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# Comparison of Three-Dimensional Motion of the Scapula during the Hawkins-Kennedy Test and the Sidelying Sleeper Stretch

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# Comparison of Three-Dimensional Motion of the Scapula during the Hawkins-Kennedy Test and the Sidelying Sleeper Stretch

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March, 25, 2017

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# ABSTRACT

Comparison of Three-Dimensional Motion of the Scapula during the Hawkins-Kennedy Test and the Sleeper Stretch.

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**PURPOSE:** The Hawkins-Kennedy test is a pain provocation test used to identify shoulder pathology. With this test, it is hypothesized the scapula tips anteriorly and compresses soft tissue structures of the shoulder, causing pain. A common intervention for this type of shoulder pathology is the sidelying sleeper stretch. Although the glenohumeral (GH) joint is in the same anatomical position for both conditions, the sleeper stretch does not typically provoke pain. In the sidelying position the scapula was stabilized by the subject’s body weight, theoretically limiting the amount of anterior tipping. Currently, there is no research investigating the scapular arthrokinematics in both conditions. The purpose of this study is to measure scapular tipping accompanying shoulder internal rotation (IR) range of motion (ROM) in the sidelying sleeper stretch position compared to the Hawkins-Kennedy test position.

**METHODS:** While passive moving from full shoulder external to internal rotation, scapular tipping and GH IR were measured in the Hawkins-Kennedy and sidelying sleeper stretch using three-dimensional motion analysis, on the dominant shoulder of 30 healthy subjects (13 male [31.3±13.0 years, 24.6±2.7 BMI] and 17 female [27.4±8.7 years, 23.2±2.3 BMI]).

**RESULTS:** Hawkins-Kennedy GH IR mean was 94.1°±13.2° and sidelying GH IR mean was 71.9°±15.9° (p<0.0001). Scapular tipping excursion was -8.7°±6.3° and in sidelying was 4.7°±4.2° (p<0.0001). In the Hawkins-Kennedy position, excursion of scapular IR was found to be 6.4°±5.2°, and in sidelying an excursion 4.0°±3.5° of scapular external rotation was found (p=<0.0001). The ratio of tip excursion to GH IR excursion mean was -9.7°±7.0° and the sidelying mean was 6.2°±5.5° (p<0.0001).

**CONCLUSION:** In a healthy population, the scapula anteriorly tipped during passive shoulder IR in the Hawkins-Kennedy test position and posteriorly tipped in the sidelying position. Posterior tipping is hypothesized to protect the subacromial space, decreasing the compressive forces on the soft tissue structures of the shoulder. Therefore, stabilizing the scapula may protect the subacromial space, lending to the lack of pain typically noted in the sidelying sleeper stretch position.

# PROJECT APPROVAL FORM

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

# COMPARISON OF THREE-DIMENSIONAL MOTION OF THE SCAPULA DURING THE HAWKINS-KENNEDY TEST AND THE SIDELYING SLEEPER STRETCH

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

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# CHAPTER I:
# INTRODUCTION

Athletes who have participated in overhead activities, as well as those whose occupations have required repetitive overhead activities, often develop a condition called Glenohumeral Internal Rotation Deficit, commonly known as GIRD.[1-4] GIRD has been defined as the dominant shoulder having a loss of internal rotation (IR) range of motion (ROM) of 20° or more compared to the non-dominant shoulder. In addition, GIRD has been defined as occurring when the difference in the total arc of motion, or the sum of IR and external rotation (ER), between shoulders was 8° or larger.[5] The prevalence of GIRD is greater in overhead athletes, as well as seen more so with increasing age.[4] Although GIRD accounts for a decrease in IR, there is usually a subsequent increase in ER of the same arm.[6] It is important to understand the underlying causes of GIRD.

GIRD can be categorized into anatomical and pathological etiologies. Manske et al.[7] proposed that anatomical GIRD is the result of bony changes in humeral retroversion, though the total arc of motion remains the same on both sides. This occurs when the head of the humerus is prepositioned more posteriorly on the dominant side compared to the other. This may occur as bones grow according to the demands placed upon them, such as in young overhead athletes. Although there is a bony limitation of IR from the position of the humeral head, the total arc of motion is compensated with increased ER. Shanley et al.[3] examined professional baseball players' retrotorsion and determined that there was a significant bony torsion in the dominant arm and also a significantly larger measure of ER. Another study by Hibberd, Oyama, and Meyers[4] noted that total arc of motion within the dominant arm may not change in overhead activities but the degree of retrotorsion is significantly greater than the non-dominant arm.

GIRD can be pathological and attributed as a predictive factor for a future injury.[7] The pathological GIRD classification includes the asymmetrical contributions of soft tissue structures. The posterior capsule of the glenohumeral joint has been studied as a major factor of GIRD as tightness can limit posterior translation of the humerus within the capsule. When measuring the total arc, there would be less motion on the dominant side than the non-dominant. This is caused by a greater loss of IR ROM of the dominant shoulder compared to the corresponding increase in ER ROM, as it would be in an anatomical GIRD.[8] Limitations in posterior capsule structures reduce the capability of flexion and internal rotation. This is due to a restriction of the normal posterior translation of the humerus in those motions.[8-9] Posterior rotator cuff muscle stiffness, or lack of tissue extensibility in the deltoid, infraspinatus, teres major and teres minor, can also play a role in reduction of IR as the shortening of the muscles restricts full active and passive range. Musculotendinous stretching of these structures has been shown to increase IR and reduce GIRD.[10] These categories of GIRD must be taken into consideration with patients susceptible to shoulder injury.

The final consideration in regards to losses of IR stems from the accessory motion of the scapula. A study by Thomas et al.[11] explored the compensatory scapular motions with patients experiencing GIRD. The results showed that overhead athletes with GIRD also displayed a significant decrease in scapular upward rotation using a digital inclinometer for measurement at the scapular spine. Also, it was shown that there is a significant increase in scapular protraction or scapular IR in collegiate athletes with GIRD. This was measured with a vernier calipers in centimeters. These factors increase the risk of injury and shoulder impingement. Another study by Borich et al.[12] determined that subjects with GIRD displayed a significant increase in scapular anterior tipping and confirmed the abnormal scapular positioning of the scapula with these patients.

Traditionally, to measure IR, a subject was placed in supine with 90° of glenohumeral abduction. The measurement was taken at end-range motion with the elbow flexed to 90° and an anterior stabilization force with the tester's palm over the subject's humeral head.[13] Although this method of positioning has been most common, others have been utilized in clinics. Other variations include seated, vertebral reach and sidelying. Research has revealed adequate reliability with both the seated and supine positions but the limitation of inadequate stabilization of the scapula has still remained in question.[14] Most recently the use of the sidelying position has been used clinically and in research. It has been demonstrated that the sidelying position elicits greater inter-rater and intra-rater reliability, likely due to an increased ability to stabilize the scapula in this position.[15,16] Recently in a study by Cieminski and colleagues,[16] norms were established for non-athletes for sidelying IR ROM. Normative values for males include 42° and 51° for the dominant and non-dominant shoulder, respectively and for females values include 49° and 54° for dominant and non-dominant shoulder, respectively. In another study, Cieminski et al established dominant shoulder IR ROM norms in overhead athletes of 35° in NCAA Division I athletes, as well as 41° in both NCAA Division III and recreational athletes.[17] Positioning had likely changed results of IR values, therefore there was a question of whether or not this was directly related to the amount of scapular stabilization.

A researcher may choose between varying types of scapular stabilization to obtain a more reliable and accurate measure of shoulder motion.[18] The literature tends to agree that some form of stabilization has been necessary to isolate true glenohumeral motion.[19-20] When the scapula has been stabilized, the IR ROM value tends to decrease as compared to when the scapula is not stabilized.[21] A greater disagreement existed between which technique of stabilization is best, the supine coracoid stabilization or the sidelying position. The coracoid stabilization technique required the subject to be positioned in supine. In order to measure, the coracoid and the spine of the scapula were stabilized using a grasping technique. The researcher then applied a posteriorly directed force against the subject's coracoid process with the heel of the hand.[22] A second technique was the sidelying position in which a subject's body weight stabilized the scapula. This position produced the highest intra-rater and inter-rater reliability amongst the more traditional methods of scapular stabilization. Additionally, sidelying scapular stabilization was more practical for clinical utilization.[23]

Another discrepancy in the literature pertains to which measurement technique was most reliable to measure shoulder internal rotation. There were a wide variety of tools available to clinicians to aide in the measurement of IR including but not limited to; standard goniometer, digital goniometer, digital inclinometer (plurimeter, acumar and smartphone app), and hand behind the back technique. The most commonly used techniques in clinical practice were standard goniometer and hand behind the back technique. Consistently, research has shown intra-rater reliability to be much higher (ICC values ranging from 0.82-.99) than inter-rater reliability (ICC values ranging from 0.12-0.85) for these common measurement techniques.[14,24-26] This discrepancy between intra-rater (ICC values ranging from 0.79- 0.99) and inter-rater (ICC values ranging from 0.44-0.90) reliability has also been found across studies for the digital goniometer and digital inclinometer.[14,25,27-28] Only one technique, a smartphone application, was found to have excellent reliability with both intra-rater (ICC= 0.98) and inter-rater (ICC=0.92) measurements, however this technique is not commonly used in practice.[27,29] This large difference between inter-rater and intra-rater reliability has been attributed to different stabilization techniques between researchers.[24,30]

Three-dimensional (3-D) motion analysis systems display the kinematics of bone beneath skin, adipose, and muscular tissue without the use of invasive bone pins. The two most commonly used 3-D motion analysis systems were electromagnetic and optical tracking systems. Both systems offered a variety of advantages and disadvantages. The optic tracking system offered advantages of accuracy in high velocity and multi joint movement as well as a large tracking volume. Despite these advantages, the costs associated with optic tracking systems were greater than electromagnetic systems and required direct line of sight between trackers and cameras used when collecting data.[31-32] Electromagnetic systems were available at a lower cost,[32-33] did not require line of sight between trackers and data collection system,[32] and provided accurate measurements.[34] Data collection programs such as the Flock of Birds have also demonstrated accuracy when compared with a digital inclinometer.[35] Disadvantages of an electromagnetic system included a smaller tracking volume,[31-32,] receivers that were heavier, potential for wires to affect movements,[31] potential for metal interference,[32-34,36] and increased possibility for error while tracking dynamic movements.[34]

As a result of repetitive overhead activities such as throwing, many athletes have developed impingement of the supraspinatus and bicipital tendon within the subacromial space. With increased repetition of overhead activities and poor scapular mechanics, the rotator cuff may degenerate or tear.[37] Hawkins developed a reliable test to detect the impingement.[38] In the test, the participant's arm is positioned at 90° of shoulder flexion and then forcibly moved through IR by a tester. A positive test resulted from a facial expression and pain in a pathological shoulder as the supraspinatus tendon was forced anteriorly towards the coracoacromial ligament. Other research suggested that the Hawkins-Kennedy test may provocatively impinge other structures in addition to the rotator cuff.[39]

Besides the Hawkins-Kennedy test, there have been many other diagnostic tests designed to detect subacromial impingement including Neer's, painful arc, empty can, Jobe, and the external rotation resistance test.[40] When compared to a reference-standard surgical diagnosis, no single test could effectively rule in or rule out subacromial impingement syndrome, but a battery of tests has been shown to be helpful in confirming or denying subacromial impingement syndrome. Although a battery of tests has been shown to be most effective at detecting subacromial impingement, the Hawkins-Kennedy test has shown good to excellent reliability when compared to other tests[38] as well as high sensitivity despite low specificity.[41] This indicates that a negative Hawkins-Kennedy test was a good indicator to deny the presence of subacromial syndrome. The Hawkins-Kennedy test was also shown to be particularly effective at detecting partial thickness rotator cuff tears.[42]

As previously discussed, the Hawkins-Kennedy test may reproduce signs and symptoms of subacromial impingement that a symptomatic individual may experience with overhead activities. The sidelying sleeper stretch has traditionally been prescribed by many therapists as an intervention to treat posterior shoulder soft tissue tightness. Many individuals who are symptomatic during the Hawkins-Kennedy test find relief with the sidelying sleeper stretch.

The glenohumeral joint is in the same anatomical position for both the Hawkins-Kennedy test position and sidelying sleeper stretch position. However, patients with shoulder impingement usually have pain with internal rotation during the Hawkins-Kennedy test and not in the sidelying sleeper stretch position. A common intervention for shoulder impingement is the sidelying sleeper stretch, where a patient lies in sidelying and internal rotates their shoulder to stretch the posterior shoulder soft tissue structures. Though the glenohumeral joint is in the same anatomical position in both conditions, only the the Hawkins-Kennedy test typically provokes pain. It was then necessary to investigate scapular tipping, an accessory motions of glenohumeral internal rotation, to provide a better explanation for the discrepancy. The primary purpose of this investigation was to measure scapular tipping that accompanies shoulder IR ROM in the sidelying sleeper stretch position compared to the Hawkins-Kennedy test position. Secondary purposes of this investigation included comparing the following variables between these two conditions; 1) glenohumeral IR ROM, 2) the ratio of the amount of scapular tipping to glenohumeral IR ROM, and 3) scapular internal and external rotation. It was hypothesized that the sidelying sleeper stretch position would yield a significantly smaller amount of anterior tipping as an accessory motion to glenohumeral IR ROM, as compared to that which occurred in the Hawkins-Kennedy test position.

# CHAPTER II:

# LITERATURE REVIEW

## *Etiology of Glenohumeral Internal Rotation Deficit*

Overhead throwing athletes generally display altered shoulder motion as a result of the high loads placed on the shoulder joints and tissues. Often, throwers demonstrate an increased external rotation (ER) and a decreased internal rotation (IR) range in the dominant arm. Kibler et al.[5] discussed the multifactorial etiology of glenohumeral internal rotation deficit (GIRD) to include; humeral retroversion (HRV), posterior capsule thickening, and muscle passive stiffness. Kibler provided the threshold for GIRD as greater than 20° difference in IR between arms or greater than an 8° discrepancy between the dominant and non-dominant arms in the total arc of rotational motion.

A comprehensive study by Manske et al.[7] differentiated between two different types of GIRD: anatomical and pathological. Anatomical GIRD is considered a normal adaptation in overhead athletes in which the loss of range of motion (ROM), when comparing the dominant arm to the non-dominant arm, is less than 18- 20° with bilateral symmetry in total range of motion (TROM). Anatomic GIRD is the result of an osseous limitation caused by HRV and cannot be changed through therapeutic intervention. Conversely, pathologic GIRD is when there is a glenohumeral loss of IR exceeding 18-20° and a loss of greater than 5° of TROM comparing shoulders bilaterally. Manske suggested how ER deficiency may be a predictor of future shoulder disability or injury. Finally, contractile restrictions involving the muscle tendon unit may respond to stretching techniques such as the sidelying sleeper stretch, whereas non-contractile restrictions involving the joint capsule, ligaments, scar tissue, and fascia may respond to joint mobilizations.

Next, it is important to consider anatomical GIRD. Lidenfield and colleagues[6] performed a study in 2013 set out to examine glenohumeral joint ROM to understand the difference in glenohumeral (GH) motion between the dominant and non-dominant arms of 37 athlete participants. Subjects were placed in a shoulder rotation testing instrument and instructed to go through the total arc of motion from neutral to full IR, full ER and then back to the starting position. The testing instrument consisted of a backboard with an arm cradle in which the patient's arm is stabilized through a hook, loop strap, and a five pound placed over the humeral head. Force, torque, and angle sensors were attached to the subject's arms. Both shoulders were tested using the same method. Results showed that consistently through subjects, ER was greater on the dominant arm (ER mean difference, 6.9°; P=0.02), IR was less on the dominant arm (IR mean difference -9.2°, P=0.00), and the total arc of motion showed no significant difference between non-dominant and dominant arms (P=0.34).

A study by Torres et al.[1] also investigated the prevalence of GIRD in an athletic population, particularly with overhead throwers. Researchers examined the glenohumeral IR in asymptomatic tennis players and related symptoms by measuring and comparing dominant and non-dominant shoulders in athletes. Fifty-four males without shoulder symptoms were divided into three groups; tennis players, swimmers, and a control group. Passive IR and ER measurements were taken with scapular stabilization through downward pressure on the anterior aspect in supine. Researchers measured both shoulders for a total of 108 measurements. Glenohumeral IR deficit was defined as the difference between IR of the non-dominant and dominant shoulder. Researchers found significant differences between dominant and non-dominant shoulders in all the categories. The difference between IR of the dominant shoulders was most significant between the group of tennis players and control group (27.5°, $P<0.001$). The difference between the group of swimmers and the control group was also statistically significant (17.9°, $P<0.001$).

With similar objectives, Dwelly et al.[2] assessed the glenohumeral ROM in a population of 48 NCAA Division I or Division II softball and baseball athletes. Athletes were assessed by two athletic trainers at three different periods during a competitive season to detect the presence of GIRD and to track changes in ROM over time. Researchers used a manual inclinometer secured to the subject's distal forearm at the radius to measure glenohumeral ROM. Subjects were positioned in supine with the glenohumeral joint abducted to 90°, the elbow flexed to 90°, and a towel placed under the humerus.[43] In order to control for scapulothoracic motion, researchers used a visual inspection technique, recording the ROM when the acromion rises from the measuring surface or at a capsular end-feel. Each arm was randomly assigned to an order of testing. Researchers started each measurement with the subject's arm positioned in neutral and moved the arm through maximal internal and ER stopping at a capsular end-feel or before the scapula lifted from the table during IR, recording the average measurement of two trials from the inclinometer. Measurements were recorded on three occasions: pre-fall, pre-spring, and post-spring seasons with 16 weeks between pre-fall and pre-spring and 15 weeks between the pre-spring and post-spring seasons. Researchers then went on to calculate GIRD by determining the difference in IR between dominant and non-dominant shoulders and as a percentage of the total arc of rotational motion. The results indicate that IR remained consistent in the dominant shoulder whereas ER increased ($F_{2,96} = 17.4°$, $P < 0.001$) and the total arc increased between time intervals ($F_{2,96} = 14.0°$, $P < 0.001$). Researchers found no changes in GIRD over time but concluded that the two methods of calculating GIRD identified different athletes as having GIRD and a more consistent method should be established.[2]

Convincing evidence correlates losses in IR with humeral torsion. A 2012 study by Shanley et al.[3] followed professional baseball players between spring training in 2009 and 2010 measuring their shoulder ROM and humeral torsion. Seventy-two asymptomatic professional pitchers from a single major league organization all presented with bilateral shoulder ROM and humeral torsion recorded at the beginning of the two seasons before any exercise, warm-ups or throwing had been done. Horizontal abduction, ER, and IR were assessed with a digital inclinometer (DI) in supine with 90° of abduction and scapular stabilization. Humeral torsion was assessed by an indirect ultrasonographic technique using a 5 MHz transducer. It was found that the GIRD subjects demonstrated 5° more humeral torsion difference between their dominant and non-dominant shoulder than the non-GIRD subjects with a higher degree of humeral torsion in the non-dominant arm with both groups. The study also found the dominant shoulders had a significant increase in ER (12° ± 8°, P=0.02) and a decrease in both IR (-8° ± 11°, P=0.03) and horizontal abduction (-17° ± 14°, P=0.001). The non-dominant shoulders had no significant differences between spring trainings. In this study, GIRD was defined as a loss of 15° or greater in IR combined with a loss of 10° or greater of the total arc of motion. During the course of the study 19 players total were found to have GIRD for a prevalence of 25% and 13 of those players developed GIRD between 2009 and 2010.

Hibberd et al.[4] were similarly interested in inspecting the role of HRV in GIRD but found slightly different conclusions than Shanley et al.[3] They evaluated the influence of age groups on GIRD, HRV, retrotorsion-adjusted GIRD and total ROM in young baseball players. Each of the 287 male subjects were placed in a category based on age, youth (6-10), junior high (JH) (11-13), junior varsity (JV) (14-16) and varsity (16-18). The young men were positioned supine with 90° shoulder abduction and elbow flexion to measure IR and ER ROM. Internal rotation ROM measurements were done with a posteriorly directed force applied to the anterior acromion to isolate glenohumeral motion. Passive end range was measured with use of a digital inclinometer. Next, each subject was assessed for HRV using indirect ultrasonographic technique previously validated by Myers et al, Whitely et al and Yamamoto et al. Glenohumeral internal rotation deficit was calculated as the bilateral difference in IR ROM and adjusted GIRD was calculated as the difference in angles of the retrotorsion-adjusted IR ROM between dominant and non-dominant limbs. This determines the actual amount of motion available from the retrotorsion position of the humerus. Results showed significant decreases in IR ROM with greater HRV and greater retrotorsion-adjusted IR ROM when comparing dominant arm to non-dominant arm. Retrotorsion-adjusted IR ROM was calculated as the angular difference in retrotorsion-adjusted IRROM between the dominant and non-dominant limbs. Mean GIRD values were significantly increased in varsity compared to youth and JH as well as JV compared to youth (p=0.02 for all). Differences in HRV between limbs was greater in varsity compared to youth (p<0.001) and JH (p=0.014) as well as JV compared to youth (p=0.001) as dominant arms had a higher HRV. No significance was found in adjusted GIRD between groups. The results suggest that GIRD significant increased with age, though retrotorsion-adjusted GIRD did not. This indicates that age related increases in GIRD is not related to soft tissue tightness but rather to HRV. As torsion increased, GIRD increased simultaneously.

Though soft tissue restriction was not indicated in the previous study by Hibberd et al.[4] capsular tightness may have an effect on available range of motion. An early study by Branch et al.[8] looked at the correlations of glenohumeral translation with medial and lateral rotation of the humerus. The study used 6 cadaveric shoulders to measure changes in capsuloligamentous structures along with translation. Muscles were excised, leaving only bony and ligamentous structures of the humerus and scapula while the capsuloligamentous complex was left intact and undamaged. The shoulders were then mounted with PVC pipe in order to maintain anatomical resting position to better mimic naturally occurring kinematic motions. Measurements were done with a protractor to determine degree of motion. At 20° increments of motion, translation of the humerus was measured concurrently. Results showed that with IR, the posterior capsule had the greatest influence on translation whereas in ER, the anterior capsule had the greater influence on translation. As translation increased, the glenohumeral ligamentous complex increased in length. The longer the ligament, the more loose the cuff and the greater ability to translate anteriorly and posteriorly ($p<0.001$). These findings lead researchers to believe that the length of the posterior capsules has an influence on the motion of IR. An increase in length leads to an increase in translation of the humerus.

Harryman and colleagues[9] also addressing posterior capsule tightness related to glenohumeral motion through an instrumental study. They aimed to determine the direction and magnitude of translations occurring with passive motion of glenohumeral joints. They hypothesized that glenohumeral translation resulted from local capsular tightness and was not the product of asphericity of the humeral head. They tested 8 cadaver specimens with normal and full shoulder joint ROM after excision of skin, subcutaneous tissues, and muscle over the medial 1/3 of scapula. The joints were secured in place and the use of a transmitter coil of a 6-degrees-of-freedom spatial sensor detected translation and rotation of the humerus with respect to the scapula. The joints were tested in flexion, extension, IR, ER, abduction, adduction and horizontal adduction passively and with varied forces and torques. Results displayed that translations were altered by the tightening of the capsule. Anterior translation of the humeral head occurred with IR. When posterior capsule was tightened, anterior displacement of the humerus occurred earlier during IR and to a greater degree. Flexion and horizontal adduction additionally were shown to produce anterior translation. These results point to the influence of capsuloligamentous tissue with regards to glenohumeral joint movement.

As the research previously discussed suggests, posterior shoulder tightness may contribute to the development of GIRD. Finding an appropriate methodology to measure to posterior shoulder tightness becomes imperative. This was the goal for a study by

Tyler et al.[44] The proposed method is described by having a subject in a sidelying position on a plinth with bilateral acromion processes perpendicular to the table. The subject was positioned so the extremity that was being tested was off the table and the subject lying on the extremity that is not being tested. The tester grasped the medial border of the scapula and stabilized it by manually retracting the scapula. The tested extremity was then positioned passively into 90° of abduction and neutral rotation. The humerus then is lowered, horizontally adducted, and stopped once there is no more motion or the humerus begins to rotate. The distance from the inferior portion of the medial epicondyle to the table is then recorded in centimeters. The 49 subjects within the reliability study had no shoulder pathology within the last 6 months. Twenty-two subjects in the validity study were NCAA Division I collegiate baseball pitchers without shoulder pain and were assessed with the non impaired group. All patients were also measured for IR and ER ROM to correlate with posterior shoulder tightness measure. Results showed high intra-rater reliability (ICC=0.92 dominant, ICC=0.95 non-dominant), and good inter-rater reliability (ICC=0.8) of measurement for posterior shoulder tightness. When testing for validity, there was significant results in the relationship between decrease IR ROM in pitchers and greater posterior shoulder tightness ($p=0.003$). This was performed by testing both pitchers and non impaired subjects. The correlation analysis showed that for every 4° of IR ROM loss there was an increase of posterior shoulder tightness, shown by an increase of 1 cm from the medial epicondyle to the table.

Tyler and colleagues,[45] also sought out to find if there was a relationship with posterior capsule tightness and changes in shoulder ROM in patients with shoulder impingement. Patients were measured for posterior capsular tightness using a technique described in another study done by Tyler et al. Subjects included were 33 people with no history of shoulder injury or disease as well as 31 people with a diagnosis of positive Neer's impingement sign indicating shoulder impingement. These results were compared to passive IR measurements of patient lying supine with their shoulder in 90° abduction in the coronal plane with standard goniometry. Results showed that patients with dominant arm impingement demonstrated significant loss of IR (p=0.01) and greater posterior capsular tightness (p=0.01). Patients with non-dominant arm impingement showed significant loss of IR (p=0.04), and greater posterior capsular tightness (p=0.03). Therefore, the researchers provided information that a relationship exists between posterior capsular tightness and limitations of IR ROM deficits.

Similarly, the objective of Thomas and colleagues,[11] was to compare the glenohumeral joint ROM and scapular position of 21 healthy high school baseball players to 31 NCAA Division I collegiate baseball players. Researchers measured IR and ER with a digital inclinometer. Subjects were placed into supine with 90° of glenohumeral abduction. Testers stabilized the humeral head with a hand as the arm was rotated until the tester detected motion of the humerus. An inclinometer was placed onto the dorsal portion of the forearm and it was set to record the three repetitions. Bilateral measurements were averaged. Results indicate that that collegiate baseball players had increased GIRD (4.8°, P=0.28) and increased total motion deficit (5.7°, $P = 0.009$) as compared to the high school players. The findings suggest that total motion deficits secondary to GIRD may result in compensatory scapular motions, increasing the likelihood for potential injury. Researchers suggested that as the level of competition increased in the baseball players with increased throwing exposure, GIRD and scapular dyskinesis increased as a pattern of athletes with shoulder injuries. Scapular dyskinesis is related to glenohumeral injury as decreased upward rotation, decreasing the subacromial space. Additionally, these athletes presented with forward shoulders and increased thoracic kyphosis, altering the resting position of the scapula, and thus the upward rotation. Decreased upward rotation as a result of inhibited serratus anterior and lower trapezius approximates the distance of the acromion and the edge of the rotator cuff, increasing risk for injury.

Additionally, a study performed by Borich et al.[12] researched the relationship of glenohumeral IR ROM deficit and scapular positioning during active motion. Twenty-three subjects were included in the study who were all considered asymptomatic overhead athletes who had competed in upper extremity sports within the last 5 years. Subjects were categorized in groups based on if they had GIRD or not, which was further defined as IR ROM of $\geq$20% deficit when comparing the dominant arm to the non-dominant arm. To accomplish their research, 3-D imaging (Flock of Birds electromagnetic motion capture system) was used with sensors on the subjects' scapula, humerus and thorax. Shoulders were measured in standing with supported with a sling to maintain $90^0$ of elevation. Then subjects performed active IR and ER in 90° of abduction and also in 90° of flexion. Scapular anterior tilt, IR and upward rotation were measured. Results showed that the GIRD deficit group had significantly greater anterior scapular tipping in both positions ($F_{1.21}$=5.02, p=<0.04) of and average 9.2° more tipping in the deficit group. Also there was a significant association between percent glenohumeral IR deficit and scapular position in both positions as described previously. Scapular upward rotation was significantly associated with GIRD at 90° humeral abduction. There was a strong and significant correlation (0.59) noted with anterior tipping and both positions of IR measurement ($p=0.005$). The difference between groups was 8.5°-9.8° of scapular tilt in peak glenohumeral IR for both positions. In conclusion, there was an increase in scapular anterior tilt at end range IR in both positions for the subjects with significant IR loss. Therefore, there is a relationship with IR deficit and abnormal scapular position.

The etiology of GIRD is clearly questioned as to what makes up the changes in ROM values. HRV, posterior capsule thickening, and muscle passive stiffness may play a role or potentially cause the changes of reduced IR. While we have a better understanding through literature as to why this happens, the measurement of IR remains variable, but necessary. Further examination of different techniques will help to guide clinical practice.

### *Positioning*

In addition to the several methods of measurement, the literature presents with varying positions in which researchers and clinicians can measure glenohumeral internal ROM. The standard method of positioning that is traditionally used is in the supine and 90° abducted position. Other methods include a seated, sidelying, standing, and a vertebral position.

Measurement in supine has been described as the traditional position. Wilk et al.[13] examined the reliability of three different stabilization techniques on the glenohumeral IR in a supine position. The positions all started in supine with the elbow flexed to 90° and the shoulder abducted to 90°. Stabilization was provided in technique one with placement of the palm of the hand over the clavicle, coracoid process and humeral head. The second technique had stabilization of the scapula with the use of grasping the coracoid process as well as the spine of scapula on the posterior side. The third technique was done by having the tested observe when the scapula began to elevate from the table but no stabilization was given. Three separate groups of a physical therapist and an athletic trainer performed measurements on a group of 20 asymptomatic overhead athletes. Therapists measured IR ROM on each of the participants in the first group within 5 minutes of each other. In total, five trials were performed on five different days. Results indicate that all three techniques yielded similar inter-rater reliability, but scapular stabilization methods had the highest intra-rater and reproducibility (ICC=0.62) as compared to the humeral head stabilization and no manual stabilization techniques. The authors indicated that scapular stabilization should be performed to obtain more precise and reproducible measurements. Wilk promoted the supine position for measurement due to its well-established norms and due to the fact that it is commonly present in clinics as described in Norkin and White.[43]

Also examining the traditional position, Ellenbecker et al.,[21] examined the supine, abducted position and sought to determine whether differences exist between IR and ER in a group of overhead athletes with regards to dominant and non-dominant arms. Subjects consisted of 203 junior elite tennis players ages 11-17. The participants were tested using goniometry in supine with 90° glenohumeral abduction and scapulothoracic stabilization was provided using a posteriorly-directed force over the coracoid process and anterior aspect of the acromion. There was no allowance of scapular protraction or elevation with this stabilization technique. Active IR and ER of both arms were tested. Results showed significantly reduced dominant arm IR (52.2° ± 10.7°, p=<0.001) and significantly reduced dominant arm total range of ROM (157.4° ± 14.9°, p=<0.001). No differences were shown in external ROM between extremities.

Cools et al.[14] compared the traditional supine position to a seated position in a study to determine their reliability by assessing differences in measurement values. The position of both supine and seated is described as 90° of glenohumeral abduction and 90° for forward flexion with differences of having the body either supine or seated. During the supine position stabilization was provided scapular and trunk stabilization. The seated position had no stabilization during measurement. Although researchers were mainly focused on finding inter-rater and intra-rater reliability of ROM measurement of shoulder IR and ER, they also made some findings about the role of positioning in measurement of ROM in their study. With use of measurements in both sitting and supine positions, reduced ICC's for goniometric measurements were noted for IR in sitting and supine (ICC=0.85). Their explanation included that the stabilization of scapula was not perfectly controlled. The researchers in this study suggested use of supine position for possible increase in body stabilization. Although there was lower results with seated IR ROM measurements, the reliability still fell within the good range showing importance for consistency and potential use of two testers to ensure as much stabilization as possible.

Also**,** a study done by McCully et al.[19] sought to determine significant variables in positioning for finding ROM values. They examined whether plane of motion, end-range determination (active vs passive), or scapular motion affects shoulder ROM measurements. Using 16 subjects ages 20-32 who had no known shoulder pathology they tested patients in multiple positions. Subjects performed both active and passive shoulder rotation in 90° humeral elevation in coronal, scapular, and sagittal planes and with the arm at the side with use of immobilizer splint in the seated position. Measurements were taken with electromyography to ensure minimal muscle activity in passive motion and shoulder kinematic measurement with Fastrak device for precise joint motion measurements. Significant results included greater IR and ER ROM when measured passively in all planes ($p=<0.05$). Overall, the results demonstrated that passive humero-thoracic motion was greater than active with the most dramatic effect in an increase of mean passive IR in coronal plane of 15°. These results stress the importance of consistent PROM measurements within clinics to achieve accurate results depending on plane of motion.

Due to the importance of consistent measurements, the use of the sidelying position has been proposed. A study done in 2015 by Cieminski et al.[46] set out to develop normative data for the sidelying total arc of motion to find differences between supine and sidelying measurements. A sample of 176 healthy, collegiate athletes were recruited for the study. In supine, examiners stabilized the scapula by giving a downward pressure through the acromion and coracoid process. Then, the subjects were passively moved through supine IR and ER although with no stabilization for ER. While participants were in the sidelying position with 90° shoulder flexion and 90° elbow flexion, measurements of IR, ER and total arc of motion were recorded. Based on the 176 healthy participants the sidelying data for total arc of motion showed to be 159.6° ± 15.0° for the dominant shoulder and 163.3° ± 15.3° for the non-dominant shoulder which is less than supine totals. In the supine position, dominant shoulders showed a 174.0° ± 17.1° total arc of motion and the non-dominant shoulder showed 177.8° ± 17.3° total arc of motion. The difference in total arc of motion was significantly different for supine and sidelying ($P<0.0001$) with a difference of 14.4° on the dominant shoulder and 14.5° on the non-dominant shoulder, with sidelying having less motion. In both the supine position and the sidelying position subjects showed less of a total arc of motion in their dominant shoulder than in their non-dominant shoulder. Next, it was noted that the difference of the dominant and non-dominant arm in both positions displayed a mean difference of 4° which is significant ($p<0.0001$). Since the sidelying position had a smaller total arc of motion difference, more investigation of the use of this position for determining shoulder injury is indicated. The intra-rater and inter rater reliability for supine IR, sidelying IR and supine ER positions were also measured. Intra-rater and inter-rater reliability was found to be highest with sidelying IR ROM with ICC values of 0.87-0.97 (intra-rater) and 0.91 (inter-rater).

Kevern, Beecher, and Rao[23] also investigated the reliability of the sidelying position, in addition to two other testing positions. Reliability of measurement was determined for glenohumeral IR, ER, and total arc of motion in each of the three separate positions. The positions tested with use of inclinometer were standard supine, supine without overpressure, and sidelying. The study was done on 38 NCAA DI baseball and softball athletes. Results displayed excellent intra-rater reliability for IR and ER ROM for all positions with a range of ICC's from 0.93-0.99. Inter-rater reliability was highest in the sidelying positions (0.68) although not as favorable as the intra-rater reliability. The sidelying position also had the most consistent levels of inter-rater reliability for all measurements. Conclusions made included that the sidelying test position has as good or better intra-rater and inter-rater reliability, compared to the supine position.

Results describing better reliability of measurement in sidelying as compared to supine were consistent with the study performed by Lunden et al.[15] This study examined the difference between inter-rater and intra-rater reliability of shoulder PROM in the supine and sidelying positions. A total of 70 subjects (51 without shoulder pathology, 19 with shoulder pathology) were examined by two physical therapists. Each patient was examined twice by each physical therapist. Two positions were measured: 1) supine with the shoulder abducted to 90°, elbow flexed to 90°, with the scapula stabilized by downward pressure through the acromion and coracoid process, and 2) sidelying with the shoulder being measured on the plinth and flexed to 90° and the elbow also flexed to 90°. A standard goniometer was used to measure PROM, one side covered with athletic tape so the rater was blinded to the measurement. ICC values were determined for inter-rater reliability and intra-rater reliability for shoulder IR measurements in a healthy and pathological population. Intra-rater reliability in both the supine and sidelying position had ICC values greater than 0.86, excluding tester one's measurement in supine for the pathology group (0.70). The healthy group had inter-rater reliability ICC values of 0.81 for the supine position and 0.88 for the sidelying position. The pathological group's inter-rater reliability was 0.74 for supine and 0.96 for sidelying. A significant difference in normative values was also noted between the supine and sidelying positions with sidelying IR ROM being significantly lower (p=<0.01). These results showed good to excellent intra-rater reliability for the sidelying position and only fair to good reliability in the supine position. Inter-rater reliability was also higher in both healthy and subjects with pathology in the sidelying position.

With knowledge of the established research in sidelying positioning, Carcia et al,[47] aimed to establish preliminary mean passive glenohumeral IR values in the sidelying position. The purpose of determining normative data was based on the new understanding that sidelying IR produced more reliable results for inter- and intra-rater reliability than the supine position.[15,23] This also addressed a need because of the increased use in clinics of the sidelying position to determine IR ROM values. Subjects included 60 healthy college-age who did not participate in overhead athletes. Measurements were taken after performing three active shoulder stretches to warm up. Participants were positioned to lie on their right side with arm perpendicular to their side having the elbow at 90°. An inclinometer was used to measure passive IR. Results showed that mean ROM for dominant arm at 52.7° ± 10.2° and non-dominant arm mean ROM at 48° ± 12.5°. There were no differences in gender.[47]

Recently, Cieminski et al.[16] examined shoulder IR ROM between three positions; sidelying, semi-sidelying, and supine. Along with this information, normative data was established from IR ROM values for the sidelying and semi-sidelying positions for non-athletic subjects. A total of 204 non-athletic subjects were studied on both dominant and non-dominant arms. Supine measurements were taken according to standard goniometry with use of a posteriorly directed stabilization to the acromion and coracoid process to stabilize scapular motion.[43] Sidelying position measurement was taken with the subject lying on the measuring side with the humerus passively flexed to 90° with horizontal adduction, elbow flexion of 90° and while maintaining neutral rotation. With semi-sidelying position measurements, the subject was supported by a wooden block fabricated to create a 45° angle of the subject. Each measurement was taken with a bubble inclinometer on the dorsum of the subject's distal forearm. The results showed that all positions had ICC values of good to excellent with the highest inter-rater reliability of 0.91 for the sidelying position. With use of IR ROM in the sidelying position, normative data for males include 42° and 51° for the dominant and non-dominant shoulder and for females values of 49° and 55° for dominant and non-dominant shoulders.

A study by Kibler and colleagues[5] noted that rotational motion should be measured with the subject in supine, the arm abducted to 90° in the plane of the scapula with a towel underneath the humerus. Kibler noted how GIRD and total arc of rotational motion may alter glenohumeral and scapular mechanics, resulting in increased clinical incidences of labral pathology and impingement syndrome. In order to treat GIRD, Kibler cited the sidelying sleeper stretch as the most common intervention. The subject should be positioned in supine in order to stress posterior shoulder musculature and capsule. The sidelying position provides scapular stabilization and often improves glenohumeral IR.

In addition to the supine and sidelying positions, a vertebral method for measuring IR has been utilized. A study by Green and colleagues[30] mentioned previously also contribute to understanding positions for IR measurements. Green and colleagues examined the inter-rater and intra-rater reliability utilizing the vertebral IR in addition to measuring IR in a 45° abducted position in supine using a Plurimeter-V inclinometer. To measure using the hand behind the back also known as the vertebral method, the tester had the patient stand and reach behind their back. Then the tester recorded the highest anatomical landmark reached by their thumb. Internal rotation in abduction was measured in supine by abducting the patient's arm to 45° or enough to clear the hip, the elbow was put into 90° of flexion and the forearm was fully pronated. The reliability for intra-rater ICC for IR in abduction was 0.79- 0.82 and for hand behind the back method was 0.84-0.90. The inter-rater ICC for IR in abduction was 0.44-0.47 and the hand behind the back method as 0.75-.090. These results suggest that the behind the back method is more reliable in both inter- and intra-rater using an inclinometer than measuring IR with abduction in supine.

A similar study done by Ginn, Cohen, and Herbert[48] in 2006 aimed to determine if active hand-behind-back ROM accurately correlate with shoulder IR measured in the standard supine position. A sample of 137 volunteer subjects with unilateral shoulder pain either over the joint or in the proximal arm were used. Testers measured the subjects in two positions: standing with hand behind the back and supine with the shoulder abducted. Testers asked the subjects to “reach up the center of their spine with their thumb as far as possible” and then the distance between the radial styloid and T1 spinous process was measured to the nearest 0.5 cm. shoulder. Active IR was measured by having the subject lie supine with their shoulder abducted to 90° and elbow flexed to 90°. The subject moved to their full ROM and a camera photographed the end range. Internal rotation ROM was assessed by measuring the angle of a line, passing through the olecranon process and ulnar styloid process, in reference to the horizontal table. The correlation was poor between active IR and hand-behind-back motion with a coefficient of 0.64 showing that the hand-behind-back is not recommended for clinical use.

Along the same lines, Hall et al.[49] compared the reliability and accuracy of IR with the shoulder in abducted position as compared to measuring by the most cephalad vertebral spinous process reached by a subject's extended thumb. Physicians trained in sports medicine or shoulder surgery measured 48 asymptomatic subjects' IR. Subjects were placed in supine with the arm abducted to 90° and the elbow bent to 90° as testers measured IR with a goniometer. Subjects were also asked to perform behind the back IR and measurements were recorded on lateral scoliosis films. Inter-rater reliability for the behind the spinous process method indicated good agreement between observers (ICC=0.75) and the examiners differed 1.8 levels, on average, from actual radiographic vertebral levels. The inter-rater reliability for the supine had an ICC of 0.81. IR measured in a supine position with a goniometer tends to maximize objectivity as it had a superior reliability and reproducibility to that of the spinous process method.

These study show that positioning of the patient can impact the measurement of IR of the shoulder. Similarity it is important to understand the role of scapular stabilization within these positions to fully grasp the actual motion that is occurring in this joint.

### *Hawkins-Kennedy Test for Diagnosing Shoulder Impingement*

In efforts to determine a subacromial impingement diagnoses, several clinical tests have been examined. Hawkins et al.[37] examined a population of symptomatic repetitive overhead athletes. Due to the repetitive overhead motions exhibited in this population, the supraspinatus and bicipital tendon tend to be impinged in the subacromial space of the shoulder. As a result of the avascular nature of the region, gradual degeneration and tears in the rotator cuff can occur in competitive and casual athletes. Hawkins described the pathology in three different stages. Stage I is distinguished by edema and hemorrhage in the region, Stage II is fibrosis and tendonitis, and Stage III is tendon degeneration, bony changes, and tendon ruptures within the glenohumeral joint. Hawkins established a diagnostic test known as the “impingement sign” that produces pain and facial expression. During the test, the patient’s arm is positioned in 90° of shoulder flexion, followed by forcible IR of the shoulder. The researchers suggest that based on high anatomic plausibility, the test reproduces pain in a pathological shoulder due to the supraspinatus tendon being forced against the anterior surface of the coracoacromial ligament. Hawkins suggests that the impingement sign tends to be a reliable physical sign in establishing a diagnosis for a pathological shoulder.

Tucker et al.[39] examined the anatomic validity of measuring subacromial pressure during the Hawkins-Kennedy test in cadaveric shoulders. Pressure transducers measured subacromial pressures in provocative and non-provocative Hawkins-Kennedy positions in the coracoid process, coracoacromial ligament, anterior acromion, and posterior acromion in addition to observation of the anatomical structures impinging on each transducer. A total of 25 repeated measures were performed on one cadaver. A split-middle method of visual analysis and the Reliability Change Index (RCI) examined the differences between the two test positions. The results indicate that the provocative position resulted in increased pressure at the coracoacromial ligament, impinging the biceps brachii at the anterior acromion, thus impinging the rotator interval. Overall, the findings suggest that the Hawkins-Kennedy test may impinge other structures in addition to the rotator cuff.

Also looking at Hawkins-Kennedy in practice, a study by Cadogan et al.[50] demonstrates a lack of acceptable reliability for the Hawkins-Kennedy test. During this study a sample of 40 subjects with current shoulder pain were examined by two seasoned physiotherapists using 6 diagnostic special tests; active compression, Hawkins-Kennedy, drop-arm, crank, the Kim, and belly-press tests. Most tests are used in practice but the Kim test is more novel. It is a test that applies axial pressure to the arm in an abducted position which if painful will indicate posteroinferior labral lesions.[51] The results displayed only fair inter-examiner agreement for the Hawkins-Kennedy test with a kappa value of 0.36 and an agreement of only 68%. These results help explain that the Hawkins-Kennedy test is not of good clinical value when inter-examiner agreement is required and displays lack of clinical application for use of this special test. The tests in the study that showed good inter-examiner reliability were the active compression, drop-arm, and Kim tests.[50]

In 2009, Johansson and Ivarson[38] performed a study to look at the reproducibility and reliability of various manual shoulder special tests for subacromial pain syndrome. The tests examined were the Neer’s Impingement, Hawkins-Kennedy, Patte maneuver, and Jobe supraspinatus test. Patients that were included all had shoulder pain for less than

16 weeks but didn’t have past shoulder surgery history. Of the 33 patients, ages ranging from 18-50, each special test was performed first by a single physical therapist and then again by that same therapist a week later, as well as an additional therapist at the follow up. The position of the Hawkins-Kennedy test was standard as the elbow and shoulder were flexed to 90°. Downward force was applied to the acromion to reduce thoraco-scapular movement. Forcibly pressure was applied in the medial direction of the forearm to determine a positive or negative test. The measurements were all taken an hour apart but guarantee of patient outcome memory could not be totally factored out. Based on the results all measures were considered to have very good to perfect reliability. The Hawkins-Kennedy had a near perfect Kappa of inter-examiner reliability of 0.91. This study concluded that the Hawkins-Kennedy is highly reliable and suitable for use in the clinical practice although most other articles describe the need for multiple tests in order to make sound judgement on a case of shoulder impingement

Similarly, Michener et al.[40] examined the reliability and diagnostic accuracy of several individual tests for subacromial impingement, including Hawkins-Kennedy. A total of 55 patients were recruited from a shoulder clinic by a shoulder surgeon. The patients were assessed for subacromial impingement with five different tests including Neer’s, painful arc, empty can Jobe, ER resistance test, and Hawkins-Kennedy. The outcomes of these tests were compared to surgical diagnosis as the reference standard. A receiver operating characteristic (ROC) analysis demonstrated significant area under the curve for all tests except for Hawkins-Kennedy. The painful arc, empty can, and ER resistance had positive likelihood ratios greater than 2.0. The painful arc, ER resistance, and Neer’s tests had negative likelihood ratios less than or equal to 0.50. Regression analysis revealed that no specific test or combination of tests effectively confirmed or ruled out subacromial impingement syndrome. Reliability for painful arc, empty can, and ER was of moderate to substantial agreement (kappa=0.45-0.67) whereas it was of fair strength of agreement for the Neer’s and Hawkins-Kennedy (kappa=0.39-0.40). The study concluded that the single tests of ER resistance, painful arc, and Neer’s are useful to rule out subacromial impingement and the single tests of painful arc, ER resistance, and empty can are useful to confirm subacromial impingement. All of the tests demonstrated acceptable reliability for clinical use. The authors provided a general guideline that 3 or more of the 5 positive tests can confirm subacromial impingement while less than 3 positive of 5 may be useful to rule out subacromial impingement.

A systematic review completed by Alqunaee et al.[41] sought to determine the accuracy of diagnostic subacromial impingement syndrome clinical tests. Many tests were considered including the Hawkins-Kennedy test. Sixteen articles were examined based on inclusion criteria of having a prospective or retrospective cohort, painful shoulder pathology and presence of a reference test. Seven of the studies addressed the Hawkins-Kennedy test. It was found that this test has a high sensitivity rate but a lower specificity. The article also presents information that the combination of multiple clinical test best predicts true pathology and is most comprehensive for diagnostic value within the clinical setting.

Finally, Park et al.[42] displayed the importance of using special tests in conjunction to determine diagnostic value when assessing impingement syndrome. A patient population of 913 individuals 4 weeks pre-surgical rotator cuff repair were examined to determine best clinical use of special tests. The tests examined included; Neer's impingement, Hawkins-Kennedy, painful arc sign, supraspinatus muscle strength, Speed's, cross-body adduction, drop-arm, and infraspinatus muscle strength tests. The Hawkins-Kennedy test was done in standing with arm at 90° of forward flexion with examiner-forced IR. End point was noted when pain was felt or the examiner determined rotation of the scapula. The test was positive if the subject expressed sensation of pain. The results of this study showed that with impingement patients, the tests with highest sensitivity and accuracy was the painful arc sign. Hawkins-Kennedy test had the highest sensitivity (75.4%) for partial thickness rotator cuff tears but lack adequate specificity (44%). It was determined that the combination of Hawkins-Kennedy, painful arc sign and infraspinatus muscles strength tests increased ratios of likelihood and post-test probabilities for overall impingement syndrome and full thickness rotator cuff tears. This is believed to be the most value and best positive combination to determine impingement disease.

### *Scapular Stabilization*

As will be discussed in the following articles, the literature tends to agree that scapular stabilization improves inter-rater and intra-rater reliability of IR measurement. The literature presents more disagreement in regards to the exact method of scapular stabilization that produces best inter-rater and intra-rater reliability. Existing methods to control for scapulothoracic excursion include visual inspection techniques, coracoid stabilization, amongst several others.

In the aforementioned study by McCully et al.[19] it was also determined that stabilizing the scapula allows for improved measurement of true glenohumeral IR while controlling for excess scapulothoracic motion. Researchers provided information regarding changes in ROM measurements based on planes of motion and muscle involvement. They also examined the motion of scapula to determine total arc of motion. By using electromyography and 3-D kinematic measurements in coronal, sagittal, and scapular planes of motion, they were able to further understand the role of scapulothoracic motion as they measured both IR and external rotation in these positions. Using analysis of the glenohumeral articulation for both passive and active motions, on average 89% of motion in all planes was due to true glenohumeral motion in rotation. In the scapular plane of motion where the scapula is most stabilized, the largest percentage of true active (90-96%) and passive (93-94%) glenohumeral motion was noted. McCully concluded that when determining true glenohumeral motion, stabilization of scapula is needed to accurately isolate desired motion.

Similarly to McCully et al., Boon[20] completed a study that examined the reliability of the technique as compared to measurements taken with no manual scapular stabilization in order to determine the effect of stabilization. Two groups of experienced and trained physical therapists, blinded to movement results, measured shoulder rotational ROM on the dominant arm of fifty high school athletes. Subjects were positioned in supine with 90° of glenohumeral abduction. The subject's arm was moved through full ER and then into IR, stopping with a capsular end-feel. The procedure was repeated twice, once with the scapula stabilized and once without for both the dominant and non-dominant arms. Measurements were repeated 5 days later. The results of the study indicate that rotational measurement with the scapula stabilized was significantly less as compared to when the scapula was not stabilized. Manual scapular stabilization revealed better intra-rater reliability (ICC=0.60) than non-stabilized (ICC=0.23). Similarly, inter-rater reliability was better for stabilized IR (ICC=0.38) than non-stabilized (ICC=0.13). When measuring glenohumeral IR, scapular stabilization should be used in order to gather more accurate, reliable measures of motion.

Awan et al.[22] explored which positions of stabilization, in particular, yield the most reliable results. Researchers measured shoulder IR in a supine position using a standard technique in which the scapula was not stabilized, manual scapular stabilization where researchers applied a posteriorly directed force against the subject’s coracoid process and clavicle with heel of hand, and visual inspection in which end range is assumed when the scapula has lifted from a surface during supine measurement. A convenience sample of 56 unimpaired high school athletes were recruited. Two independent groups of examiners completed the 3 measurement techniques twice on the subjects in order to determine intra- and inter-rater reliabilities. With each of the 3 techniques, shoulder IR ROM was measured with a digital inclinometer. The results suggest that intra-rater reliability for each of the 3 different techniques was good to excellent (ICC=0.63-0.71). Conversely, inter-rater reliability was lower than intra-rater reliability for all of the measurements. The results also indicate that IR ROM by visual inspection was significantly less as compared to the standard technique in which the scapula was not stabilized (p=0.001). The authors conclude that due to the fact that visual inspection and scapular stabilization techniques control for accessory scapulothoracic motion, they may represent more valid measures of shoulder IR ROM with adequate reliability for clinical use.

In comparison to the visual inspection technique, a previously described study by Ellenbecker et al.[21] investigated posteriorly-aimed coracoid stabilization method. The study was structured to determine ROM difference in dominant versus non-dominant arms of elite overhead motion athletes. They measured 203 junior elite tennis players for active internal and external ROM using scapular stabilization. This was done to find true glenohumeral motion by using a posterior force upon the coracoid process and anterior portion of acromion process to limit scapular elevation and protraction in a supine 90° abduction position. Significant results were noted with diminished IR of the dominant arm, as well as diminished total ROM in dominant arms as compared to IR ROM with no stabilization.

Wilk et al.[13] also hypothesized that significant differences exist in the amount of IR ROM depending on the method of a variety of scapular stabilization. Two groups of asymptomatic overhead athletes were recruited. The non-dominant shoulder was measured in the first group which consisted of 20 males in order to determine inter and intra-rater reliabilities as previously described. The second group consisted of 39 professional baseball players who were assessed during spring training physicals in order to detect any differences between the measurement techniques. Subjects were positioned in supine with 90° of glenohumeral abduction, 10° of horizontal adduction, and 90° of elbow flexion. Researchers then measured glenohumeral IR ROM through three different techniques. The first method involved stabilizing the humeral head by placing the palm of the hand over the clavicle, coracoid process, and humeral head; the second involved posteriorly grasping the coracoid process and the spine of the scapula; and the third method involved no stabilization with visual inspection to detect humeral head or scapular elevation from the measuring surface.

In order to detect any differences between the three separate methods in Wilk et al.,[13] one examiner positioned the shoulder and another read the measurements taken by a standard goniometer with a bubble level attachment. Order of arm dominance was randomized and the examiners were blinded to the results. The center of rotation was placed over the tip of the olecranon with the stationary arm placed perpendicularly to the ground and the moving arm along the ulna with respect to the ulnar styloid process. Examiners found a statistically significant difference between the measurement results of all three methods ($p=0.001$) and found that the visual inspection technique produced the greatest amount of motion and the humeral head stabilization produced the least amount. The authors recommend that the scapular stabilization technique be applied in order to allow for normal glenohumeral arthrokinematics while controlling for excessive scapulothoracic motion.

In comparison to the above techniques, Kevern et al.[23] proposed improved reliability and accuracy with a subject’s body weight stabilizing the scapula in a sidelying position for IR ROM measurements. With the 38 overhead athletes, researchers tested consistency and reliability of IR, ER and total arc of motion with varying positions. The positions included: 1) supine with overpressure and a capsular end feel, 2) supine without overpressure with a gravitational end feel, and 3) sidelying with a capsular end feel. The sidelying position was tested to limit torso rotation and maintain scapular position and decrease movements of the scapula. With the added force and weight of the patient's body, the shoulder's posterior musculature is more strained. The sidelying position showed excellent intra-rater reliability for IR ROM (ICC=0.99). It also showed the highest inter-rater reliability (ICC=0.68) and most consistent inter-rater reliability with regards to ER and total ROM as well. This study gives evidence that the sidelying position is as good or of greater value than traditional testing positions. There is reduced need to a second tester to stabilize the scapula due to the body self-stabilizing with the force of body weight. Not only is this position as reliable but it is also more practical in the clinical setting.

Normative side-lying IR ROM values were established in a study by Cieminski et al.[16] in 2016 for both genders with respective bilateral upper extremities in the non-athletic population. With the use of 204 subjects, values were measured in the supine, semi-sidelying and full side-lying positions. The intra-rater and inter-rater reliability were excellent in the side-lying position with values of ICC=0.87-0.97 and ICC=0.91. The results displayed IR ROM values for males as 42° in the dominant arm and 51° in the non-dominant shoulder. For females, the values were significantly greater ($p<0.0001$ for the dominant shoulder and $p=0.04$ for the non-dominant shoulder) with dominant shoulder averaging at 49° and non-dominant shoulder measuring at 55°. These values help to establish ease of clinical use with objective comparisons when using this position.

### *Measuring Shoulder Internal Rotation*

Measuring IR can be very valuable in understanding pathologies in the shoulder. However, there is controversy in the literature about what technique measuring the glenohumeral IR is most accurate. Currently there are multiple tools used to assist a clinician in measuring IR including: standard goniometer, digital goniometer, digital inclinometer (plurimeter, acumar and smart phone app), hand behind the back technique, and 3-D kinematics. Our study includes 3-D kinematics as a measurement technique, therefore, a more in depth review of the literature was conducted.

One of the most commonly used tools for measuring shoulder IR is a standard goniometer. Riddle et al.[24] examined the intra and inter-rater reliabilities for goniometric measurements of shoulder passive ROM with two different sized goniometers. A total of 50 subjects for two different testing sessions volunteered for the study ranging in age from 21-77 years of age for the first trial and 19-77 years for the second trial. A random pair of experienced physical therapists conducted all of the measurements with two plastic goniometers, one with a 5” moving arm and the other with a 10” moving arm. Therapists were blinded to the results of the measurements. Each therapist was allowed to use their own body positioning technique (supine, prone, side lying, standing, sitting). Researchers recorded information about subject positioning. Each therapist used the same body positioning technique when measuring IR; however, the position was not specifically stated. Therapists conducted each measurement twice with the two goniometer with the subjects in a standard supine position. The intra-rater reliability for IR for small and large goniometers yielded an ICC of 0.93 and 0.94, respectively. The inter-rater reliability for IR was poor (ICC large=0.55 and ICC small=0.43). The authors determined the poor reliability to not be related to body positioning due to each therapist using the same body position. The exact cause was not determined; however, the authors did not record how each therapist stabilized the scapula and questioned if this affected the reliability.

A study by Cools et al.[14] compared goniometric and inclinometer measurements in hopes to determine reliability for several procedures measuring IR and ER ROM and strength. The study examined the reliability of both the standard plastic goniometer with 1° increments along with a digital inclinometer having a capability of measuring a range up to 180° with an accuracy of 1°. Thirty college-age participants met the inclusion criteria which consisted of no reported history of shoulder or neck pain and no involvement in overhead sports competition. To test reliability, researchers had subjects perform ROM exercises to warm up muscles and improve flexibility before measurements. Then, subjects were tested by two researchers who were blinded to the results. One tester was in charge of stabilizing the scapula and trunk as well as performing shoulder ER or IR while the other tester handled the measurement tool. The subjects were tested in both sitting and supine with the goniometer and inclinometer separately. Results from measurements displayed good to excellent reliability for intra-rater and inter-rater for all procedures. Goniometric measurements displayed good to excellent intra-rater reliability (ICC=0.85) and inter-rater reliability (ICC= 0.99) with lowest ICC value for measurements in IR in 90° forward flexion in both sitting and supine. Researchers attribute this to lack of complete stabilization of scapula. Inclinometer measurements displayed excellent intra-rater reliability  (ICC=0.89) and inter-rater reliability (ICC=0.99). Minimal detectable change (MDC) for intra-rater measure with the goniometer was 4.4°-8.0°, whereas MDC for the inclinometer was 4.0°-6.4° at a 90% confidence interval. The results show good to excellent reliability for both measurement tools.

A 2015 study done by Furness et al.[25] found similar results after examining the reliability of a digital goniometer and inclinometer for measuring active motion in the shoulder in both prone and supine. Thirty shoulders were measured from 15 subjects with a mean age of 26.8. Subjects were excluded if they had acute or chronic shoulder pathology that would be affected by repeated internal and external ROM. Two physiotherapists were trained in the digital goniometer and inclinometer use, both therapists evaluated the participants by having them actively move through ER and IR in both supine and prone. The inclinometers results showed excellent intra-rater reliability for both ER in prone and supine and also in IR in prone and supine (ICC= ER: 0.82, 0.88; IR: 0.96, 0.96). Measurements taken by the digital goniometer yielded similar results with excellent intra-rater reliability for both ER in prone and supine and IR in prone and supine (ICC= ER: 0.85, 0.93; IR: 0.96, 0.84). Results of this study suggest that both the digital goniometer and the inclinometer are valid and reliable tools to use within clinical practice.

This study also set out to determine the concurrent validity for a digital goniometer due to lack of pre-existing evidence. The authors performed a correlation analysis comparing the digital goniometer to the inclinometer. ICC values for the digital goniometer revealed a significant ($p<0.01$) correlation with IR and ER in both the prone and supine positions. Researchers also found that IR had a stronger correlation between the two devices based on the calculated squared correlation coefficient.[25]

Another form of measuring shoulder ROM is using a Plurimeter-V Inclinometer, a study from 1998 done by Green and colleagues[30] was designed to assess inter-rater and intra-rater reliability and develop a protocol for measuring ROM of the shoulder using a Plurimeter-V Inclinometer. Six patients with differing degrees of pain and stiffness in unilateral or bilateral shoulders, were recruited from a private physiotherapy clinic. Six physiotherapists, independent of each other, measured total shoulder flexion, glenohumeral flexion, total shoulder abduction, glenohumeral abduction, ER in neutral abduction, ER in 90° abduction, IR in abduction and hand behind the back twice in each patient. The results of this study showed high intra-rater reliability (ICC=0.79 and 0.82) for IR in a 90° abduction position and a high intra-rater reliability (ICC= 0.84 and 0.90) for the hand behind the back method. The study also showed there was poor inter-rater reliability (ICC= 0.44 and 0.47) for IR in a 90° abduction position and a high inter-rater reliability (ICC= 0.75 and 0.90) for the hand behind the back method. The authors concluded that the protocol tested for the Plurimeter-V Inclinometer is reliable and would clinically appropriate for many populations due to the variety in the patients tested.

There are many downloadable phone apps for smart phones that have been used in the clinics to measure range of motion. A study done by Shin et al.[27] in 2012 examined the use of an inclinometer application on a smartphone compared to a standard goniometer for measuring varying shoulder ROM positions. The study also examined intra and inter-rater reliability of the two measurement techniques. Forty-one subjects with unilateral shoulder symptoms were recruited to participate in this study. Three examiners measured each subject in the following shoulder motions: flexion, abduction, ER with arm at the side, ER with 90° abduction, IR with 90° abduction. The examiner secured the smartphone to the ventral side of the subject's forearm at the wrist and then also measured the range with a goniometer. This procedure was repeated twice for every subject. The authors concluded that shoulder rotation with a smartphone application is comparable to the traditional goniometer when testing shoulder ROM except for IR at 90° abduction where inter-rater reliability had an ICC value ranging from 0.63 to 0.68. All other motions done by subjects had an ICC value from 0.79 and 0.89 and showed satisfactory inter-rater reliability. The researchers attributed this differences in ICC values between different motions to the variability of the degree of uncontrolled elbow flexion and carrying angle in the abduction position. This could affect the measurement because the position of the smartphone on the forearm.

Similarly, Werner et al.[28] aimed to establish the reliability and validity of measuring shoulder ROM with another smartphone digital clinometer application. A group consisting of a surgeon, fellow, resident, physician assistant, and a student examined bilateral shoulder ROM in 24 asymptomatic subjects and 15 postoperative, symptomatic patients. Examiners first measured ROM of each shoulder using a visual estimation, a goniometer, and then a smartphone clinometer (Plaincode Software Solutions for an iPhone). Patients were positioned in supine with the arm abducted to 90° and the elbow flexed to 90°. The inter-rater reliability among the testers was significant for visual estimation, goniometer, and digital inclinometer (ICC=0.61, 0.69, and 0.80, respectively) in asymptomatic patients. Inter-rater reliability results for the symptomatic population also showed significant correlation. The smartphone clinometer demonstrated excellent agreement with goniometric-based measurements across all levels of experience.

Another common method used to measure IR is the hand behind the behind the back method. A study by Edwards et al.[26] examined the inter-rater and intra-rater reliability of measuring IR by the vertebral level reached by the thumb behind the back. Three healthy male subjects were examined by two physical therapists and eleven orthopedic surgeons. A radiographic mark was placed on a vertebral level of the subject and then their thumb was placed on the marker, the examiner then made their measurement based on the mark and recorded the vertebral level they believed the patient was reaching to. This process was repeated twice more with each examiner. The subject then received an anteroposterior x-ray with the radiographic marker, the vertebral body measurement based on the X-ray was determined to be the true measurement. The inter-rater ICC for the three rounds included; 0.12, 0.27 and 0.25, indicating poor reliability. The intra-rater ICC for the three rounds showed slightly better results with a range from 0.02 to 0.82 with an average of 0.44. Results of this study found that measuring shoulder IR by recording the vertebral level reached behind the back is not reliable when measured within and between raters. They attributed this poor reliability to measuring healthy subjects with full ROM, assuming that the larger the range being measured the more room for error.

Lidenfield and colleagues[6] set out to examine glenohumeral joint ROM to understand the inter-rater and intra-rater reliability for a new clinical instrument called a shoulder rotation testing instrument. Two orthopedic surgeons examined 37 subject by setting the subject up in a shoulder rotation testing instrument (subject lying supine) and then instructing them to move through the entire arc of motion from neutral to IR to ER and then back to the starting position. The device stabilized the shoulder by placing a five pound weight over the humeral head to prevent it from lifting off the table. Each tester took measurements 3 separate times. Researchers found that the standard deviation between measurements was no greater that 2° showing there was no significant source of variance for measurements due to the trial, setup of the subject in the shoulder rotation testing instrument or observer differences. These results suggest that this new clinical device is a reliable tool to measure glenohumeral IR and ER.

Next, a study by Rhoad[52] investigated a method to measure shoulder ROM that combines magnetic resonance imaging (MRI) and a software system. This method allows for analysis of glenohumeral kinematics with a non-invasive technique. The study aimed to validate the quantitative accuracy of the measurement technique and to illustrate the glenohumeral motion during internal and ER of asymptomatic subjects. First, the accuracy of the system was determined by assessing glenohumeral cadaveric translations as compared to MRI images from the cadaver. Subjects were placed in a positioning device that held the arm in ER. Each subject’s arm was then moved through 10° increments of active internal and ER. The software program generated three-dimensional images in each position of the glenoid and humerus in order to demonstrate the glenohumeral positioning and relationship. Results from the study indicate that the system yielded a 0.61mm error (SEM=0.11mm) and a normal relationship about the glenohumeral joint during shoulder rotations. The technique was beneficial to produce a detailed image of the bony anatomy of the shoulder and to produce a cinematic, three-dimensional reconstruction of active shoulder movements.

The literature shows varying degrees of reliability and validity when measuring internal rotation. Consistently the research has shown that intra-rater reliability is much higher than inter-rater reliability for standard goniometer, digital goniometer, digital inclinometer, and hand behind the back technique. This discrepancy has been attributed to different stabilization techniques between therapists. Two measurement techniques have shown to have strong reliability for both inter-rater and intra-rater measurements: the gravity goniometer and smart phone application. These ranges of reliability has led to further research to determine the best scapular stabilization techniques to allow for consistent measurements between therapists. Commonly in this research, a 3-D kinematic system is used to measure ROM.

### *Three-Dimensional (3-D) Kinematics*

In order to measure movement of underlying bones without use of invasive bone pins, several systems using skin-based markers have been developed, including optical and electromagnetic tracking systems.

#### Optical Tracking Systems

Optical tracking systems estimate movement of underlying bones using light, cameras, and passive or active skin-based markers. Active optical systems utilize trackers with light-emitting diodes attached. The tracker position is calculated based on light from the diodes that has been picked up by multiple high-speed cameras. Passive optical systems function by surrounding camera lenses with infrared light-emitting diodes. This light hits the retroreflective or high-contrast printed pattern sensors and is reflected back to the camera lens by one of at least three reflectors surrounding each tracker.[32,34]

Optical tracking systems are extremely accurate, able to locate individual markers within 1 millimeter. They also provide a larger tracking volume compared to other types of systems. Optical tracking systems can capture a volume of $20m^3$, making it a system of choice for high velocity and multi-joint movements.[31] However, the sizable trackers and a requirement for a direct line-of-sight between the trackers and cameras limit the practical use of these systems.[31-32]

### Electromagnetic Tracking Systems

Electromagnetic (EM) systems use a transmitter to generate an electromagnetic field.[32] The system measures the orientation of the tracker based on the orientation of the magnetic field.[53] Electromagnetic tracking systems utilize smaller trackers and are available at a lower cost than optical tracking systems.[32-33] These systems may either be active, using wires to connect the sensors to the tracking system, or passive, using radiofrequency. The methods of communication between the trackers and the system negates the need for direct line-of-sight required when working with an optical tracking system.[32] Electromagnetic systems have been shown to accurately measure the distance between sensors within 3.0 mm during static tests.[34]

A study by Ludewig et al.[54] compared EM motion tracking system data to the gold standard, bone-pins. The subject was a 48-year-old man with an external humeral fixator consisting of four steel pins in the humeral shaft. The sensors were attached to a thermoplastic cuff worn at the distal humerus, as well as the sternum, and the acromion process. Data was collected from 4 trials of 4 movements including ER and IR with an adducted arm, scapular plane abduction, and sagittal plane flexion. The study found that movement of underlying bone was accurately represented by the measurements taken using the thermoplastic cuff with the exception of IR and ER, where the discrepancy of 15.6° between bone-pins and the sensors reached statistical significance. The study also found that the electromagnetic system accurately measured humeral helical axis translation, with only one value, x-axis translation in flexion, found statistically different than data from bone pins except.

Karduna et al.,[55] found similar results when testing the accuracy of the Flock of Birds systems. To measure the bone movement under the skin, Karduna attached sensors to the acromion in 8 healthy subjects as well as one subject with a history of subacromial impingement syndrome. To measure the bone movement under the skin, Karduna attached sensors to the acromion in 8 healthy subjects as well as one subject with a history of subacromial impingement syndrome. Electromagnetic tracking sensors were placed on the scapula and thorax and were compared to bone pins, drilled into cortical bone by an orthopedic surgeon. The bones were placed 20 mm apart at the lateral aspect of the scapular spine. The use of bone pins in this manner is the current gold standard for measuring movement of underlying bones. The humerus receiver was mounted to a cuff that could be strapped to the distal humerus to allow for a flat spot to attach the sensor. The receivers were attached using double-sided tape to the flat part of the acromion just above the posterolateral corner. Bone pins were inserted into the scapula by an orthopedic surgeon to assess the concurrent validity. Four shoulder motions of flexion in the scapular and sagittal plane, horizontal adduction, and IR to ER was observed. This method demonstrated good agreement between the skin and bone based receivers when assessing humeral elevation up to 120°. There were large discrepancies between skin and bone based receivers when assessing humeral elevation at end range. From these studies, we can conclude that an electromagnetic motion tracking system using sensors on the skin accurately measure movement of underlying bone, though rates of error increase above 120° of humeral elevation and with rotational motions.

A study completed by Myers et al.[56] recruited 15 healthy subjects to determine reliability and precision of scapular kinematics in an intra-session research designs. An electromagnetic tracking device was used to measure scapular movement while subjects moved through humeral elevation and depression in various planes. This data was used to calculate an intra-session intra-class correlation coefficient (ICC) and a standard error of measurement (SEM) for each scapular variable. A mean ICC of 0.97± 0.03 for reliability and 0.99±0.36° for precision suggest that electromagnetic tracking devices have high reliability and precision when measuring scapular kinematic measurements and can be used effectively in intra-session research designs.

Reliability and validity of the Flock of Birds EM system specifically, was investigated by Scibek and Carcia.[35] Eleven healthy subjects with no history of shoulder, neck, back, or lower extremity pathology in the past 6 months were recruited. Subjects were to complete 2 testing sessions, between 12-24 hours apart and performed no strenuous physical activity during that time. The Flock of Birds electromagnetic system was utilized with sensors at the distal humerus with a strapping system, on the acromion process of the scapula, and on the spinous process of the seventh cervical vertebrae. The kinematic data from this system was compared to a digital inclinometer for 3 repetitions of humeral elevation to 120° in scapular, frontal, and sagittal planes. Fair to excellent intra-session reliability was found for humeral and scapular kinematics, as well as angular measurements with ICC values ranging from 0.49 to 1.00 and most inter-session reliability values fell between moderate to excellent categories though the ICC values ranged from 0.05-1.00 in this case. Strong correlations were found between electromagnetic range of motion data and the range of motion measurements from the digital inclinometer. This study suggests that the Flock of Birds electromagnetic system can reliably measure humeral elevation range of motion within a session and between sessions.

Disadvantages of an EM tracking system include a smaller tracking volume, 1 $m^3$ compared to the $20m^3$ displayed with the optical tracking systems,[31-32] heavier receivers, potential for wires to affect measurements,[31] potential for metal interference,[32-33] and increases in error for tests where sensors are in motion.[34]

## Sources of Error and Confounding Variables in 3-D Motion Analysis

### Skin Motion Artifact Error

The skin-based sensors used with these systems is a potential source for error. Skin marker displacements ranging from several millimeters up to 40 millimeters have been shown.[57] Numerous studies have investigated if these sensors accurately depict the movements of underlying bone compared to the current gold-standard, cortical bone pins.

A study by Reinschmidt et al.[58] investigated the effect of skin artifact error at the knee joint in three male subjects during running. Six skin-based sensors were attached to both the thigh and lower-leg. Two cortical bone pins were inserted into the lateral tibia and femoral condyle of the subjects' right legs for comparison. Data was gathered for flexion, extension, internal and external knee rotation, abduction, and adduction. Errors were notably greater with the markers on the thigh compared to the lower-leg, where errors did not exceed five degrees. It was suggested that most of the error with the thigh markers was due to muscle activation, and could be decreased by placing sensors on bony landmarks rather than muscle bellies.

Sensor placement can be difficult on bones with few large, flat, bony landmarks, such as the scapula and the humerus. Due to its shape, the scapula can be it increasingly difficult to study the movement of the bone under the skin.[55] MRI gives an accurate picture of the bone however, they are expensive and not always an available resource when conducting research.[59] The aforementioned study by Karduna et al.[55] compared measurements from an electromagnetic system to the gold-standard, bone pins. It was determined, that below 120° of humeral elevation, the skin and bone based receivers demonstrated good agreement. Over the entire range of ER, root mean square (RMS) error was 9.4° for the acromial method. Using this acromial method, the RMS error represented as a percentage of the total ROM was 19° for posterior tipping was 4° for upward rotation, 32° for ER, 11° for clavicular plane, and 10° for clavicular elevation. Application of a correction factor helped reduced the RMS error for the acromion method from 6.3° to 2.0° when measuring upward rotation. Overall, an electromagnetic tracking system for shoulder movements was found to be accurate for shoulder motions where the humerus was elevated less than 120°. However, when the shoulder is elevated over 120° there is an increased risk of skin artifact error and may have higher rates of error in those with greater body mass index (BMI).[55]

Another study attempted to look at the accuracy of different placements of skin surface markers when measuring scapular kinematics. Skin movement can cause significant error when trying to track the scapula, especially at the inferior angle where there is significant skin movement. This skin movement can reduce the accuracy of measuring scapular kinematics. In the study by Bourne et al.[60] it was discovered that markers used in the cranial caudal direction were the most accurate at measuring posterior tipping, Markers used along the spine of the scapula were most accurate at measuring ER of the scapula. Lastly, an intermediate arrangement of the markers was found to be most accurate for measuring upward rotation and is the best overall marker arrangement.

In the studies by Karduna et al. and Bourne et al.,[55,60] only scapular markers were examined and humeral surface sensors were not assessed. It can be difficult when trying to use an electromagnetic sensor on the distal humerus as there it lacks a flat spot to attach the sensor. Hamming et al.[61] conducted further research to determine the accuracy of using a surface humeral cuff when assessing glenohumeral motion. Bone pins were inserted on 19 subjects. Humeral cuffs were created for small, medium, and large sized arms. The study concluded the humeral cuff had accurate results when assessing elevation of the arms and measuring elevation rotation and humeral elevation rotation, along with axial rotations. Typically these values were less than 5°. However, there was a significant amount of error associated with axial rotation (12-14°) especially at the end of ER (30°). Overall these findings indicate skin motion artifact can be underestimated up to 30% at maximum excursion when measuring axial rotation.

The aforementioned study by Ludewig et al.[54] further studied the accuracy of the use of a thermoplastic cuff to create a flat bony landmark on the humerus. Maximal errors of 5.7° were reported for non-rotational movements, with rotational errors up to 15.6°. This suggests that thermoplastic cuffs can be utilized to measure most upper extremity movements with only small errors, but care should be taken when using the cuffs while measuring internal and ER as errors are large and therefore results cannot be directly compared to other measurement devices, such as goniometry.

### Metal Interference

When using an electromagnetic system, it is possible to have measurement errors related to metal interference in the environment.[33,34] These errors are thought to be caused by eddy currents found in the nearby metals which produce secondary magnetic fields that can then interfere with the electromagnetic field the transmitter produces. A study conducted by LaScalza and colleagues[33] attempted to determine the relationship of sampling rate on the accuracy using a Flock of Birds tracking system. A metal block was placed between a transmitter and 6 measurements positions. Data was collected at varying frequencies with aluminum, steel, and one without the metal present. The study concluded an EM device is considered to be more accurate when using a lower frequency in an aluminum environment and a higher frequency in a steel environment. Furthermore, it may be possible to minimize some of the effects from metal by carefully choosing an appropriate sampling rate. It also possible thanks to recent advances in technology, that the effect of metal artifact can be minimized due to decrease in size and increased accuracy of the sensors. System improvements have allowed researchers to detect when metal interference is occurring.[32]

Meskers et al.[36] conducted a study assessing the accuracy of the FOB electromagnetic tracking system. During the study, it was recognized that possible sources of error could be from metal interference in the environment. It was determined the electromagnetic systems needed calibration in order to help reduce some of this possible error. When the data points that were taken close to the steel enforced floor were removed from the analysis, the root-mean-square error became distinctly smaller.

### Effects of Motion Velocity

Other sources of error that could be present when using electromagnetic systems is the effects of motion velocity. Fayad's[62] study evaluated the effects of arm elevation in healthy subjects had on 3-D scapular kinematics. Surface sensors were attached to 30 healthy subjects over the sternum, the flat surface just above the posterior angle of the acromion process and a humeral cuff with a sensor attached to it was attached to the forearm. A fourth sensor was used for digitizing. Each participant was asked to raise their arm in the sagittal and frontal planes at both a self-selected slow speed and at a self-selected fast speed. Scapular orientation was also recorded at 60°, 90° and 120° of arm elevation in the frontal and sagittal planes in a static position. Euler angles were used to describe rotations. The results found concluded scapular rotation measurements did not differ between patient self-selected slow and fast movements. However, scapular ER mostly in the sagittal plane differed significantly between static and dynamic tasks. Scapular ER was found to be less in the static position than in the dynamic position especially when measured in the sagittal plane.

### Age

In a study by Lin and Olsen,[63] 3-D kinematics of the shoulder joint were measured on 25 healthy male subjects during four functional tasks. A FASTRAK motion analysis system and four sensors were used. Results of the study were analyzing using ANOVA calculations. This study showed that while body weight and body height did not significantly influence the result of the analysis ($p>0.05$), age had an effect on the amount of scapular motion. Older adults experienced significantly greater degrees of peak scapular upward rotation paired with lesser degrees of peak scapular tipping compared to younger participants. The SEM for functional tasks was found to be less than or equal to 2° and 4°, SEM for scapular mechanics were 3° and 2° using a 95% CI, and a good to excellent Pearson correlation values (0.81) was found. These measures suggest repeatability between trials.

## Range of Motion

McClure[64] set out to quantify and describe the three dimensional movement of the scapula when moving the arm through dynamic motions. They took 8 healthy subjects and inserted bone pins to the lateral spine of the scapula. An electromagnetic tracking device was then used to measure the rotational motion of the scapula through 3 active motions. The 3 motions were scapular plane elevation, shoulder flexion in the sagittal plane, and internal to ER with the arm elevated to 90° in the frontal plane. Motions were described in respect to the thorax using the basis of an Euler angle sequence. (ER/IR=z axis, upward/downward rotation=y axis and Posterior/anterior tipping=x axis). Each subject was asked to move their arms to a count of 3 on the way up and down while data was collected continuously at a rate of 10 Hz. The study found ER/IR of the humerus had relatively small amounts of scapular rotation except at end range in ER. At the end range of humeral ER, the scapula upwardly rotated, posterior tilted, and externally rotated while the clavicle retracted. The greatest difference assessed during humeral ER/IR rotation was found in scapular tipping and upward rotation at 30° to 60° of humeral ER.

Further examination demonstrated that the plane of motion of the humerus may affect the amount of movement of the scapula, though the glenohumeral movement remains the same. In a study by Pascoal and Morais[65] 3-D kinematics of the scapula were measured using electromagnetic tracking device Flock of Birds at 100 Hz with a 3 sensor set-up. Active ER was measured and compared in two positions, using the Hand Behind Neck test (HBN) and using a standard shoulder ER in an elevated position test (EREP). Results were analyzed using paired-sample *t*-tests. The study found that although end range ROM was not significantly different between the two tests, the scapula displayed an increase in internal/downward excursion and anterior spinal tilt during the HBN test than the EREP test. The differences in scapular excursion were deemed to be significant with values of $P<0.01$ scapular upward rotation and $P<0.01$ for scapular spinal tilt.

### History of Overhead Throwing Sports

A study by Ribeiro and Pascoal[66] recruited 26 healthy male subjects, half of whom were athletes, to analyze scapular movements at end-range active internal and ER. The measurements were taken in a 90/90 position in the scapular plane with support under the elbow to prevent adduction. The study used an electromagnetic tracking system. Four sensors on bony landmarks were used and data was collected at a 100 Hz per sensor for sampling rate. Data was analyzed using Independent sample t-tests and bivariate correlations. The study found that during ER, thoracohumeral angles were significantly less ($P<0.05$) for the athletes compared to the non-athletes. They also found that athletes' dominant scapulae were more posteriorly tilted and retracted. They also showed that there is a positive correlation between glenohumeral angles and scapular tilt ($r=0.68$; $p<0.01$). During IR, the opposite was observed, athletes showed significantly greater thoracohumeral angles ($p<0.05$) by a difference of about 18°, and the scapula had more retraction and anterior tilt than non-athletes. There was no significant difference in glenohumeral ROM overall. These findings suggest that over time, repeated overhead throwing leads to changes in shoulder mechanics.

# CHAPTER III:

# METHODS

## *Participants*

Participants included in this study were a sample of convenience, recruited by means of a flyer posted on the Minneapolis and St. Paul campus of St. Catherine University. No incentives were offered to subjects for their participation in this research study. Thirty healthy adults (Table 1) volunteered to participate. Criteria for inclusion in the study were that subjects were 18 years of age or older and were not currently experiencing shoulder pain. Exclusion criteria included: 1) history of previous shoulder surgery, fracture or dislocation; 2) pain that limits shoulder ROM; 3) currently participating in a medically-supervised shoulder rehabilitation program; 4) unable to sit or lie on their side; and 5) previous history of sensitivity to tape/adhesive that required medical attention.

## *Instrumentation*

Three-dimensional kinematic data was collected with Model 800 Trakstar sensors and a mid-range transmitter (Ascension Technology Corporation, Burlington, VT, USA). The Trakstar sensor can track up to six degrees of freedom with a reported static accuracy of 1.4 mm root-mean-square (RMS) for position and 0.5° RMS for orientation. The sensors were of minimal size, 8.0 mm x 20.0 mm, with a 3.3 m cable. The small size of sensors minimizes the potential of skin motion artifact that accompanies kinematic analysis of active shoulder motions. Kinematic data was gathered at 120 Hz and processed with Motion Monitor software (Innovative Sports Training, Chicago, IL, USA). This 3-dimensional electromagnetic tracking system consisted of a transmitter, three sensors, and a digitizer stylus and was used to measure 3-D scapular, humeral and thorax motion during various shoulder movements.

### *Procedures*

Approval from the St. Catherine University Institutional Review Board was obtained before collection of any data. Upon arrival all participants signed a consent form and completed a brief questionnaire to collect demographics and history of overhead shoulder activities and previous shoulder problems or surgeries. Demographics collected included age, height, weight, gender and arm dominance, which was determined by which arm a subject would use to throw a ball.

In order to standardize all data collection procedures, one researcher was responsible for placing the sensors on the skin, digitizing the subjects, and visually assessing participant's test positions. The clinician was considered to be criterion standard due to having 28 years of orthopedic physical therapy experience, as well as 14 years of experience with 3-D kinematic research.

Three-dimensional motion sensors were placed over bony landmarks by the researcher. Two sensors were placed directly on skin with double sided tape, one on the superior aspect of the sternum just inferior to the suprasternal notch and the other over the flat surface of the scapula immediately posterior to the acromioclavicular joint. If subjects were deemed to have excessive hair over the trunk sensor location a two square inch area was shaved to ensure for proper sensor adhesion. A third sensor was placed on a thermoplastic cuff that fit around the distal humerus just above the epicondyles. This cuff was secured to the distal humerus with Velcro straps. Another sensor was used to digitize various bony landmarks on the subject’s thorax, scapula, and humerus to create an anatomic coordinate system. The subject was in a seated position on the edge of a plinth for the digitization process.

Scapular and humeral kinematic variables were gathered from each participant's dominant arm using two positions: sidelying and sitting. In an attempt to minimize any order effect, a coin was flipped to determine the sequence of these two test positions. In the sidelying position, subjects were asked to lie on the table with their dominant arm down. To ensure consistency positioning while in sidelying, the researcher visually assessed the acromion processes and the pelvis to ensure they were in a vertical plane that was perpendicular to the table. The participant’s dominant shoulder and elbow were flexed to 90°. While maintaining this position, the rater passively moved the shoulder from maximal external rotation to maximal internal rotation and back at a rate of two seconds in each direction. This was repeated a total of 3 times. No manual scapular stabilization was provided by the researcher for sidelying data collection.

In the sitting position the subject dominant shoulder was placed into the Hawkins-Kennedy test position with the shoulder and elbow flexed to 90°. The distal humerus was supported by the researcher to maintain shoulder flexion during data collection. The researcher’s other hand was placed on the subject’s distal forearm.  While maintaining this position, the rater passively moved the shoulder from maximal external rotation to maximal internal rotation and back at a rate of two seconds in each direction. This was repeated a total of 3 times. Prior to collecting data for these two test positions, the resting orientation of the scapula was determined by collecting a resting file with the subject in a static sitting position.

*Data Reduction*

Scapular orientation relative to the trunk was described using a z, y', x" Cardan angle sequence. This sequence describes scapular internal/external rotation about an approximately vertical z-axis of the scapula, upward/downward rotation about the scapular y-axis directed approximately perpendicular to the plane of the scapula in an anterior direction, and anterior/posterior tipping about the x-axis of the scapula directed approximately parallel to the scapular spine in a lateral direction toward the posterior-lateral aspect of the acromion process. This sequence is recommended by the International Shoulder Group of the International Society of Biomechanics.[67]

Humerus orientation relative to the thorax was described using a z, y′, z″ Euler angle sequence. This sequence describes rotation first about the longitudinal z-axis of the humerus (plane of elevation), rotation about the humeral y-axis directed in an approximate anterior direction (elevation), and rotation again about the longitudinal z-axis of the humerus (internal/external rotation). The coordinate systems and humerus to thorax orientation sequences were used in accordance with recommendations from the International Shoulder Group of the International Society of Biomechanics.

A y, x′, z″ Cardan angle sequence was used to describe humerus motion relative to the scapula. This sequence describes humeral adduction/abduction about an approximately anteriorly-directed humeral y-axis, humeral flexion/extension about a laterally-directed x-axis of the humerus, and medial/lateral humeral rotation about a vertically-directed z-axis of the humerus. All of the rotation sequences chosen for this study minimized possible mathematical inconsistencies, such as gimbal lock.[67-68]

Raw kinematic data was filtered with a low-pass fourth-order zero-phase shift filter with a cutoff frequency of 6 Hz. Sensor position and orientation data relative to the transmitter was mathematically transformed into a local anatomic coordinate system for the humerus and thorax. Each of these segments underwent matrix transformation to move from the global to a local anatomic coordinate system, producing a 4 x 4 position and orientation matrix. Local anatomical axis systems on each of the segments were defined by vectors and planes created by the digitized points, and by the resultant orthogonal vectors created by taking the cross product of these vectors. Left-sided data was mathematically converted to right-sided data for statistical purposes.

### *Statistical Analysis*

The independent variables include participant position, BMI, age, gender, and dominant hand. Dependent variables include scapular tipping, glenohumeral (GH) IR ROM, the ratio of scapular tipping to GH IR ROM, and scapular internal/external rotation. All dependent variables were tested for normality for all test motions. The assumption of normal distribution was not violated for these variables for any test motion, so the use of parametric statistical tests was justified.

To determine the resting scapular position of subjects, a resting file of scapular position of all subjects with the arms resting at their side was taken at an arbitrary point in time (point 50). Next, researchers computed the mean of all of the subjects resting scapular position values. Subsequently, the average of the three repetitions in each testing position was utilized for statistical analyses.

Paired t-tests were used to test for a significant difference in means of scapular tipping, GH IR ROM, the ratio of scapular tipping and GH IR ROM, and scapular internal/external rotation between the sidelying sleeper stretch and Hawkins-Kennedy test positions. The level of statistical significance was set *a priori* at $\alpha=.05$. An Analysis of Covariance (ANCOVA) was used to examine the influence of the independent variables of BMI, age, and gender on the dependent variables.

# CHAPTER IV:

# RESULTS

The average resting position of the scapula for all subjects in this study was as follows: internal rotation of 38°±7.1°, upward rotation of 2.5°±5.7°, and anterior tipping of 2.9°±4.4°. To examine differences in the starting position of the scapula between the Hawkins-Kennedy test and the sidelying sleeper stretch position, paired *t*-tests were utilized to assess scapular IR/ER, scapular tipping, and scapular upward/downward rotation angles. No statistical difference was noted in the starting position of the scapula between the two positions for any of the scapular variables (p=0.54, p=0.36, p=0.48, respectively).

In order to determine total scapular tipping excursion of each subject between the Hawkins-Kennedy test and sidelying sleeper stretch position, scapular tipping was quantified at peak glenohumeral external and internal rotation. From these two values, the tipping excursion was calculated. The tipping excursion during the Hawkins-Kennedy test was 8.7°±6.3° of anterior tipping, while 4.7°±4.2° of posterior tipping was noted in the sidelying sleeper stretch position (Figure 1). A paired *t*-test determined this difference of 13.4° of tipping was statistically significant (p<0.0001).

Glenohumeral internal rotation excursion was measured in the same manner, again quantified from peak external rotation to peak internal rotation. The glenohumeral internal rotation excursion was 94.1°±13.2° during the Hawkins-Kennedy test position and 71.9°±15.9° in the sidelying sleeper stretch position (Figure 2). A paired *t*-test revealed this difference of 22.2° of excursion of glenohumeral internal rotation between the Hawkins-Kennedy test and sidelying sleeper stretch position was statistically significant ($p<0.0001$).

In order to normalize for the significant difference in glenohumeral internal rotation excursion between the two positions, scapular tipping excursion was then divided by glenohumeral internal rotation excursion and multiplied by 100. This was done for both positions. Therefore, a ratio was created between the scapular tipping excursion and glenohumeral internal rotation excursion for both positions. The amount of scapular tipping measured in the Hawkins-Kennedy test position was 9.7°±7.0° of anterior tipping per 100º of GH IR ROM and in the sidelying sleeper stretch there was 6.1°±5.5° of posterior tipping per 100º of GH IR ROM (Figure 3). This difference of 15.8° was statistically significant ($p<0.0001$).

Scapular internal and external rotation was also quantified at peak glenohumeral external and internal rotation and its excursion was determined. During the Hawkins-Kennedy test an excursion of 6.4°±5.2° of scapular internal rotation was noted. During the sidelying sleeper stretch position an excursion of 4.0°±3.5° of scapular external rotation was recorded (Figure 4). A paired t-test revealed that this difference of 10.4° was found to be statistically significant ($p<0.0001$). ANCOVA's revealed there was no effect of BMI, age, or gender on the scapular dependent variables.

# CHAPTER V:

# DISCUSSION

The primary purpose of this study was to investigate scapular kinematics during glenohumeral IR in the Hawkins-Kennedy and sidelying sleeper stretch positions and provide an explanation as to why one provokes pain and one does not, though the glenohumeral joint is in the same anatomical position in both conditions. There is currently a lack of research in this area and this study is the first to quantify scapular kinematics in both the sidelying sleeper stretch and Hawkins-Kennedy test positions.

Secondary purposes of this investigation were to compare the amount of glenohumeral IR ROM between these two conditions, as well as comparing the ratio of the amount of scapular tipping to glenohumeral IR ROM between the two conditions.

It was hypothesized that the sidelying sleeper stretch position would yield a significantly smaller amount of anterior tipping as an accessory motion to glenohumeral IR ROM, as compared to that which occurred in the Hawkins-Kennedy test position. The results reveal that the scapula anteriorly tipped in the Hawkins-Kennedy position and posteriorly tipped in the sidelying sleeper stretch position with the difference of amount of tipping between the two positions being significant. Karduna et al.[55] demonstrated that a difference >5° of scapular motion is considered clinically relevant. The results of this study exceeded this threshold.

The 3-D kinematic findings for scapular resting position in this study (IR of 38°$\pm$7.1°, upward rotation of 2.5°$\pm$5.7°, and anterior tipping of 2.9°$\pm$4.4°) are consistent with normal values from current literature. The population within this study, therefore, is considered to be relatively normal at baseline. A paired *t*-test revealed there was no significant difference between the starting position of the scapula at full shoulder ER between the two tests when analyzing scapular IR/ER (p=0.53), upward/downward rotation (p=0.48), and the degree of tilting (p=0.36). Although the positions were not significantly different, the power analysis was relatively low which suggests that a larger number of subjects would be necessary for future research.

Anterior tipping is known to be an accessory motion of IR and it is hypothesized that this reduces subacromial space, possibly leading to pain in the Hawkins-Kennedy test position.[69] Our results showed 8.7°±6.3° of anterior tipping excursion during the Hawkins-Kennedy test positions and 4.7°±4.2° of posterior tipping excursion during the sidelying sleeper stretch position (Figure 1). Considering this study focused on a healthy population, the tipping wasn't a result of a protective mechanism for pain but may have resulted from scapular positioning and stabilization. Differences not only exists but were found to be statistically different for the two tests positions when comparing tipping excursion (p<0.0001).

Glenohumeral IR excursion was recorded to determine baseline comparisons between the two test positions. Our study found an IR excursion of 94.1°±13.2° during the Hawkins-Kennedy test position and 71.9°±15.9° in the sidelying sleeper stretch position (Figure 2). The difference between these values were found to be statistically significant with a p-value <0.0001. These results are comparisons of excursion and not end-range ROM. It is shown that 3-D sensors with the humeral cuff under-represent end range ROM and therefore may not be comparable with end range IR values in previous studies.[61] In a study by Cieminski et al.[46] normative values for the total arc of glenohumeral rotational motion on the dominant shoulder in the sidelying position for healthy subjects was found to be 159.6°±15.0°. The data in the current study does not fall within Cieminski's established limits which may be attributed to several factors. First, the sidelying position produces a smaller arc of rotational motion from maximum ER to maximal IR due to the nature of the position. In addition, it also must be considered that assessing humeral rotation via 3-D techniques tends to grossly underestimate the actual total arc of motion in comparison to measurements taken with a goniometer.[61]

Due to the fact that there was a significant difference between glenohumeral IR excursion between the Hawkins-Kennedy and sidelying sleeper stretch position, it was necessary to account for this difference. A ratio was utilized to permit comparison between the two positions by taking the scapular tipping excursion divided by glenohumeral IR excursion and multiplying by 100. By normalizing scapular tipping excursion, it allowed for equal comparison of glenohumeral IR in each testing position. Each ratio that was calculated represents the amount of scapular tipping per 100° of glenohumeral IR. The ratio of scapular tipping calculated in the Hawkins-Kennedy test position was 9.7°±7.0° of anterior tipping excursion and in the sidelying sleeper stretch position was 6.1°±5.5° of posterior tipping excursion (Figure 3). The difference of 15.8° was statistically significant with a p-value of <0.0001. Karduna et al.[55] indicates that a difference greater than 5° of scapular motion is considered clinically significant. Before applying the ratio the difference in scapular tipping between the two test positions was 13.4°. After applying the ratio, the difference in scapular tipping between the two positions increased to 15.8°.

Besides anterior tipping, another scapular accessory motion of glenohumeral IR that has been found to decrease subacromial space is scapular IR.[69] These motions could contribute to pain provoked during the Hawkins-Kennedy test.[37,39] This study examined the IR and ER of the scapula during GH IR ROM. The results revealed 6.4°±5.2° of scapular IR excursion during the Hawkins-Kennedy test and 4.0°±3.5° of scapular ER excursion during the sidelying sleeper stretch positions. The difference of 10.4° was statistically significant ($p<0.0001$), further demonstrating the magnitude of differences in scapular positioning in the two conditions. In addition to scapular internal rotation observed, the Hawkins-Kennedy test position yielded 9.7° of anterior tipping excursion. In combination, the scapular internal rotation and anterior tipping motions likely decrease the subacromial space, which is consistent with the test provoking pain in patients with symptomatic shoulders. Again, this study is the first to specifically quantify the 3-D scapular kinematics in both the Hawkins-Kennedy test and sidelying sleeper stretch positions.

As our findings display, when placed in the sidelying sleeper stretch position, not only did the scapula significantly decrease the amount of anterior tipping but it completely reversed. In the Hawkins-Kennedy position, the tipped excursion had a mean of 9.7° of anterior tipping, whereas the sidelying sleeper stretch position had a mean of 6.1° of posterior tipping. Although it was hypothesized that the sidelying sleeper stretch position would yield less anterior tipping of the scapula, posterior tipping of the scapula was actually noted. This begs the questions as to how a passive stretch could reverse the position of the scapula while the humeroscapular and glenohumeral joints are in the same anatomical starting position.

One hypothesis for this phenomenon was how stabilization of the scapula changed functional muscular attachments. In a non-stabilized position of the Hawkins-Kennedy, the muscles stretched included the infraspinatus and the teres minor, the primary external rotators. The proximal attachment for the infraspinatus is the infraspinatus fossa, and for the teres minor, the lateral border of the scapula. When stretched, the passive tension on these attachments may produce scapular IR, elevation, and anterior tipping. It is assumed that there would be no muscle activation during a passive stretch, therefore the difference between the directional pull of the scapula due to muscle tensions may be based on positioning and stabilization of the lateral border of the scapula.

During the sidelying sleeper stretch position, the lateral border of the scapula was stabilized. This caused compression of tissue in that location and may have changed the point of stabilization for muscle pull to the lateral border of the scapula. That being assumed, the muscle tension would no longer originate at the muscle insertion but the lateral border instead. With change in muscle pull and the downward force assistance of gravity within the sidelying position, a force pulling the scapula into a posterior tipping position may have been created. As the muscle fibers of the teres minor specifically run from inferior to superior, the pull on the scapula would produce posterior tipping, and the scapular stabilization eliminated scapular elevation as an accessory motion. Gravity would play a role for downward force on the scapula in the sidelying positioning as it would assist for posterior tipping after the muscles initiated the change of scapular position. If the force came from the lower portion of the lateral border and the scapula and was influenced by gravity, the pull would likely have led to an increase in posterior tipping.

This relates also to the idea that during a closed chain movement, there is a change in muscle function during active movement as the pulling originates from the proximal attachment. When there is stabilization in active movement, the pull of the muscles surrounding the joint change. If compared to the passive pull of the scapula when the lateral border is stabilized, it was deduced there was a change in pull on the joint which is thought to be the reason for posterior tipping in the sidelying sleeper stretch position. No stabilization of the scapula exists in the Hawkins-Kennedy position, so the motion had no alterations that may arise during scapular stabilization. In order to more fully investigate this hypothesis, a cadaveric study would be required to measure the length tension of muscles in passive stretch and the involvement of the scapular joints.

### *Clinical Implications*

Clinical implications for this study include the following three components. First, the scapular posterior tipping and ER noted during the sidelying sleeper stretch may assist in maintaining the subacromial space. Ludewig[69] indicates that the motions that maintain the subacromial space include scapular posterior tipping, upward rotation, and ER. The findings of the current study of increased posterior tipping and ER may explain why pain does not typically occur during the sleeper stretch. Furthermore, research has shown that the sidelying sleeper stretch can help reduce posterior soft tissue tightness.[70] A study by Laudner found that the sidelying sleeper stretch position increases the flexibility of the posterior soft tissue structures of the shoulder, resulting in increased glenohumeral IR ROM.[70] Currently, no literature exists to specifically differentiate between posterior soft tissue tightness as compared to posterior glenohumeral joint capsule tightness.

Second, the findings were consistent with current research that suggests that the sidelying sleeper stretch can be utilized in the clinic as a non-provocative method to stretch the posterior soft tissue structures of the shoulder.[16,47,70] Laudner[70] discusses that the sidelying position stabilizes and externally rotates the scapula, which allows the stretch to be focused to the posterior capsule of the shoulder. As mentioned prior, during this study it was shown that passive GH IR in the sidelying position produces significant increases in scapular ER and posterior tipping despite having no significant difference in starting position between sidelying and the Hawkins-Kennedy test. The results from this study agreed with findings from Laudner,[70] and may even suggest that the sidelying sleeper stretch is a protective position for a symptomatic shoulder due to scapular posterior tipping and ER.

Finally, this study reinforces the need to strengthen the scapular stabilizing muscles in patients with shoulder pathologies in order to promote activation of muscles that preserve the subacromial space. The findings of this study highlight the importance of incorporating scapular strengthening exercises into the plan of care for those with shoulder pathology. Strengthening interventions may be focused on exercises that activate middle trapezius, lower trapezius, and especially serratus anterior. Serratus anterior is known to perform the three scapular accessory motions that preserve the subacromial space including posterior tipping, scapular upward rotation, and scapular IR. These motions function to maintain the subacromial space and protect soft tissue structures of the shoulder. Strengthening and activation of serratus anterior leads to decreased compressive forces on the soft tissue structures of the shoulder during active IR.

### *Limitations*

Previous research has demonstrated that there are sources of error associated with tracking 3-D kinematics. Skin motion artifact error, for example, is the discrepancy between movement picked up by the skin based sensors and the bony movement it intends to track. This phenomenon can affect the accuracy of the results, though it was minimized by placing sensors on bony prominences where there was less soft tissue to interfere.

Rates of error have been observed to increase with movements occurring above 120° of humeral elevation. A study by Karduna et al.[55] noted analysis of scapular motion with electromagnetic skin sensors were consistent with the gold standard measurement using bone pin when working below 120° of shoulder elevation and show an accurate representation of scapular motion. Therefore, limiting humeral elevation to 90° in both the Hawkins-Kennedy test and the sidelying sleeper stretch positions in this study helps to minimize this source of error.[55]

In addition, it has been observed that 3-D kinematic systems tend to underestimate glenohumeral rotational motion when compared with goniometric measurements.[61] This was a systematic error, however, and would not affect the overall ratio of GH IR to scapular tipping. While it is a limitation, it likely did not affect the results.

Finally, this research only looked at a sample of convenience, comprised of a healthy population, as history of shoulder pathology was an exclusion criteria for the study. This meant that these results could not be applied to other populations, such as those with history of shoulder pathology.

### *Future Studies*

A future study may incorporate additional subjects in order to determine if there was a significant difference in initial scapular positions between the Hawkins Kennedy test and sidelying sleeper stretch positions. Other future studies may investigate the scapular kinematics in the two positions with a symptomatic population to confirm that kinematics would not differ from that of the healthy controls. The anatomical cause of posterior tipping in the sidelying sleeper stretch position could also be investigated. With the scapula stabilized by the table, it was anticipated that either the scapula would not move or the amount of anterior tipping would be reduced. Not only did it reduce anterior tipping, but it created a posterior tipping. There is no current literature addressing this phenomenon. The combination of the stabilization of the lateral border of the scapula and tension produced in the posterior soft tissue structures may lead to the posterior tipping motion observed. Another area for future research would be to investigate which structure is being stretched in the sidelying sleeper stretch position. This research could help identify whether the posterior capsule or the posterior rotator cuff musculature is limiting the GH IR.

# CHAPTER VI:

# CONCLUSION

This study was the first to compare the examine the scapular kinematics associated with the Hawkins-Kennedy test and sidelying sleeper stretch positions in a healthy population. The Hawkins-Kennedy test position is known to be a provocative position in individuals with shoulder pathologies whereas previous literature suggests that the sidelying sleeper stretch is known to be a protective position for the shoulder soft tissue structures.

Typical scapular accessory motions that accompany glenohumeral IR include anterior tipping, upward rotation, and scapular IR. The data from this study suggests that the scapula anteriorly tipped and internally rotated during the Hawkins-Kennedy test. Data from this study also indicates that not only did the sidelying sleeper stretch position limit the amount of anterior tipping occurring at the scapula, but conversely, posterior tipping and scapular external rotation were observed. This combination has been hypothesized to be a protective mechanism at the shoulder, increasing the subacromial space and decreasing the potentially painful compressive forces on soft tissue structures.

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# TABLES

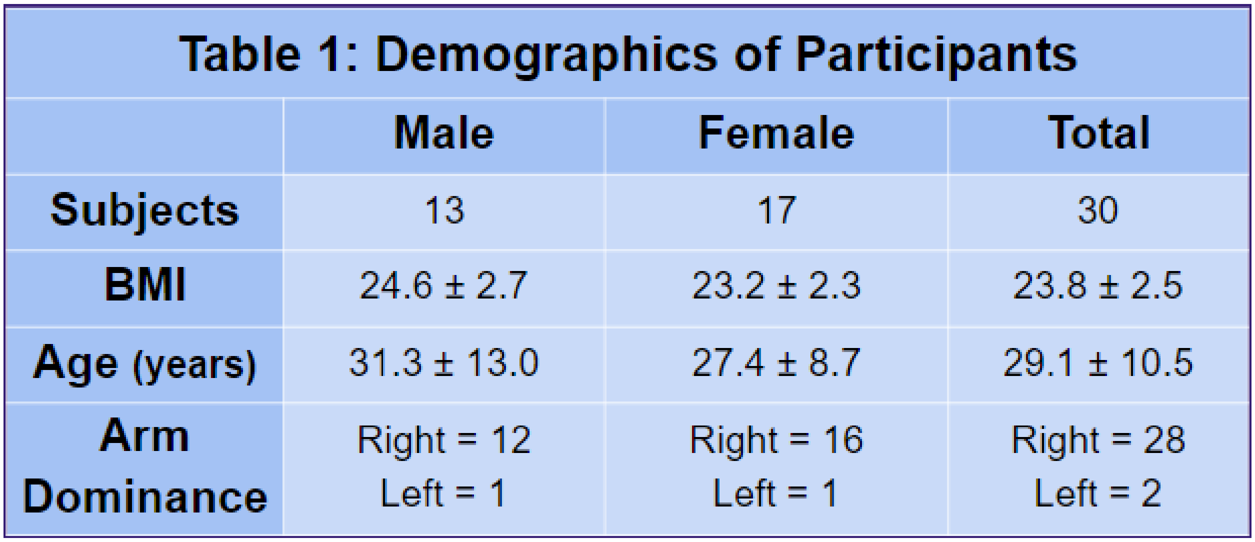

**Table 1: Demographics of Participants**

| | Male | Female | Total |
|---|---|---|---|
| **Subjects** | 13 | 17 | 30 |
| **BMI** | 24.6 ± 2.7 | 23.2 ± 2.3 | 23.8 ± 2.5 |
| **Age (years)** | 31.3 ± 13.0 | 27.4 ± 8.7 | 29.1 ± 10.5 |
| **Arm Dominance** | Right = 12<br>Left = 1 | Right = 16<br>Left = 1 | Right = 28<br>Left = 2 |

TABLE 1. Demographics of participants.

# FIGURES

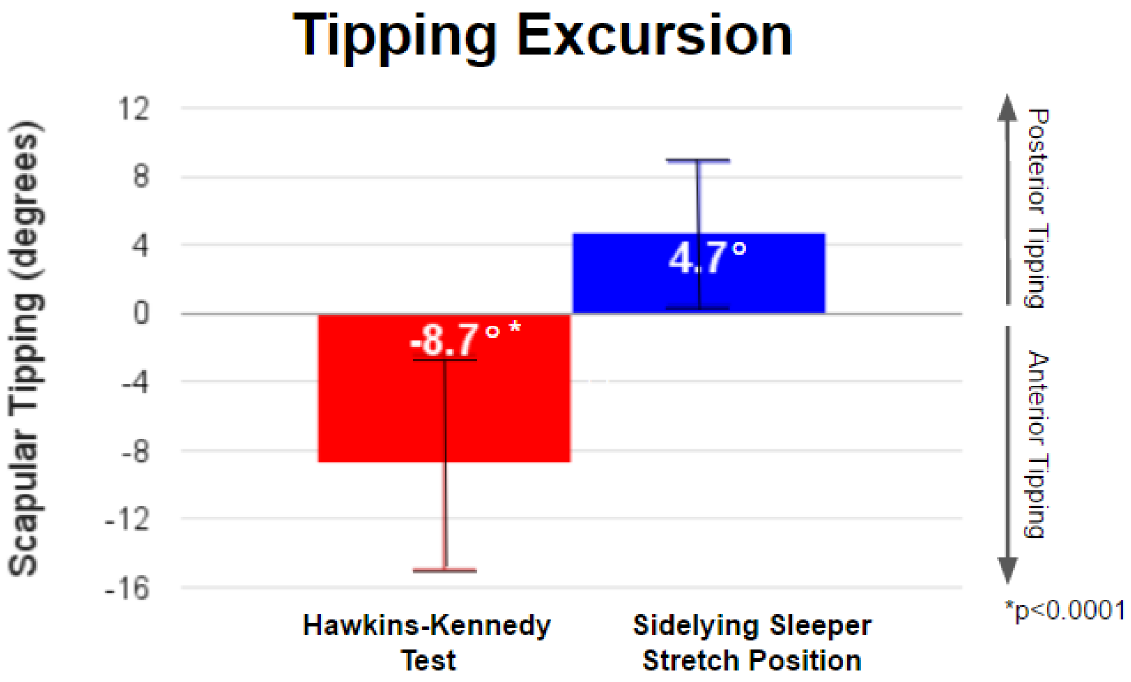

FIGURE 1: Scapular tipping excursion (Error bars indicate standard deviations of each group).

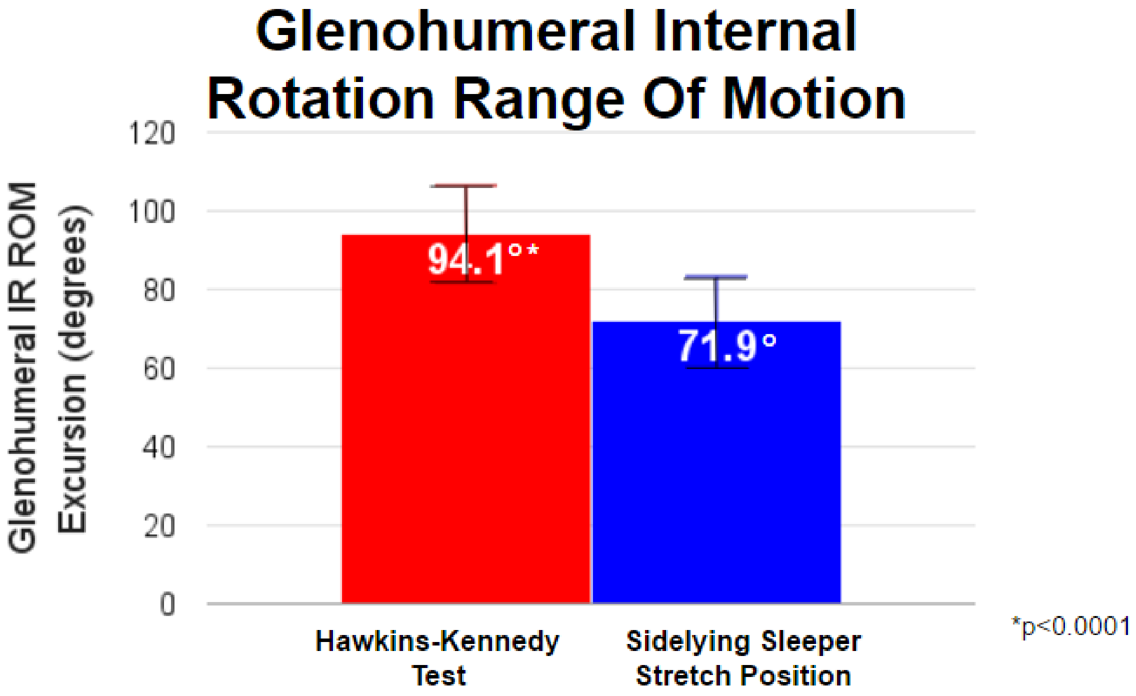

FIGURE 2: Glenohumeral internal rotation range of motion (error bars indicate standard deviations of each group).

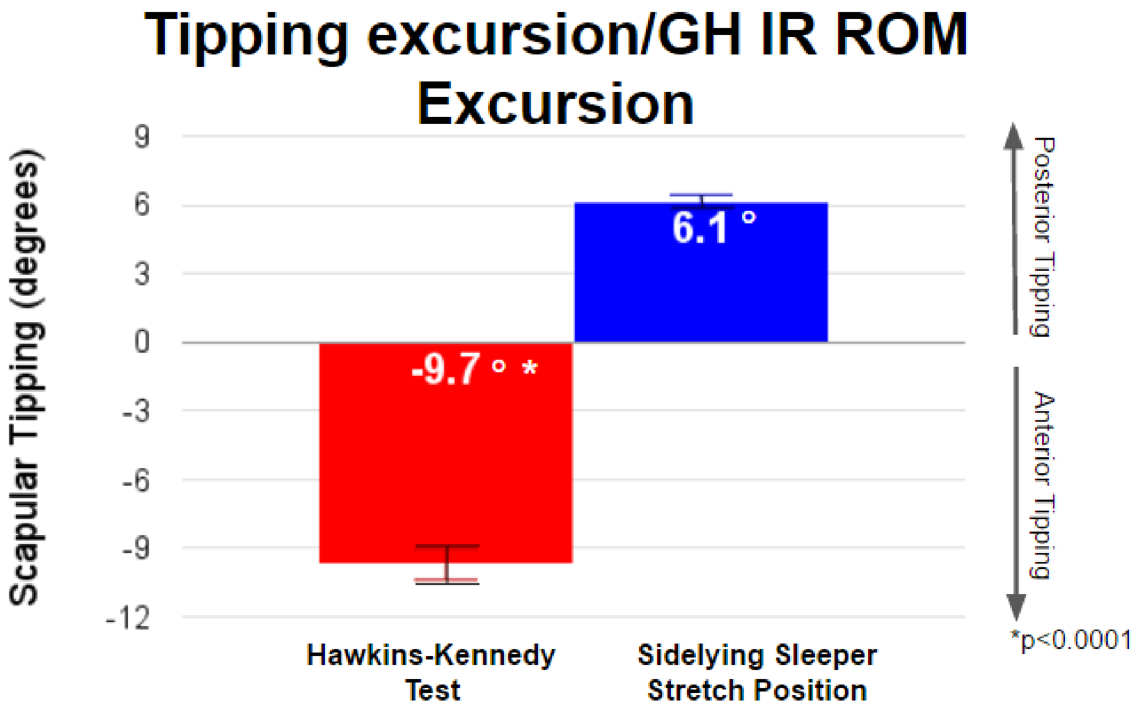

FIGURE 3: Ratio of scapular tipping excursion to glenohumeral internal rotation range of motion excursion (error bars indicate standard deviations of each group).

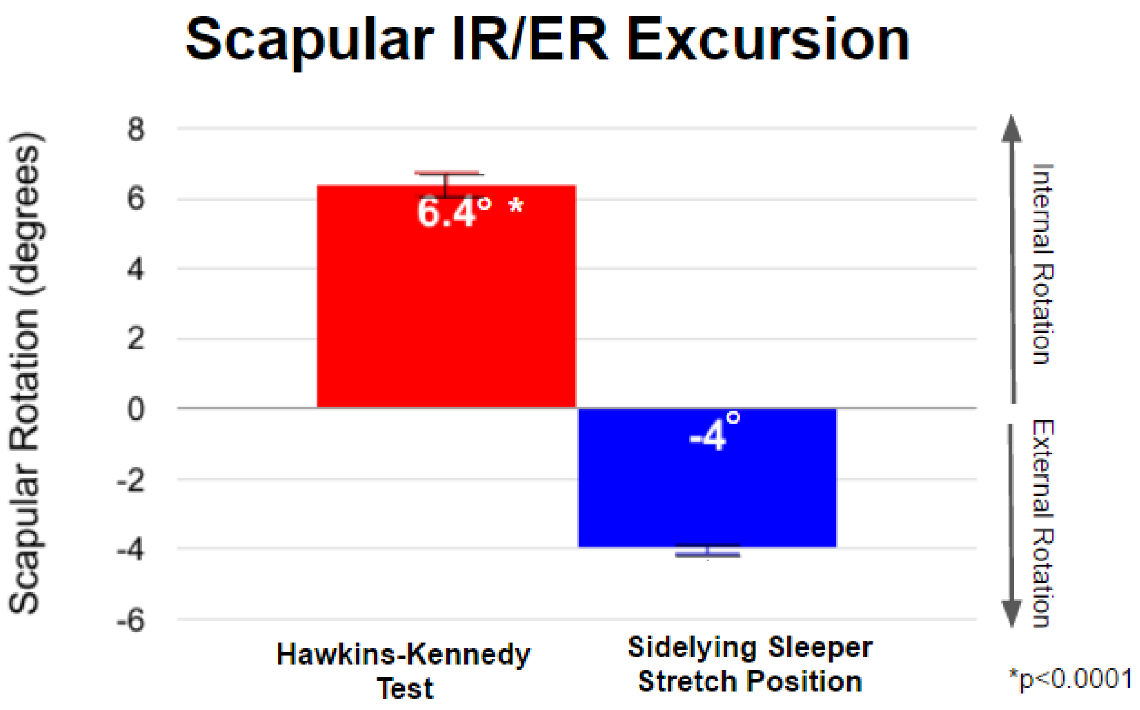

FIGURE 4: Scapular internal rotation and external rotation excursion (error bars indicate standard deviations of each group).

# APPENDIX A

## COMPARISON OF THE THREE-DIMENSIONAL MOTION OF THE SCAPULA DURING THE HAWKINS-KENNEDY TEST AND THE SIDELYING SLEEPER STRETCH

## RESEARCH INFORMATION AND CONSENT FORM

Introduction:
You are invited to participate in a research study to determine the three-dimensional motion of the shoulder blade during shoulder internal rotation range of motion activities. This study is being conducted by Dr. Cort Cieminski, faculty member in the Doctor of Physical Therapy (DPT) Program at St. Catherine University and 2nd year DPT students Alyssa Buchner, Tami Buus, Brittany Evans, Kirsten Lambert, and Lisa Scheevel. All testing will take place at the Women's Health Integrative Research Center in Fontbonne Hall on the St. Paul campus of St. Catherine University. Participants must be 18 years of age or older. You will be excluded from participation in the study if, on your dominant shoulder, you: 1) have a history of previous shoulder surgery, fracture, or dislocation; 2) have pain that limits your shoulder range of motion; 3) are currently participating in a medically-supervised shoulder rehabilitation program, or 4) are unable to sit or lie on your side. You will also be excluded from the study if you have a previous history of sensitivity to tape/adhesive that has required medical attention. Please read this form and ask questions before you decide whether to participate in the study.

Background Information:
Individuals who are experiencing shoulder pain are examined with a technique (Hawkins-Kennedy test) that is designed to reproduce their symptoms in order to determine the source of the pain. This technique is performed in a sitting positon; the arm is passively elevated to shoulder height and the shoulder is then internally rotated such that the hand is brought towards the floor. During this technique the shoulder blade has been hypothesized to tip forward and compresses soft tissue structures of the shoulder, leading to shoulder pain. In physical therapy treatment, individuals with this type of shoulder pain are typically given a stretch (Sleeper stretch) in a sidelying position that places the shoulder in the exact position as described above; a key difference is that the shoulder blade is stabilized by lying on it, theoretically stopping this forward tipping motion of the shoulder blade. While the shoulder assumes the same position during this stretch, very little shoulder pain has been reported in this sidelying position. This study, therefore, will examine differences in the three-dimensional motion of the shoulder blade, particularly this forward tipping motion, during shoulder internal rotation between the sitting and sidelying positions. Approximately 25 subjects are expected to participate in this research study and testing will take place during one session lasting between 45-60 minutes.

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

1. <u>Shoulder questionnaire</u>: An investigator will give you a brief questionnaire asking about your history of overhead shoulder activities and any previous shoulder problems or surgeries. This information includes providing your self-reported height and weight.
2. <u>Arm dominance:</u> This will be determined by asking you which arm you use to throw a

ball.

3. Three-dimensional motion sensor placement: While you are sitting, several bony locations on your trunk, shoulder blade and upper arm will be located by the researcher using their fingertips. This will allow two small motion sensors (each approximately 1/2 square inch in size) to be taped to your skin with double-sided tape -- one on your upper trunk just below your neck and one over the shoulder blade at the top of your shoulder. A third sensor will be placed on a plastic cuff that will fit around your arm just above the elbow; this cuff will be secured to your arm with Velcro straps. These sensors will detect the amount of three-dimensional movement of the shoulder that occurs during the two testing motions. Prior to placement of the sensors if it is determined that you have excessive hair over the upper trunk sensor location, you will be asked to gently shave a two square inch area to allow for proper adhesion of this sensor.
4. Testing positions: Once the sensors have been placed, you will be asked to lie on a treatment table on your side. The investigator will first move your arm away from your side to shoulder level with your elbow bent. The investigator will then passively rotate your shoulder to its end range so that the palm of your hand moves towards the floor (internal rotation). This process will be repeated three times. This same technique with then be performed with you in a sitting position. The sequence of these two test positions will be randomized to minimize any order effect. Data will only be collected on your dominant shoulder.

Risks and Benefits:

You may experience temporary minor muscle soreness after completing the shoulder motions. The use of ice packs, gentle stretching and/or possible rest from activity for a brief period of time after your testing session will minimize potential soreness. If soreness persists for more than two days, please contact a medical professional for appropriate treatment; the researchers are not responsible for any costs incurred for treatment secondary to your participation in this study. You may also experience some skin irritation due to the use of the adhesive tape; if present, you will be given an adhesive removal wipe. There are no direct benefits to you for participating in this research.

Confidentiality:

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

We will keep the research results in a password protected computer and in a locked file cabinet in the Women's Health and Integrative Research Center on the St. Paul campus of St. Catherine University and only the researcher(s) named in this form will have access to the records while we work on this project. We will finish analyzing the data by December 2016. We will then destroy all original reports and identifying information that can be linked back to you.

Voluntary nature of the study:

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

Contacts and questions:

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

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

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

I consent to participate in the study.

Signature of Participant Date

Signature of Researcher Date

## APPENDIX B

Subject ID# ______

## GENERAL INFORMATION
### Shoulder Questionnaire

Age (years)______________________
Height (inches)___________________
Weight (pounds)_____________________
Date of Birth ____/_____/__________
Sex: M / F

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

Have you played competitive or recreational sports within the last 5 years? Y/N
If yes: which sport(s)? ___________________________________________
What level of competition? _________________________________
How often? (per week)_____________________________________
For how long? (years & months) _____________________________

Have you ever injured your shoulder(s)?
Y/N
If yes, what type of injury:
Shoulder dislocation Y/N L/R
Labral tear Y/N L/R
AC or SC joint instability Y/N L/R
what if any stabilization was performed?_______________________________
what if any displacement was noted?__________________________________
Fracture: collarbone (clavicle) Y/N L/R
upper arm (humerus) Y/N L/R
shoulder blade (scapula) Y/N L/R
shoulder tendonitis Y/N L/R
shoulder impingement Y/N L/R
rotator cuff tear Y/N L/R
shoulder bursitis Y/N L/R
shoulder strain Y/N L/R
Other:

Have you ever had surgery on your shoulder(s)? Y/N
L/R
If yes, describe: ____________________________________________

Are you currently experiencing pain in your shoulder(s) during motion? Y/N
L/R
If yes, describe: ______________________________________________

Are you currently receiving any treatment for your shoulder(s)? Y/N
L/R
If yes, describe: ______________________________________________

Have you ever received any treatment for your shoulder(s)? Y/N L/R
If yes, describe: ______________________________________________

Are you currently able to lie on either side comfortably? Y/N
L/R
If no, describe: ______________________________________________

Are you currently able to lie on your back? Y/N
If no, describe: ______________________________________________

# APPENDIX C

## HIPAA AUTHORIZATION TO USE AND DISCLOSE

## INDIVIDUAL HEALTH INFORMATION FOR RESEARCH PURPOSES

1. **Purpose. As a research participant, I authorize [investigator names]to use and disclose my individual health information for the purpose of conducting the research project entitled [research project title here].**
2. **Individual Health Information to be Used or Disclosed. My individual health information that may be used or disclosed to conduct this research includes: [list the data that will be retrieved from the patient's health record].**
3. **Parties who may disclose my Individual Health Information. The principal investigator and co-investigators may obtain individual health information from:**

**[List the hospital, clinic, health care provider, or health plan/insurer from which the data will be obtained. Put "None" or "Not applicable" if data will not be used from that source]**

**Hospitals: ____________________________________________________________**

**Clinics: ______________________________________________________________**

**Other Providers: ______________________________________________________**

**Health Plan: __________________________________________________________**

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

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

1. **Right to Refuse to Sign This Authorization. I do not have to sign this Authorization. If I decide not to sign the Authorization, I may not be allowed to participate in this study or receive any benefits that are provided through this study. However, my decision not to sign this Authorization will not affect any other treatment, payment, or relationship with the College of St. Catherine, health care plans or health care providers.**
2. **Right to Revoke. I can change my mind and withdraw this Authorization at any time by sending a written notice to [list investigator name and address here] to**

**inform the researcher of my decision. If I withdraw this Authorization, the researcher may only use and disclose the protected health information already collected for this research study. No further health information about me will be collected by or disclosed to the researcher for this study.**

3. **Potential for Re-disclosure. My individual health information disclosed under this Authorization may be subject to re-disclosure outside the research study and no longer protected. For example, researchers in other studies could use my individual health information collected for this study without contacting me if they get approval form an Institutional Review Board (IRB) and agree to keep my information confidential.**

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

**This authorization does not have an expiration date.**

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

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

______________________________________

______________________________________

**signature of research participant or research participant's personal representative** **date**

______________________________________

______________________________________

**Printed name of research participant or research description of person representative's participant's personal representative authority to act on behalf of the research participant**