posterior shoulder musculature and the role that increased humeral retroversion may have in decreasing IR motion, it may be prudent to include a measurement of HAd-ROM when evaluating the rotational ROM of the overhead athlete's shoulder. Table 2.3 provides a summary of the reliability and validity of the various techniques described in the following section.

HAd or cross-body flexion is thought to be the "gold standard" position for assessing posterior shoulder tightness (PST).[171] Subjects are placed in a supine position and the point at which their scapula begins to move during HAd is recorded as representing the excursion of the posterior capsule. Researchers and clinicians have criticized the method because the scapular motion is very difficult to detect with the subject lying supine. Pappas et al[98] tried to improve upon this technique, advocating manual stabilization of the scapula while performing the same test. Repeated trials of this technique produced inconsistent starting positions of the scapula that led to varying degrees of HAd. Subsequent research has attempted to improve on these earlier methods.

Tyler et al.[110] conducted a study with the purpose of developing a clinically reliable measurement tool to assess for PST. They evaluated the intra- and inter-rater reliability, as well as the construct validity of a side-lying HAd technique. Subjects started in side- lying on their unaffected shoulder with their body perpendicular to the treatment table. The scapula was then set in a retracted position and the lateral border stabilized by the examiner. The arm was then positioned in 90º abduction and passively led by the examiner into HAd to end range or until the humerus began to internally rotate. The distance from the medial epicondyle to the bed was measured and indicated the amount of flexibility of the posterior shoulder tissue. A greater distance between the medial epicondyle and the examination table indicated less flexibility of the posterior shoulder. Conversely, the closer the medial epicondyle was to the table (i.e. the smaller distance), the more flexible the posterior shoulder was. Unlike the supine cross-body technique, Tyler[110] suggested that side-lying allowed better monitoring of scapulothoracic motion and provided a more standardized starting position by placing the scapula in a fully retracted position. Intra-rater reliability values were high at ICC = 0.92 for the dominant shoulder and ICC = 0.95 for the non-dominant shoulder. Inter-rater reliability was measured as well with two evaluators and produced an ICC value of 0.80 indicating good reliability.

The construct validity between PST and IR and ER was assessed using pitchers and non-pitchers as subjects. In the pitcher group, a statistically significant inverse relationship between PST and IR was found. No relationship was found in the non-pitcher group. A significant inverse relationship was also noted between PST and ER in non-pitchers; a relationship that was not found in the group of pitchers. Based on a correlation analysis, Tyler determined that for every one centimeter increase of PST, a 4° loss of IR could be expected. Tyler and his research group concluded from these results that the side lying HAd position was a valid and reliable method of measuring PST.

Table 2.3 – Summary of Reliability of Posterior Shoulder Flexibility Measurement Techniques

Technique Author	**Intra-rater (ICC*)**	**Inter-rater (ICC)**	**Construct Validity Between IR-ROM & Posterior Shoulder Tightness (P-Value)**
SIDE LYING HORIZONTAL ADDUCTION			
Borstad et al. (2007)	0.40 (symptomatic) 0.63 (asymptomatic)	-	-
Myers et al. (2007)	-	0.69	-
Tyler et al. (1999)	0.92 (Dominant) 0.95 (Non-Dominant)	0.80	0.003 (Pitchers) 0.107 (Non- Pitchers)
SUPINE HORIZONTAL ADDUCTION			
Borstad et al. (2007)	0.79 (Symptomatic) 0.74 (Asymptomatic)	-	-
Lin & Yang (2006)	0.84	0.82	0.002 *(0.006 Posterior shoulder tightness and FLEX-SF)*
Laudner et al. (2006)	0.93	0.91	0.001 (Dominant & Non-Dominant) *(0.001 Dominant total arc of motion and internal rotation)*
Myers et al. (2007)	-	0.94	-
SUPINE INTERNAL ROTATION			
Borstad et al. (2007)	0.67 (Symptomatic) 0.79 (Asymptomatic)	-	-

*ICC=Intra-Class Correlation Coefficient

In 2000, these same researchers conducted a study[111] to quantify PST and motion loss in non-athletic patients with shoulder impingement. They used their previously described side-lying technique to measure PST and passive IR and ER at 90° of abduction to represent ROM. Their results showed a significant correlation between PST and loss of IR in patients with impingement syndrome. A more pronounced loss of total rotation ROM was noted in patients with non-dominant shoulder impingement. Of interest from this study's results is the implication that non-athletic shoulder patient populations possess similar clinical findings related to PST and pathology that overhead athletes do. This is an important area of future study.

Myers et al.[127] demonstrated good reliability using the side-lying method described by Tyler[110] and found that it was capable of identifying PST in baseball players diagnosed with pathologic internal impingement. While the side-lying assessment described by Tyler et al. [110] provides a reliable, valid means to assess posterior shoulder tightness, a common complaint is that the assessment can be difficult to perform. Specifically, it is difficult to stabilize the scapula in patients who are large in stature or by testers who are small in stature or have small hands. Additionally, it is critical to maintain the torso perpendicular to the treatment table during the side-lying method. Often, patients have difficulty relaxing the periscapular muscles while maintaining this side-lying posture.

Myers[127] hypothesized that a modified supine assessment that included the benefits of scapular positioning and stabilization described by Tyler[111] and addressed the criticisms associated with the assessments described by Warner[171] and Pappas[98] might provide an alternative to the side-lying method for assessment of PST. Intra-session, inter-session and inter-rater reliability were calculated for both side-lying and supine methods and the results indicated that both test positions produced good intra-session reliability (ICC of 0.83 and 0.91 respectively). Inter-session and inter-rater reliability values produced different findings, with the supine method generating good inter-session (ICC = 0.75) and inter-rater reliability (ICC = 0.94) values while the side-lying method produced an ICC of 0.42 for inter-session and ICC = 0.69 for inter-rater testing. Myers and his colleagues[127] concluded from these results that the supine assessment technique was better when measures were to be taken over a number of sessions or when multiple testers are used. (Table 2.4)

Table 2.4 - Posterior Capsule Tightness - Reliability and Precision

	Intra-Session		Inter-Session		Inter-Rater	
Assessment	ICC	SEM	ICC	SEM	ICC	SEM
Side lying	0.83	0.9cm	0.42	1.7cm	0.69	1.4cm
Supine	0.91	1.1º	0.75	1.8º	0.94	1.8º

*ICC=Intraclass Correlation Coefficient / SEM = Standard Error of Measurement

*From Myers JB, Oyama S, Wassinger CA, Ricci RD, Abt JP, Conley KM, Lephart SM: Reliability, precision, accuracy and validity of posterior shoulder tightness assessment in overhead athletes, *Am J Sports Med* 35:11, 2007.

In this same study, Myers[127] attempted to establish construct validity for the supine method of assessing PST. They compared the two methods (supine and side lying) and found that both baseball and tennis players exhibited significant internal rotation deficits and posterior shoulder tightness using the supine method. This was not the case with the side lying position. Overall, these authors felt that both side lying and supine assessment positions produced low clinician error and good precision, but the supine method was found to be more reliable when used between sessions and between testers.

Borstad et al.[126] conducted a study in 2007 that compared three methods commonly used to measure posterior shoulder flexibility. They felt that if posterior capsule stretching was being promoted as a treatment technique, a reliable assessment method should be established to allow for appropriate outcome measurement. The three assessment methods compared were IR in supine, supine HAd and side lying HAd. Intra-rater reliability and the smallest real difference necessary to detect meaningful clinical changes were calculated for each technique over an 8-12 week period.

This was the first study that examined reliability or responsiveness of subjects over a specific treatment interval. Fifty-nine construction workers involved in overhead work were divided into an impingement group and an asymptomatic group. Three different flexibility measurements were taken on each subject by the same therapist. These measurements were taken at baseline and again at 8 to12 weeks. No intervention was administered in this time period. IR and supine HAd was measured with a goniometer, while side lying adduction was measured, according to Tyler et al.,[111] with a carpenter's square.

The results of this study revealed that none of the three measurement techniques were highly reliable or had the ability to detect small clinical changes when used at least 8 weeks apart by the same rater. Low to moderate intra-rater reliability values were reported for the symptomatic subjects (side-lying HAd ICC = 0.40, supine HAd ICC = 0.79, supine IR ICC = 0.67) and asymptomatic group (side-lying HAd ICC = 0.63, supine HAd ICC = 0.74, supine IR ICC = 0.79). The results indicated that these measurements might not be adequately stable for a single rater to detect within subject treatment effects beyond five days, as has been previously reported.[111]

Lin and Yang[130] conducted a study in 2006 that assessed the intra- and inter-rater reliability of measuring PST using the supine HAd technique described by Tyler et al.[111] In addition, supine IR with the arm abducted to 90º was recorded. Construct validity was assessed by determining the relationship between PST, shoulder ROM, and self-reported measures of functional limitations. Subjects were asked to complete the Self-Reported Flexilevel Scale of Shoulder Function, a measure designed to assess shoulder function and disability.[172] This was an important feature of this study as it highlighted the important relationship between PST and functional limitations in patients. Both intra-rater and inter-rater reliability for the measurement of PST were found to be good yielding ICC values of 0.84 and 0.82 respectively. Construct validity was assessed by studying the relationship between PST, IR and ER-ROM and the functional disability scale.

A significant relationship was discovered between PST and IR-ROM as well as a significant correlation between the HAd results, IR deficits and perceived functional disability. These authors concluded that the HAd test was a reliable method of detecting PST and that a correlation existed between IR and PST.

Laudner et al.[128] reviewed the intra- and inter-rater reliability and concurrent validity of measuring glenohumeral HAd as a means of assessing for PST. To assess glenohumeral HAd, subjects were positioned supine with both shoulders flush against a standard examination table. The tester stood at the head of the examination table toward the head of the subject and positioned the test shoulder and elbow in 90° of both abduction and flexion. The tester stabilized the lateral border of the scapula by providing a posteriorly directed force (i.e. toward the examination table) to limit scapular protraction, rotation, and abduction motions. The tester's opposite hand then held the proximal portion of the subject's forearm, slightly distal to the elbow, and passively moved the humerus into HAd. An inclinometer was used to measure the ROM.

Both intra-rater and inter-rater reliability values were high in this study at ICC=0.93 and ICC=0.91 respectively. Concurrent validity of this method was tested by measuring bilateral HAd and IR and ER-ROM with the shoulder abducted to 90°. Statistically significant differences were found between HAd, IR and total arc of motion when comparing the dominant and the non-dominant arm of the study group. A moderate to good linear relationship between HAd and IR was noted in the dominant shoulder of the baseball pitchers. A similar relationship was also noted in the non-dominant shoulders. Finally, a moderate to good linear relationship was noted between total arc of motion and IR in the dominant shoulders.

Regardless of which posterior soft tissue structures are contracted, the loss of IR motion in conjunction with an overall decrease in total rotation has been suggested to be associated with the development of shoulder injuries in the overhead athlete. Therefore, accurate assessment of posterior shoulder motion is necessary for the recognition of pathologic shoulder characteristics as well as for monitoring treatment effectiveness in addressing this problem. Clinicians may be inclined to simply measure shoulder IR motion as the best indicator of posterior shoulder contracture. However, because of the possible contribution of the posterior shoulder musculature and the role that increased humeral retroversion may have on decreasing IR motion, it may be prudent to include a measurement of HAd-ROM when evaluating the rotational ROM of the overhead athlete's shoulder. Therefore, this study included measures of the subjects' glenohumeral joint IR and ER-ROM as well as HAd-ROM.

2.6 Posterior Shoulder Tightness – Treatment

Earlier sections of this review described the unique pattern of glenohumeral rotation in the overhead athlete. When compared to the non-dominant arm, the total humeral rotation ROM is typically the same; however, the ratio of IR to ER alters in response to the demands of the activity. When the overall rotation arc on the dominant shoulder is diminished, usually from the IR range decreasing without ER increasing, the shoulder complex is believed to be at significant risk of developing an injury. As a result, researchers and clinicians have advocated preventative and rehabilitative stretching and/or mobilization techniques to lengthen the tissue(s) that potentially restrict this motion.[6-8,11,16,17,36,40,41,43,44,91,95,98,152,153,173-180]

Many different methods have been proposed to address IR-ROM deficits and PST including manual stretching and joint mobilization techniques, proprioceptive neuromuscular facilitation (PNF), and static and ballistic stretching. Despite evidence from various sources suggesting a link between decreased IR, PST and shoulder pathology, very few studies have compared the effectiveness of different techniques in managing this clinical finding. Table 2.5 provides a summary of the various stretch techniques described in the following section.

Goldman and Sauers[173] studied the acute effects of PNF stretching of the shoulder rotators and posterior joint mobilizations in 31 professional baseball pitchers and position players. Subjects were randomly assigned to one of the two treatment groups and measurements of glenohumeral IR and PST were obtained pre- and post-intervention. No significant difference was found between the two treatment techniques in producing acute changes in IR-ROM when compared to the control shoulder (7.4° versus <1°). PST, indicated by HAd-ROM, also decreased to a greater extent in the experimental group (2.8 cm versus 1.3 cm).

Sauers[174] in 2007 studied the acute effects of Fauls stretching routine on the mobility of the throwing shoulder of 30 male, asymptomatic collegiate baseball players. The Fauls stretching routine has been widely used since the 1980s to presumably improve the ROM of the throwing shoulder in baseball athletes.[181] It consists of a mixture of gentle rolling and waving motions with static stretches in a prescribed progression to promote muscular relaxation and increased range. Results from this study revealed an overall gain of 11.7° of shoulder rotation on the treated side leading the authors to support their hypothesis that the Fauls passive shoulder stretching routine would be effective in producing acute increases in throwing shoulder IR and ER-ROM and reducing PST.

McClure et al.[43] compared the “cross body stretch” and the “sleeper stretch” in a randomized controlled trial to determine which technique led to the greatest improvement in IR-ROM in individuals with PST. Different from earlier studies that measured the acute effects of stretching, this research observed the effects over a 4-week period of time.

Table 2.5 – Summary of Posterior Shoulder Stretch Techniques

Author	Study Description	Conclusions / Results
CROSS BODY ADDUCTION		
Lorenz (2004)	Descriptive Review	Not recommended as difficult to stabilize scapula
Izumi (2008)	Controlled Laboratory Cadaveric Study	No positive strain on posterior capsule observed (p>0.05)
McClure et al (2007)	Randomized Control Trial Compared effectiveness of cross-body stretch and sleeper stretch	Significant difference between groups in IR at 90˚ post stretch (p<0.05) ↑IR on the intervention shoulder compared to the other shoulder (p<0.05)
SLEEPER STRETCH		
Laudner et al (2008)	Prospective Cohort Effectiveness of sleeper stretch on 33 male baseball players	↑ in posterior shoulder flexibility and IR-ROM on dominant arm (p<0.05) Acute effects measured only; no long-term effects or follow up done
Lorenz (2004)	Clinical Experience	Recommended - maintains stable scapula Can be modified to increase comfort and progressed to increase stretch

McClure et al (2007)	Randomized Control Trial Compared effectiveness of cross-body stretch and sleeper stretch	Non-significant difference between stretch and control groups in IR at 90˚ ($p>0.05$) ↑IR on the intervention shoulder compared to the other shoulder ($p<0.05$)
Izumi et al (2008)	Controlled Laboratory Cadaveric Study	Mean strain on posterior capsule greatest at 30˚and 60˚of elevation and IR ($p<0.05$)
OTHER STRETCHES		
Goldman & Sauers (2004)	Prospective Cohort Compared PNF IR stretch vs. joint mobilizations in 31 baseball pitchers	Both equally effective at increasing IR ROM (7.4° vs. <1°) ($p<0.001$)
Sauers (2007)	Repeated Measures Evaluate acute effects of Fauls modified passive stretching routine on throwing mobility in 30 college baseball players	Gain of 11.7° of total shoulder rotation on treated (dominant) side ($p<0.05$)
Decicco et al (2005)	Prospective Cohort Effectiveness of 6 wk PNF stretch program on 12 overhead athletes	ER-ROM ↑ 13° ($p<0.05$) IR-ROM not measured

The “cross-body stretch” is a commonly used stretch where the shoulder is elevated to approximately 90° of flexion and pulled across the body into HAd with the opposite arm.[182] It is similar to another stretch called the “towel stretch” which is performed by adducting, extending and internally rotating the glenohumeral joint to place the affected arm behind the individual’s back. A towel, held overhead by the opposite hand, is then used to pull up the affected arm into more ROM.[182]

Both the "towel stretch" and the "cross-body stretch" have been criticized for not selectively stretching the posterior capsule as neither technique stabilizes the scapula. As a result, the force of the stretch is placed on the scapulothoracic tissues and those tissues crossing the glenohumeral joint. The "sleeper stretch"[6,14,71,180] that McClure compared to the "cross-body stretch" in this study is believed to address this by placing the patient in side lying to stabilize the scapula. The humerus is then flexed forward at a right angle to the trunk and internally rotated as much as possible, placing stress through the posteroinferior capsule. (Figures 2.3 and 2.4)

Figure 2.3 - Cross Body Adduction Stretch

Figure 2.4 – Sleeper Stretch

The results of McClure et al.'s study revealed that the cross body stretch produced a significantly greater increase in IR than the control group. The gains in the sleeper stretch group were not significant compared to the control group. The baseline IR measurements for both groups demonstrated a significant increase in IR on the side that the stretch was performed. McClure concluded that both stretches resulted in an increase of IR at 90°, but the cross-body stretch appeared to be more effective as it showed a significant increase when compared to the control group.

Average self-reported compliance for the cross-body stretch was 89% compared to the sleeper stretch at 81%. Three subjects in the sleeper stretch group complained of pain compared to one subject in the cross-body stretch group. Four subjects in the sleeper stretch group reported increasing an exercise workout during the study period compared to only one in the cross-body group. The authors acknowledge the possibility that the subjects in the sleeper stretch group performed the stretch less intensely and for less time because of pain or the inconvenient position. Other limitations of this study were not including a measure of HAd for PST, as well as measurements being taken on separate days, which may have affected the precision of measurement.

The sleeper stretch was also reviewed in a recent study by Laudner et al[175] who looked at the effectiveness of the sleeper stretch in increasing shoulder IR in overhead and non-overhead athletes. A group of thirty-three NCAA Division I male baseball players were assessed for IR-, ER-ROM and PST after performing the sleeper stretch (three sets with a 30 second hold). The overhead athlete group had a statistically significant improvement in posterior shoulder flexibility and IR of the dominant arm. This study only looked at the acute effects of performing the sleeper stretch; no long-term effects or follow up of the treatment were established.

Decicco et al.[176] examined the effects of a six-week proprioceptive neuromuscular facilitation stretching regime on shoulder ROM in overhand athletes and found that it increased the ER-ROM by approximately 13° in this study population. They did not measure the change in IR, but the amount of increase in ER was similar to reports made later by McLure.[43] Of interest, both Decicco et al.'s and McClure et al.'s studies that measured the effects of stretching after six and four weeks respectively, reported greater changes in rotation ROM than the studies that looked at the immediate, acute response to stretching on the shoulder. This would suggest that long-term stretching programs are capable of even greater increases in ROM than those observed immediately post stretching.

In 2007, Lintner and his research group[44] evaluated the IR deficits in 85 male professional baseball pitchers and measured the impact of an IR stretching program on that deficit. They divided their cohort into two groups: pitchers with three or more years in a stretch program and pitchers with less than three years in a stretch program. The stretch program was done daily and consisted of passive stretching of IR in the 90° abducted position and the cross-body posterior capsular stretch performed with the scapula stabilized.

They found that there was a significant difference between the average IR and total ROM for the dominant arm of pitchers in the two groups of athletes. Those in group one, with three or more years of stretching, had considerably higher ranges of IR and total rotation ROM. No significant differences were found between the two groups' ER measurements. These authors demonstrated an interesting phenomenon with their results. They found that in athletes who had been participating for more than three years in a regular regime of IR stretching had a greater total arc of rotation motion in their throwing arm that was almost entirely attributable to increased ER of the dominant arm without the compensatory loss of IR. The authors suggested that these findings demonstrate that loss of IR is not mandatory when gaining ER and that the loss of IR, when it occurs, is primarily due to soft tissue contracture.

Another study that made reference to posterior shoulder stretching was Lorenz [179] in 2004. In this work, Lorenz discussed the importance of treating the posterior capsule in the overhead athlete and described three stretches for the posterior shoulder: prone IR with assistance[183], HAd of the humerus in standing, and the sleeper stretch. He stated that the sleeper stretch was the most effective for treating a number of shoulder pathologies as it targeted the posterior capsule specifically and progressions could be easily implemented. He described progressions for this stretch by placing a towel under the humerus to increase HAd as well as rolling the patient towards a more prone position. Decreasing the amount of shoulder flexion to 45° was also suggested as a method of decreasing the symptoms of impingement.

Izumi et al.[178] simulated eight posterior capsule stretching positions using cadaveric shoulders in an effort to measure the amount of strain/stretch that is being imposed on the posterior capsule. The shoulders were disarticulated from the thorax and fixed to the scapula by a wooden column to simulate scapular resting position. The strain on the posterior capsule was measured with a displacement sensor placed within the posterior capsule, which was partitioned into the upper posterior capsule (area corresponding to 10-11 o'clock), middle posterior capsule (area corresponding to 9 o'clock) and lower posterior capsule (area corresponding to 7 - 8 o'clock).

Eight stretching positions were used that simulated the common stretch positions in vivo described by previous researchers.[110,111,183-185] These included IR of the humerus at 0°, 30°, 60° and 90° of elevation in the scapular plane, IR with 60° of flexion, IR with 60° of abduction and IR with 30° of abduction. To stretch the tissue, a force was applied for 10 to 12 seconds after the passive motion had reached end-range and until no increase or decrease in strain values were observed.

The researchers found a positive strain for the upper capsule with the simulated arm positions of the shoulder at 0° elevation and internally rotated, as well as with the shoulder in 30° extension and the shoulder maximally internally rotated. For the middle aspect of the posterior capsule, the largest strain came with the simulated arm position in 30° of elevation and internally rotated, as well as a small amount of strain in 0° of elevation and the arm internally rotated. The lower posterior capsule was strained at 30° and 60° of elevation in the scapular plane, as well as 30° extension with the arm internally rotated. It should also be noted that the strains on the posterior capsule ranged from 2.23% to 5.65%, which present little risk of injury to the capsule.[13]

They concluded from these results that current posterior stretching programs for the shoulder might not be sufficient to stretch the posterior capsule. The largest strain on the posterior capsule was obtained with the arm in 30° of elevation in the scapular plane with IR, as well as 30° of extension with IR. In considering the common stretches described in the literature (i.e. sleeper stretch, HAd and IR with the arm abducted 90°), there are positive findings within this study's results. Although the study did not specifically simulate the sleeper stretch, the position closest to it of IR at 30° and 60° of elevation produced an increased strain on the posterior capsule.

This study does also note that the HAd stretch described by Tyler, [110] as well as the arm abducted to 90° and internally rotated as described by Johansen[183] both increase the strain on the posterior capsule. A limitation to this study included the age of the cadavers (mean = 82.4 years), which is considerably older than the average age of individuals described as having shoulder problems related to posterior shoulder immobility. The mechanical properties and ROM available in the shoulder of these two populations is expected to be different and may have influenced the results.

2.6.1 Stretching Parameters

Very little information was found regarding the specific parameters of performing a posterior shoulder stretch. Studies often mention using some type of stretch technique, but provide little or no details regarding the dosage, frequency and total treatment time. McClure et al.[43] suggested doing stretches once daily for 5 repetitions, holding each stretch for 30 seconds to the point of mild discomfort. This protocol was prescribed for a total of four weeks. Another source[186] suggested that patients with posterior capsular tightness perform gentle stretches five times per day to the point of feeling a pull, not pain and holding this stretch for one minute. These authors suggested that in most cases, obvious improvements in internal rotation ROM were noted within the first month, but three months may be required to completely eliminate the problem.

One possible explanation for the vague reporting of parameters for posterior shoulder stretching might be the controversy regarding what tissue is being targeted with the stretch: the posterior capsule, posterior muscles and tendons or both. Research has taught clinicians that these two types of soft tissue respond differently when stretched and therefore require special consideration of the type of stretch, length of hold, and degree of stretch necessary.[187,188]

When soft tissue is stretched, elastic, viscoelastic or plastic changes occur. Both muscle and tendon (contractile) tissue and capsular (inert) tissue have elastic and plastic qualities; however, only the capsular (inert) tissue, has viscoelastic properties. This is an important distinction to recognize as the primary method believed to affect the viscoelastic properties of tissue such as joint capsule, is to remodel its basic architecture through low-force, long duration stretching.[187,188] Although there is no clear agreement upon how long the duration of this low-force stretch should be, most would agree that it should be greater than the stretch duration used for muscle and tendon tissue.

In a recent systematic review of the literature on hamstring stretching[189], a 30-second manual or self-stretching procedure performed for one or more repetitions was the most frequently used duration per repetition of stretch in static stretching programs.

In the final study of this overall project, subjects participated in a posterior shoulder stretching program (i.e. sleeper stretch). The sleeper stretch was chosen for this study as it is commonly prescribed and provides stabilization of the scapula. Because it was believed that this stretch impacted both the contractile and non-contractile tissue of the shoulder, the duration of stretch chosen addressed both of these tissues.

2.7 Conclusion

It is very clear that the inherent anatomical and biomechanical challenges placed upon the overhead athlete's shoulder contribute significantly to the development of injuries in this specific population. It is also clear that there are particular adaptations that occur as a result of repetitive, overhead rotation at the glenohumeral joint; namely an increase in ER and a decrease in IR. This observation has led to considerable research on why this alteration takes place, what tissues are most affected, the consequences associated with this change and the best method of detecting and treating it.

The presented study aimed to contribute to the understanding of the athlete's shoulder by determining the reliability of the key measures used to represent the rotational changes present in this population: IR, ER and HAd. Reliability was reported through the SEM; a value that provides the magnitude of error associated with the measure and the MDC which determines whether a statistically significant difference is in excess of measurement error and therefore clinically meaningful. It is believed that these two measures provide clinicians with meaningful information about the range of expected values when measuring overhead shoulder rotation and HAd.

The large majority of research on the overhead athlete reports on male, professional baseball players with a much smaller proportion related to sports such as volleyball, tennis and swimming. Study's II and III of the present project recruited male and female participants involved in a variety of overhead sports and compared their shoulder motions to controls not involved in competitive overhead activities. Very few studies have compared athlete groups to one another and even fewer have looked at gender differences amongst the different sports.

The third study investigated the effectiveness of a commonly prescribed posterior shoulder stretch, known as the “sleeper stretch” on a group of athletes identified as having an IR-ROM deficit. Only one randomized controlled trial was found that compared the effectiveness of two stretch techniques in a group of asymptomatic subjects[43]. The subjects in this study were male and female college age students and the proportion of overall subjects who were involved in overhead sports was 11/83. The study presented also used the sleeper stretch as its intervention; however, the study groups consisted of all overhead athletes, randomized into stretching and no-stretching groups. The parameters of the exercise differed from McClure et al.’s study, by increasing the stretch duration from 30 seconds to two minutes to target both contractile and inert tissue and the overall stretch program continued for eight weeks in this study, which is longer than earlier reported at four weeks[43].

Thus, this study hoped to add to the current body of evidence by providing meaningful information regarding the reliability and range of expected values when measuring overhead shoulder rotation and HAd; two measures commonly used to identify and monitor PST in the overhead athlete population. These measurement techniques were used to determine if alterations in overhead rotation and HAd-ROM existed in male and female varsity level athletes involved in a variety of overhead sports. The majority of research related to this topic has been conducted on male, professional level baseball players.

Studies related to the treatment of the overhead athlete, identified as having a tight posterior shoulder, are sparse.[43] This study investigated the effectiveness of performing a common stretch technique used to increase the posterior shoulder's flexibility, on a group of overhead athletes. The stretching parameters chosen for use in this study were different than previously reported[43] and are believed to represent a more typical time frame of stretch duration and frequency.

Chapter 3 METHODS AND PROCEDURES

3.1 Study I

3.1.1 Objectives

Despite goniometry being the most commonly used method for measuring joint range of motion (ROM), relatively few studies have been undertaken to determine the reliability of this measure. Previous studies were also not specific to the test positions used in this study.

This study was also interested in the standard error of measurement (SEM) and minimal detectable change (MDC) associated with the previously noted shoulder ranges of motion. These parameters are relevant to both clinicians and researchers as they allow reliable quantification of rotational movement of the shoulder and "true" change in the movement. SEM indicates whether a real change in status has occurred in patients in excess of what one might expect as a result of measurement error. It provides a measure of the magnitude of the error associated with the measurement. The MDC provides information about whether a difference between two motions is in excess of the measurement error and therefore a clinically meaningful change.

The objective of study I was to determine the SEM and MDC associated with measuring internal rotation (IR), external rotation (ER) and horizontal adduction (HAd) at the glenohumeral joint both within and between 2 evaluators.

3.1.2 Research Hypotheses

The following hypotheses were proposed for Study I:

1. The ROM measurements of IR, ER and HAd being investigated will be found to demonstrate good inter-rater reliability. (ICC values ≥ 0.70)[193]
2. The ROM measurements of IR, ER and HAd being investigated will be found to demonstrate good intra-rater reliability. (ICC values ≥ 0.70) [193]
3. The ROM measurements of IR, ER and HAd being investigated will be found to demonstrate a SEM of equal or less than 10° for all three measurements in all test situations.

3.1.3 Study Design

A cross-sectional study design was used for Study I.

3.1.4 Study Participants

Participants consisted of 30 men and women between the ages of 22 and 51 years who underwent an examination of their shoulder(s). The examination included standard goniometric measurements of shoulder IR, ER and HAd. Because the objective of this study was to determine the SEM associated with obtaining these ranges of motion (ROMs) as well as the MDC, participants consisted of subjects under the age of 55 years old, with and without shoulder pathology.

The technique involved in measuring shoulder ROM is well established and used in a wide variety of clinical situations and patient populations. Thus, it was appropriate that the sample of subjects used in this first study reflect subject diversity and variation. In addition, Studies II and III of this project utilized the SEM and MDC generated from this phase of the study. As subjects participating in Studies II and III were expected to present with a wide range of shoulder movement, it was important that Study I subjects be similarly representative of these study populations. If both shoulders of the potential subject met the inclusion criteria, then both were assessed and represented two units of analyses as a unit of analysis for this study was defined as one shoulder. Sensitivity analyses were done to test the independence of the shoulders examined.

Inclusion Criteria:

- Men and women between the ages of 16 and 55 years
- Able to abduct arm to test position of 90°

Exclusion criteria:

- Unable to abduct arm to test position of 90˚
- Individuals with *significant* pain and/or dysfunction at the time of testing. The presence of severe pain, weakness, fatigue and/or apprehension can contribute to extremely large variations in ROM measurements and therefore individuals with symptoms to this extent were excluded to

control for the possible influence that these factors may have had on the repetitive nature of this study's measurements.

- Individuals with post–operative restrictions and/or pre-existing conditions that did not allow shoulder IR-and ER-ROM
- Individuals over 55 years of age as this group has a high incidence of significant, concurrent rotator cuff pathology[42,109].

3.1.5 Power

Sample size calculations for this study were based on an alpha value of 0.05, a beta of 0.20 (80% power) and a minimum ICC value in a one-sided 95% confidence interval of 0.70. Using these parameters and defining the unit of analyses as one shoulder, the estimated sample size required that 19 shoulders be assessed. In order to account for attrition and to support the possibility of pathological shoulders increasing the variability of the results, this study aimed to assess at least 40 shoulders; increasing the power of this study close to 100%.

3.1.6 Subject Recruitment and Data Collection

The following section describes the process of subject recruitment and data collection used for Study I. (Table 3.1) Subjects were recruited from the general student population at the University of Alberta as well as the patient population at the Glen Sather Sports Medicine Clinic (GSSMC). Information posters, email and direct communication with the staff at the GSSMC were used to recruit subjects. A brief description of the testing procedures was provided as well as the investigator's contact information (see Appendix D).

Table 3.1 – Study I Subject Recruitment and Data Collection Process

Subject Recruitment
Potential Subject Contacted Investigator **(appointment time set up)**
Appointment: Inclusion/Exclusion Criteria Reviewed Explanation of Study / Consent Form Signed Demographic Information / Shoulder Health Form Completed Pre-Test Warm – Up Session Shoulder Range of Motion Measurements recorded (assessor 1)** • Internal rotation (2 times) • External rotation (2 times) • Horizontal Adduction (2 times) Shoulder Range of Motion Measurements taken (assessor 2)** • Internal rotation (2 times) • External rotation (2 times) • Horizontal Adduction (2 times)

***Order of testing was randomized*

Potential subjects were scheduled for one appointment session of approximately 60 minutes duration. This session consisted of a review of the inclusion and exclusion criteria, a description of the study and testing procedures including an explanation of any possible risks associated with the testing procedures. These risks were identified as muscle and shoulder joint soreness; however, the risk of sustaining this type of reaction was considered very low as the movements being measured were normal shoulder ranges of motion and all participants underwent a warm-up period prior to being measured. Subjects were advised to contact the principal investigator if they had any questions or concerns regarding their shoulder following testing. A consent form (see Appendix C) was signed if the subject agreed to participate.

Data collection included demographic information, a brief Shoulder Health History Questionnaire (SHHQ) and the shoulder ROM measurements for IR, ER and HAd (See Appendices E - G). The SHHQ was included to try to determine the role shoulder pathology played on this study's results. Questions related to current and past history of shoulder injuries or problems were asked as well as information related to pain and functional ability at rest and during activity. In order to reduce the risk of a mobilization effect occurring as a result of repeated movements in testing, all participants performed a standardized set of ROM warm-up exercises before measurements were taken. These exercises were performed in supine lying and included gentle, active ROM exercises in flexion and abduction as well as internal and external rotation. Ten repetitions of each movement were completed as a warm-up. In addition, subjects returned to sitting (from supine-lying) between each successive ROM measurement taken.

Two examiners and one research assistant were used in this study to determine the SEM and MDC for inter-rater shoulder ROM assessment. Both examiners were physical therapists with 15 and 22 years experience assessing and treating orthopedic patients. The research assistant was a graduate student with three years experience assisting with orthopedic research projects. The physical therapists were responsible for subject positioning, goniometric landmark placement, stabilization and end feel determination while the research assistant was responsible for aligning, reading and recording all goniometric measurements for all test sessions. The physical therapists and the research assistant participated in two pre-testing training sessions to establish the assessment positions, goniometric landmark placement and to run through a complete measurement procedure. To prevent assessor bias, the goniometer dial was covered with white paper as described by Riddle et al[155], before the test session. This ensured that the assessor was blind to the measurement values during the test session, but allowed the research assistant to view the reverse side of the goniometer and read the values on the dial.[155] The recorded values of the rotation measures were not made available to the assessor and feedback was not provided by the assistant during the testing sessions.

3.1.7 Equipment

There was very little equipment required to carry out the three phases of this study. All testing sessions took place at either the Department of Physical Therapy in Corbett Hall or at the Glen Sather Sports Medicine Clinic. A standard examination table was used as well as towels and pillows. A standard, double-armed goniometer of 360°, constructed of clear plastic (JAMAR Technologies, PA, USA) was to measure the rotation ranges of motion.

3.1.8 Testing Procedures

For testing, the subject lay supine with the shoulder positioned at 90° of abduction. This is the standard method of measuring IR and ER in shoulder abduction, previously described by Norkin and White[190] and represents the most commonly used technique for measuring rotation in the overhead athlete. (Figure 3.1) HAd-ROM was also measured with the subject in a supine position. (Figure 3.2)

External Rotation: Subjects lay supine on a standard treatment table with their shoulder and elbow in 90° of abduction and flexion, respectively, and the humerus supported by a towel to ensure neutral horizontal positioning (i.e. humerus level with acromion process). The starting position consisted of placing the forearm perpendicular to the floor so the hand was directed upward towards the ceiling. In this position (0° of rotation), the examiner passively externally rotated the shoulder while stabilizing the scapula. End range of ER was defined as a stoppage of rotation or when scapular movement was noted. The goniometer was centered at the olecranon with the arms aligned along the shaft of the ulna and the vertical axis of the movement. A level was attached to the vertical axis arm of the goniometer to ensure that this position was maintained. At the end range of ER, the noted measure was recorded.

Internal Rotation: Subjects were supine as described above for measuring ER. The starting position consisted of placing the forearm perpendicular to the floor so the hand was directed upward towards the ceiling. The goniometer was centered at the olecranon with the arms aligned along the shaft of the ulna and the vertical axis of the movement. A level was attached to the vertical axis arm of the goniometer to ensure that this position was maintained. End range of IR was defined as a stoppage of rotation or when scapular movement was noted. At the end range of IR, the measure was recorded by the research assistant according to the same procedures outlined earlier for ER.

Figure 3.1 – Test Position for External and Internal Rotation ROM

Horizontal Adduction: Subjects were lying supine on a standard treatment table with the examiner positioned beside the treatment table of the shoulder being tested. Subjects were asked to fully retract their scapula while the examiner placed her hand under the scapula, pressing her thenar eminence against the lateral border of the scapula, stabilizing the scapula in the maximally retracted position. Using the other hand, the examiner passively moved the subject’s arm into HAd while maintaining neutral humeral rotation. End range of HAd was defined as a stoppage in joint motion or when the scapula was felt to move. At the end range of HAd, the noted measure was recorded by the research assistant following the same procedures as outlined for IR and ER.

Figure 3.2 – Test Position for Horizontal Adduction ROM

Each subject was assessed successively by two examiners in separate, enclosed examination rooms. The examiners independently measured one or both shoulders of each subject twice during the test session, providing a total of four measures for each shoulder's IR-ROM, 4 measures for each shoulder's ER-ROM and four measures for each shoulder's HAd-ROM. Intra-rater values were calculated from the two ROM measurements taken by each examiner and inter-rater values were calculated by comparing the ROM measurements taken from Examiner 1 and Examiner 2. Random assignment of the order of examiner, the order of motion assessed and the order of which shoulder to assess first was done at the start of the test session by the research assistant. Subjects were repositioned in sitting after each range of motion measure was taken.

3.1.9 Statistical Analysis

Descriptive statistics and frequency analyses were performed on all of the subject demographic information collected in this study, to reveal any significant differences that could confound the results. These variables were age, sex, weight, height, sport and hand dominance. In addition, subjects were asked to complete a short questionnaire (see Appendix F) regarding their shoulder's health history. Information from these questions was analyzed to determine the role shoulder pathology played on the results.

ICC values were used to quantify the reliability of measuring IR, ER and HAd in this study. It has been recommended that ICC values be greater than or equal to 0.70 in order to be considered acceptable as a clinically meaningful measurement tool[191-193]; therefore this value represented the lower limit of the 95% one-sided confidence interval for this study. Intra- and inter-rater ICC values were calculated by performing a 2-way analysis of variance (ANOVA) for each movement using the random effects statistical methodology described by Eliasziw et al[162] in 1994. Secondary, exploratory analyses were performed on the healthy and symptomatic shoulder groups separately and comparisons made between these analyses on which movements achieved the criterion level of reliability.

Because ICC values do not provide quantification of the magnitude of error, the SEM was also calculated. Intra- and inter-rater SEM was calculated using the square root of the mean sum of squares of the two-way ANOVA error term. Associated with SEM is the MDC. The MDC for a single assessor was calculated from the intra-rater SEM $[(1.96)\sqrt{2}(\text{SEMintra})]$ and for two assessors, the MDC was calculated using the inter-rater SEM $[(1.96)\sqrt{2}(\text{SEMinter})]$.[162]

3.2 Study II

3.2.1 Objective

The objective of Study II was to investigate whether or not differences in shoulder rotational ROM, specifically IR, ER and HAd existed between two groups of individuals: (1) Varsity athletes involved in overhead sports and (2) University students not involved in competitive sports. This study aimed to establish discriminant validity by measuring IR-ROM and PST in two groups of subjects where a difference was expected.

3.2.2 Research Hypothesis

It was hypothesized that subjects who used their arm in overhead, repetitive motions would demonstrate adaptive changes resulting in decreased dominant arm IR- and HAd-ROM and increased ER-ROM relative to their non-dominant arm and University students who were not involved in overhead sports.

Specifically the hypotheses for Study II were:

1. Subjects in the overhead athlete group will exhibit a greater glenohumeral internal rotation deficit (GIRD) when compared to subjects in the non-competitive student group.

2. Subjects in the overhead athlete group will exhibit a greater glenohumeral external rotation gain (GERG) when compared to subjects in the non-competitive student group.
3. Subjects in the overhead athlete group will exhibit greater posterior shoulder tightness (PST) when compared to subjects in the non-competitive student group.

3.2.3 Study Design

Study II used a cross-sectional study design.

3.2.4 Study Participants

Participants in Study II consisted of 66 male and female varsity-level athletes and 30 age matched University students not involved in competitive sports. Ages ranged from 18 to 25 years; the typical age range of the majority of University students. Some research suggests that individuals over the age of 30 may begin to show signs of bony and soft tissue degenerative changes, particularly if there has been a history of overuse or injury to the shoulder region.[1,3-6,9,10,104,134] In order to minimize the potential effects of these anatomical changes, subjects over the age of 25 were excluded from participation in this phase of study.

Each participant was classified as either an overhead athlete or not. Sports considered as “overhead” were volleyball, swimming, and tennis.

The inclusion and exclusion criteria for the *overhead varsity athlete* group was as follows:

Inclusion Criteria:

- Men and women between the ages of 18 and 25
- Able to abduct arm to at least 90°
- University of Alberta varsity level athlete involved in a sport that is considered overhead
    - Volleyball
    - Swimming
    - Tennis

Exclusion Criteria:

- Surgical procedure or previous fracture of either shoulder and/or shoulder girdle
- Presently receiving treatment (i.e. physical therapy, injections, medication) for a shoulder condition/complaint in either shoulder

It was believed that a proportion of subjects who fell into the overhead athlete group would possess signs and/or symptoms related to ongoing, chronic shoulder complaints. These athletes were not excluded from participation; however sub-group analysis was performed to determine if athletes with chronic shoulder pain and/or dysfunction exhibited different characteristics than those with asymptomatic shoulders. In order to classify athletes into asymptomatic and symptomatic groups for the study, all subjects filled out a questionnaire on their shoulder health history. (See Appendix F)

The inclusion and exclusion criteria for the *non-competitive student* group was as follows:

Inclusion Criteria:

- University student (men and women) between the ages of 18 and 25
- Able to abduct arm to at least 90°
- Not involved in competitive overhead sports

Exclusion Criteria:

- Surgical procedure or previous fracture of either shoulder and/or shoulder girdle
- Presently receiving treatment (physical therapy, injections, medication) for a shoulder condition/complaint on either shoulder

3.2.5 Power

The determination of sample size for Study II warranted several considerations. One of the key objectives of this 3-study project was to determine if differences in shoulder rotation and posterior shoulder flexibility existed between two groups of individuals; those involved in overhead sports and those who did not. This question was addressed specifically within Study II.

Previous studies[7,8,11,12,18-21,25-28,36,37,113-122] have reported deficits in IR that range from 10° to 40° in overhead athletes. The majority of these results have come from studies on baseball pitchers with far fewer results from research on tennis players, swimmers and volleyball players. No study to date has looked specifically at comparing these values in a variety of overhead, varsity level male and female athletes and matched non-competitive University students. Therefore, based on an alpha level of 0.05 and 80% power, sample size calculations suggested a minimum of 20 subjects per study group (i.e. overhead varsity athlete and non-competitive student groups). Study II aimed to recruit greater than 20 subjects in the varsity athlete group so that exploratory sub-group analysis could be done between the varsity athlete groups. If a larger sample size was achieved and was coupled with a moderate to large effect size, the power of this study would be close to 100%.

Different from Study I, this study defined one subject as equal to one unit of measurement. This was because glenohumeral internal rotation deficit (GIRD), glenohumeral external rotation gain (GERG) and posterior shoulder tightness (PST), the values compared in this study, were calculated from the differences between the involved (dominant) and uninvolved (or non-dominant) shoulders of each subject.

3.2.6 Subject Recruitment and Data Collection

The following section describes the process of subject recruitment and data collection used for Study II (Table 3.2).

Table 3.2: Study II Subject Recruitment and Data Collection Process

Subject Recruitment
Potential Subject Contacts Investigator **(Appointment time set up)**
Test Session: Inclusion/Exclusion Criteria Reviewed Explanation of Study / Consent Form Signed Demographic Information and Shoulder Health Questions Collected Pre-test Warm-up Session Shoulder Range of Motion Measurements recorded* • Internal Rotation (2 times) • External Rotation (2 times) • Horizontal Adduction (2 times)

**order of testing was randomized*

Subjects in the overhead athlete group were recruited through the University of Alberta's head athletic therapist and information was provided to the coaches of these teams, informing them of the purpose and intent of this study. Subjects for the non-competitive student group were recruited from the general student population at the University of Alberta. Potential subjects were reviewed for inclusion and exclusion criteria, and received a description of the study and testing procedures including an explanation of any possible risks associated with the testing procedures. A consent form was signed if the subject was willing to participate. (Appendix C) If subjects from Study I of this project successfully met the inclusion criteria of Study II, they were considered suitable for participation and their data was carried through to the second study. Eleven of the 30 subjects enrolled in Study I met the inclusion criteria for Study II and were included in the non-competitive student group.

Demographic information was collected on all subjects who met the inclusion and exclusion criteria. These measures were age, sex, weight, height, sport and hand dominance. In addition, subjects were asked to fill out the questionnaire on their shoulder health history, previously described in Study I (Appendix F). This information was analyzed to determine if there were any characteristic patterns or significant differences amongst and between the study groups.

Study II required one test session of approximately 30 minutes for each subject. The purpose of this session was to determine if there were significant differences in IR, ER and HAd-ROM between the two study groups. Similar to Study I, assessor bias was addressed by covering the goniometer dial with white paper as described by Riddle et al[155], before the test session. This action ensured that the assessor was blind to the measurement values during the test session, but allowed a research assistant to view the reverse side of the goniometer and read the values on the dial. The recorded values of the rotation measures were not made available to the assessor and the assistant did not provide feedback during the testing sessions.

3.2.7 Testing Procedures

The testing procedures used for Study II were the same as those described earlier in section 3.1.8 and involved measuring glenohumeral joint IR, ER and HAd-ROM.

Measurements were taken on both of the subjects' shoulders in this study as the calculations for GIRD, GERG and PST were calculated from the differences between the involved (dominant) and uninvolved (or non-dominant) shoulders. In all cases, two measures were taken and an average calculated for each measure. Previous studies[110,111,120] have adopted this method.

3.2.8 Statistical Analysis

Descriptive statistics and frequency analyses via independent measures t-tests were performed on the demographic information and shoulder health questions collected in this study, to reveal any systematic differences between study groups. These variables were age, sex, weight, height, sport and hand dominance.

Independent t-tests were used to determine whether the mean differences observed among the two separate sample groups (i.e. overhead athletes and non-competitive students) provided enough evidence to conclude that there were mean differences between the 2 populations. Three separate analyses were performed; one for the IR deficit (GIRD), one for ER gain (GERG) and one for reduced HAd (PST). Results obtained from Study I were used to determine if the differences observed between these ranges of motion fell outside of the SEM and MDC. A secondary exploratory analysis of the varsity athlete group was conducted through an analysis of variance, to determine if there were significant differences between the various sports.

The values of GIRD, GERG and PST were obtained by calculating the difference between each subject's dominant and non-dominant ROM. The advantage of using values such as these is that they take into consideration an individual's "normal" amount of ROM by comparing both sides. As is the case with most joints in the body, there is a normal variation in how much movement is normally available at the glenohumeral joint; therefore reporting ROM of one shoulder does not provide a true indication of altered motion. Appendix G includes a table that illustrates the measures that were taken for each study participant.

3.3 Study III

3.3.1 Objectives

The primary objective of Study III was to determine if an 8-week posterior shoulder stretching program increased IR-ROM and posterior shoulder flexibility of the shoulder in individuals identified as having reduced IR-ROM and tightness of their posterior shoulder structures. The secondary objective was to investigate the pattern of change in IR and HAd-ROM over time; measured at four and eight weeks.

3.3.2 Research Hypotheses

It was expected that subjects in the experimental group (stretching group) would demonstrate a greater increase in dominant arm IR-ROM and posterior shoulder flexibility (HAd-ROM) over the 8-week time period, when compared to the control group (no stretching) and that this increase would be greatest between the 4- and 8-week testing periods.

Thus the following hypotheses were set for Study III:

1. An 8-week posterior shoulder stretching program will result in an increase in the experimental groups' dominant arm glenohumeral IR-ROM and HAd-ROM when compared to subjects in the control group.
2. The change in glenohumeral IR-ROM and HAd-ROM will be greatest at the 8-week testing period.

3.3.3 Study Design

Study III utilized a randomized controlled trial study design.

3.3.4 Study Participants

Subjects in Study III were overhead athletes identified as having a tight posterior shoulder, as indicated by a deficit of IR greater than or equal to 15°. Fifteen degrees was chosen based on previous literature that has determined overhead athletes with IR deficits greater than or equal to 15° are at risk of developing shoulder pathology[6-8,17-19,21,22]. Study I of this overall project found the SEM and MDC associated with measuring IR-ROM was 4˚ and 10˚ respectively. These findings suggest that the criterion level of 15˚ of IR was adequate to detect a true difference rather than one caused by measurement error. HAd-ROM, believed to represent PST, was not used as an inclusion criterion as Study II did not find this value to be a good discriminator between the athletes participating in this study and the non-competitive University students. HAd-ROM measures were however included in Study III's results to determine whether the 8-week stretch program caused a change in this shoulder motion.

As mentioned earlier, IR-ROM is the most common clinical finding used to represent tightness of the posterior shoulder. Subjects included in Study III who demonstrated an IR-ROM deficit of equal to or greater than 15˚ were randomly assigned to one of two study groups: experimental (stretch) group and control (no stretch) group. Subjects blindly selected one of two pieces of paper from a box. A number was written on each piece of paper indicating to the investigator, which study group the subject was assigned to.

Inclusion Criteria:

- Overhead athletes identified as having a GIRD equal to or greater than 15°

Exclusion Criteria:

- Surgical procedure or previous fracture of either shoulder and/or shoulder girdle
- Presently receiving treatment (e.g. physical therapy, injections, medication) for a shoulder condition/complaint of either shoulder

3.3.5 Power

Statistical analysis was used to determine if a significant difference in IR-ROM and HAd-ROM was seen in athletes who participated in an 8-week stretching regime when compared to a control group of athletes who did not. Only one other study was found that measured pre- and post-IR-ROM in subjects who performed the sleeper stretch.[43] This study reported IR-ROM median increases of 12.4° (±10.4°) after four weeks of performing the sleeper stretch[43]. Sample size calculations for Study III were therefore calculated on an estimated average increase in IR-ROM in the stretching group of 20°. An alpha level of 0.05 and a beta of 0.20 (power 80%) was used. Based on 80% power and a hypothesized effect size of 0.80, a minimum of 20 subjects was recommended for each study group. Thirty-seven overhead varsity athletes (stretch group=20, control group=17) were recruited for participation in this study.

3.3.6 Subject Recruitment and Data Collection

The following section describes the process of subject recruitment and data collection used for Study III. (Table 3.3) Overhead athletes who successfully met the inclusion and exclusion criteria for Study III were recruited. Subjects underwent a similar first session with the investigator to review their inclusion and exclusion criteria, be informed of the purpose and possible risks associated with participation in this study and if appropriate, signed a consent form. Subjects were then randomized into one of two groups; the experimental group or the control group.

Demographic information, including the shoulder health questionnaire, was analyzed, as it was in Studies I and II to look for any systematic differences both within and between the two study groups. Subjects who participated in this study were required to attend three, 30-minute testing sessions; one at the time of entry into the study, considered baseline, one at four weeks and one at eight weeks.

The primary research question regarding the effectiveness of a stretch technique for the posterior capsule was addressed by comparing the amount of dominant arm IR and HAd-ROM at baseline (0 weeks) and eight weeks in the two study groups. The 4-week measure was added to address a secondary question related to the rate of change. Normal treatment and stretching parameters are extremely variable, ranging between two and 10 weeks and none of these guidelines are specific to stretching the posterior shoulder.

Table 3.3: Study III Subject Recruitment and Data Collection Process

Subject Recruitment
Investigator Contacts Potential Subjects **(appointment time set up)**
Test Session #1 (Baseline): Inclusion/Exclusion Criteria Reviewed Explanation of Study / Consent Form Signed Demographic Information & Shoulder Health Questionnaire Done Randomization to Experimental or Control Group Pre-test Warm-up Session Shoulder Range of Motion Measurements recorded (Baseline)* • Internal Rotation (2 times) • External Rotation (2 times) • Horizontal Adduction (2 times)
Test Session #2 (4 weeks): Shoulder Health Questionnaire Done Pre-test Warm-up Session Shoulder Range of Motion Measurements recorded* • Internal Rotation (2 times) • External Rotation (2 times) • Horizontal Adduction (2 times)
Test Session #3 (8 weeks): Shoulder Health Questionnaire Done Pre-test Warm-up Session Shoulder Range of Motion Measurements recorded* • Internal Rotation (2 times) • External Rotation (2 times) • Horizontal Adduction (2 times)

**Order of testing was randomized*

All three measurement sessions consisted of similar ROM testing outlined in the previous two studies. Following the initial baseline measure, subjects allocated to the experimental group began an 8-week posterior shoulder stretching program, while subjects in the control group continued with their regular exercise and training routines and did not participate in any posterior shoulder stretches.

3.3.7 Testing Procedures

The testing procedures used in this phase of the study involved measuring glenohumeral joint IR and HAd-ROM. The same procedure was followed that was described previously in section 3.1.8.

Only the values of IR-ROM and HAd-ROM were required for analysis in Study III of this project as stretching of the posterior structures of the shoulder is believed to selectively affect these two motions at the shoulder joint, not ER. GIRD and PST were calculated in the same way as the previous study, by taking the difference between each subject’s involved and non-involved IR- and HAd-ROM. Two measurements of IR- and HAd-ROM were recorded and the average used for the calculation of GIRD and PST. Appendix G illustrates the measures that were obtained for each study participant at each of the three testing sessions; 0 weeks, 4 weeks and 8 weeks.

3.3.8 Intervention – Stretching Technique

The stretch technique that was used in this phase of study is referred to as the “sleeper stretch”, proposed by several authors as an effective method of stretching the posterior structures of the shoulder.[6,11,14,71] The stretch is performed with the individual lying on his/her affected side with the shoulder flexed to 90° and the elbow also flexed to 90°. The shoulder is passively internally rotated by pushing the forearm toward the table around a fixed elbow that acts as a pivot point. (See Figure 2.3)

Athletes in the experimental group of this study were taught how to do the sleeper stretch by a single investigator and were provided with an instruction sheet describing and illustrating the proper technique and parameters to follow while performing the stretch. Also included in the instruction sheet was information on how to warm-up their shoulder prior to stretching. Subjects were instructed to perform the stretch once daily for five repetitions, holding each stretch for two minutes to a point of mild discomfort, but not pain. Rest time between repetitions was 1 - 2 minutes or as long as was necessary to allow any discomfort from the stretch to subside. Athletes allocated to the control group of this study did not engage in any additional exercises other than what they do normally within the context of practices and play.

All athletes in the stretching group were given a daily log (see Appendix H) and were encouraged to fill it out as accurately as possible. All varsity level athletes worked closely with a team trainer and this person provided an important link for the author. Trainers were present at all practice and game sessions and were able to remind their athletes to adhere to their stretching regime. The author followed-up weekly with the athletes to provide encouragement and monitor progress.

3.3.9 Statistical Analysis

Descriptive statistics and frequency analyses via independent t-tests were performed on all of the subject demographic information and shoulder health questionnaires collected in this study, to reveal any systematic differences that may have been present and confounded the results. These variables were age, sex, weight, height, sport and hand dominance.

Independent t-tests were used to address the primary research question of this phase of the study: to determine if there was a significant difference between the 2 study groups' dominant arm IR- and HAd-ROM values at the completion of the 8-week treatment period. Specifically, the question to be answered was whether subjects who performed the 8 week stretching program (experimental group) demonstrated a significant change (increase) in their IR and HAd-ROM, indicating improvement in the flexibility of the posterior shoulder structures when compared to subjects in the control group who did not stretch.

A secondary analysis using 2-way, repeated measures ANOVA was conducted to investigate the change in IR and HAd-ROM over time. Comparisons were made between the 2 study groups at baseline (0 weeks), 4 weeks and 8 weeks. Post-hoc contrasts were performed to determine the rate and trajectory of change between groups over the 8 weeks.

Chapter 4 RESULTS

4.1 Study I

The objective of this phase of the study was to determine the standard error of measurement (SEM) and minimal detectable change (MDC) associated with measuring internal rotation (IR), external rotation (ER) and horizontal adduction (HAd) at the glenohumeral joint both within and between 2 evaluators.

4.1.1 Study Participants

Thirty men and women with 47 assessed shoulders participated in this study. Subjects' age ranged from 22 – 51 years old and the sample consisted of eight males and 22 females. Twenty of the 47 shoulders tested were categorized as being "symptomatic". Subjects were classified as "symptomatic" if they were currently receiving treatment for a shoulder injury/condition or if they complained of shoulder pain and/or dysfunction that interfered with their ability to perform daily life or recreational activities. Sensitivity analyses to determine the independence of shoulders revealed no difference between using one shoulder as the unit of analysis (n=47) and one subject as the unit of analysis (n=30). Thus, both shoulders were analyzed in those subjects who had two shoulders that met the inclusion criteria. Frequency analyses and descriptive statistics for subjects who participated in Study I are presented in Tables 4.1 to 4.2. Separate descriptive analyses were performed according to subject's designation as a "healthy" or "symptomatic" shoulder and this information is provided in Table 4.3.

Independent t-tests were computed to determine if any significant differences existed between the two groups relative to these variables (Table 4.3). As can be seen in Table 4.3, differences were noted between the average age, as well as the average weight and height of the healthy and symptomatic shoulder groups. These findings were expected and although statistically significant, were not felt to have any influence on this study’s findings related to reliability. Subjects with shoulder conditions/complaints were intentionally included in this study to determine whether differences normally seen between individuals with and without shoulder symptoms have any effect on the ability to measure ROM reliably. Subsequent reliability test results would suggest that they did not.

Table 4.1: Study I Frequency Distribution -
Sex, Activity Level, Occupation and Hand Dominance (N=30)

Sex:	
▪ Male	8
▪ Female	22
Activity Level:	
▪ Competitive	9
▪ Recreational • volleyball (6), swimming (7), tennis (2), hockey (3), slo-pitch (4), other (18)	19
▪ None	2
Occupation:	
▪ Student	27
▪ Homemaker	1
▪ Pharmaceutical representative	1
▪ Police officer	1
Hand Dominance:	
▪ Right	29
▪ Left	1

Table 4.2: Study I Descriptive Statistics - Age, Weight and Height (N=30)

Age (yrs):	
▪ Mean	26.3
▪ Standard Deviation	6.4
▪ Range	22-51
Weight (lbs):	
▪ Mean	146.9
▪ Standard Deviation	22.2
▪ Range	100-185
Height (cm):	
▪ Mean	170.5
▪ Standard Deviation	9.978
▪ Range	150-193

Table 4.3: Study I Descriptive Statistics - Age, Weight & Height

(Healthy & Symptomatic Shoulders*)

	Healthy Shoulders (n=27)	*Symptomatic Shoulders (n=20)*	*P-value*
Age (yrs):			
▪ Mean	23.9	27.5	
▪ Standard Deviation	1.5	7.5	**0.020**
▪ Range	22-28	23-51	
Weight (lbs):			
▪ Mean	138.8	152.4	
▪ Standard Deviation	22.6	20.0	**0.039**
▪ Range	100-172	118-185	
Height (cm):			
▪ Mean	166.7	172.9	
▪ Standard Deviation	9.2	9.5	**0.030**
▪ Range	150-178	157-193	

*some subjects included twice as 1 unit of analysis = 1shoulder

4.1.2 Shoulder Health History Questionnaire (SHHQ)

All subjects in this study completed a short questionnaire regarding their shoulder's health history (See Appendix F) in order to determine the role that shoulder pathology played on the results. Questions related to current and past history of shoulder injuries or problems were asked as well as information related to pain and functional ability at rest and during activity. Table 4.4 presents the results from this questionnaire. Interestingly, only 6 of the 30 subjects reported they were currently receiving treatment for a shoulder injury; however 20 subjects complained of pain and/or dysfunction severe enough that it was affecting their activities of daily life (ADL) and/or sport participation. A related finding was that greater than half (17) of the 30 subjects participating in Study I reported having had a previous injury or problem with their shoulder; a fairly high proportion considering the average age of this group was 26 years old. Not surprisingly, the most common types of injuries reported by subjects in this study were rotator cuff and instability syndromes; conditions often associated with a younger population.

Table 4.4: Study I Shoulder Health History Questionnaire Results

Question	Subject Response N = 30
1 – Current treatment	Yes - 6 No - 24
2 –Shoulder Injury Type	Instability - 3 Rotator Cuff Pathology - 2 Frozen Shoulder - 1
3 – Length of injury	13 to 26 weeks - 1 > 26 weeks - 5
4 – Shoulder pain (rest)	Mean = 2.3/100 SD = 4.8
5 – Shoulder pain (activity)	Mean = 15.6/100 SD = 16.0
6 – Shoulder Function	Mean = 10.1/100 SD = 12.5
7 – Past shoulder injury	Yes - 17 No -13
8 – Past shoulder injury type	Instability - 6 Rotator Cuff Pathology - 7 Muscle Strain - 1 Acromioclavicular Joint Trauma - 2 Shoulder Pain - 1

4.1.3 Reliability Test Results – Intra-class Correlation Coefficients (ICCs)

Reliability within examiners (intra-rater) and between two examiners (inter-rater) was computed and is presented in Tables 4.5 and 4.6. Separate exploratory analyses were conducted on the symptomatic (n=20) and healthy shoulders (n=27) to determine if goniometric measurement was affected by the presence of pathology. This analysis is presented in Tables 4.7 to 4.10 below.

4.1.3a Intra- and Inter-Rater Reliability: Healthy & Symptomatic Shoulders Combined

All ICC_{intra} values were found to be above 0.70: the criterion level of reliability set for this study. All but one ICC_{intra} value (rater 2 – HAd) were above 0.80 with measurements of IR and ER yielding ICC_{intra} values above 0.90. Measures of HAd-ROM produced the lowest ICC_{intra} values of 0.80 and 0.761 for rater 1 and rater 2 respectively. (Table 4.5) Both IR and ER ICC_{intra} values had lower limit 95% CIs that were above 0.800 while HAd's lower limit CI values were 0.668 and 0.761 for rater 1 and 2 respectively.

The reliability between 2 raters measuring shoulder ROM on the same subject (inter-rater) was also found to be good to excellent in this study. ICC_{inter} values ranged from 0.806 (HAd measure 1) to 0.966 (IR measure 2). All lower limit 95% CIs were above 0.70 except HAd (measure 1), which was 0.676. (Table 4.6) Similar to the intra-rater reliability findings, IR-ROM yielded the highest ICC_{inter} point estimates and lower limit CI values.

Table 4.5: Intra-Rater Reliability of 2 Raters - Healthy & Symptomatic Shoulders Combined

Internal Rotation Range of Motion

	Measurement1: Mean±SD	Measurement2: Mean±SD	ICC (95% CI)
Rater 1	50.7° ± 15.7°	52.6° ± 15.6°	0.932 (0.882,0.962)
Rater 2	52.5° ± 15.9°	53.6° ± 16.1°	0.949 (0.911,0.972)

External Rotation Range of Motion

	Measurement1: Mean ± SD	Measurement2: Mean±SD	ICC (95% CI)
Rater 1	101.7 °± 14.2°	101.2 °± 13.8°	0.915 (0.852,0.952)
Rater 2	102.1° ± 14.2°	104.0° ± 14.1°	0.935 (0.887,0.963)

Horizontal Adduction Range of Motion

	Measurement1: Mean±SD	Measurement2: Mean±SD	ICC (95% CI)
Rater 1	14.9 °± 5.0 °	15.4 °± 5.4°	0.800 (0.668,0.884)
Rater 2	16.1 °± 5.1 °	15.6 °± 5.0°	0.761 (0.609,0.860)

* ICC=Intra-class correlation coefficient / CI=Confidence Interval

Table 4.6: Inter-Rater Reliability of 2 Raters – Healthy & Symptomatic Shoulders Combined

Internal Rotation Range of Motion			
	Rater 1: Mean ± SD	Rater 2: Mean ± SD	ICC (95% CI)
Measure1	50.7° ± 15.7 °	52.5° ± 15.9°	0.947 (0.906,0.970)
Measure2	52.6 °± 15.6°	53.6° ± 16.1°	0.966 (0.939,0.981)

External Rotation Range of Motion			
	Rater 1: Mean ± SD	Rater 2: Mean ± SD	ICC (95% CI)
Measure1	101.7 °± 14.2°	102.1° ± 14.2°	0.953 (0.917,0.973)
Measure2	101.2° ± 13.8 °	104.0 °± 14.1°	0.930 (0.878, 0.960)

	Horizontal Adduction Range of Motion		
	Rater1: Mean ± SD	Rater 2: Mean ± SD	ICC (95% CI)
Measure1	14.9° ± 5.0 °	16.1 °± 5.1°	0.806 (0.676,0.887)
Measure2	15.4 °± 5.4°	15.6 °± 5.0°	0.834 (0.720,0.904)

* ICC=Intra-class correlation coefficient / CI=Confidence Interval

4.1.3b Intra-Rater Reliability: Healthy & Symptomatic Shoulders Divided

Separate exploratory analyses were performed on subjects according to whether or not they had a shoulder injury or complaints severe enough to affect daily life and recreational activities. The number of shoulders deemed "symptomatic" was 20 out of a total of 47 shoulders tested. As seen in Tables 4.7

and 4.8 below, ICC_{intra} values achieved good to excellent levels for both the healthy and symptomatic shoulder groups. The movement that produced the highest level of reliability within raters was IR-ROM. ICC_{intra} values for the healthy group (0.890 and 0.924) were comparable to ICC_{intra} values calculated when all shoulders were combined as a group (0.932 and 0.949). (Table 4.7)

Table 4.7: Intra-Rater Reliability of 2 Raters - Healthy Shoulders

Internal Rotation Range of Motion

	Measurement1: Mean±SD	Measurement2: Mean±SD	ICC (95% CI)
Rater 1	58.9±11.6	59.2±13.3	0.890(0.774,0.948)
Rater 2	59.9±12.6	61.0±13.4	0.924(0.841,0.965)

External Rotation Range of Motion

	Measurement1: Mean ± SD	Measurement2: Mean±SD	ICC (95% CI)
Rater 1	103.7±9.8	103.9±8.7	0.766(0.550,0.886)
Rater 2	103.6±8.5	106.2±8.3	0.782(0.577,0.894)

Horizontal Adduction Range of Motion

	Measurement1: Mean±SD	Measurement2: Mean±SD	ICC (95% CI)
Rater 1	16.3±4.8	16.8±5.1	0.702(0.445,0.852)
Rater 2	17.4±5.2	16.8±5.3	0.750(0.523,0.878)

* ICC=Intra-class correlation coefficient / CI=Confidence Interval

Table 4.8: Intra-Rater Reliability of 2 Raters - Symptomatic Shoulders

Internal Rotation Range of Motion

	Measurement1: Mean±SD	Measurement2: Mean±SD	ICC (95% CI)
Rater 1	40.2±14.3	43.0±13.4	0.916(0.801,0.966)
Rater 2	42.7±14.6	43.9±13.7	0.930(0.831,0.971)

External Rotation Range of Motion

	Measurement1: Mean ± SD	Measurement2: Mean±SD	ICC (95% CI)
Rater 1	99.1±18.5	97.8±18.4	0.960(0.902,0.984)
Rater 2	100.3±19.7	101.4±19.4	0.977(0.942,0.991)

Horizontal Adduction Range of Motion

	Measurement1: Mean±SD	Measurement2: Mean±SD	ICC (95% CI)
Rater 1	13.2±4.8	13.8±5.0	0.872(0.706,0.947)
Rater 2	14.3±4.6	14.0±4.2	0.714(0.407,0.876)

* ICC=Intra-class correlation coefficient / CI=Confidence Interval

4.1.3c Inter-Rater Reliability: Symptomatic Shoulders

Tables 4.9 and 4.10 present the ICC_{inter} values calculated when shoulders were divided according to healthy and symptomatic. Good to excellent between rater reliability was achieved yielding ICC_{inter} values ranging from 0.735 (HAd-ROM, measure 1, healthy shoulder group) (Table 4.9) to 0.980 (ER-ROM, measure 1, symptomatic shoulder group) (Table 4.10). Lower limit 95% CI values reached the 0.70 level for IR and all but 1 measure of ER (measure 2, healthy shoulder group = 0.601) but did not for any of the 4 HAd-ROM measures (0.498 - 0.656).

Table 4.9: Inter-Rater Reliability of 2 Raters - Healthy Shoulders

Internal Rotation Range of Motion

	Rater1:Mean±SD	Rater2:Mean±SD	ICC (95% CI)
Measure1	58.9±11.6	59.9±12.6	0.915(0.823,0.960)
Measure2	59.2±13.3	61.0±13.4	0.957(0.908,0.980)

External Rotation Range of Motion

	Rater1:Mean ± SD	Rater2:Mean±SD	ICC (95% CI)
Measure1	103.7±9.8	103.6±8.5	0.866(0.727,0.937)
Measure2	103.9±8.7	106.2±8.3	0.796(0.601,0.902)

Horizontal Adduction Range of Motion

	Rater1:Mean± SD	Rater2:Mean±SD	ICC (95% CI)
Measure1	16.3±4.8	17.4±5.2	0.735(0.498,0.870)
Measure2	16.8±5.1	16.8±5.3	0.806(0.619,0.907)

* ICC=Intra-class correlation coefficient / CI=Confidence Interval

Table 4.10: Inter-Rater Reliability of 2 Raters - Symptomatic Shoulders

Internal Rotation Range of Motion			
	Rater1:Mean±SD	Rater2:Mean±SD	ICC (95% CI)
Measure1	40.2±14.3	42.7±14.6	0.932(0.836,0.972)
Measure2	43.0±13.4	43.9±13.7	0.911(0.790,0.964)

External Rotation Range of Motion			
	Rater1:Mean ± SD	Rater2:Mean±SD	ICC (95% CI)
Measure1	99.1±18.5	100.3±19.7	0.980(0.950,0.992)
Measure2	97.8±18.4	101.4±19.4	0.959(0.901,0.984)

Horizontal Adduction Range of Motion			
	Rater1:Mean± SD	Rater2:Mean±SD	ICC (95% CI)
Measure1	13.2±4.8	14.3±4.6	0.848(0.656,0.937)
Measure2	13.8±5.0	14.0±4.2	0.798(0.558,0.915)

*IR-ROM=Internal Rotation Range of Motion, ER-ROM=External Rotation Range of Motion, HAd-ROM=Horizontal Adduction Range of Motion, ICC=Intra-class correlation coefficient, CI=Confidence Interval

4.1.4 Standard Error of Measurement (SEM) and Minimal Detectable Change (MDC)

4.1.4a SEM and MDC: Healthy and Symptomatic Shoulders Combined

Results from this phase of the study produced SEM values ranging from 2.1˚ (HAd between rater) to 4.1˚ (IR- and ER-ROM within rater) well below the hypothesized 10˚ SEM (Tables 4.11 and 4.12). Both intra and inter-rater tests produced low SEM values suggesting a similar degree of measurement error accompanied shoulder ROM measured by one examiner repeatedly as well as two examiners separately.

The within rater MDC$_{95}$ for IR-ROM was calculated at 11.3˚ and 10.0˚ for rater 1 and 2 respectively (Table 4.11) and between raters at 10.0˚ and 8.0˚ for measures 1 and 2 respectively (Table 4.12). This means that a difference in IR-ROM of at least these calculated amounts would be necessary to be able to say that a true change had occurred rather than a change due to measurement error. ER-ROM produced similar MDC$_{95}$ values to those of IR-ROM ranging from 8.5˚ to 11.3˚. (Tables 4-11 and 4-12) Finally, HAd-ROM measurements yielded MDC$_{95}$ amounts between 5.8˚ and 6.9˚. (Tables 4.11 and 4.12)

Table 4.11: Standard Error of Measurement (SEM) and Minimal Detectable Change (MDC) - Intra-Rater (Healthy & Symptomatic Shoulders Combined)

Internal Rotation Range of Motion		
	SEM	**MDC$_{95}$**
Rater 1	4.1˚	11.3˚
Rater 2	3.6˚	10.0˚
External Rotation Range of Motion		
	SEM	**MDC$_{95}$**
Rater 1	4.1˚	11.3˚
Rater 2	3.6˚	10.0˚
Horizontal Adduction Range of Motion		
	SEM	**MDC$_{95}$**
Rater 1	2.3˚	6.4˚
Rater 2	2.5˚	6.9˚

*****SEM=Standard Error of Measurement / MDC$_{95}$=Minimal Detectable Change

Table 4.12: Standard Error of Measurement (SEM) and Minimal Detectable Change (MDC) - Inter-Rater (Healthy & Symptomatic Shoulders Combined)

Internal Rotation Range of Motion		
	SEM	**MDC_{95}**
Measure 1	3.6˚	10.0˚
Measure 2	2.9˚	8.0˚
External Rotation Range of Motion		
	SEM	**MDC_{95}**
Measure 1	3.1˚	8.5˚
Measure2	3.7˚	10.2˚
Horizontal Adduction Range of Motion		
	SEM	**MDC_{95}**
Measure 1	2.2˚	6.2˚
Measure2	2.1˚	5.8˚

*****SEM=Standard Error of Measurement / MDC_{95}=Minimal Detectable Change

4.1.4b SEM and MDC: Healthy and Symptomatic Shoulders Divided

Secondary, exploratory analyses of SEM and MDC_{95} were also calculated with subjects divided according to shoulder injury and/or complaint. Results from these analyses are presented in Tables 4.13 and 4.14. Subjects were subdivided to determine whether shoulder pathology or the presence of chronic pain and/or shoulder dysfunction affected the ability to reliably measure shoulder rotation and horizontal adduction ROM. Similar to the results obtained from the ICC calculations, SEM and MDC_{95} values computed from the healthy and symptomatic shoulder groups' measures were comparable to one another as well as to the SEM and MDC$_{95}$ values of the combined shoulder group. All MDC$_{95}$ values were within 2 degrees of each other with most being closer to 1 degree or less.

Table 4.13: Standard Error of Measurement (SEM) and Minimal Detectable Change (MDC) - Intra-Rater (Healthy & Symptomatic Shoulders Divided)

Internal Rotation Range of Motion

	SEM-health	**SEM-sympt**	**MDC$_{95}$-health**	**MDC$_{95}$-sympt**
Rater 1	4.2°	4.0°	11.6°	11.0°
Rater 2	4.0°	3.7°	11.0°	10.2°

External Rotation Range of Motion

	SEM-health	**SEM-sympt**	**MDC$_{95}$-health**	**MDC$_{95}$-sympt**
Rater 1	4.5°	3.7°	12.4°	10.2°
Rater 2	3.9°	3.0°	10.8°	8.2°

Horizontal Adduction Range of Motion

	SEM-health	**SEM-sympt**	**MDC$_{95}$-health**	**MDC$_{95}$-sympt**
Rater 1	2.7°	1.8°	7.5°	5.0°
Rater 2	2.6°	2.4°	7.2°	6.8°

*SEM=Standard Error of Measurement / MDC$_{95}$=Minimal Detectable Change

*SEM-health = Standard Error of Measurement in healthy shoulder group / *SEM-sympt = Standard Error of Measurement in symptomatic shoulder group

*MDC$_{95}$-health=Minimal Detectable Change in healthy group / MDC$_{95}$-sympt=Minimal Detectable Change in symptomatic shoulder group

Table 4.14: Standard Error of Measurement (SEM) and Minimal Detectable Change (MDC) - Inter-Rater (Healthy & Symptomatic Shoulders Divided)

Internal Rotation Range of Motion				
	SEM-health	**SEM-sympt**	**MDC_{95}-health**	**MDC_{95}-sympt**
Measure 1	3.5˚	3.8˚	9.7˚	10.4˚
Measure 2	2.8˚	4.0˚	7.7˚	11.1˚
External Rotation Range of Motion				
	SEM-health	**SEM-sympt**	**MDC_{95}-health**	**MDC_{95}-sympt**
Measure 1	3.4˚	2.7˚	9.3˚	7.5˚
Measure 2	3.8˚	3.8˚	10.6˚	10.6˚
Horizontal Adduction Range of Motion				
	SEM-health	**SEM-sympt**	**MDC_{95}-health**	**MDC_{95}-sympt**
Measure 1	2.6˚	1.8˚	7.1˚	5.0˚
Measure 2	2.3˚	2.1˚	6.3˚	5.6˚

*SEM=Standard Error of Measurement / MDC_{95}=Minimal Detectable Change

*SEM-health = Standard Error of Measurement in healthy shoulder group / *SEM-sympt = Standard Error of Measurement in symptomatic shoulder group

*MDC_{95}-health=Minimal Detectable Change in healthy group / MDC_{95}-sympt=Minimal Detectable Change in symptomatic shoulder group

4.2 Study II

The objective of Study II was to investigate whether or not differences in shoulder rotational ROM, specifically IR, ER and HAd exist between 2 groups of individuals: (1) Varsity athletes involved in overhead sports and (2) University students not involved in competitive sports.

4.2.1 Study Participants

Participants in Study II consisted of male and female varsity-level overhead athletes and 30 University students not involved in overhead, competitive sports. Sports that were considered as “overhead” for this study were volleyball, swimming and tennis. Sixty-six overhead varsity athletes and 30 non-competitive students ranging in age from 18 to 25 years of age participated in this study. Tables 4.15 to 4.18 present the frequency analyses and descriptive statistics of subject demographic information collected in this phase of study.

Differences in age were detected between the varsity athlete and non-competitive student groups. (Tables 4.17 and 4.18) The age range of the varsity athletes extended to the lower limit of 18 years while the student group had its lowest age at 22 years. Average weight and height was also found to be different between the varsity athletes and non-competitive students with swimmers and volleyball players in particular being taller and heavier than tennis players and University students of similar age. Table 4-18 compares the means of the 3 types of athletes tested in this study. Post hoc Tukeys’ tests revealed significant differences ($p<0.05$) between the weight of volleyball and tennis players ($p<0.001$) and swimmers and tennis players ($p=0.042$). Height differences were significantly different between volleyball and tennis players ($p<0.001$) and volleyball players and swimmers ($p<0.001$) but not between swimmers and tennis players ($p=0.423$). Although statistical significance was found between the variables of age, weight and height in this study’s subjects, these differences are not believed to have had any influence on this study’s findings as the primary outcome measure (i.e. shoulder ROM) has not been shown to be affected by factors such as height, weight or younger age.

Table 4.15: Study II Frequency Distribution - Sex, Activity Level, Occupation and Hand Dominance of Varsity Athletes and Non-competitive Students (N=96)

	Combined N=96	*Varsity Athletes N=66*	*Non-comp. Students N=30*
Sex:			
▪ Male	39	33	6
▪ Female	57	33	24
Activity Level:			
▪ Competitive	66	66	0
▪ Recreational	26	0	26
▪ None	4	0	4
Occupation:			
▪ Student	96	66	30
Hand Dominance:			
▪ Right	87	59	28
▪ Left	9	7	2

Table 4.16: Study II Frequency Distribution of Varsity Athlete Group Divided by Sport (N=66)

	Volleyball *N=33*	*Swimming* *N=22*	*Tennis* *N=11*
Sex:			
▪ Male	17	12	4
▪ Female	16	10	7
Activity Level:			
▪ Competitive	33	22	11
▪ Recreational	0	0	0
▪ None	0	0	0
Occupation:			
▪ Student	33	22	11
Hand Dominance:			
▪ Right	30	21	8
▪ Left	3	1	3

4.2.2 Shoulder Health History Questionnaire (SHHQ)

Similar to Study I, subjects in Study II completed a short questionnaire regarding their shoulder's health history in order to determine the role shoulder pathology played on the results. Appendix F and Table 4.19 present the questions and corresponding answers to the questionnaire. It was believed that a proportion of subjects in the overhead athlete group would possess signs and/or symptoms related to ongoing, chronic shoulder complaints. Similar to Study I, the number of subjects reported to be currently receiving shoulder treatment was low (2/96) compared to the degree of shoulder pain and dysfunction recorded on question four to six of the questionnaire. The two subjects receiving treatment were swimmers and their injuries involved the rotator cuff. Shoulder pain experienced at rest (question 4) was predictably low at 3.2/100 (standard deviation, SD=8.8) and 0.9/100 (SD=3.0) for the varsity and student groups respectively. Shoulder pain experienced with activity (question 5) was higher yielding an average value of 19.97 (SD=21.0) for the varsity athletes and 4.8 (SD=10.4) for the non-competitive students. If the responses were broken down by sport, the average means were 21.5/100 for swimmers, 20.4/100 for volleyball players and 13.8/100 for tennis players.

Table 4.17: Study II Descriptive Statistics - Age, Weight and Height
Varsity Athletes and Non-competitive Students (N=96)

	Total (N=96)	*Varsity Athletes (N=66)*	*Non-comp. Students (N=30)*	*P-value (Varsity athlete & Non-comp. students)*
Age (yrs):				
▪ Mean	21.3	20.3	23.3	**<0.001**
▪ Standard Deviation	2.1	1.7	1.0	
▪ Range	18-26	18-26	22-25	
Weight (lbs):				
▪ Mean	157.0	165.4	138.4	**<0.001**
▪ Standard Deviation	28.4	27.6	20.6	
▪ Range	100-250	117-250	100-172	
Height (cm):				
▪ Mean	176.9	180.9	168.1	**<0.001**
▪ Standard Deviation	12.0	11.7	6.9	
▪ Range	150-203	155-203	150-178	

Table 4.18: Study II Descriptive Statistics of Varsity Athlete Group Divided by Sport (N=66)

	Volleyball *N=33*	*Swimming* *N=22*	*Tennis* *N=11*	*P-value*
Age (yrs):				**0.939**
▪ Mean	20.3	20.4	20.2	
▪ Standard Deviation	1.4	1.8	2.5	
▪ Range	18-23	18-25	18-25	
Weight (lbs):				**<0.001**
▪ Mean	176.7	161.5	139.3	
▪ Standard Deviation	27.9	21.6	15.8	
▪ Range	130-250	125-200	117-165	
Height (cm):				**<0.001**
▪ Mean	186.9	176.5	171.8	
▪ Standard Deviation	10.1	9.8	10.4	
▪ Range	165-203	160-191	155-193	

When asked how pain affected their shoulder’s functional ability (question 6), the average score for varsity athletes was 17.7/100 (SD=20.1). Volleyball players rated this highest at 22/100. These findings would suggest that overhead athletes are either not seeking medical care for shoulder injuries/conditions or have simply accepted that this is how their shoulder should normally feel and act given their activity level.

Table 4.19 Study II Shoulder Health History Questionnaire Results

Question	**Varsity Athlete N = 66**	**Non-competitive Student N = 30**
1 – Current treatment	Yes - 2 No - 64	Yes - 0 No – 30
2 – Shoulder Injury Type	RC* Pathology - 2	N/A
3 – Length of injury	7 to 12 weeks - 1 13 to 26 weeks - 1	N/A
4 – Shoulder pain (rest)	Mean = 3.2/100 SD = 8.8	Mean = 0.9/100 SD = 3.0
5 – Shoulder pain (activity)	Mean = 19.7/100 SD = 21.0	Mean = 4.8/100 SD = 10.4
6 – Shoulder Function	Mean = 17.7/100 SD = 20.1	Mean = 5.1/100 SD = 11.0
7 – Past shoulder injury	Yes - 34 No - 32	Yes – 9 No – 21
8 – Past shoulder injury type	Instability - 5 RC* - 24 Biceps Tendonitis - 4 AC* Joint Trauma - 1	Instability - 6 RC* Pathology - 2 AC* Joint Trauma - 1

*RC = Rotator Cuff / AC = Acromioclavicular

Overhead athletes were sub-divided according to their responses on questions 5 and 6 of the questionnaire regarding pain with activity and functional ability. As mentioned above, the athlete group’s mean was 19.97 (SD= 21.7) in response to question 5 and 18.00 (SD=20.1) in response to question 6. If a cut-off point of 1 standard deviation above the mean is used to distinguish those athletes playing with significant pain and dysfunction from those who had no symptoms, 15 of the 66 athletes (23%) in this study fell in to the symptomatic group. If the cut-off point was dropped to 0.5 standard deviations above the mean, the number of athletes considered to be playing with pain and dysfunction increased to 25 out of 66 (38%). These percentages are seemingly high considering only 2 of the 66 overhead athletes who participated in this study were receiving treatment for their shoulder at the time they filled out the questionnaire.

Table 4.20 presents an overview of the characteristics of athletes categorized as having symptomatic shoulders. The proportion of male to female athletes was fairly similar amongst the different sports. Only volleyball had a slightly higher number of female to male players. Mean age was also comparable between athlete groups and to the combined varsity athlete group mean of 20.3 years. Most, but not all, of the athletes classified as symptomatic, at the 0.5 standard deviation level, reported a previous history of shoulder problems (19/25, 76%). When the cut-off point was increased to 1 standard deviation from the mean, 14/15 (93%) of the athletes reported a prior injury. The types of injuries reported were most commonly rotator cuff-related, followed by biceps tendonitis and glenohumeral joint instability syndromes. A variety of specific player positions and swim strokes were represented in the symptomatic athlete group suggesting that shoulder pain and dysfunction can affect all athletes involved in these three sports.

Table 4.20: Study II Characteristics of Varsity Athletes Classified with a Symptomatic Shoulder (0.5 SD and 1.0 SD from the Mean)

	> 0.5 SD from the Mean ***30.80 (Q#5) / 28.03 (Q#6)***	***> 1.0 SD from the Mean*** ***41.69 (Q#5) / 38.06 (Q#6)***
Volleyball	**N** = 13/33 **Sex -** 6 male/7 female **Mean Age -** 20.8 yrs **Position -** outside hitter (4) / middle (3) / left side (2) / right side (1) / power (1) / setter (1) / libero (1) **Previous Shld History**–10/13 rcuff tendonitis (8) / biceps tendonitis(1) / shld pain (1)	**N**=10/33 **Sex -** 4 male/6 female **Mean Age** = 20.6 yrs. **Position -** outside hitter (4) / middle (2) / left side (1) / right side (1) / power (1) / setter (1) **Previous Shld History**–10/10 rcuff tendonitis (8) / biceps tendonitis(1) / shld pain (1)
Swimmers	**N** = 10/22 **Sex** – 5 male/5 female **Mean Age** – 20.4 yrs **Stroke** – freestyle (5) / freestyle/backstroke (1) / breaststroke/backstroke (1) / freestyle/butterfly (2) /butterfly (1) **Previous Shld History**–7/10 Rotator cuff tendonitis (3) / biceps tendonitis(2) / instability (2)	**N** = 4/22 **Sex** – 2 male/2 female **Mean Age** – 21 yrs **Stroke** – freestyle (1) / breaststroke/backstroke (1) / freestyle/butterfly (2) **Previous Shld History**–3/4 Rotator cuff tendonitis (3)
Tennis	**N**= 2/11 **Sex** – 1 male/1 female **Mean Age** – 23 yrs **Position** – n/a **Previous Shld History** – 2/2 Instability (1) / rotator cuff tendonitis (1)	**N** = 1/11 **Sex** – 1 female **Age** – 25 yrs **Position** – n/a **Previous Shld History** – 1/1 Instability (1)

4.2.3 Study Group Comparisons

Tables 4.21 to 4.23 present the average ROM scores for the 2 study groups' dominant and non-dominant arms and the calculated value of the difference between these 2 values (i.e. for GIRD, GERG or PSF). Total dominant and non-dominant shoulder rotation arcs are also presented in Table 4.24. This value represents the amount of full rotation present in the shoulder and is calculated by adding IR and ER together. Tables 4.21B, 4.22B and 4.23B present the t-test values associated with the GIRD, GERG and PST measurements.

4.2.3a Glenohumeral Internal Rotation Deficit (GIRD), Glenohumeral External Rotation Gain (GERG) and Posterior Shoulder Tightness (PST) of Varsity Overhead Athlete & Non-competitive Students

The values presented in the tables below demonstrate a significant difference between the varsity athlete group and the non-competitive student group on all three of the key outcome measures: GIRD, GERG and PST (Tables 4.21B to 4.23B). This difference was greatest between the two groups when GIRD was compared and although still statistically significant, slightly less when comparing the difference between PST.

Table 4.21A: Internal Rotation Range of Motion – Varsity Athlete Group and Non-competitive Student Group

	IRDOM-Var	*IRDOM-St*	*IRNDOM-Var*	*IRNDOM-St*
N	66	30	66	30
Mean	44.82	58.03	59.53	60.37
Std. Deviation	12.116	11.078	10.516	12.268
Range	23˚- 75˚	36˚- 80˚	33˚-81˚	40˚-86˚

*IRDOM - Internal rotation dominant arm / IRNDOM – Internal rotation non-dominant arm

Var – Varsity athlete group / St – Non-competitive student group

Table 4.21B: Glenohumeral Internal Rotation Deficit – Varsity Athlete Group and Non-competitive Student Group

	GIRD-Var	*GIRD-St*	*P-value*
N	66	30	**<0.001***
Mean	**14.76**	**2.67**	
Std. Deviation	8.411	6.321	
Range	1˚-32˚	-14˚- 11˚	

*GIRD – Glenohumeral internal rotation deficit / ***GIRD = IRNDOM – IRDOM*** * mean difference is significant at the 0.05 level

Table 4.22A: External Rotation Range of Motion -
Varsity Athlete Group and Non-competitive Student Group

	ERDOM-Var	***ERDOM-St***	***ERNDOM-Var***	***ERNDOM-St***
N	66	30	66	30
Mean	114.08	109.33	107.27	105.90
Std. Deviation	9.786	10.940	9.59˚3	11.275
Range	91˚-134˚	73˚-127˚	85˚-133˚	72˚-122˚

*ERDOM - External rotation dominant arm / ERNDOM – External rotation non-dominant arm / Var – Varsity athlete group / St – Non-competitive student group

Table 4.22B: Glenohumeral External Rotation Gain – Varsity Athlete Group
and Non-competitive Student Group

	GERG-Var	***GERG-St***	***P-value***
N	66	30	**0.009***
Mean	**6.80**	**3.23**	
Std. Deviation	6.274	5.594	
Range	-8˚-26˚	-10˚-15˚	

GERG – Glenohumeral external rotation gain / ***GERG = ERDOM – ERNDOM***

* mean difference is significant at the 0.05 level

4.23A: Horizontal Adduction Range of Motion – Varsity Athlete Group and Non-competitive Student Group

	HAdDOM-Var	***HAddDOM-St***	***HAdNDOM-Var***	***HAdNDOM-St***
N	66	30	66	30
Mean	16.36	18.27	20.17	20.30
Std. Deviation	4.693	3.279	4.447	3.852
Range	7˚-29˚	9˚-25˚	12˚-34˚	10˚-27˚

*HAdDOM – Horizontal adduction dominant arm / HAdNDOM – Horizontal Adduction non-dominant arm / Var – Varsity athlete group / St – Non-competitive student group

4.23B: Posterior Shoulder Tightness –

Varsity Athlete Group and Non-competitive Student Group

	PST-Var	***PST-St***	***P-value***
N	66	30	**0.014***
Mean	**3.80**	**1.97**	
Std. Deviation	3.604	2.632	
Range	-2˚-11˚	-3˚-7˚	

PST–Posterior shoulder tightness / ***PST=HAdNDOM-HAdDOM*** *mean difference significant at 0.05 level

4.24: Total Rotation Arc (TRA) –

Varsity Athlete Group and Non-competitive Student Group

	TRADOM-Var	***TRADOM-St***	***TRANDOM-Var***	***TRANDOM-St***
N	66	30	66	30
Mean	159.61	167.37	167.18	166.23
Std. Deviation	14.988	14.070	14.165	18.070
Range	116˚-189˚	134˚-191˚	124˚-205˚	122˚-201˚

*TRADOM – Total rotation arc dominant arm / TRANDOM – Total rotation arc non-dominant arm / Var – Varsity athlete group / St – Non-competitive student group

TRADOM = IRDOM + ERDOM / TRANDOM = IRNDOM+ERNDOM

4.2.3b Glenohumeral Internal Rotation Deficit (GIRD), Glenohumeral External Rotation Gain (GERG) and Posterior Shoulder Tightness (PST) of Varsity Overhead Athletes

Additional, secondary exploratory analyses were carried out for the individual sports. Tables 4.25 to 4.28 present the average IR, ER and HAd-ROM values as well as the calculated GIRD, GERG, PST and TRA values for the three sports. Volleyball players were found to have the greatest GIRD values overall followed by tennis players and then the swimmers. (Table 4.25C) All of the athlete groups' average GIRD values were substantially more than the non-competitive student group average. (Table 4.25C) Swimmers had a slightly greater GERG than volleyball players (Table 4.26C) and both volleyball players and swimmers possessed greater ER-ROM gains when compared to tennis players. (Table 4.26C) PST was greatest amongst volleyball players, followed by tennis players and then swimmers. (Table 4.27C) All three of the calculated values (GIRD, GERG and PST) were higher in the individual athlete groups compared to the non-competitive student group. (Tables 4.25C, 4.26C and 4.27C)

Table 4.25A: Internal Rotation Range of Motion (Dominant Arm)

Varsity Athlete Group Divided by Sport vs. Non-competitive Student Group

	IRDOM-Vball	***IRDOM-Swim***	***IRDOM-Tennis***	***IRDOM-St***
N	33	22	11	30
Mean	42.30	46.45	49.09	58.03
Std. Deviation	11.215	13.982	9.710	11.078
Range	23˚- 69˚	24˚- 75˚	39˚-74˚	36˚-80˚

IRDOM - Internal rotation dominant arm/Vball-volleyball/St–Non-competitive student group

Table 4.25B: Internal Rotation Range of Motion (Non-Dominant Arm)

Varsity Athlete Group Divided by Sport vs. Non-competitive Student Group

	IRNDOM-Vball	***IRNDOM-Swim***	***IRNDOM-Tennis***	***IRNDOM-St***
N	33	22	11	30
Mean	59.67	58.14	61.91	60.37
Std. Deviation	10.024	11.997	9.192	12.268
Range	33˚- 74˚	37˚- 79˚	46˚-81˚	40˚-86˚

IRNDOM - Internal rotation non-dominant arm/Vball-volleyball/St–Non-competitive student group

Table 4.25C: Glenohumeral Internal Rotation Deficit

Varsity Athlete Group Divided by Sport vs. Non-competitive Student Group

	GIRD-Vball	***GIRD-Swim***	***GIRD-Tennis***	***GIRD-St***
N	33	22	11	30
Mean	**17.42**	**11.68**	**12.91**	**2.67**
Std. Deviation	8.588	7.214	8.154	6.321
Range	1˚-32˚	1˚-29˚	2˚-23˚	-14˚- 11˚

GIRD – Glenohumeral internal rotation deficit / ***GIRD = IRNDOM – IRDOM***

Table 4.26A: External Rotation Range of Motion (Dominant Arm)

Varsity Athlete Group Divided by Sport vs. Non-competitive Student Group

	ERDOM-Vball	***ERDOM-Swim***	***ERDOM-Tennis***	***ERDOM-St***
N	33	22	11	30
Mean	115.52	113.41	112.45	109.33
Std. Deviation	9.510	8.562	7.660	10.940
Range	96˚- 134˚	91˚- 125˚	101˚-124˚	73˚-127˚

ERDOM - External rotation dominant arm/Vball-volleyball/St – Non-competitive student group

Table 4.26B: External Rotation Range of Motion (Non-Dominant Arm)

Varsity Athlete Group Divided by Sport vs. Non-competitive Student Group

	ERNDOM-Vball	***ERNDOM-Swim***	***ERNDOM-Tennis***	***ERNDOM-St***
N	33	22	11	30
Mean	108.36	105.86	106.82	105.90
Std. Deviation	9.404	7.858	13.303	11.275
Range	90˚- 133˚	87˚- 120˚	85˚-124˚	72˚-122˚

ERNDOM - External rotation non-dominant arm / Vball-volleyball / St – Non-competitive student group

Table 4.26C: Glenohumeral External Rotation Gain

Varsity Athlete Group Divided by Sport vs. Non-competitive Student Group

	GERG-Vball	***GERG-Swim***	***GERG-Tennis***	***GERG-St***
N	33	22	11	30
Mean	**7.15**	**7.55**	**4.27**	**3.23**
Std. Deviation	6.021	6.493	6.528	5.594
Range	-3˚-23˚	-2˚-26˚	-8˚-16˚	-10˚- 15˚

GERG – Glenohumeral external rotation gain / ***GERG = ERNDOM - ERDOM***

Table 4.27A: Horizontal Adduction Range of Motion (Dominant Arm)

Varsity Athlete Group Divided by Sport vs. Non-competitive Student Group

	HAdDOM-Vball	***HAdDOM-Swim***	***HAdDOM-Tennis***	***HAdDOM-St***
N	33	22	11	30
Mean	14.73	17.95	18.09	18.27
Std. Deviation	4.072	3.443	6.891	3.279
Range	7˚- 25˚	10˚- 24˚	7˚-29˚	9˚-25˚

HAdDOM – Horizontal adduction dominant arm / Vball-volleyball / St – Non-competitive student group

Table 4.27B: Horizontal Adduction Range of Motion (Non-Dominant Arm)

Varsity Athlete Group Divided by Sport vs. Non-competitive Student Group

	HAdNDOM-Vball	***HAdNDOM-Swim***	***HAdNDOM-Tennis***	***HAdNDOM-St***
N	33	22	11	30
Mean	19.33	20.55	21.91	20.30
Std. Deviation	4.075	4.044	5.924	3.852
Range	13˚- 28˚	12˚- 29˚	14˚-34˚	10˚-27˚

HAdNDOM – Horizontal adduction non-dominant arm/Vball-volleyball/St – Non-competitive student group

Table 4.27C: Posterior Shoulder Tightness

Varsity Athlete Group Divided by Sport vs. Non-competitive Student Group

	PST-Vball	***PST-Swim***	***PST-Tennis***	***PST-St***
N	33	22	11	30
Mean	**4.61**	**2.59**	**3.82**	**1.97**
Std. Deviation	3.588	3.459	3.573	2.632
Range	-2˚-11˚	-2˚-11˚	-1˚-8˚	-3˚- 7˚

PST – Posterior Shoulder Tightness / ***PST = HAdNDOM – HAdDOM***

Table 4.28A: Total Rotation Arc (Dominant Arm)

Varsity Athlete Group Divided by Sport vs. Non-competitive Student Group

	TRADOM-Vball	***TRADOM-Swim***	***TRADOM-Tennis***	***TRADOM-St***
N	33	22	11	30
Mean	158.76	160.14	161.09	167.37
Std. Deviation	13.428	15.703	18.971	14.070
Range	132˚- 187˚	116˚- 185˚	136˚-189˚	134˚-191˚

TRADOM – Total rotation arc dominant arm / Vball-volleyball / St – Non-competitive student group

Table 4.28B: Total Rotation Arc (Non-Dominant Arm)

Varsity Athlete Group Divided by Sport vs. Non-competitive Student Group

	TRANDOM-Vball	***TRANDOM-Swim***	***TRANDOM-Tennis***	***TRANDOM-St***
N	33	22	11	30
Mean	168.58	164.32	168.73	166.23
Std. Deviation	13.973	14.601	14.304	18.070
Range	128˚- 205˚	124˚- 183˚	152˚-195˚	122˚-201˚

TRANDOM – Total rotation arc non-dominant arm / Vball-volleyball / St – Non-competitive student group

Independent t-tests comparing the mean differences between volleyball players and non-competitive students' shoulder ROM revealed statistically significant differences between all three values; the biggest difference being between the GIRD values (Table 4.29A). Swimmers were significantly different from the student group in their GIRD and GERG values but not in the amount of posterior shoulder tightness they had (Table 4.29B). Finally, tennis players were only significantly different when comparing GIRD to the student group (Table 4.29C). One-way analysis of variance calculations were carried out to determine whether significant differences existed between the three types of athletes included in this study on the same values (i.e. GIRD, GERG and PST). The only value found to be statistically different amongst the athletes was GIRD ($p = 0.032$) and this difference was detected between volleyball players and swimmers. (Table 4.30) No significant differences were detected when the different athlete groups' GERG ($p = 0.338$) and PST ($p = 0.127$) values were compared.

Separate exploratory analyses were also performed to determine if differences existed between athletes based on shoulder symptoms. Using the earlier mentioned classification, those athletes who rated their shoulder pain and dysfunction above 0.5 standard deviation of the mean on the shoulder health history questionnaire were compared to athletes who fell below this level. As can be seen in Table 4.31, there were no significant differences found between the GIRD, GERG and PST means of the two groups. This result was consistent with earlier findings that did not reveal significant differences between athletes with and without shoulder symptoms.

Table 4.29: T-tests Comparing Mean Differences of GIRD, GERG and PST Between Varsity Athlete Groups and Non-competitive Students

A. Volleyball Players & Non-competitive Students

	GIRD	***GERG***	***PST***
Mean Difference	14.758	3.918	2.639
P-value	<0.001*	0.010*	0.002*

B. Swimmers & Non-competitive Student Group

	GIRD	***GERG***	***PST***
Mean Difference	9.015	4.312	0.624
P-value	<0.001*	0.013*	0.463

C. Tennis Players & Non-competitive Student Group

	GIRD	***GERG***	***PST***
Mean Difference	10.242	1.039	1.852
P-value	<0.001*	0.617	0.078

GIRD=Glenohumeral Internal Rotation Deficit / GERG=Glenohumeral External Rotation Gain / PST=Posterior Shoulder Tightness

* mean difference is significant at the 0.05 level

Table 4.30: Analysis of Variance and Post Hoc Tukey's test - **Glenohumeral Internal Rotation Deficit** between Volleyball Players, Swimmers and Tennis Players

		Mean Difference	*Std. Error*	*Sig.*
Volleyball	Swimmers	5.742*	2.225	0.032*
	Tennis	4.515	2.815	0.251
Swimmers	Volleyball	-5.742*	2.225	0.032*
	Tennis	-1.227	2.985	0.911
Tennis	Volleyball	-4.515	2.815	0.251
	Swimmers	1.227	2.985	0.911

* mean difference is significant at the 0.05 level

Table 4.31: T-tests Comparing Mean Differences of Symptomatic (n=25) & Asymptomatic (n=41) Varsity Athletes

	GIRD	***GERG***	***PST***
Mean Difference	2.966	0.158	0.391
Degrees of Freedom	64	64	64
P-value	**0.166**	**0.923**	**0.672**

4.3 Study III

The primary objective of Study III was to determine if an 8-week posterior shoulder stretching program increased IR-ROM and HAd-ROM in the dominant shoulder of individuals identified as having reduced IR-ROM and tightness of their posterior shoulder structures. The secondary objective was to investigate the pattern of change in IR- and HAd-ROM over time; measured at 4 and 8 weeks.

4.3.1 Study Participants

Participants in Study III consisted of 20 male and 17 female varsity-level overhead athletes identified as having a tight posterior shoulder as indicated by a deficit of IR-ROM greater than or equal to 15˚. Sports considered "overhead" for this study were the same as in Study II: volleyball, swimming and tennis. All of the subjects from Study II who met the IR-ROM criterion consented to participation in Study III. Twenty-four of the 33 volleyball players tested in Study II had an IR-ROM deficit equal or greater than 15˚ and were included in Study III. Eight swimmers and five tennis players from Study II also met the 15˚ criterion level and consented to participate in Study III. Tables 4.32 and 4.33 present the frequency analyses and descriptive statistics of subject demographic information collected in this study. Information is presented on the combined subject group (n=37) as well as the two study groups utilized in this study: the experimental (stretch) group and the control (no stretch) group (Table 4.33).

A significant difference was detected between the height of the two study groups (stretch and control) in Study III (Table 4.33). An almost significant difference was found when the two group's weight was compared as well. (Table 4.33) These findings are consistent with the results obtained in Study II and are due to the size difference between the volleyball players and the other two groups of athletes (i.e. swimmers and tennis players) in this study. The proportion of volleyball players allocated to each study group was greater than the other two athlete groups, with 11 out of 20 (55%) volleyball players assigned to the stretch group and 13 out of 17 (76%) volleyball players assigned to the control group. Although this resulted in a statistically significant difference, these findings were not believed to have had any influence on this study's results. No evidence was found that suggests height and/or weight affect the ability to accurately measure shoulder internal rotation and horizontal adduction ROM. The ability to perform a stretch such as the one used in this study (i.e. the sleeper stretch), and in turn benefit from the stretch is not known to be affected by the weight and/or height of the individual performing the stretch.

4.3.2 Shoulder Health History Questionnaire (SHHQ)

Subjects in Study III also completed a short questionnaire regarding their shoulder's health history in order to determine the role shoulder pathology played on this study's results. Subjects filled out the full questionnaire at the baseline (0 week) testing session and then re-answered questions four to six regarding shoulder pain and functional ability, at subsequent testing periods (4 weeks and 8 weeks). Appendix F and Table 4.34 presents the questions and responses to the questionnaire. Questions one to three of the SHHQ were not applicable to Study III as subjects in this study were excluded if they were currently receiving treatment for a shoulder injury. As mentioned previously, subjects were asked to reply to questions four to six at the three testing periods (i.e. 0 weeks, 4 weeks, and 8 weeks). This was done to determine if the subjects' reporting of pain and functional ability changed over the 8-week study period and between the 2 study groups.

Table 4.32: Study III Frequency Distribution of Subjects'
Sex, Activity Level, Occupation and Hand Dominance (N=37)

	Combined N=37	*Stretch Group N=20*	*Control Group N=17*
Sex:			
▪ Male	20	10	10
▪ Female	17	10	7
Activity Level:			
▪ Competitive	37	20	17
▪ Recreational	0	0	0
▪ None	0	0	0
Occupation:			
▪ Student	37	20	17
Hand Dominance:			
▪ Right	35	19	16
▪ Left	2	1	1

Table 4.33: Study III Descriptive Statistics of Subjects'
Age, Weight and Height (N=37)

	Total (N=37)	*Stretch Group (N=20)*	*Control Group (N=17)*	*P-value*
Age (yrs):				**0.350**
▪ Mean	20.3	20.1	20.5	
▪ Standard Deviation	1.4	1.3	1.5	
▪ Range	18-23	18-23	18-23	
Weight (lbs):				**0.051**
▪ Mean	169.1	161.1	178.5	
▪ Standard Deviation	27.2	27.0	25.1	
▪ Range	117-250	117-218	140-250	
Height (cm):				**0.010***
▪ Mean	183.4	180.3	188.4	
▪ Standard Deviation	11.2	12.3	8.8	
▪ Range	157-203	157-203	175-203	

*mean difference is statistically significant at the 0.05 level

As can be seen in Table 4.34, there was a difference found in the reporting of shoulder pain with activity (question 5) as well as functional ability (question 6) over the 8 weeks. This difference was statistically significant for question 6 regarding functional ability at the 4 and 8 week testing period. As expected, the two groups were similar in their rating of pain at rest (question 4). Subjects who were assigned to the stretch group who performed the posterior shoulder stretch for 8 weeks reported an overall decrease in the amount of pain with activity from a mean visual analogue score (VAS) of 18.15/100 (SD=17.4) at 0 weeks to 8.9/100 (SD=16.1) at 8 weeks. In comparison, subjects in the control group, who did not perform the daily stretch exercise increased their average VAS score from 21.71/100 (SD=18.1) at 0 weeks to 25.24/100 (SD=21.3) at 4 weeks and then decreased down slightly to 17.76/100 (SD=22.1) at 8 weeks. A similar pattern was seen with the results of question 6 that asked about functional ability relative to their shoulder. Subjects in the control group only differed slightly from their 0 week (25.12/100, SD=19.4) to 8 week scores (26.59/100, SD=21.4), whereas subjects in the stretch group went from 17.6/100 (SD=20.5) at 0 weeks to 8.05/100 (SD=10.4) at 8 weeks. These findings would suggest that the stretch technique utilized in Study III not only had an effect on shoulder range of motion, but also on the degree of shoulder pain associated with activity and functional ability.

Questions seven and eight of the questionnaire inquired about past history of shoulder problems. Twenty-four of the 37 subjects in Study III reported a prior history of shoulder injury and the most commonly reported type of injury was rotator cuff pathology.

Table 4.34A: Visual Analogue Scores (out of 100)

SHHQ #4 (shoulder pain at rest) - Mean (Standard Deviation) & P-Values

	0 Weeks	**4 Weeks**	**8 Weeks**
Mean (SD)			
- Stretch Group	2.35 (5.7)	2.5 (5.5)	2.35 (4.8)
- Control Group	2.47 (4.2)	5.29 (8.4)	3.35 (5.8)
P-Value:	**0.802**	**0.233**	**0.568**

Table 4.34B: Visual Analogue Scores (out of 100)

SHHQ #5 (shoulder pain with activity) - Mean (Standard Deviation) & P-Values

	0 Weeks	**4 Weeks**	**8 Weeks**
Mean (SD)			
- Stretch Group	18.15 (17.4)	13.85 (14.6)	8.9 (16.1)
- Control Group	21.71 (18.1)	25.24 (21.3)	17.76 (22.1)
P-Value:	**0.547**	**0.063**	**0.142**

Table 4.34C: Visual Analogue Scores (out of 100)

SHHQ #6 (shoulder function) - Mean (Standard Deviation) & P-Values

	0 Weeks	**4 Weeks**	**8 Weeks**
Mean (SD)			
- Stretch Group	17.6 (20.5)	10.95 (9.1)	8.05 (10.4)
- Control Group	25.12 (19.4)	23.71 (17.6)	26.59 (21.4)
P-Value:	**0.262**	**0.008***	**0.002***

*mean difference is significant at the 0.05 level

4.3.3 Study Group Comparisons: Independent T-tests - Internal Rotation Range of Motion

The primary research question of Study III aimed to measure the effectiveness of a stretch technique for the posterior shoulder. The question was addressed by measuring the difference between the stretch and control groups' dominant IR-and HAd-ROM at baseline (0 weeks) and the final (8 weeks) testing periods. As can be seen in Table 4.35, there were statistically significant differences in IR-ROM found between the 2 study groups' dominant arm at the 4 week ($p=<0.001$) and 8 week ($p=<0.001$) testing periods but not at 0 weeks ($p=0.188$). This would suggest that the stretch and control group subjects' IR-ROM measures were similar at baseline prior to the stretch group beginning the intervention. Subjects in the stretch group increased their dominant arm IR-ROM by an average of 19˚ compared to subjects in the control group who increased the same motion by 3˚ over the eight week period. The SEM and MDC value associated with measuring IR-ROM were calculated in Study I to be 4˚ and 10˚ respectively. These findings would suggest that the 19˚ increase in IR-ROM exhibited by subjects who performed the stretch intervention represents a true, clinically meaningful change.

The results from the IR-ROM measurements on the stretch and control groups' non-dominant shoulder revealed no significant difference at 0 weeks and at 4 weeks but a statistically significant difference at 8 weeks. This finding was unexpected as the non-dominant shoulder was not to be stretched in either group. Subjects who were assigned to the stretch group were instructed to perform the sleeper stretch on their affected, dominant shoulder only.

Table 4.35C presents the calculated GIRD values of the 2 study groups at 0, 4 and 8-weeks time. Athletes in both study groups had similar amounts of restriction in their dominant arm IR-ROM at baseline (0 weeks) however by 4 and certainly 8 weeks time, the 2 groups differed significantly in the amount of IR-ROM deficit they had between their 2 shoulders (p=<0.001).

4.3.3a. Study Group Comparisons: Independent T-tests - Horizontal Adduction Range of Motion

HAd-ROM was also measured on subjects participating in Study III as recent research[6-8,13,15,99-102] has suggested that this shoulder measurement may be better than IR-ROM at distinguishing tightness in the posterior capsule from tightness in the posterior musculature.

The results from the HAd-ROM measures taken at the 3 testing periods are presented in Table 4.36. As can be seen in Table 4.36A, a statistically significant difference between the 2 study groups was detected in the dominant arm HAd-ROM measures at the completion of the 8-week intervention. Similar to the findings in Table 4.35B, subjects were also found to differ significantly in their non-dominant HAd-ROM at the final, 8-week testing time although less so than the difference seen in the dominant arm. The difference between HAd-ROM (Dominant Arm) and HAd-ROM (Non-Dominant Arm) was calculated as PST. Relatively small differences were found between subjects’ 0 and 8-week PST measures and although the stretch group appeared to improve their posterior shoulder flexibility more than the control group over the 8-week timeframe, this was not found to be statistically significant.

Table 4.35: Internal Rotation Range of Motion and Glenohumeral Internal Rotation Deficit of Stretch and Control Group - Mean (Standard Deviation) and P-values

A. IR-ROM (Dominant Arm)			
	0 weeks	***4 weeks***	***8 weeks***
Stretch Group	41.90˚ (6.29˚)	54.70˚ (6.9˚)	60.45˚ (5.5˚)
Control Group	38.12˚ (10.6˚)	40.88˚ (8.9˚)	40.71˚ (7.6˚)
P-value	**0.188**	**<0.001***	**<0.001***
B. IR-ROM (Non-Dominant Arm)			
	0 weeks	***4 weeks***	***8 weeks***
Stretch Group	63.85˚ (4.9˚)	61.30˚ (4.8˚)	64.80˚ (5.6˚)
Control Group	58.88˚ (10.6˚)	59.12˚ (8.8˚)	60.24˚ (6.9˚)
P-value	**0.068**	**0.347**	**0.033***
C. GIRD (GIRD = IR-ROM($_{NDOM}$) – IR-ROM($_{DOM}$))			
	GIRD 0 weeks	***GIRD 4 weeks***	***GIRD 8 weeks***
Stretch Group	21.95˚	6.6˚	4.35˚
Control Group	20.76˚	18.24˚	19.53˚
P-value	**0.452**	**<0.001***	**<0.001***

*mean difference is significant at the 0.05 level

Table 4.36: Horizontal Adduction Range of Motion and Posterior Shoulder Tightness of Stretch and Control Group - Mean (Standard Deviation) and P-values

<table>
<tr><th colspan="4">A. HAd-ROM (Dominant Arm)</th></tr>
<tr><td></td><td><i>0 weeks</i></td><td><i>4 weeks</i></td><td><i>8 weeks</i></td></tr>
<tr><td>Stretch Group</td><td>15.90° (4.6°)</td><td>18.70° (4.1°)</td><td>20.35° (3.8°)</td></tr>
<tr><td>Control Group</td><td>15.59° (3.4°)</td><td>17.65° (3.2°)</td><td>16.76° (2.8°)</td></tr>
<tr><td>P-value</td><td>0.819</td><td>0.400</td><td>0.003*</td></tr>
<tr><th colspan="4">B. HAd-ROM (Non-Dominant Arm)</th></tr>
<tr><td></td><td><i>0 weeks</i></td><td><i>4 weeks</i></td><td><i>8 weeks</i></td></tr>
<tr><td>Stretch Group</td><td>18.95° (4.6°)</td><td>21.60° (4.3°)</td><td>21.40° (3.2°)</td></tr>
<tr><td>Control Group</td><td>19.65° (4.5°)</td><td>19.88° (3.7°)</td><td>19.35° (2.9°)</td></tr>
<tr><td>P-value</td><td>0.645</td><td>0.207</td><td>0.050*</td></tr>
<tr><th colspan="4">C. PST (HAd-ROM($_{\text{NDOM}}$) – HAd-ROM($_{\text{DOM}}$))</th></tr>
<tr><td></td><td><i>PST
0 weeks</i></td><td><i>PST
4 weeks</i></td><td><i>PST
8 weeks</i></td></tr>
<tr><td>Stretch Group</td><td>3.05°</td><td>2.9°</td><td>1.05°</td></tr>
<tr><td>Control Group</td><td>4.06°</td><td>2.23°</td><td>2.59°</td></tr>
<tr><td>P-value</td><td>0.348</td><td>0.847</td><td>0.068</td></tr>
</table>

*mean difference is significant at the 0.05 level

4.3.3b Two-way Analysis of Variance - Internal Rotation Range of Motion over Time

As can be seen in Table 4.37 and Figure 4.1, a statistically significant difference was found between the 2 study groups IR-ROM (dominant arm) measures at both time intervals (0 to 4 weeks and 4 to 8 weeks). This finding was consistent with previously reported results that found significant differences between the subjects who stretched their dominant shoulder and those subjects who did not at the completion of the 8-week treatment period (Table 4.35). The interaction between IR-ROM and time suggests that there was a differential effect over time between the 2 study groups. This result however, suggests that the effect from the stretch intervention occurred by 4 weeks time and continued to change/improve towards 8 weeks. Table 4.38 and Figure 4.2 present the results computed on the study group's non-dominant IR-ROM measures. As previously noted, the stretch group demonstrated an unexpected increase in their non-dominant shoulder's IR-ROM at 8 weeks.

Table 4.37: Two-Way Analysis of Variance between Stretch and Control Groups over Time - Internal Rotation Range of Motion (Dominant Arm)

Source of Variance	**df**	**Type III Sum of Squares**	**Mean Square**	**F**	**Sig.**
Between Subjects (group)	2	1196.457	598.229	55.305	<0.001*
Within Subjects (time)	2	2205.863	1102.931	101.964	<0.001*
Error (time)	70	757.182	10.817		

Source	**Time**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Time	0wk vs 4 wk	2226.174	1	2226.174	119.091	<0.001*
	4 wk vs 8 wk	285.455	1	285.455	15.654	<0.001*
Time	0 wk vs 4 wk	925.417	1	925.417	49.506	<0.001*
(Groups)	4 wk vs 8 wk	322.752	1	322.752	17.700	<0.001*
Error(time)	0 wk vs 4 wk	654.259	35	18.693		
	4 wk vs 8 wk	638.221	35	18.235		

*mean difference is significant at the 0.05 level

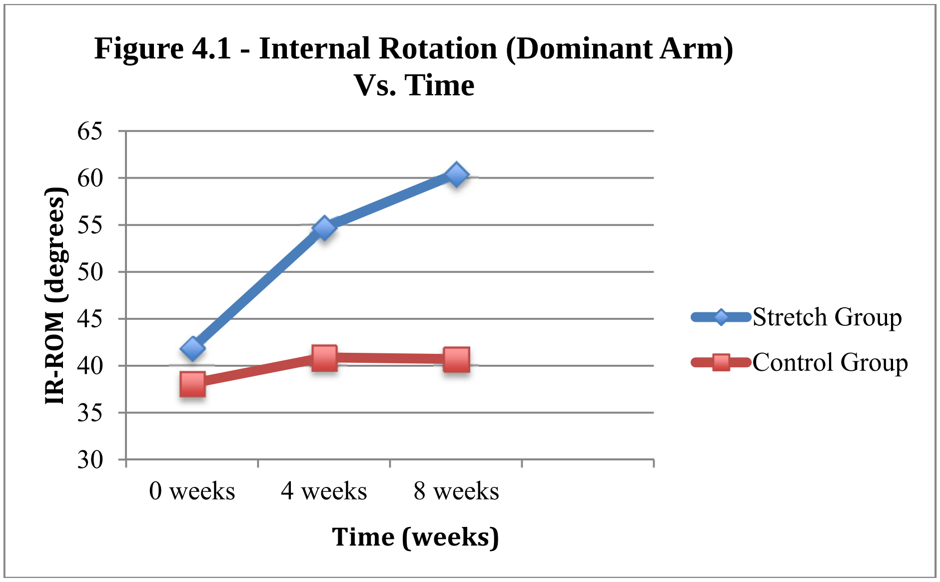


Figure 4.1 - Internal Rotation (Dominant Arm) Vs. Time

Table 4.38: Two-Way Analysis of Variance between Stretch and Control Groups over Time - Internal Rotation Range of Motion (Non-Dominant Arm)

Source of Variance	**df**	**Type III Sum of Squares**	**Mean Square**	**F**	**Sig.**
Between Subjects (group)	2	97.969	48.985	4.618	0.013*
Error (time)	70	742.535	10.608		

Source	**Time**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Time	0wk vs 4 wk	49.234	1	49.234	2.692	0.110
	4 wk vs 8 wk	195.938	1	195.938	11.648	0.002*
Time (Groups)	0 wk vs 4 wk	71.288	1	71.288	3.899	0.056*
	4 wk vs 8 wk	52.154	1	52.154	3.100	0.087
Error (time)	0 wk vs 4 wk	640.009	35	18.286		
	4 wk vs 8 wk	588.765	35	16.822		

*mean difference is significant at the 0.05 level

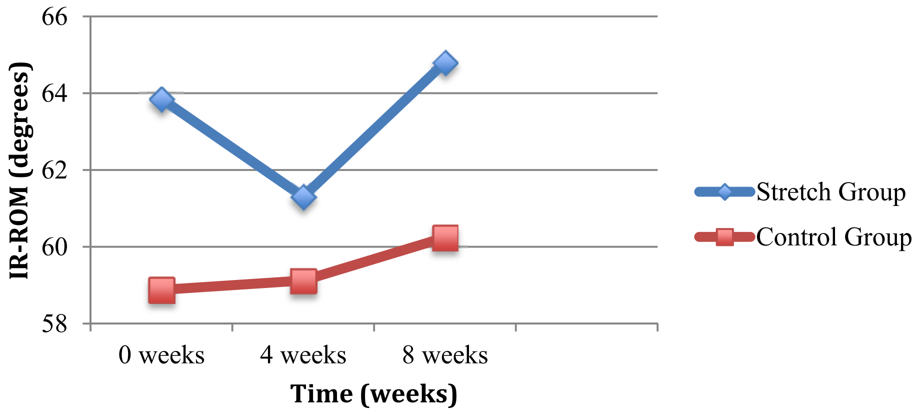


Figure 4.2 -Internal Rotation (Non-Dominant Arm) Vs. Time

4.3.3c Two-way Analysis of Variance - Horizontal Adduction Range of Motion over Time

Similar analyses were performed on the effect of time on subjects' HAd-ROM measures and are presented in Tables 4.39 and 4.40 and Figures 4.3 and 4.4. Statistically significant differences were noted between the 2 groups' dominant arm HAd-ROM measures at the 8-week testing period only (p=0.014). No statistically significant differences were detected between the stretch and control group's non-dominant HAd-ROM measures.

Table 4.39: Two-Way Analysis of Variance between Stretch and Control Groups over Time - Horizontal Adduction Range of Motion (Dominant Arm)

Source of Variance	df	Type III Sum of Squares	Mean Square	F	Sig.
Between Subjects (group)	2	171.086	85.543	12.906	<0.001*
Within Subjects (time)	2	54.149	27.075	4.085	0.021*
Error (time)	70	463.959	6.628		

Source	Time	Type III Sum of Squares	df	Mean Square	F	Sig.
Time	0 wk vs 4 wk	216.940	1	216.940	13.507	0.001*
	4 wk vs 8 wk	5.415	1	5.415	0.611	0.440
Time (Groups)	0 wk vs 4 wk	5.048	1	5.048	0.314	0.579
	4 wk vs 8 wk	58.929	1	58.929	6.646	0.014*
Error (time)	0 wk vs 4 wk	562.141	35	16.061		
	4 wk vs 8 wk	310.315	35	8.866		

*mean difference is significant at the 0.05 level

Figure 4.3 - Horizontal Adduction (Dominant Arm) Vs. Time

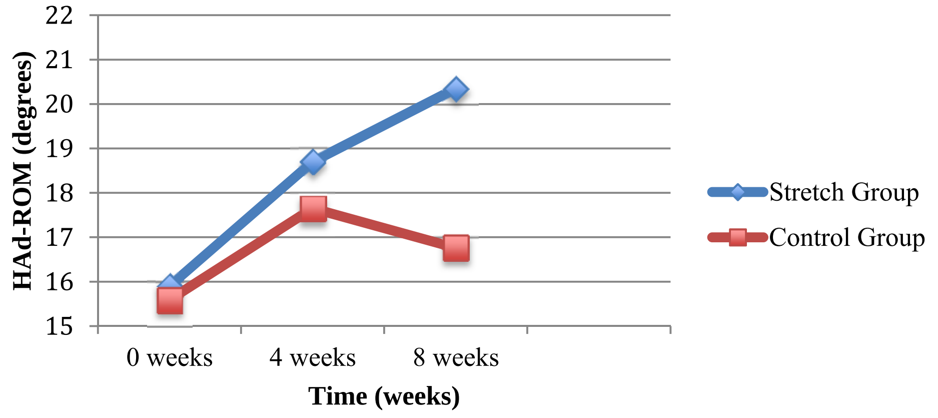
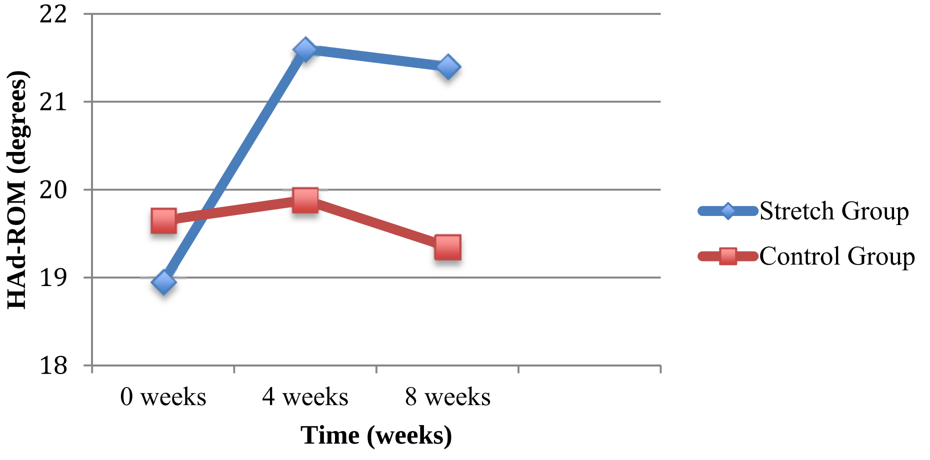


Table 4.40: Two-Way Analysis of Variance between Stretch and Control Groups over Time - Horizontal Adduction Range of Motion (Non-Dominant Arm)

Source of Variance	**df**	**Type III Sum of Squares**	**Mean Square**	**F**	**Sig.**
Between Subjects (group)	2	41.366	20.683	2.699	0.074
Within Subjects (time)	2	41.258	20.629	2.692	0.075
Error (time)	70	536.508	7.664		

Source	**Time**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Time	0wk vs 4 wk	76.499	1	76.499	3.905	0.056*
	4 wk vs 8 wk	4.889	1	4.889	0.340	0.564
Time (Group)	0 wk vs 4 wk	53.580	1	53.580	2.735	0.107
	4 wk vs 8 wk	0.997	1	322.752	0.069	0.794
Error (time)	0 wk vs 4 wk	685.609	35	19.589		
	4 wk vs 8 wk	503.435	35	14.384		

*mean difference is significant at the 0.05 level



Chapter 5 DISCUSSION

The inherent anatomical and biomechanical challenges placed upon the overhead athlete's shoulder contribute significantly to the development of injuries in this specific population. Adaptations that occur as a result of repetitive, overhead rotation at the glenohumeral joint; namely an increase in external rotation (ER) and a decrease in internal rotation (IR) are alleged to be a primary cause of these injuries. This observation has led to considerable research on why this alteration takes place, what tissues are most affected, the consequences associated with this change and the best method of detecting and treating the condition.

The overall goal of this project was to determine whether there were reliable and clinically meaningful differences in glenohumeral joint IR, ER and horizontal adduction (HAd) between 2 distinct populations: varsity level, overhead athletes and University students not involved in overhead competitive sporting activities. If differences were found and could be reliably measured, this study tried to determine if a commonly used posterior shoulder stretch technique was effective in improving these ROM limitations. Three individual, but related research questions were examined to meet this study's objectives. Study I sought to determine the reliability of key measures used to represent the shoulder rotational changes present in this population: IR, ER and HAd. These results were used to discriminate between those with and without altered shoulder movement. Finally, overhead athletes identified as having an IR-ROM deficit of ≥ 15° in

Study II were randomly allocated to either a stretch (experimental) or no stretch (control) group in Study III.

5.1 Study I

5.1.1 Overview of Findings

Overall, the results from Study I regarding the reliability of measuring functional, overhead shoulder rotation and HAd indicate that these three shoulder motions can be consistently measured by the same physical therapist as well as between different, experienced physical therapists. Good to excellent point estimate ICC values, greater than 0.70, a level considered acceptable as a clinically meaningful measurement tool[191-193] were obtained. As well, fair to good lower limit confidence interval values were found with all ROM measures, providing information on the margin of error accompanying each ICC point estimate. The SEM and MDC values of IR, ER and HAd-ROM obtained in this initial study provide clinicians with meaningful values, in degrees, that can be used to determine whether a patient’s shoulder motion has changed as a result of a treatment intervention versus a change that simply represents measurement error. All shoulder ROM measures, in all measurement situations produced SEM values less than or equal to10°.

5.1.2 Intraclass Correlation Coefficients (ICC)

Study I revealed good to excellent reliability of IR-, ER- and HAd-ROM within and between 2 experienced physical therapists. ICC values ranged from 0.70 (HAd-ROM) to 0.98 (ER-ROM) for within-therapist measures and 0.74 (HAd-ROM) to 0.97 (IR-ROM) for between-therapist measures. All ROM measurements examined in Study I met the hypothesized ICC value of ≥ 0.70. Almost all IR- and ER-ROM measures yielded lower limit confidence intervals above 0.70 as well. The reporting of confidence intervals around a measure's ICC value is considered essential as it provides the margin of error that accompanies the ICC point estimate. The point estimates for HAd-ROM were all above 0.70; however lower limit confidence intervals ranged from 0.41 – 0.72 suggesting a greater margin of error with this shoulder ROM measure.

Only 1 other study[169] has reported reliability measures of both IR and ER at 90° of abduction; a position of function in sport, overhead work and several activities in daily life. Comparisons between the current study and Muir et al.'s study could only be made between the ER-ROM results as Muir et al.'s study measured IR-ROM actively, which was different than the passive method used in Study I. The within-therapist reliability of passive ER-ROM reported by Muir et al.[169] was comparable to Study I's results producing ICC values between 0.86 and 0.95. The between-therapist reliability in Study I was higher than those reported by Muir et al. Interestingly, both studies reported that reliability appeared to be slightly better when assessing passive ER-ROM in individuals with symptomatic shoulders. Most individuals with symptomatic shoulders present with pain at the end of ER-ROM, thus it may have been easier for the therapists to identify the end point of passive ER-ROM.

Study I achieved good reliability in measuring supine lying HAd-ROM both within and between-therapists. However the reliability obtained was lower than that measured in IR and ER. Previous research has reported variable reliability of HAd-ROM ranging from ICC=0.80 to 0.95. This heterogeneity might be related to differences in subject positioning (supine vs. sitting vs. standing), the type of range measured (passive vs. active) and whether stabilization was provided during the test, making it difficult to compare amongst studies[98,110,111,127,169,171]. The reliability of measuring HAd-ROM has been reported in a relatively small number of studies as well, most recently in those that have proposed this motion as a better method of detecting posterior shoulder tightness[110,111,127]. Researchers and clinicians have criticized this method because the scapular motion is very difficult to detect with the subject lying supine[98,171]. Tyler[110] proposed measuring HAd with the subject in side lying and reported good to excellent intra- and inter-reliability with this method. This method was not utilized in the current study as it was found to be difficult to maintain a larger subject's torso perpendicular to the examination table, as well as stabilize the scapula while moving the arm passively into HAd.

5.1.3 Standard Error of Measurement (SEM) & Minimal Detectable Change (MDC)

Reliability was also reported through the SEM and MDC; values that provide clinicians with meaningful information about the range of expected values when measuring overhead shoulder rotation and HAd. All three shoulder ROM measures (IR, ER and HAd), in all measurement situations, yielded SEM values less than or equal to 10˚, successfully meeting Study I's hypothesis. The MDC values of IR and HAd-ROM were established for use in Studies II and III. Intra- and inter-rater SEM values for IR-ROM were similar, ranging from 3˚ to 4˚. The MDC value for IR-ROM measures extended from 8˚ to 12˚. In assessing IR-ROM, these values mean that a change in IR-ROM between a pre-intervention and a post-intervention measurement needs to exceed 12˚ to be fairly certain a real change has occurred in the patient's shoulder status. ER-ROM measurements generated similarly low SEM values ranging from 3˚ to 5˚ (intra-rater) and 3˚ to 4˚ (inter-rater). The MDC for ER-ROM was therefore calculated to be between 8˚ and 12˚ for within-therapist measurements and 8˚ and 11˚ for between-therapist measurements. The SEM associated with HAd-ROM was comparable for both intra- and inter-rater reliability tests ranging from 2˚ to 3˚. This produced MDC values extending from 5˚ to 8˚.

Very few studies include measures such as SEM and MDC with their reliability test results. Muir et al.[169] was the only study found that reported shoulder rotation SEM and MDC values similar to those established in the current study. Comparisons could be made to Muir et al.'s ER-ROM results only as IR-

ROM was measured actively in their study. Overall, Study I yielded lower SEM values for both intra- rater and inter-rater ER-ROM measurements when compared to Muir et al.'s results. The MDC values for within-therapist measurements followed the same pattern with Study I values slightly lower than those reported by Muir. This difference was greater in the between-therapist situation with Study I's MDC values between 8° and 11° compared with Muir et al.'s between 18° and 24°. The lower values obtained in the present study may be as a result of the two training sessions that the physical therapists and research assistant participated in prior to the study which allowed for time to practice the measurement technique.

Study I differed from previous studies of ROM reliability in that its within-therapist and between-therapist reliability results were quite similar. Most authors have reported better reliability when the same therapist measures a subject's ROM repeatedly versus different therapists measuring the same subject. There are several reasons why this study's results may have been different. Prior to the study, the 2 physical therapists and research assistant, who read and recorded the values, participated in 2 practice/training sessions. These occurred well before the onset of the study so the therapists and research assistant could practice the measurement techniques between sessions and determine any issues well in advance. Care was taken to ensure that the same criteria were used to determine the end points of the passive movements as well as proper subject positioning and scapular stabilization. In addition, the goniometer had a standard carpenter's bubble level affixed to it, which made arm alignment easier and more precise. All subjects performed the same warm-up exercises prior to testing in order to avoid any mobilization effect that might have occurred as a result of the passive ROM. This would suggest that physical therapists can be trained to measure shoulder ROM in a very reproducible way.

5.1.4 Role of Pathology

Comparable ICCs, SEMs and MDC values were found when subjects with and without shoulder symptoms were compared in Study I. In fact, within-therapist values were higher for all shoulder movements taken in the symptomatic shoulder group when compared to the healthy shoulder group, suggesting that shoulder pathology does not adversely affect the ability to reliably measure shoulder rotation and HAd-ROM. Subjects with healthy and symptomatic shoulders were included in Study I to determine the role pathology had on reliably measuring shoulder IR, ER and HAd. This question was clinically relevant as goniometry is used to measure shoulder ROM in a wide variety of clinical situations. Furthermore, subjects in Studies II and III were expected to present with varying degrees of shoulder ROM therefore, it was important to determine the impact this might have on subsequent study results.

5.1.5 Summary of Study I

The results of Study I had important consequences for the overall project. Findings proved that IR- and HAd-ROM could be reliably used to measure posterior shoulder flexibility as well as being key outcome measures of the effectiveness of the intervention examined (i.e. sleeper stretch). Fifteen degrees was used as the criterion level for distinguishing overhead athletes with and without a GIRD in the subsequent studies. This value was chosen based on previous literature[7,8,11,12,18-21] that reported dominant shoulder IR-ROM deficits in overhead athletes; however it had not been determined whether 15˚ represented an amount greater than that attributed to measurement error. The results of this study indicate that 15˚ is an acceptable level, well within the SEM of IR-ROM (4˚) and greater than the MDC value required to be clinically meaningful (10˚). Finally, the key outcome measures used in Study III to determine the effectiveness of the posterior shoulder stretch were IR-ROM and HAd-ROM. Knowing the SEM and MDC values associated with these measures allowed for clinical interpretation of the results obtained.

5.2 Study II

5.2.1 Overview of Findings

The majority of research related to the overhead athlete's shoulder stems from male, professional baseball players. A much smaller proportion relates to athletes involved in overhead sports such as volleyball, tennis and swimming. The second evaluation in this series of studies recruited both male and female participants involved in three varsity level overhead sports (volleyball, swimming and tennis) and compared their shoulder movements to University students of similar ages not involved in competitive overhead activities. It was hypothesized that a difference would be detected between the two study populations and that the overhead athletes would have the same dominant shoulder rotation pattern described in other overhead athletes; namely an increase in ER and a decrease in IR. The results from Study II supported this hypothesis, finding statistical differences between the varsity-level overhead athletes in volleyball, swimming and tennis examined and students not involved in overhead activities on all three shoulder measurements obtained (glenohumeral internal rotation deficit (GIRD), glenohumeral external rotation gain (GERG) and posterior shoulder tightness, (PST)). The greatest difference between the two groups was found in the GIRD measurements. Sub-group analyses among the different athlete groups revealed that volleyball players exhibited the greatest change in shoulder ROM when compared to other athletes and non-competitive students.

5.2.2 Varsity Athletes and Non-Competitive Students

Three key measures were compared between the overhead varsity athletes and the non-competitive students: GIRD, GERG and PST. These measures represent the amount of difference in IR, ER and HAd-ROM between an individual's non-dominant and dominant shoulder. A statistically significant difference between the varsity athlete group and the non-competitive student group was found on all 3 measures, supporting Study II's hypotheses that athletes who use their arm in overhead, repetitive motions would demonstrate adaptive changes resulting in reduced IR- and decreased HAd-ROM of their involved shoulder relative to the shoulders of students not involved in competitive, overhead activities. The difference between the 2 study groups was greatest when GIRD was compared with the varsity athletes producing an average IR-ROM deficit of 15° compared to the non-competitive student's average loss of 3°.

As a group, the varsity athletes had an average increase in dominant shoulder ER (GERG) of 7°compared to their non-dominant shoulder. The non-competitive student group had an average ER-ROM increase of 3° on their dominant shoulder. This finding was different from studies on baseball pitchers that have reported gains in ER-ROM ranging from 11° to 18°[6,17,18,37]. The few studies that have examined shoulder rotation ROM in volleyball, swimming and tennis athletes have reported ER gains closer to those found in this study: 4° and <5° (volleyball[48,75]), 10° (swimming[122]) and 7.9° (tennis[118]). The discrepancy is likely due to the different overhead positions and shoulder movements required in the various sports. Professional baseball pitchers abduct their shoulders to 90° and often externally rotate to positions greater than 180° in order to maximize the wind-up phase of the pitching motion. Volleyball players position their hand to strike the ball with their shoulder abducted higher, between 110° and 130°and use a combination of extension and rotation from both their thoracolumbar spine and shoulder girdle. Swimmers are unique in that they function with both shoulders abducted well above 90°, and like volleyball players, do not utilize excessive amounts of glenohumeral ER to perform their sport. Tennis players were included in this evaluation in part because of the similarities between the tennis serve and the preparatory phase of the baseball pitch. Of the overhead sports included in this study, tennis players were expected to demonstrate the greatest increase in ER-ROM on their dominant shoulder. This was not the case; in fact compared to the volleyball players and swimmers, tennis players had the smallest average difference between their non-dominant and dominant shoulders' ER-ROM. The small number of tennis players (11/66) in the varsity athlete group may have influenced this finding or perhaps there are greater shoulder biomechanical differences between tennis and baseball than was anticipated. More study is needed with larger samples to detail change in shoulder ROM in tennis players.

In addition to noting the GIRD and GERG of an athlete's dominant shoulder, it is helpful to compare the total amount of rotation (i.e. IR and ER) in the dominant and non-dominant shoulders. If the loss of IR equals the gain of ER, the total rotation arc (TRA) of the dominant shoulder has been maintained and this amount of rotation should be similar to the TRA of the non-dominant shoulder. This is the normal physiologic adaptation that occurs in the shoulder of the overhead athlete. When the loss of IR of the dominant shoulder exceeds the gain in ER and the TRA of motion is also decreased, the athlete is believed to have soft tissue changes of the posterior shoulder structures and may be at risk of developing shoulder pathology.[7] This pattern was detected in this study, with a lower average TRA of the overhead athlete's dominant shoulder (160°) compared to their non-dominant shoulder (167°). Earlier discussions have shown that this loss was as a result of decreased dominant shoulder IR-ROM of the athletes' shoulders without the compensatory increase in ER-ROM. The non-competitive student group had no difference in their 2 shoulders' TRA (dominant shoulder=167˚/ non-dominant = 166˚).

Posterior shoulder tightness (PST) was represented by the difference in HAd-ROM between a subject's dominant and non-dominant shoulder. On average, the difference in HAd-ROM between the varsity athletes' dominant and non-dominant shoulders was 4˚ compared to the student groups' difference of 2˚. Although the difference between the 2 study group's PST was found to be statistically significant (p=0.014), it represents a small difference in actual degrees, only slightly more than the standard error associated with measuring HAd-ROM (2˚) and therefore was not found to be a strong discriminator of individuals with and without a tight posterior shoulder.

When individual athlete groups were compared to the non-competitive student group, statistically significant differences were found between volleyball players and students on all 3 key measures. Swimmers were significantly different from the student group on their GIRD and GERG values but not in PST. Tennis players were only statistically different from the non-competitive student group when their GIRD values were compared.

5.2.3 Varsity Athletes

Very few studies have compared the shoulder rotation pattern of athletes in different overhead sports. The current study performed separate exploratory analyses on the 3 athlete groups to determine if there was a difference in GIRD, GERG and PST among volleyball players, swimmers and tennis players. Only GIRD was statistically different between volleyball players and swimmers. Volleyball players had the greatest loss of dominant arm IR-ROM overall with an average GIRD of 17˚ followed by tennis players at 13˚ and swimmers at 12˚. The results concur with those of previous reports that found GIRD values ranging from 5˚ to 18˚for volleyball players[48,75], 12˚ and 40˚ for swimmers[21,122] and 15˚ to 23˚ for tennis players[21,118].

There were no statistically significant differences found between the GERG values of the 3 overhead athletes examined in Study II. Swimmers had a slightly greater increase in ER on their dominant shoulder compared to volleyball players (8˚ versus 7˚) and both volleyball players and swimmers possessed greater ER-ROM gains compared to tennis players (4˚). As earlier mentioned, the difference in ER-ROM between the athlete's shoulders was consistent with previous findings on volleyball, swimming and tennis athletes[21,48,75,118,122].

The amount of PST was also similar amongst the three athlete groups with volleyball players exhibiting the greatest difference in HAd-ROM between their 2 shoulders (5˚), followed by tennis players (4˚) and swimmers (3˚).

The results obtained from comparing individual athlete groups to one another produced findings similar to those earlier reported between all the varsity athletes and non-competitive students; that IR-ROM deficit (GIRD) was the best discriminator amongst and between subjects examined in Study II. GIRD was the only value found to be different between the three types of athletes as well as between all three of the individual sports and the non-competitive student group.

Conversely, PST was found to be the weakest discriminator between the athlete groups, only demonstrating a difference between volleyball players and non-competitive students.

5.2.4 Summary of Study II

Varsity-level overhead athletes involved in volleyball, swimming and tennis possess a different dominant shoulder rotation ROM pattern when compared to University students not involved in overhead sporting activities. The levels of discrimination between the 2 study groups were well beyond the SEM and MDC values established in Study I. This is the same pattern of decreased IR and increased ER described in prior research on the overhead athlete. Volleyball players exhibited the greatest alterations in their shoulder ROM when compared to other athletes and non-competitive students. Swimmers also demonstrated this characteristic shoulder pattern; despite swimming being a sport that utilizes both arms equally. Four swimmers in this study had bilateral reductions in IR-ROM. In other words, they had lower than normal shoulder IR-ROM values bilaterally, not just on the dominant arm. Because GIRD was calculated by subtracting dominant shoulder IR-ROM from non-dominant IR-ROM, these 4 athletes did not produce high GIRD values making it difficult to quantify their ROM changes. Further work is required to establish normal ranges of IR-ROM for bilateral overhead athletes such as swimmers, so that athletes with tightness in both posterior shoulders at risk of developing injury may be detected and treated.

5.3 Study III

5.3.1 Overview of Findings

The final study determined that an 8-week posterior shoulder stretching program was effective in increasing dominant arm IR- and HAd-ROM in a group of overhead athletes identified as having reduced IR-ROM and tightness of their posterior shoulder structures: clinical findings believed to contribute to the development of shoulder injuries. Using the findings from the initial study, the SEM and MDC values associated with key measures were used to identify and determine treatment effectiveness in this study (i.e. IR- and HAd-ROM). The second study confirmed that the difference between an individual's dominant and non-dominant shoulder IR-ROM, represented by GIRD, was a valid measure that could be used as a criterion in Study III to distinguish varsity-level, overhead athletes at risk of developing shoulder pathology.

Of the 66 varsity-level overhead athletes tested in Study II, 37 were identified as having a tight posterior shoulder as indicated by a deficit of dominant arm IR-ROM (GIRD) ≥ 15˚; all agreed to participate in the intervention study. Volleyball had the highest percentage of athletes with a GIRD ≥ 15˚ at 73%, followed by tennis players at 45% and swimmers at 36%. As previously noted, four swimmers presented with reduced IR-ROM in both of their shoulders excluding them from participation in Study III as the difference between their IR-ROM (GIRD) was less than 15˚. If these four swimmers had been included, the proportion of swimmers examined in Study II with IR-ROM deficits would have increased to 55%. Further work is required to determine the best method of identifying swimmers with IR-ROM deficits of one or both shoulders.

Overall, the results from Study III proved this study's hypothesis demonstrating that athletes who were assigned to the experimental group (stretching group) exhibited a greater increase in dominant arm IR- and HAd-ROM over the 8-week intervention period when compared to athletes in the control group who did not perform the stretch exercise. Secondary analyses regarding when the effects of the stretch were noted revealed significant changes as early as 4 weeks to IR-ROM with further adaptations noted at 8 weeks. HAd-ROM improved at a slower rate demonstrating significant changes only by 8 weeks.

Athletes who participated in Study III answered questions regarding their shoulder pain and function at the 0, 4 and 8 week testing periods. The subjects' ratings were compared to determine whether performing the sleeper stretch had any effect on shoulder pain and/or functional ability. Differences were detected between the stretch and control groups' reporting of shoulder pain with activity as well as functional ability. This difference was statistically significant for shoulder function at both 4 and 8 weeks indicating the posterior shoulder stretch also had a positive effect on the athletes' shoulder function.

5.3.2 Internal Rotation Range of Motion (IR-ROM)

Statistically significant differences in IR-ROM values were detected between the 2 study groups' dominant arm at the completion of the 8-week stretch program. Athletes who performed the stretch exercise increased their dominant arm IR-ROM by an average of 19˚ compared to athletes in the control group who increased the same motion by only 3˚. The SEM and MDC values associated with measuring IR-ROM were calculated in Study I to be 4˚ and 10˚ respectively suggesting that the 19˚ increase in IR-ROM exhibited by the athletes who stretched was well beyond the measurement error and therefore a true, clinically meaningful change. Interestingly, the results from the IR-ROM measurements on the 2 study groups' non-dominant shoulder revealed no difference at 0 and 4 weeks, but a statistically significant difference was discovered at 8 weeks. It is not known why this occurred as subjects in the stretch group were instructed to perform the sleeper stretch on their dominant side only. It is possible that some athletes, having noticed an increase in their dominant arm IR-ROM and improved shoulder function, began stretching their non-dominant shoulder as well, however this information was not collected.

The amount of IR-ROM difference between the individual athletes' dominant and non-dominant shoulders (GIRD) was also markedly different between the 2 study groups at 8 weeks. GIRD takes into consideration an individual's "normal" amount of shoulder IR-ROM by comparing both shoulders. Although it is very beneficial to see that athletes who participated in the stretch program had an overall average improvement in the amount of dominant shoulder

IR-ROM of 19˚, the relevance to the athlete is that his/her dominant shoulder IR-ROM approached the “normal” non-dominant shoulder IR-ROM. At the beginning of Study III (0 weeks), athletes in both groups had similar amounts of GIRD: stretch group = 22˚ and control group = 21˚. By 4 weeks, the stretch group had reduced their GIRD to 7˚ compared to the control group’s average of 18˚. By the end of the study (8 weeks), the 2 groups GIRD values were even further apart at 4˚ (stretch group) and 20˚ (control group) meaning that athletes who participated in the stretch program had improved their dominant shoulder IR-ROM to within 4˚ of their non-dominant shoulders’ IR-ROM.

Knowing the rate that tissue responds to various interventions helps clinicians and patients set exercise guidelines and goals. Literature related to posterior shoulder stretching parameters, specifically the duration required, is sparse and varies from 2 to 12 weeks[43,186,187]. The results from Study III revealed statistically significant differences between the stretch and control groups IR-ROM measures at 4 weeks time (mean difference=14˚) however these changes continued between 4 and 8 weeks (mean difference=20˚). This suggests that although the effects of performing the sleeper stretch are measurable as early as 4 weeks, changes continue to occur to at least 8 weeks. Further study is warranted to determine at what point the effects from the sleeper stretch level off, as well as if and how much stretching is required to maintain the increased IR-ROM of the athlete’s dominant shoulder.

5.3.3 Horizontal Adduction Range of Motion (HAd-ROM)

HAd-ROM was included as an outcome measure in this study as recent research has proposed it as an alternate method of measuring posterior shoulder tightness[110,111,126-128]. Study II demonstrated a statistical difference in the amount of dominant shoulder HAd-ROM between varsity-level overhead athletes and non-competitive students, but the difference was only slightly greater than the SEM associated with measuring HAd-ROM and therefore not considered clinically relevant. When dominant arm HAd-ROM was compared between the 2 study groups investigated in Study III, a statistically significant difference was detected at the completion of the 8-week study. The actual degree difference in HAd-ROM measurements from 0 to 8 weeks was relatively small (control group=1˚/stretch group=5˚) and although the stretch group's HAd-ROM measures exceeded the SEM calculated in Study I (i.e. 2˚), it falls short of the MDC value of 7˚. An MDC value of 7˚ indicates that a change or difference of at least 7˚ between successive HAd-ROM measures is required to presume a true change, independent from measurement error. As 5˚ fell below the MDC value of 7˚, one cannot be certain that the difference in HAd-ROM in the stretch group, occurred as a result of performing the stretch or if it is related to measurement error.

Similar to the IR-ROM findings, athletes in the stretch group demonstrated an unexpected increase in their non-dominant shoulder HAd-ROM from 0 to 8 weeks when compared to athletes in the control group. As previously noted, this may have occurred as a result of athletes in the stretch group performing the sleeper stretch on both shoulders.

The difference between the stretch and control groups' dominant and non-dominant shoulder HAd-ROM, represented by PST, was not found to be significantly different at the 0 and 4 week testing times, but almost reached the significance level at 8 weeks (p=0.068). The rate that HAd-ROM changed in response to the 8-week intervention was slower than that observed with IR-ROM. Statistically significant differences between the stretch and control groups were noted at the 8 week testing time only (p=0.014). Although it appears that the sleeper stretch did not have as significant an effect on the athletes' HAd-ROM, the trend towards increasing significance at 8 weeks coupled with the results demonstrating a delayed rate of change, raises the question of duration of stretch. Further study is required to determine whether extending the stretch program beyond 8 weeks and/or increasing the stretch hold time would have resulted in greater changes to the athletes' HAd-ROM.

5.3.4 Summary of Study III

The results from this study suggest that overhead, varsity-level athletes with an IR-ROM deficit ≥ 15° benefit from performing an 8-week posterior shoulder stretch exercise. Benefits were noted through increased dominant arm IR- and HAd-ROM as well as an increase in subjects' self-reported shoulder functional ability. Further research, specifically related to the duration of stretch program, is required to determine whether IR- and HAd-ROM continue to improve over time.

5.4 Strengths and Weaknesses of the Project

The following strengths and weaknesses were associated with this project:

Study I

Strengths:

- The inclusion of clinically relevant reliability measures was a strength of this study. The SEM and MDC values calculated provide clinicians with meaningful values, in degrees for IR-, ER- and HAd-ROM. These values can be used to determine whether a patient's shoulder motion has changed as a result of treatment intervention versus a change that simply represents measurement error.
- This study presented confidence intervals with its ICC point estimates providing information on the margin of error that accompanies each ICC point estimate.
- The shoulder ROM testing protocol was well defined and practiced. Prior to Study I, the two assessors and research assistant participated in two training sessions. These occurred well before the onset of the study so the assessors and research assistant could practice the measurement techniques. Care was taken to follow the same criteria for subject positioning, stabilization and end point determination. In addition, the goniometer had a standard bubble level attached to it which made goniometer arm alignment easier and more precise.

Weaknesses:

- In Study I of this project, one unit of analysis was defined as one shoulder. As a result, 47 shoulders were tested in 30 subjects. Sensitivity analyses, done to determine the independence of shoulders, revealed no difference between the analysis utilizing one shoulder as one unit (n=47) versus one subject as one unit (n=30). As a result, all 47 shoulders were included in Study I.
- The majority of subjects in Study I were between the ages of 22 and 28 years. Only three individuals over the age of 40 participated in this study therefore the results may not be as generalizable to individuals over the age of 40.
- The intra-rater reliability testing was carried out within the same test session therefore the reliability results may not be generalizable to shoulder rotation and HAd-ROM testing that takes place on different days.
- Two, experienced physical therapists were used in Study I to determine the reliability of measuring shoulder rotation and HAd-ROM. The findings from this study may therefore lack generalizability to novice physical therapists and/or other clinicians. Further study to investigate the effect that both clinical experience and practice have on shoulder goniometry is warranted.

Study II

Strengths:

- Subject recruitment was an important strength of Study II. The University of Alberta coaches and athletes involved in volleyball, swimming and tennis were very supportive of this project and thus participation rates were high. All of the mens' and womens' volleyball team players, 22/28 available swimmers and 11/15 tennis players consented to participation. As a result, the sample size for Study II consisted of 66 male and female varsity-level overhead athletes and 30 University students not involved in overhead, competitive sports. The large number of different varsity-level overhead athletes allowed for secondary, exploratory analyses of the individual athlete groups.
- The identical ROM testing procedures, including the same assessor and research assistant , that were followed in Study I were utilized in Study II therefore the benefits of practice and experience also applied to this study phase of the overall project.
- All of the subjects' ROM values were read and recorded by the same research assistant and no feedback was provided to the assessor until the study was completed.

Weaknesses:

- As expected, the varsity athletes were found to be significantly taller and heavier when compared to the non-competitive student group. These differences were not believed to have had any influence on this study's findings as the primary outcome measure (shoulder ROM) has not been shown to be affected by factors such as height and weight however further study to determine if these factors constitute confounding variables is warranted.
- The majority of research related to the overhead athlete's shoulder stems from male, professional baseball players. This study chose to investigate the shoulder of male and female varsity-level athletes involved in different overhead sports (i.e. volleyball, swimming and tennis) to determine whether the same dominant shoulder rotation pattern could be identified within and between athlete groups. Research on these athlete populations[21,48,75,118,122] suggest that similar patterns of shoulder rotation ROM do exist and that athletes involved in volleyball, swimming and tennis are also at risk of developing shoulder pathologies as a result of shoulder ROM limitations. The results from Study II found that varsity-level athletes involved in volleyball, swimming and tennis do possess a similar pattern of altered shoulder ROM however differences between the 3 athlete groups were also found, suggesting that overhead athletes have inherent differences that may dictate more individualized management.

- The number of tennis players included in Study II's varsity overhead athlete group was proportionally smaller (n=11) than the number of swimmers (n=22) and volleyball players (n=33). The University of Alberta's tennis team was much smaller than the volleyball and swim teams therefore this was unavoidable. The smaller number of tennis players may have affected the secondary sub-group analyses that compared the shoulder ROM findings amongst the 3 athlete groups. Additional research, utilizing larger samples of tennis players is warranted.

Study III

Strengths:

- The identical ROM testing procedures, including the same assessor and research assistant, that were followed in Studies I and II were utilized in Study III therefore the benefits of practice and experience also applied to this study phase of the overall project.
- All of the subjects' ROM values were read and recorded by the same research assistant and no feedback was provided to the assessor until the study was completed.
- All of the varsity athletes from Study II who met the inclusion criteria for Study III, agreed to participate. In addition, there were no subjects lost to follow up in this Study.
- All of the varsity teams at the University of Alberta have a team trainer who is present at all practices and games. This individual

provided an important link between the author and the athletes by monitoring and encouraging athletes to adhere to their stretch program and reminding subjects of upcoming testing sessions.

Weaknesses:

- The number of subjects in Study III was 37 (stretch group = 20 / control group = 17). A priori sample size calculations recommended 20 subjects per group based on 80% power and a hypothesized effect size of 0.80. The effect size produced in this study was well over 1.0 therefore the smaller sample size utilized is not believed to have negatively affected the power of this study.
- Compliance was not measured in this study therefore the role that compliance played on the results is unknown. Subjects were provided with a stretch log and were encouraged to keep track of their stretch adherence. As well, the team trainers and the author provided daily and weekly monitoring of the athlete's stretching.
- Although the randomization method used in Study III did not adversely affect the study's outcome, it could have been strengthened by using a computer generated table of random numbers.
- The smaller proportion of tennis players at the University of Alberta affected the number of tennis players available for participation in Study III. Further study with larger numbers of tennis players is warranted.

Overall, the multi-phase design of this project was its greatest strength. It provided an important foundation for the final, randomized control study that determined an 8-week shoulder stretch program was effective in improving shoulder ROM in athletes identified as having a tight posterior shoulder. The results from Studies I and II established that the key outcome measures used in Study III (IR- and HAd-ROM) could be measured reliably and could be used to discriminate athletes with and without IR deficits greater than or equal to 15°; a level used to identify athletes at risk for developing shoulder pathology[6-8,10,11,17,18,22,99-102].

Chapter 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The findings of this study add to the current body of evidence by providing meaningful information regarding the reliability and range of expected values when measuring overhead shoulder rotation and horizontal adduction; two measures commonly used to identify and monitor posterior shoulder tightness in the overhead athlete population. Both within and between-rater situations achieved good to excellent reliability; therefore goniometric measurement of shoulder internal rotation, external rotation and horizontal adduction ROM should be considered acceptable measures capable of identifying and monitoring change over time.

These measurement techniques were used to determine that alterations in overhead rotation and horizontal adduction ROM existed in male and female varsity level athletes involved in volleyball, swimming and tennis relative to University students not involved in overhead, competitive activities. Volleyball players in this study demonstrated the most marked alterations in overhead shoulder rotation and horizontal adduction however this may be due to the fact that volleyball players constituted the largest proportion of varsity athlete examined (33/66). Further research is warranted with larger samples of swimmers and tennis players. A common posterior shoulder stretch was found to be effective in increasing the posterior shoulder's flexibility in a group of overhead athletes. Improvements in internal rotation ROM, as a result of performing the stretch, were detected at 4 weeks time and continued to increase between 4 and 8 weeks. Changes in horizontal adduction ROM were not detected until 8 weeks, suggesting this movement may have a slower rate of response to the stretch technique. The stretching parameters chosen for use in this study were different than previously reported by McClure et al.[43] who suggested doing the sleeper stretch once daily, holding each stretch for 30 seconds for a total of 4 weeks. Because it was believed that the sleeper stretch impacted both the contractile and non-contractile tissue of the posterior shoulder, the duration of stretch hold was increased to 2 minutes and the stretch program was prescribed for a total of 8 weeks.

6.2 Recommendations

6.2.1 For Research

Additional research should be conducted on the reliability of measuring functional, overhead shoulder motions. Consideration should be given to defining specific testing positions, stabilization methods and type of movement tested (active versus passive) so that researchers and clinicians can reproduce measurement techniques. Values such as SEM and MDC that provide clinically meaningful information should be included in reliability results.

Future studies related to the adaptations that occur in the overhead athletes shoulder, should include male and female athletes participating in a variety of different sports at varying levels of participation. Key questions regarding the similarities and differences amongst and between overhead athlete groups will assist clinicians in identifying and treating athletes at risk of developing shoulder pathology. Overhead sports that function bilaterally such as swimming require special consideration to determine normal ranges of overhead rotation and horizontal adduction ROM. Future research should focus on the relationship between altered shoulder rotation and horizontal adduction ROM and other shoulder measures such as scapular stability and rotator cuff strength.

Treatment of PST in the overhead athlete requires further examination to determine the most effective parameters for performing exercises such as the sleeper stretch. In particular, the duration of performing the stretch should be extended beyond 8 weeks to determine whether improvements continue to occur as well as establishing the level of stretching required to maintain posterior shoulder flexibility. Other stretching parameters such as the length of time each stretch should be held as well as the number of repetitions required would also benefit from more study. Additional treatment interventions such as scapular stabilization exercises and rotator cuff strengthening should be investigated in conjunction with posterior shoulder stretching to find out what effect these treatments have on shoulder flexibility and injury prevention. Finally, the relevance of this research must be investigated to determine whether athletes who participate in posterior shoulder stretching and/or future treatment interventions benefit from doing so and have a lower incidence of shoulder injury.

6.2.2 For Practice

Clinicians involved in the management of overhead athletes and workers should include overhead internal rotation, external rotation and horizontal adduction ROM measurements as part of their overall assessment. These shoulder measures have been shown to be different in populations that use their arm in repetitive, overhead positions. Reductions in dominant arm internal rotation ROM in particular, have been associated with the development of shoulder pathology. The sleeper stretch is an effective exercise for improving posterior shoulder flexibility and therefore should be included within rehabilitation programs for individuals with posterior shoulder tightness. Specific dosage parameters require further study. Benefits were achieved after performing the sleeper stretch 5 times with a 2-minute hold, daily for 8 weeks. Values such as MDC, that help clinicians determine how much change in ROM is required to conclude a real change has occurred as a result of the treatment rather than measurement error, improve clinical decision making.

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APPENDICES

Appendix A – Standardized Warm-Up Exercise Program

1. Supine Flexion Active ROM – 10 repetitions

2. Supine Abduction Active ROM – 10 repetitions

3. Supine Internal and External Rotation at 0° of Abduction – 10 repetitions

4. Supine Internal and External Rotation at 90° of Abduction – 10 repetitions

Appendix B – Information Sheets

Study I

UNIVERSITY OF ALBERTA

Title of Project: **Standard Error of Measurement (SEM) and Minimal Clinical Difference (MCD) Associated with Shoulder Joint Rotation and Horizontal Adduction Range of Motion (ROM).**

Principal Investigator / Academic Advisor:	David Magee 780-492-5765
Co-Investigator:	Judy Chepeha 780-492-9413

Background

Alterations in shoulder internal and external rotation ROM have been associated with changes in posterior shoulder tightness and linked to certain conditions at the shoulder, particularly in individuals who use their arm repetitively and in overhead positions. Confidence in assessing these shoulder motions is therefore important in the detection of abnormalities as well as for monitoring a treatment's effectiveness. Very few studies have been done to determine how reliable clinicians are at measuring shoulder rotation. You are being asked to participate in this research study to help determine how accurately we can measure particular movements at the shoulder joint.

Purpose

The purpose of this study is to determine the reliability associated with measuring 3 motions at the shoulder joint: internal rotation, external rotation and horizontal adduction. This will be calculated by comparing measurements taken by the same examiner and measurements taken by 2 different examiners.

Procedure

If you agree to participate in this study and sign the consent form, you will undergo 1 test session of approximately 60 minutes. The testing will consist of 3 measures of shoulder ROM (internal rotation, external rotation and horizontal adduction) using a non-invasive, protractor-like instrument called a goniometer.

Measurements will be taken 4 times, by 2 different examiners. You will be asked to perform a gentle shoulder warm-up exercise routine prior to being tested.You will be asked to complete 1 questionnaire regarding your shoulder's health history.

Possible Benefits

There are no personal benefits associated with your participation in this study. Your participation may help the investigators better understand the accuracy of measuring shoulder rotation and horizontal adduction.

Possible Risks

This study involves the measurement of 3 typical shoulder movements; therefore the only risk associated with participating in this study would be as a result of moving your shoulder into these ranges of motion.

Costs

There is no cost to you by taking part in this study. You will not receive any payment for joining the study.

Privacy

All information you provide will be held private, except when professional codes of ethics or the law requires reporting. The information that you provide will be kept at least seven years after the study is done. The information will be stored in a secure area. Your name or any other identifying information will be kept separate from all other data collected. Your name will never be used in any presentations or publications of the study results.

Right to Refuse or Withdraw

The choice to join or not join in this study is yours. If you decide to join this study, you will have the right to quit at any time. You may refuse to join this study or change your mind about being in this study at any time. You may also refuse to answer any questions we may ask.

If you have any questions and/or concerns regarding the study, procedure or your rights as a research subject, please feel free to contact Dr. Joanne Volden (780) 492-0655, Associate Dean – Research in the Faculty of Rehabilitation Medicine. If you have any questions regarding the study you can contact Judy Chepeha at (780) 492-9413, my supervisor Dr. David Magee at (780) 492-5765 or the University of Alberta Student OmbudService at (780) 492 - 4689.

Information Sheet - Study II

UNIVERSITY OF ALBERTA

Title of Project: **Posterior Shoulder Tightness in the Varsity Level Overhead Athlete**

Principal Investigator / Academic Advisor: David Magee
780-492-5765

Co-Investigator: Judy Chepeha
780-492-9413

Background

When examined, the shoulder of an overhead athlete has been shown to demonstrate a particular pattern of rotation. Compared to the non-dominant limb, the throwing or dominant arm, at 90° of abduction, presents with an increase in external rotation and a decrease in internal rotation. The alteration in the ratio of external to internal rotation is believed to be a natural and seemingly necessary adaptation that develops in order to accommodate positions such as the wind up in throwing or overhead spike in volleyball. It does not appear to become problematic unless the amount of shoulder internal rotation loss is greater than the compensatory gain in external rotation.

Authors have identified a link between the loss of internal rotation and shoulder pathology in overhead athletes and have suggested that clinicians who work with these patient populations, asses and carefully monitor shoulder rotational range of motion (ROM).

You are being asked to participate in this study because you are either a varsity level athlete involved in an overhead sport or a University student not involved in competitive overhead activities.

Purpose

The purpose of this study is to determine whether or not differences in shoulder rotational ROM and posterior shoulder flexibility exist between 2 groups of individuals: (1) Varsity athletes involved in overhead sports and (2) University students not involved in competitive sports. This will be done by measuring the

ROM of your shoulder's internal rotation, external rotation and horizontal adduction and comparing the values obtained from the 2 study groups. ROM measurements will be taken using a non-invasive, protractor-like instrument called a goniometer.

Procedure

If you agree to participate in this study and sign the consent form, you will undergo 1 test session of approximately 30 minutes. The testing will consist of 3 goniometric measures of shoulder ROM (internal rotation, external rotation and horizontal adduction). Measurements will be taken 3 times, by 1 examiner. You will be asked to perform a gentle shoulder warm-up exercise routine prior to being tested.

You will be asked to complete 1 questionnaire regarding your shoulder's health history.

Possible Benefits

There are no personal benefits associated with your participation in this study. The information gained from the results of this study may help clinicians understand rotational ROM abnormalities in the overhead athlete and lead to early prevention, monitoring and management of individuals at risk of developing shoulder pathologies.

Possible Risks

This study involves the measurement of 3 typical shoulder movements; therefore the only risk associated with participating in this study would be as a result of moving your shoulder into these ranges of motion.

Costs

There is no cost to you by taking part in this study. You will not receive any payment for joining the study.

Privacy

All information you provide will be held private, except when professional codes of ethics or the law requires reporting. The information that you provide will be kept at least seven years after the study is done. The information will be stored in a secure area. Your name or any other identifying information will be kept separate from all other data collected. Your name will never be used in any presentations or publications of the study results.

Right to Refuse or Withdraw

The choice to join or not join in this study is yours. If you decide to join this study, you will have the right to quit at any time. You may refuse to join this study or change your mind about being in this study at any time. You may also refuse to answer any questions we may ask.

If you have any questions and/or concerns regarding the study, procedure or your rights as a research subject, please feel free to contact Dr. Joanne Volden (780) 492-0655, Associate Dean – Research in the Faculty of Rehabilitation Medicine. If you have any questions regarding the study you can contact Judy Chepeha at (780) 492-9413, my supervisor Dr. David Magee at (780) 492-5765 or the University of Alberta Student OmbudService at (780) 492 - 4689.

Information Sheet - Study III

UNIVERSITY OF ALBERTA

Title of Project: **Effectiveness of an 8-Week Posterior Shoulder Stretching Program on Varsity Level Overhead Athletes**

Principal Investigator / Academic Advisor: David Magee
780-492-5765

Co-Investigator: Judy Chepeha
780-492-9413

Background

When examined, the shoulder of an overhead athlete has been shown to demonstrate a particular pattern of rotation. Compared to the non-dominant limb, the throwing or dominant arm, at 90° of abduction, presents with an increase in external rotation and a decrease in internal rotation. The alteration in the ratio of external to internal rotation is believed to be a natural and seemingly necessary adaptation that develops in order to accommodate positions such as the wind up in throwing or overhead spike in volleyball. It does not appear to become problematic unless the amount of shoulder internal rotation loss is greater than the compensatory gain in external rotation.

Authors have suggested that the loss of internal rotation is due to tightness of the posterior shoulder structures (i.e. joint capsule and muscle/tendon tissue). Different stretching techniques have been described to address this decreased motion, but only 1 study has investigated whether or not this stretch is effective in increasing internal rotation ROM.

You are being asked to participate in this study because you have been identified as having a deficit in your shoulder internal rotation ROM.

Purpose

The purpose of this study is to determine if an 8-week posterior shoulder stretching program increases internal rotation ROM and posterior shoulder flexibility of the shoulder. This will be done by comparing the measurements of shoulder internal rotation, external rotation and horizontal adduction at the beginning of the study, at 4 weeks and at 8 weeks. ROM measurements will be taken using a non-invasive, protractor-like instrument called a goniometer.

Procedure

If you agree to participate in this study and sign the consent form, you will be randomly selected (like the flip of a coin) to be in 1 of 2 study groups: (1) stretching group, or (2) non-stretching group. If you are allocated to the stretching group you will be asked to do a particular stretch, daily for 8 weeks. If you are allocated to the non-stretching group, you will be advised to continue with your normal training schedule that will not include posterior shoulder stretching.

You will undergo 3 test sessions of approximately 30 minutes each. The testing will consist of 3 goniometric measures of shoulder ROM (internal rotation, external rotation and horizontal adduction). Measurements will be taken 3 times, by 1 examiner. You will be asked to perform a gentle shoulder warm-up exercise routine prior to being tested.

You will be asked to complete 1 questionnaire regarding your shoulder’s health history.

Possible Benefits

You might receive no personal benefit from this study. You might receive some information about your shoulder’s ROM and you might receive some benefit from participating in the posterior shoulder stretch program. The stretch that you might do is commonly used to help prevent and treat shoulder symptoms in overhead athletes.

The information gained from the results of this study may help clinicians to know whether the particular stretch used in this study is effective at increasing internal rotation ROM.

Possible Risks

This study involves the measurement of 3 typical shoulder movements; therefore the only risk associated with participating in this study would be as a result of moving your shoulder into these ranges of motion.

If you are allocated to the Stretching Group of this study you might experience mild muscle soreness at the beginning of your 8-week stretching program. If you agree to participate, you will be provided with ongoing monitoring and feedback to ensure that you are performing the stretch properly and therefore minimizing your risk of soreness.

Costs

There is no cost to you by taking part in this study. You will not receive any payment for joining the study.

Privacy

All information you provide will be held private, except when professional codes of ethics or the law requires reporting. The information that you provide will be kept at least seven years after the study is done. The information will be stored in a secure area. Your name or any other identifying information will be kept separate from all other data collected. Your name will never be used in any presentations or publications of the study results.

Right to Refuse or Withdraw

The choice to join or not join in this study is yours. If you decide to join this study, you will have the right to quit at any time. You may refuse to join this study or change your mind about being in this study at any time. You may also refuse to answer any questions we may ask.

If you have any questions and/or concerns regarding the study, procedure or your rights as a research subject, please feel free to contact Dr. Joanne Volden (780) 492-0655, Associate Dean – Research in the Faculty of Rehabilitation Medicine. If you have any questions regarding the study you can contact Judy Chepeha at (780) 492-9413, my supervisor Dr. David Magee at (780) 492-5765 or the University of Alberta Student OmbudService at (780) 492 - 4689.

Appendix C – Consent Forms

UNIVERSITY OF ALBERTA

Title of Project: **Standard Error of Measurement (SEM) and Minimal Clinical Difference (MCD) Associated with Shoulder Joint Rotation and Horizontal Adduction Range of Motion (ROM)**

Part 1: Researcher Information

Academic Advisor and Principal Investigator: Dr. David Magee (780) 492-5765
Co-Investigator: Judy Chepeha (780) 492-9413

Part 2: Consent of Subject (to be completed by the research subject)

Do you understand that you have been asked to be in a research study?	Yes	No
Have you read and received a copy of the attached Information Sheet?	Yes	No
Do you understand the benefits and risks involved in taking part in this research study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason.	Yes	No
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records?	Yes	No

Part 3: Signatures

I have read the information sheet and this study was explained to me by:
______________________________ Date:______________________________

I agree to take part in this study.
Signature of Research Participant:______________________________

Printed Name:____________________ Date:______________________________

Signature of Witness:______________________________

Printed Name:____________________ Date:______________________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.
Signature of Investigator or Designee:
____

Printed Name:______________________ Date:
____

** A copy of this consent form must be given to the subject.*

UNIVERSITY OF ALBERTA

Title of Project: **Posterior Shoulder Tightness in the Varsity Level Overhead Athlete**

Part 1: Researcher Information		
Academic Advisor and Principal Investigator: Dr. David Magee (780) 492-5765 Co-Investigator: Judy Chepeha (780) 492-9413		
Part 2: Consent of Subject (to be completed by the research subject)		
Do you understand that you have been asked to be in a research study?	Yes	No
Have you read and received a copy of the attached Information Sheet?	Yes	No
Do you understand the benefits and risks involved in taking part in this research study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason.	Yes	No
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records?	Yes	No
Part 3: Signatures		
I have read the information sheet and this study was explained to me by: ______________________________ Date:______________________________		
I agree to take part in this study. Signature of Research Participant:______________________________ Printed Name:____________________ Date:______________________________		
Signature of Witness:______________________________ Printed Name:____________________ Date:______________________________		
I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate. Signature of Investigator or Designee: ______________________________ Printed Name:____________________ Date: ____________________		
* *A copy of this consent form must be given to the subject.*		

UNIVERSITY OF ALBERTA

Title of Project: **Effectiveness of an 8-Week Posterior Shoulder Stretching Program on Varsity Level Overhead Athletes**

Part 1: Researcher Information

Academic Advisor and Principal Investigator: Dr. David Magee (780) 492-5765
Co-Investigator: Judy Chepeha (780) 492-9413

Part 2: Consent of Subject (to be completed by the research subject)

Do you understand that you have been asked to be in a research study?	Yes	No
Have you read and received a copy of the attached Information Sheet?	Yes	No
Do you understand the benefits and risks involved in taking part in this research study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason.	Yes	No
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records?	Yes	No

Part 3: Signatures

I have read the information sheet and this study was explained to me by:
______________________________ Date:_________________________

I agree to take part in this study.
Signature of Research Participant:___________________________________

Printed Name:____________________ Date:_________________________

Signature of Witness:____

Printed Name:____________________ Date:_________________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.
Signature of Investigator or Designee:

____

Printed Name:_______________________ Date:
____

** A copy of this consent form must be given to the subject.*

Appendix D –Recruitment Letters

Study I

UNIVERSITY OF ALBERTA

Title of Study: Reliability of Measuring Shoulder Joint Rotation and Horizontal Adduction Range of Motion (ROM)

Background: Overhead athletes and workers are at a high risk of developing shoulder injuries. An important clinical measure used to examine the integrity of the shoulder is Range of Motion (ROM). It is important that the measurement techniques that clinicians use provide consistent, accurate values so that decisions regarding the management of individuals with shoulder complaints are made appropriately.

Participants will be included if:

- You are a man or woman between the ages of 16 and 65
- You are able to raise your arm out to the side to the height of your shoulder

Participants will be excluded if:

- You have a condition affecting your shoulder that is causing you significant pain and dysfunction
- You have had recent shoulder surgery and are not able to move your shoulder into overhead or rotated positions
- You have a shoulder condition that does not allow you to move your shoulder on your own

Testing Procedures: Study participants will be seen for 1 session that will be approximately 60 minutes in length. Three different movements will be measured using a standard measuring device (goniometer): internal rotation, external rotation and horizontal adduction. These motions will be taken 2 times by 2 different examiners.

If you are interested in participating in this study, please call Judy Chepeha at the Department of Physical Therapy: 780-492-9413 or email @ jchepeha@ualberta.ca to set up an appointment time.

Recruitment Letter - Study II

UNIVERSITY OF ALBERTA

Title of Study: Posterior Shoulder Tightness in the Varsity Level Overhead Athlete

Background: Athletes involved in overhead sporting activities have been shown to develop altered shoulder rotation ranges of motion with a tendency towards greater external rotation and reduced internal rotation. This study will examine two groups of individuals: Varsity athletes involved in overhead sports and University students not involved in competitive sports to determine whether or not differences exist.

Participants will be included in the <u>Overhead Athlete</u> group if:

- You are a man or woman between the ages of 18 and 25
- You are able to raise your arm out to the side to the height of your shoulder
- You are on one of the following University of Alberta teams:
  - Volleyball
  - Swimming
  - Tennis
  - Football (throwing positions)

Participants will be excluded from the <u>Overhead Athlete</u> group if:

- You have had shoulder surgery and/or a fracture to your shoulder and/or shoulder girdle
- You are presently receiving treatment (physical therapy, injections, medication) for a shoulder condition/complaint on either shoulder

Participants will be included in the Non-Overhead Athlete group if:

- You are a male or female University student between the ages of 18 and 25
- You are able to raise your arm out to the side to the height of your shoulder
- You are NOT involved in competitive overhead sports

Participants will be excluded from the Non-Overhead Athlete group if:

- You have had shoulder surgery and/or a fracture to your shoulder and/or shoulder girdle
- You are presently receiving treatment (physical therapy, injections, medication) for a shoulder condition/complaint on either shoulder

Testing Procedures: Study participants will be seen for 1 session that will be approximately 30 minutes in length. Three different movements will be measured using a standard measuring device (goniometer): internal rotation, external rotation and horizontal adduction. These motions will be taken 3 times by the same examiner.

If you are interested in participating in this study, please call Judy Chepeha at the Department of Physical Therapy: 780-492-9413 or email @ jchepeha@ualberta.ca to set up an appointment time.

Recruitment Letter - Study III

UNIVERSITY OF ALBERTA

Title of Study: Effectiveness of an 8-Week Posterior Shoulder Stretching Program on Varsity Level Overhead Athletes

Background: It has been shown that individuals who have an internal rotation deficit are at a greater risk of developing shoulder pathologies such as impingement and instability. Stretching of the posterior shoulder structures has been suggested as an effective means of improving this ROM and lowering the risk of injury.

Participants will be included in if:

- You are a male or female varsity level athlete between the ages of 18 and 35 involved in an overhead sport
- You have a glenohumeral internal rotation deficit (GIRD) equal to or geater than 15 degrees as compared to the other shoulder

Participants will be excluded if:

- You have had shoulder surgery and/or a fracture to your shoulder and/or shoulder girdle
- You are presently receiving treatment (physical therapy, injections, medication) for a shoulder condition/complaint on either shoulder

Testing Procedures: Study participants will be seen for 2 sessions that will be approximately 30 minutes in length. Three different movements will be measured using a standard goniometer: internal rotation, external rotation and horizontal adduction. These motions will be taken 3 times by the same examiner.

If you are interested in participating in this study, please call Judy Chepeha at the Department of Physical Therapy: 780-492-9413 or email @ jchepeha@ualberta.ca to set up an appointment time.

Appendix E – Demographic Information

Demographic Information Form

Please complete this form for all patients in phase III of the study.
☐ Control Group
☐ Intervention Group

Last Name:
First Name:

Gender: ☐ Male ☐ Female

Street Address:
City:
Province:
Postal Code:

Home Phone:
Cell Phone:
Email:

ALTERNATE CONTACT:
Name:
Phone Number:

Appendix F

Shoulder Health History Questionnaire

Please complete this form for all patients in each phase of the study.

Section A: Current Shoulder History

1. Are you currently receiving treatment for a shoulder injury?

☐ Yes ☐ No

If yes, continue to question #2.
In no, skip to question #4.

2. If yes, what is your shoulder injury?

☐ Rotator cuff injury
☐ Instability
☐ Frozen shoulder
☐ AC trauma
☐ Other; please specify:

3. How long have you had this injury? In other words, when do you recall your shoulder problems began?

☐ Less than 6 weeks
☐ 7 to 12 weeks
☐ 13 to 26 weeks
☐ More than 26 weeks; please specify:

____

For the following three questions, place an X on the line at the point that best answers the question being asked.

4. How would you rate your shoulder pain at rest (arm at side, not moving)?

No pain at all ____________________________________ *Worst pain imaginable*

5. How would you rate your shoulder pain with activity?

No pain at all ____________________________________ *Worst pain imaginable*

6. How would you rate your shoulder's functional ability?

No restriction (full function) ____________________________________ *No functional ability at all*

Section B: Past Shoulder History?

7. Have you had any previous shoulder problems or injuries?

☐Yes ☐ No

If yes, continue to question #8.
If no, you are done.

8. If yes, what were the injuries or conditions and when did they occur? (Check all that apply.)

	Type of injury	**Date occurred (dd/mmm/yyyy)**
☐	Rotator cuff injury	__ __ / __ __ __ / __ __ __ __
☐	Instability	__ __ / __ __ __ / __ __ __ __
☐	Frozen shoulder	__ __ / __ __ __ / __ __ __ __
☐	AC trauma	__ __ / __ __ __ / __ __ __ __
☐	Other; please specify: ______________________________	__ __ / __ __ __ / __ __ __ __
☐	Other; please specify: ______________________________	__ __ / __ __ __ / __ __ __ __
☐	Other; please specify: ______________________________	__ __ / __ __ __ / __ __ __ __

Appendix G - Data Collection Forms

Study I Data Collection Form

Examiner: ____

Testing Order Sequence Used: ☐ A ☐ B ☐ C ☐ D ☐ E

Variables Measured	**Measure 1**	**Measure 2**
Internal Rotation (degrees) • Dominant arm		
Internal Rotation (degrees) • Non-dominant arm		
External Rotation (degrees) • Dominant arm		
External Rotation (degrees) • Non-dominant arm		
Horizontal Adduction (degrees) • Dominant arm		
Horizontal Adduction (degrees) • Non-dominant arm		

Study II Data Collection Form

Group: ☐ Overhead ☐ Non-competitive student

Variables Measures	Measure 1	Measure 2	Average
Internal Rotation (degrees) • Dominant arm			
Internal Rotation (degrees) • Non-dominant arm			
External Rotation (degrees) • Dominant arm			
External rotation (degrees) • Non-dominant arm			
Horizontal Adduction (degrees) • Dominant arm			
Horizontal Adduction (degrees) • Non-dominant arm			
Total Rotation Arc • Dominant arm			
Total Rotation Arc • Non-dominant arm			

Subject appropriate for study III? ☐ Yes ☐ No

Study III Data Collection Form

Group: ☐ Control ☐ Experimental

Interval: ☐ Baseline Measure (Week 0) ☐ Week 4 ☐ Week 8

Variables Measures	**Measure 1**	**Measure 2**	**Average**
Internal Rotation (degrees) • Dominant arm			
Internal Rotation (degrees) • Non-dominant arm			
Horizontal Adduction (degrees) • Dominant arm			
Horizontal Adduction (degrees) • Non-dominant arm			

Appendix H – Subject Daily Log

Subject Daily Log

Name: ____

Instructions: Once per day, please complete one set of five reps of the stretch for a 2-minute hold. Write the date each day in the “date” column” and indicate if you successfully completed the 5 reps that day. If not, please indicate why and use the “comments” column for further notes if needed.

Date (dd/mmm/yyyy)	Stretch Record	Comments (Optional)
Week ________		
	☐ Yes ☐ No If no, please indicate reason: ☐ Pain ☐ Forgot ☐ Time constraints ☐ Other (please specify)	
	☐ Yes ☐ No If no, please indicate reason: ☐ Pain ☐ Forgot ☐ Time constraints ☐ Other (please specify)	
	☐ Yes ☐ No If no, please indicate reason: ☐ Pain ☐ Forgot ☐ Time constraints ☐ Other (please specify)	
	☐ Yes ☐ No If no, please indicate reason: ☐ Pain ☐ Forgot ☐ Time constraints ☐ Other (please specify)	
	☐ Yes ☐ No If no, please indicate reason: ☐ Pain ☐ Forgot ☐ Time constraints ☐ Other (please specify)	

	☐ Yes ☐ No If no, please indicate reason: ☐ Pain ☐ Forgot ☐ Time constraints ☐ Other (please specify)	
	☐ Yes ☐ No If no, please indicate reason: ☐ Pain ☐ Forgot ☐ Time constraints ☐ Other (please specify)	