Evaluation of Three on-the-Field Non-Assisted Posterior Shoulder Stretches in Collegiate Baseball Pitchers

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EVALUATION OF THREE ON-THE-FIELD NON-ASSISTED POSTERIOR SHOULDER STRETCHES IN COLLEGIATE BASEBALL PITCHERS

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Introduction: Shoulder musculoskeletal adaptations commonly occur in baseball pitchers due to repetitive throwing and extremely high shoulder velocities. Some observed adaptations include posterior shoulder tightness (PST) and glenohumeral internal rotation deficit (GIRD). The static capsular structures and dynamic muscles of the shoulder that are responsible for controlling normal glenohumeral arthrokinematics, must be properly stretched for normal shoulder movement. It is speculated that appropriate posterior shoulder stretching of the glenohumeral joint can decrease the amount of PST in an overhead athlete, help minimize the risk of developing shoulder pathologies, and increase the ability of the overhead athlete to perform. The purpose of this study was to evaluate three on-the-field posterior shoulder stretches among collegiate baseball pitchers. It was hypothesized that the standing sleeper stretch at 90º, sleeper stretch at 45º, and the horizontal cross arm stretch would create acute ROM differences and provide scapular stabilization for increasing shoulder IR ROM and decreasing PST.

Methods: Glenohumeral ROM, PST, and scapular kinematics were measured in 15 male collegiate pitchers. All subjects were free of shoulder pain. Each subject performed one posterior shoulder stretch during 3 individual sessions. Glenohumeral ROM and PST were measured using an inclinometer/anthropometer, pre and post stretch while scapular kinematics were assessed using an electromagnetic tracking device during each stretch.

Results: The results of this study show that stretching created significant acute increases in glenohumeral IR ($p<0.0001$) and decreases in supine PST ($p<0.0001$) and side-lying PST ($p=0.012$). There were no significant differences between stretches for IR ($p=0.919$), ER ($p=0.494$), Supine PST ($p=0.536$), and Side-lying PST ($p=0.177$). The five scapular kinematic values showed no significant differences among stretches when compared for scapular upward rotation ($p=0.066$), external rotation ($p=0.077$), posterior tilting ($p=0.101$), protraction ($p=0.221$), and elevation ($p=0.228$).

Conclusions: This study has demonstrated that performing a posterior shoulder stretch for a single session of 3 repeated 30 seconds is adequate to significantly increase acute GH IR ROM and decrease PST. Sufficient scapular stabilization can be achieved when the standing sleeper stretch at 90º, standing sleeper stretch at 45º, and the standing horizontal cross arm stretch are performed correctly.

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PREFACE

I would like to acknowledge my committee members, Dr. Joseph Myers, Dr. Scott Lephart and Ms. Sakiko Oyama. My advisor, Dr. Joseph Myers has contributed significant time, support and guidance throughout the completion of this project. Dr. Scott Lephart has been a role model who has encouraged me throughout, and Ms. Sakiko Oyama, my doctoral mentor, has been more than supportive throughout this thesis project. I couldn't have completed this project without her dedication, assistance, and all her contributions. Lastly, I am grateful to my classmate and fiancé, Benjamin Goerger whose love and support has helped fulfill my academic experience.

1.0 INTRODUCTION

The overhead pitching motion is a highly dynamic movement requiring a balance of strength and flexibility, as well as coordination of all body segments for optimal performance. Physical examination of overhead-throwing athletes consistently demonstrates adaptive changes in glenohumeral range of motion (ROM)[1]. Current literature has documented that increased capsular and muscular tightness of the dominant posterior shoulder in throwing athletes has been associated with the development of altered shoulder rotational motion[2, 3].

Baseball pitchers are a population known to have a decrease in internal rotation (IR) ROM with a subsequent increase in external rotation (ER) ROM in their throwing arm[4-9]. Burkhart et al[6] have termed the loss of degrees of glenohumeral IR of the throwing shoulder compared to the non throwing shoulder as glenohumeral internal rotation deficit (GIRD). Pitchers demonstrate as much as 9º more external shoulder rotation at 90º abduction and 15º less internal shoulder rotation compared to the non dominant side[7]. Even though the components of total ROM in the throwing shoulder may be altered, the total arc of motion (ER + IR) is equal bilaterally [10].

Pitchers can generate arm velocities greater than 7000 deg/sec[3, 11-13]. Based on the qualitative and quantitative analysis of pitching presented by Dillman et al[14], they concluded that throwing a baseball at maximum velocity is one of the most highly dynamic skills in sports, displaying a rotational ROM that is significantly greater in their throwing shoulder[7, 11, 12, 15, 16].

The manifestation of this altered arc of motion has been hypothesized to be the result of a physiologic adaptation of the dominant shoulder through repetitive microtrauma that leads to selective stretching of the anterior capsule[17] and tightening of the posterior capsule during the cocking phase of throwing[2, 6, 8, 10, 18]. The cocking phase yields a 'tight wringing' of the anterior capsule when the throwing shoulder reaches the extreme range of ER, which subsequently leads to micro-injury[3]. During the deceleration phase of throwing, which is recognized to be the most violent phase of the throwing cycle[19], a simultaneous contraction of all muscle groups occurs with an eccentric contraction of the posterior capsule decelerating the arm. Due to the chronic tensile forces imparted during the deceleration phase, contracture of the posterior capsule is reportedly caused by reactive scarring[17]. The increase in ER has been theorized by Jobe et al[20] to result from a gradual attenuation of the anterioinferior capsular and ligamentous restraints, whereas the loss of IR has been theorized by Burkhart et al[6] to result from a reactive tightening of the posteriorinferior shoulder structures due to the loads that act on the dominant shoulder[10]. Posterior shoulder tightness (PST) is thought to be a possible cause of lost IR and is predominately found in the throwing athlete[2] due to the previously stated repetitive overhead motions[12, 21, 22]. Contracture of the posterior shoulder occurs in response to the loads that are placed upon it during the deceleration phase[6]. In response to the great strain that is placed on the shoulder complex, both the soft tissue and bony architecture may undergo adaptive changes[11], leading to the excessive ER and diminished IR in baseball pitchers[23].

The extreme range of ER coupled with tremendously high joint forces during the throwing motion can exceed the physiological limits of the joint, thereby placing tremendous stresses on the static stabilizing structures[12], such as the glenoid labrum, glenohumeral (GH) ligaments and capsule, and rotator interval[24]. These structures along with the dynamic stabilizing structures have been shown to play a significant role in allowing and controlling normal arthrokinematics between the humeral head and the glenoid[2].

Coordinated rotator cuff contraction plays a significant role in the maintenance of stability of the GH joint[25]. The posterior rotator cuff muscles have been found to be a critical component of the throwing shoudler[26], however, a contracture of the posterior capsule may result in anterior and superior migration of the humeral head[19]. With weakness in the rotator cuff muscles, fatigue, or improper mechanics, an inability to generate needed forces can lead to superior migration of the humeral head as well. Increased anterior humeral head translation along with loss of scapular upward rotation leads to diminished acromial elevation and rotator cuff impingement[27].

Particularly in the throwing athlete, tightness of the posterior shoulder musculature and lack of GH IR affects the normal motion of the scapulothoracic articulation[28] and leads to increased protraction of the scapula in cocking and follow through phases[13, 19]. This creates a "wind up" effect so that the glenoid and scapula are pulled in a forward inferior direction, thus resulting in excessive scapular protraction. This allows more anterior and inferior movement of the acrominon process, decreasing the subacromial arch[29], which leads to decreased clearance of the rotator cuff and increased risk for subacromial impingement[19]. With an increase in protraction, the scapula lacks the ability to fully retract, preventing the scapula from providing a stable base for cocking the arm during throwing[28, 30]. As acceleration proceeds, the scapula must protract laterally in a smooth fashion, to maintain a normal position in relation to the humerus and to dissipate some of the deceleration forces that occur during follow-through[28]. The movement of the scapula is vital in maintaining the synergism of the static and dynamic restraints of the glenohumeral joint[31], as well as providing a link to the proximal-to-distal sequencing of velocity, energy, and forces of shoulder function[28].

A considerable bony adaptation that is present in habitual throwers is humeral retroversion[4]. Krahl[32] proposed that humeral retroversion is produced as a result of muscular forces about the proximal humerus that act in constant opposition. Humeral retroversion is defined as the acute angle, in a medial and posterior direction, between the axis of the elbow joint and the axis through the center of the humeral head[11, 33]. This osseous adaptation of humeral retroversion has been reported, in previous studies, to allow greater degrees of ER and decrease the degrees of IR in the throwing athlete[16, 18]. An increase in humeral retroversion allows the articulating surface of the humeral head to remain in contact with the glenoid articulating surfaces while the GH joint externally rotates to a higher degree before the humeral head is constrained by the anterior capsule[19, 20, 34]. The increased ER angle temporarily extends the arm-cocking phase of the throw, providing a greater angle over which to accelerate the arm and ball[35]. It is important to keep in mind that gains in ER are not limited to anterior shoulder soft tissue adaptations.

The combination of PST, GIRD, excessive ER, and scapular dyskinesis may lead to intensified chronic shoulder pathology and altered throwing mechanisms. Burkhart et al[6] have hypothesized that many shoulder and elbow abnormalities, such as glenoid labrum lesions and ulnar collateral ligament sprains are due to PST, despite the lack of evidence of this tightness in prospective clinical studies[10]. PST has also been associated with SLAP lesions[6]. Because the posterior capsule is tight, ER causes the humerus to translate superiorly, placing stress on the biceps/labral complex. Eventually the posterior superior labrum begins to peel off the glenoid, resulting in posterior superior instability[6]. Abnormal superior or anterior translations of the humeral head in the glenoid, abnormal scapular motions, imbalances of the rotator cuff musculature, excessive capsular laxity, and or loss of capsular flexibility, have been implicated as etiologic factors in both GH instability and impingement syndrome[36, 37]. In the usual case of impingement the coracoacromial ligament and the anterior-inferior aspect of the acromion press on the bursal side of the rotator cuff during forward humeral elevation. That traditional mechanism of cuff injury does not explain the observed findings in overhead athletes[38]. Internal impingement in contradistinction to external impingement is the result of increased GH motion[38], shoulder instability, scapulothoracic weakness and PST[4, 37, 39]. As the humerus is brought into external rotation and abduction, such as in the late cocking phase of throwing, the articular side of the rotator cuff tendon is pinched against the posterior-superior glenoid rim[38]. Tyler et al[4] evaluated patients with subacromial impingement and correlated an increase in PST and a loss of GH IR. A recent study conducted by Myers et al[1] evaluated throwing athletes with pathologic internal shoulder impingement on GH ROM and PST. They concluded that throwers with impingement presented with a significant increase in GIRD and PST. These studies suggest that injury management should include stretching of the posterior shoulder to restore GH ROM[1, 4].

Any repetitive overhead activity requires complete synchrony of these dynamic stabilizers working in combination with the static capsulolabral structures. To achieve peak performances during overhead athletics, there must be an optimal balance between mobility and functional stability[8, 40]. The thrower's shoulder must be lax enough to allow excessive ER, but stable enough to prevent symptomatic humeral head subluxations. Loss of posterior shoulder mobility and dynamic control in the throwing shoulder of baseball players has been cited as a major contributing factor to pathologic shoulder dysfunction[27] and decreased level of performance in athletes[41]. It has been shown that increasing IR and decreasing PST enhances the ability of the overhead athletes to perform[42] and may decrease the risk of injury. Many overhead athletes simply want to maximize their performance and have the most efficient and functional shoulder possible, which makes a posterior shoulder stretching program important for the overhead athlete[21, 43].

Stretching during the warm-up has become a traditional practice in preparing for exercise or athletic activity[44]. Static stretching is one of the safest and most commonly performed stretching methods used to increase muscle length[45]. The literature supports that a static stretch of 30 seconds at a frequency of 3 repeated stretches per single session is sufficient to increase muscle length[46].

Baseball players repeatedly perform posterior shoulder stretches prior to activity for reasons of increasing flexibility[45, 47-49], preventing injuries[48, 50, 51], and improving muscular performance[47, 51]. Because the posterior shoulder inflexibility affects efficient motion of the shoulder[13, 21], studies have suggested that preseason baseball shoulder conditioning and rehabilitation should concentrate on stretching the posterior shoulder structures as well as obtaining a normal GH arc of motion[3] and strength[22]. Stretching of the posterior shoulder and rotator cuff is proposed as a fundamental component of treatment for overhead athletes[41] and any injury prevention program needs to be carefully designed to emphasize stretching of the posterior shoulder rather than stretching the entire upper limb[13] to address the limitation of IR[43].

The importance of stretching the posterior shoulder has been evident in previous studies. Kibler[52] divided two groups of high-level tennis players and evaluated them over two years. One group performed daily posterior inferior capsular stretches to minimize GIRD, and the control group performed no stretches. Over the 2 year period, those who stretched significantly increased IR and total rotation compared to the control group. In addition, those who stretched had a 38% decrease in the incidence of shoulder problems compared with the control group. Burkhart et al[6] states that approximately 90% of all throwers with symptomatic GIRD (greater than 25%) will respond positively to a compliant posteroinferior capsular stretching program. With the use of the sleeper stretches, they also state that GIRD can be reduced to an acceptable level within two weeks[6]. The Professional Baseball Athletic Training Society (PBATS) reported that baseball players with medial elbow pain and an IR deficit of more than 30º have increased their IR ROM after performing the sleeper stretch for 3-12 weeks[53]. Moreover, the baseball players' elbow pain decreased as their GIRD improved[53]. These reports support the theory that PST may be one of the factors leading to GIRD. Conversely, Burkhart et al[6] documented that 10% of throwers do not respond to stretching. These individuals tend to be older elite pitchers who have been throwing for years and tend to be on the severe end of the GIRD spectrum. It is important to understand that it is extremely unusual for high school and college pitchers to be non-responsive to stretching[6]. These facts should be used to mandate a posterior shoulder stretching program not only into all-aged baseball leagues but also as an injury prevention tool to be performed among all age players. This study has validated three non-assisted stretches that can be performed on-the-field prior to competition.

Even though there is a high prevalence of PST in baseball pitchers, no study has evaluated the effectiveness of non-assisted posterior shoulder stretches after 3 bouts of static stretching. Previous studies focusing on the lower extremity have shown that static stretching essentially creates acute decreases in strength output[54-60], and should not be done prior to high intensity competition. Knudson et al[61], did however, focus on tennis players and measured serve speed after two 15 second static stretches were performed on the dominant shoulder. Their results found no decrease in tennis serve performance after stretching and suggest that pre-activity stretching may not decrease performance in high-speed or accuracy-related movements.

This study evaluated the acute ROM differences after performing a static posterior shoulder stretch. A slow static stretch without warm-up could possibly produce sufficient warming of the muscles to aid in increases in flexibility[47]. It has been suggested in the literature that warmer muscles are more extensible leading to less injury, so therefore a mild warm-up should precede stretching exercises[62]. Myers et al [63] evaluated several rubber-tubing resistance exercises used by throwers as part of their pre-throwing warm-up routine. Their results found activation of the shoulder musculature used during pitching and suggest that those exercises may be beneficial for throwers during their pre-throwing warm-up routine. Those exercises may be used in conjunction with the posterior shoulder stretches to assure the baseball pitchers have the most appropriate warm-up session. Although the amount of stretching that must be performed to see immediate changes in muscle length as related to musculotendinous stiffness is unknown[57], this current study used three 30 second trials to compare each posterior shoulder stretch for specific increases in IR ROM and decreases in PST.

There are two categories of posterior shoulder stretches used among baseball players; assisted and non-assisted stretches. Assisted stretches are often done prior to the field with the help of the athletic trainer or clinician. Johansen et al [64] describes a prone position stretch where the clinician manually holds the inferior angle of the scapula along the thoracic wall in a retracted position to isolate the infraspinatus muscle. By pressing the scapula to the chest wall, the IR motions are applied directly to the GH joint[64]. Current literature[8, 65, 66] describes a supine horizontal adduction stretching technique where the clinician moves the humerus horizontally across the body while providing scapular stabilization. Scapular protraction is prevented by holding the scapula along its lateral border. This prevents the scapula from moving laterally during the stretch[66]. The most common stretch is an IR stretch with the subject in a supine position with their shoulder in 90º of GH abduction and elbow in 90º of flexion. The examiner stabilizes the GH joint and passively positions the arm into IR. Although these are all excellent stretching techniques, they all require assistance of another person.

The horizontal cross-arm stretch and the sleeper stretch are very common non-assisted posterior shoulder stretches. These stretches can both be performed independently on-the-field without the assistance of another person. Meister et al[67] states that the posterior shoulder is most effectively stretched when using cross-arm adduction techniques and rotational stretches with the patient lying on their side with the shoulder in 90º of forward flexion. The horizontal cross-arm stretch is easily performed with the patient standing with the selected shoulder flexed to 90º. The non-dominant arm passively horizontally adducts the dominant arm across the chest. A concern with this stretch is that the scapula is easily abducted.[21] Burkhart et al[6] and Mullaney[65] believe this stretch is most beneficial when the scapula remains retracted and stabilized when the arm is adducted across the chest. During the horizontal cross-arm stretch, care must be taken to ensure that stretching does not occur at the scapulothoracic articulation, but at the GH joint. Kibler [13] suggests that if the stretching occurs at the scapulothoracic articulation, it will increase rather than solve the biomechanical problem by allowing too much scapular protraction. To overcome this limitation, a wall support can be used to stabilize the scapula to isolate the GH joint. When the upper back and lateral border of the scapula is pressed against the wall, the scapula cannot follow the humerus across the body during the stretch.[68] The fixation of the scapula decreases the amount of stretching coming from the scapulothoracic articulation[68], thus allowing this traditional posterior shoulder stretch to isolate the posterior shoulder structures to a greater degree.[6]

The sleeper stretch is a stretching technique that specifically isolates the posterior-inferior shoulder structures, and has become very popular in the clinical setting. It can be performed either in a side lying position or standing position, both with the dominant shoulder flexed to 90º and elbow flexed to 90º. Stretching occurs when the non-dominant hand passively positions the dominant forearm into IR. Lorenz[21] believes the side lying position to be most ideal because the table helps keep the scapula retracted. To further progress this stretch, a towel can be placed under the humerus to add a horizontal adduction component, or the athlete can roll further on to their side[21]. If the athlete is suffering from impingement or the 90/90 position is painful, the sleeper stretch can also be performed with the shoulder flexed to 45º and elbow flexed to 90º[21]. Although the side-lying position has found to be most ideal for stabilizing the scapula, it is not very practical for an on-the field warm up stretch. In this current study, both sleeper stretches at 90º and 45º of GH flexion were evaluated in a standing position using a wall for support. We believe the standing sleeper stretch is just as affective as the side-lying position but more applicable to an on-the-field warm-up session.

As mentioned previously, to truly stretch the posterior shoulder, the scapula must be retracted[21] and stabilized[3]. Scapular stabilization is an important technique used for isolating GH motion[41, 69]. Posterior shoulder stretches must be performed properly with scapular stabilization to assure accurate stretching of the posterior shoulder and not the scapulothoracic articulation.

Despite the recognized importance of scapular stabilization during stretching to isolate GH movement, no current research has investigated scapular movement during a non-assisted posterior shoulder stretch. The horizontal cross-arm stretch and sleeper stretches are designed to stabilize the scapula without assistance of another person. This study evaluated the standing horizontal cross-arm stretch and the standing sleeper stretches at 90º and 45º of GH flexion for proper scapular stabilization and also evaluated shoulder ROM pre and post stretching to evaluate acute effects of GH ROM. As previously mentioned, PST is believed to be the culprit in causing altered kinematics and leading to the development of several injuries and degenerative changes[6]. As a result, the most appropriate posterior shoulder stretch must be identified to reduce the risk of injury and enhance the performance of overhead athletes.

Thus, the purpose of this study was to evaluate three on-the-field non-assisted posterior shoulder stretches and determine (1) the acute effects of each posterior shoulder stretch on GH IR and ER ROM and PST and (2) to determine which posterior shoulder stretch best stabilizes the scapula to isolate GH ROM. The results of this study are able to assist coaches and baseball players in developing the most beneficial stretching program. If baseball pitchers can replace their excessive warm-up pitches with a posterior shoulder stretch that allows them to feel "warmed up", baseball pitchers may increase their number of pitches and their number of innings played during a single game. Additionally, finding the most appropriate shoulder stretch that increases GH IR may help pitchers during the deceleration and follow through phases of pitching. If pitchers can increase the distance over which their throwing shoulder is decelerated, they may be decreasing the stress placed on the posterior shoulder, in terms, may decrease the risk of injury, decrease onset of fatigue, and increase the number of pitches throw, or innings played. Furthermore, performing posterior shoulder stretches will possibly increase their pitching ability over the course of the season, and may also decrease their risk of injury and soreness. Possible alterations in stretching routines prior to competition may aid in injury prevention and performance enhancement.

Specific Aim 1: To examine acute stretching effects of three posterior shoulder stretches (horizontal cross arm stretch, standing sleeper stretch at 90° GH flexion, and standing sleeper stretch at 45° GH flexion) in 15 asymptomatic collegiate baseball pitchers. This was accomplished by measuring GH IR and ER ROM and PST with an inclinometer on the dominant shoulder before and after each posterior shoulder stretch (one stretch per session) has been completed for three bouts of thirty seconds.

Hypothesis 1a: The sleeper stretch at 90° and the sleeper stretch at 45° of GH flexion will result in the greatest increase in IR ROM.

Hypothesis 1b: PST measurements will show the most improvement with the horizontal cross arm stretch in all baseball pitchers.

Specific Aim 2: To determine which posterior shoulder stretch (horizontal cross arm stretch, standing sleeper stretch at 90° GH flexion, and standing sleeper stretch at 45° GH flexion) results in the most scapular stabilization in 15 asymptomatic collegiate baseball pitchers. Each posterior shoulder stretch was individually performed on different days to the dominant shoulder three times and held for 30 seconds while scapular motion is recorded with an electromagnetic tracking device.

Hypothesis 2a: It is hypothesized that the horizontal cross arm stretch will provide the most scapular stabilization (i.e. the least scapular movement) during the stretch.

Hypothesis 2b: The standing sleeper stretch at 45° is hypothesized to show increased scapular motion while being performed.

TABLE 1: Dependent Variables

Type of Tests	Dependent Variable	
ROM	Internal Rotation ROM (deg.) *	
	External Rotation ROM (deg.)*	
PST	Side lying cross body horizontal adduction test (cm) *	
	Supine cross body horizontal adduction test (deg) *	
Scapular Kinematics	Scapula internal/external rotation (deg.)	Measured during 30 seconds of posterior shoulder Stretches
	Scapula protraction/retraction (deg.)	
	Scapula elevation/depression (deg.)	
	Scapula upward/downward rotation (deg.)	
	Scapula anterior/posterior tilt (deg.)	

*Measurements will be taken bilaterally prior to each posterior shoulder stretch. This was used to determine bilateral differences within the subject. After each posterior shoulder stretch, measurements were only retaken on the dominant arm to determine acute effects of the stretch.

2.0 MATERIAL & METHODS

2.1 SUBJECTS

Data was collected on fifteen male collegiate baseball pitchers. Age, height, mass, and throwing experience was collected for all subjects and can be found in **TABLE 2**. All subjects were physically active and have been pitching and participating on an organized baseball team for 5 years or more. Baseball pitchers with previous history of neurologic disease, arthritis, connective tissue disease, or shoulder surgery were excluded from this study. All subjects hand dominance defined by the primary limb they throw a ball with. 11 right handed pitchers and 4 left handed pitchers participated.

TABLE 2: Subject Demographics

	Mean	±SD
Age (yrs)	20.40	1.35
Height (m)	1.86	0.06
Mass (kg)	91.30	10.26
Pitching Experience (yrs)	10.26	2.40

2.2 INSTRUMENTATION

All measurements were completed on a standard examination plinth. Internal and external rotation ROM was taken with an inclinometer (Saunders Group, Chaska, MN). Supine

PST measurements were taken with an inclinometer as well, and the side lying PST measurements were taken with an anthropometer. Both PST measurements were also quantified with the Motion Monitor electromagnetic tracking device for higher precision.

2.2.1 Motion Monitor Electromagnetic Tracking Device

The Motion Monitor (Innovative Sports Training Inc, Chicago, IL) electromagnetic tracking device was used to collect PST measurements and 3-dimentional scapular kinematics. The Motion Monitor software uses data conveyed by electromagnetic receivers for the calculation of receiver position and orientation relative to an electromagnetic transmitter. The specific hardware used in this study consisted of an extended-range direct current transmitter and five receivers. The instrumentation sampling frequency was 100Hz for all kinematic assessments. It was previously determined that the region of the measurement space that is between 3ft (0.91m) and 4ft (1.2m) directly in front of the transmitter demonstrated the least amount of position (.7mm) and orientation (.27º) error[70]. Thus, all kinematic assessments in the current study were performed with the subject positioned .91m in front of the transmitter. High reliability of the scapular kinematics measurement protocol using Motion Monitor has been reported (ICC= 0.97 ± .03)[70].

2.3 PROCEDURE

Each subject signed an informed consent form approved by the University Institutional Review Board prior to the first testing session. All subjects attended three testing sessions, at least 2 days apart, which consisted of performing one posterior shoulder stretch with pre and post stretch ROM and PST assessments. All stretches were counterbalanced to assure each subject performed each posterior shoulder stretch. During each session, the same two examiners recorded the pre-test and post-test measurements of internal and external rotation ROM and PST measurements. IR, ER and PST assessments were performed in the same order for each subject throughout the course of the testing sessions. Testing of all subjects occurred during their off-season participation.

Of the two examiners, one was named the positioning/testing examiner and one was the measuring/recording examiner. All measurements were performed by these two examiners. Before the study, both examiners discussed measurement techniques and procedures. Each of the techniques were reviewed, shown and practiced to ensure consistency.[5] Intrasession and intersession reliability has been previously determined and is shown in **TABLE 3.**

TABLE 3 : Intrasession and Intersession Reliability

	Intrasession		Intersession	
	ICC	SEM	ICC	SEM
Internal Rotation ROM[71]	0.97	1.36 º	0.92	2.46 º
External Rotation ROM[71]	0.98	1.2 º	0.91	2.56 º
Supine PST[72]	0.91	1.1 º	0.75	1.8 º
Side Lying PST[72]	0.83	0.9 cm	0.42	1.7 cm

2.3.1 Pre & Post-test Measurements of Internal & External Range of Motion & Posterior Shoulder Tightness

To begin passive IR and ER ROM measurements, all subjects were positioned supine on the plinth with their tested arm in 90º of GH abduction[73] and 90º of elbow flexion. The testing examiner positioned the arm stabilized the scapula while the recording examiner measured and recorded the angle of humeral internal or external rotation ROM with the inclinometer. Scapular stabilization was achieved by the testing examiner applying a posteriorly directed force against the subject's coracoid process and clavicle with the palm of the hand[5] to prevent elevation and anterior/posterior tilting of the scapula[73]. Awan et al [5] has defined the end point for passive motion by patient comfort and by capsular end-feel. A total of three measurements were taken for each shoulder position bilaterally. The mean value was used for statistical analysis.

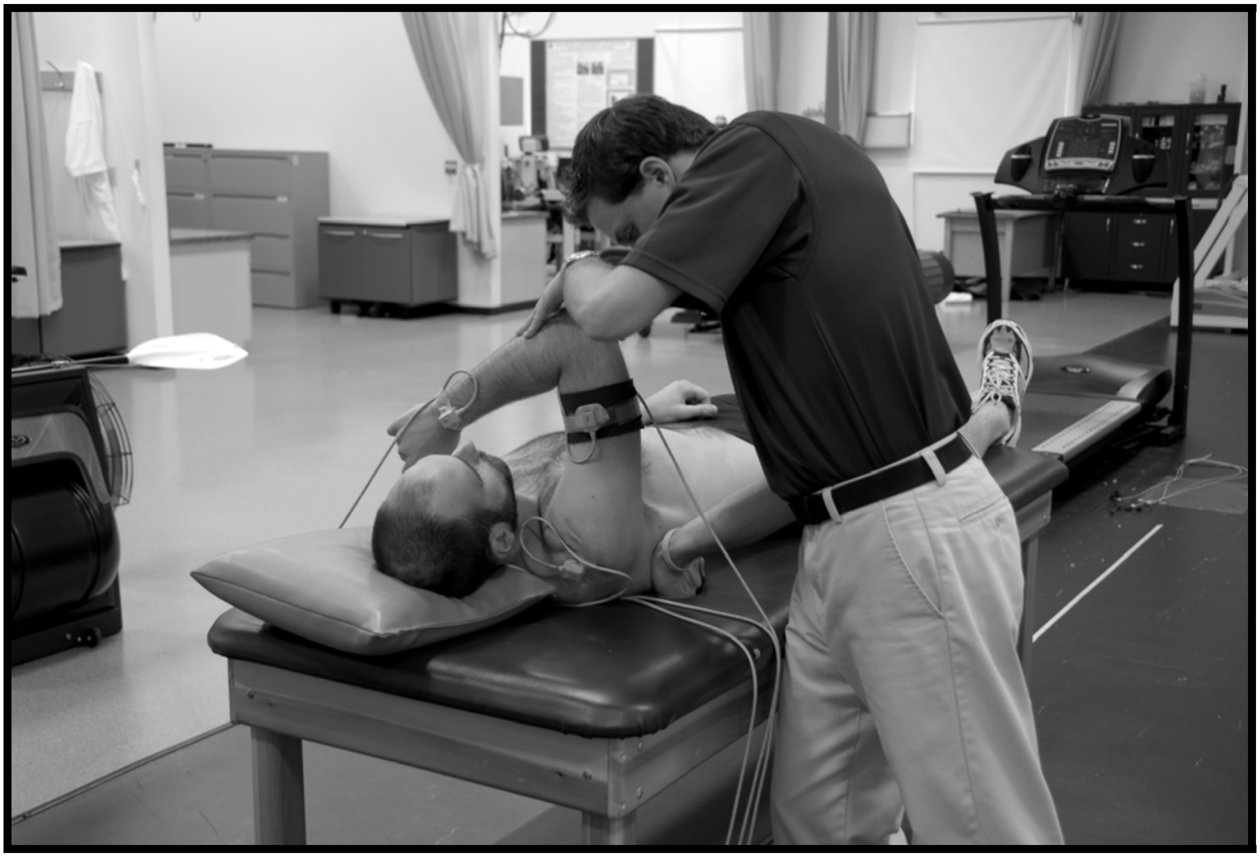
PST was measured by two different assessments: (1) supine method and (2) side lying cross body humeral adduction method as described by Tyler et al[2]. High reliability has been reported in the literature for the side lying testing procedure (ICC dominant= 0.92, ICC non-dominant= 0.95). Reliability obtained in our laboratory can be found in **TABLE 3**.

After the IR and ER ROM measurements, the subject was then instrumented with electromagnetic receivers for quantification of the supine and side lying PST assessments. The setup of the electromagnetic receivers and the PST measurements were completed one limb at a time. The supine and side lying PST measurements were taken on the non-dominant shoulder first, followed by the dominant shoulder. Six electromagnetic receivers were used in this study while only four electromagnetic receivers were secured to body segments: thorax, scapula, humerus, and forearm. The electromagnetic receivers were secured with double-sided adhesive disks (3M Health Care, St. Paul, Minn) and hypoallergenic tape (to further reduce receiver-to-skin movement). The thorax receiver was placed superficially on the seventh cervical vertebra and the scapular receiver was placed on the flat, broad portion of the acromion. The humeral receiver was secured to the mid-portion of each humerus using a neoprene cuff, and the forearm receiver was secured to the broad portion of the dorsal wrist between the ulnar and radial styloid processes. The fifth receiver was placed on the undersurface of the plinth for the side lying PST measurement, and the sixth receiver was attached to a stylus used for digitization of bony landmarks.

Digitization took place with the subject standing with their arms at their sides within the most accurate and reliable location in front of the Motion Monitor transmitter. During that time several bony landmarks on the thorax, scapula, humerus and wrist of the selected limb were palpated and digitized with the stylus. Descriptions of the digitized landmarks appear in **TABLE 4**. The GH joint center was defined by the point that moves least with respect to the scapula when the humerus is moved through short arcs (≤45º) as calculated by a least squares algorithm[74]. Digitization of the bony landmarks allowed for transformation of the receiver data from a global coordinate system to anatomically based local coordinate systems. The definition of the local coordinate system appears in **TABLE 5**[75]**.**

After digitization, the subject returned to the plinth for the first supine measurement of PST (**FIGURE 1**). This supine procedure was performed in addition to the side lying PST assessment in this study because unpublished data collected in our laboratory suggests that although both the side lying and supine testing procedures can be performed consistently, the supine method can be performed with higher precision. For the supine assessment, the testing examiner stood on the side of the shoulder being tested and asked the subject to lift the tested shoulder off the table. The testing examiner then wedged a hand under the scapula, pressing the thenar eminence against the lateral border of the scapula to stabilize the scapula in a retracted position. The tester used the other hand to passively move the subject's arm into horizontal adduction. At the end of the ROM, the recording examiner recorded the angle formed between the humerus and the horizontal plane from the superior aspect of the shoulder. The inclinometer was aligned on the humerus and a digital reading was recorded. The motion monitor recorded the measurement as well.

FIGURE 1: Supine Posterior Shoulder Tightness Assessment



After the supine PST assessment, the subject moved into a side lying position on the non-tested extremity side as described by Tyler[2] **(FIGURE 2)**. The entire body was in contact with the table with both the hips and knees in 90º of flexion, and the non-testing arm positioned under the subject's head. Alignment of the subject resulted in bilateral acromion processes to be perpendicular to the plinth. Proper positioning of the subject was crucial to a reliable measurement, for any rotation of the torso forward or backward resulted in a corresponding increase or decrease in the measurement. A small mark with a felt-tip pen was made on the medial epicondyle of the tested arm.

To begin the side lying measurement, the examiner was positioned facing the subject and grasped the subject's extremity just distal to the epicondyles of the elbow. The humerus was passively placed in a position of 90º of shoulder abduction and 0º of humeral IR and ER.

At that point the scapula was grasped at the lateral border and it was stabilized in a retracted position to restrict excessive movement. With the subject relaxed, and while the position of the scapula was maintained, the humerus was passively and gently lowered into a horizontally adducted position with neutral rotation. The humerus was lowered until the adduction motion ceased or there was rotation of the humerus, indicating the end of posterior shoulder tissue flexibility.

At the termination of the horizontal adduction ROM, the recording examiner placed the anthropometer perpendicular to the plinth and measured the distance from the undersurface of the plinth to the medial epicondyle. Once that distance was recorded in centimeters, the electromagnetic tracking device recorded the distance from the plinth as well. The distance measured indicated the amount of flexibility of the posterior shoulder tissues. A greater distance between the medial epicondyle and the plinth indicated increased tightness of the posterior shoulder tissues. Conversely, the closer the medial epicondyle fell to the table (shorter distance), the more flexible the posterior shoulder. This distance is a quantification of the PST present within the subject and can be compared bilaterally. Three measurements were taken bilaterally and averaged for statistical analysis.

FIGURE 2: Side Lying Posterior Shoulder Tightness Assessment

Once all the pre-test measurements were obtained, the subject performed the posterior shoulder stretch specifically assigned to their individual testing session. The posterior shoulder stretches were chosen based on, not only a clinical recommendation by several certified athletic trainers, physical therapists, and overhead athletes, but also the ability to be performed independently during an on-the-field warm-up session. Non-assisted stretches are more practical for athletes who immediately stretch prior to competition[57]. Each static stretch was repeated 3 times and held for 30 seconds (timed by a stopwatch), recommended by the National Strength and Conditioning Association (NSCA).[57] During all 30 seconds of each stretch trial, the electromagnetic transmitter collected scapular kinematic data and recorded scapular movement. The specific scapular kinematics of interest are listed in **TABLE 1.** The examiner demonstrated the appropriate stretching technique and gave instructions to each subject. Each subject was given the opportunity to ask questions. A valid stretch was determined by having proper position against the wall and verbal feedback from the subject of when a stretch is felt in the posterior shoulder. The subjects had a 30 second rest period in between trials. The three posterior shoulder stretches and descriptions were as follows.

TABLE 4: Description of Bony Landmarks

Bony Landmarks	Description of Palpation Point
Thorax	
8^{th} Thoracic Spinous Process (T8)	Most dorsal point
Processus xiphoideus (PX)	Most caudal point of sternum
7^{th} Cervial Spinous Process (C7)	Most dorsal point
Incisura jugularis (IJ)	Most cranial point of sternum (suprasternal notch)
Scapula	
Angulus acromialis (AA)	Most lateral-dorsal point of scapula
Trigonum spinae (TS)	Midpoint of triangular surface on the medial border of the scapula in line with the scapular spine
Angulus inferior (AI)	Most caudal point of scapula
Humerus	
Medial epicondyle (ME)	Most medial point on the medial epicondyle
Lateral epicondyle (LE)	Most lateral point on the lateral epicondyle
Glenohumeral joint center (GH) *	
Forearm	
Radial styloid (RS)	Most lateral point on the radial styolid
Ulnar styloid (US)	Most medial point on the ulnar styloid

*The GH joint center was not palpated but rather estimated with a least square algorithm for the point on the humerus that moves the least during several short arc humeral movements[75].

TABLE 5: Definition of Local Coordinate Systems

Local Coordinate System	Axis	Definition
Thorax	y_t	Vector from the midpoint of PX and T8 to the midpoint between IJ and C7
	x_t	Vector perpendicular to the plane fitted by midpoint of PX and T8, the midpoint of IJ and C7, and IJ
	z_t	Vector perpendicular to x_t and y_t
	Origin	IJ
Scapula		
	x_s	Vector from TS to AA
	y_s	Vector perpendicular to the plane fitted by TS, AA, And AI (scapular plane)
	z_s	Vector perpendicular to x_s and y_s
	Origin	AA
Humerus		
	y_h	Vector from midpoint of ME and LE to GH
	x_h	Vector perpendicular to the plane fitted by GH, ME, And LE
	z_h	Perpendicular to y_h and x_h
	Origin	GH
Forearm		
	y_f	Vector from US to the midpoint between LE and ME
	x_f	Perpendicular through US, RS, and midpoint of LE And ME
	z_f	Perpendicular to x_f and y_f
	Origin	US

Horizontal Cross-arm Stretch

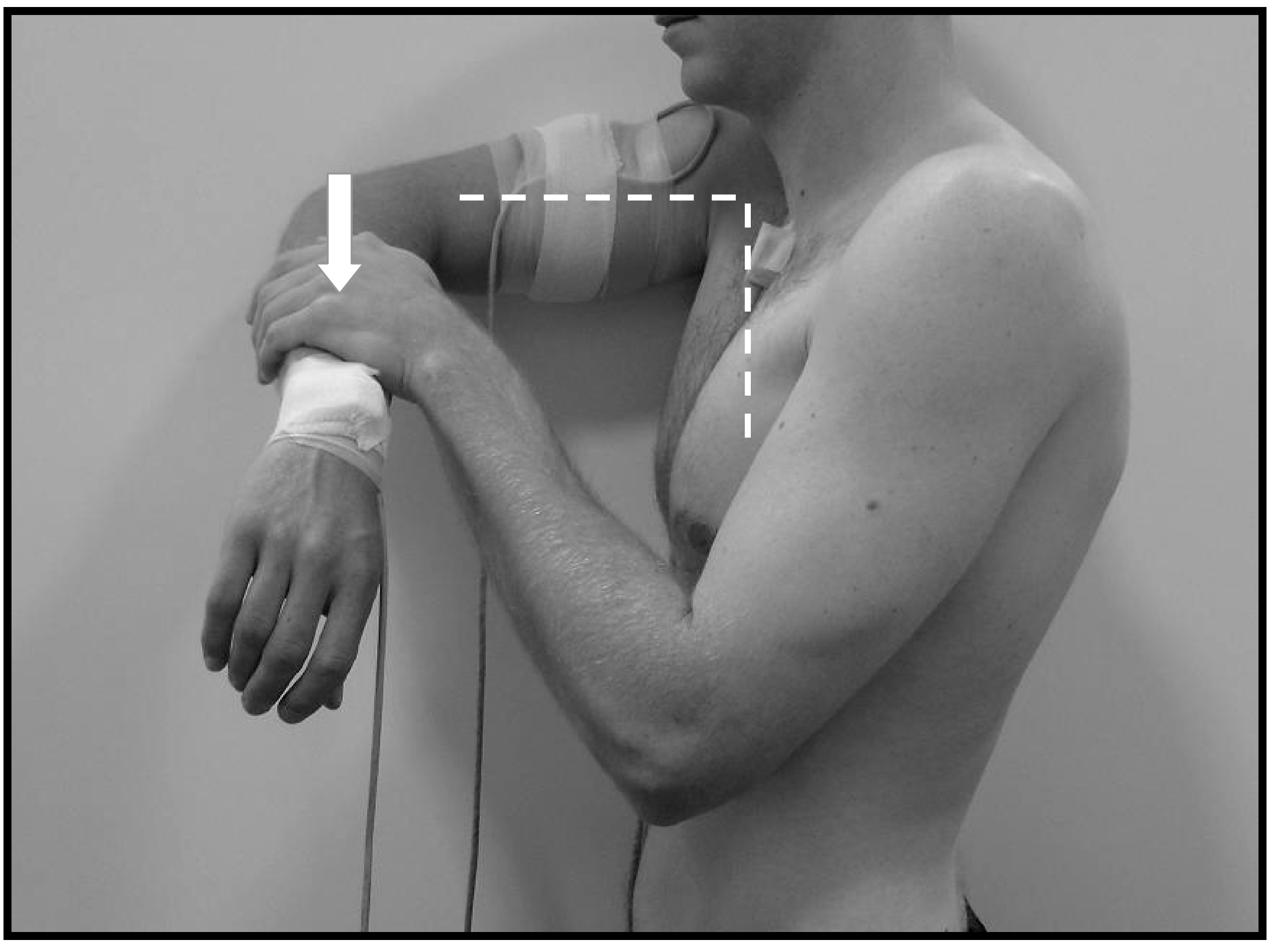
The patient stood with their dominant shoulder and lateral border of their scapula against a wall **(FIGURE 3).** The dominant shoulder was flexed to 80-90º and passive horizontal adduction was applied by the non-dominant arm to the dominant elbow[6]. The end position resulted in flexion of the dominant elbow and the dominant hand reaching toward the opposite shoulder. By leaning against the wall and using the subject's body weight, the lateral border of the scapula remained against the wall to prevent the scapula from following the humerus across the body[68]. The subject should feel a stretch in the posterior shoulder musculature.

FIGURE 3: Horizontal Cross-arm Stretch

Standing Sleeper Stretch at 90º

The subject stood with their dominant shoulder against the wall and flexed at 90º and elbow also in 90º of flexion **(FIGURE 4).** The subject leaned against the wall applying pressure to the lateral border of the scapula. Their head and neck remained in neutral position, looking straight ahead. The scapula remained pressed against the wall while the dominant shoulder was moved into IR by having the non-dominant hand slowly press the forearm down.

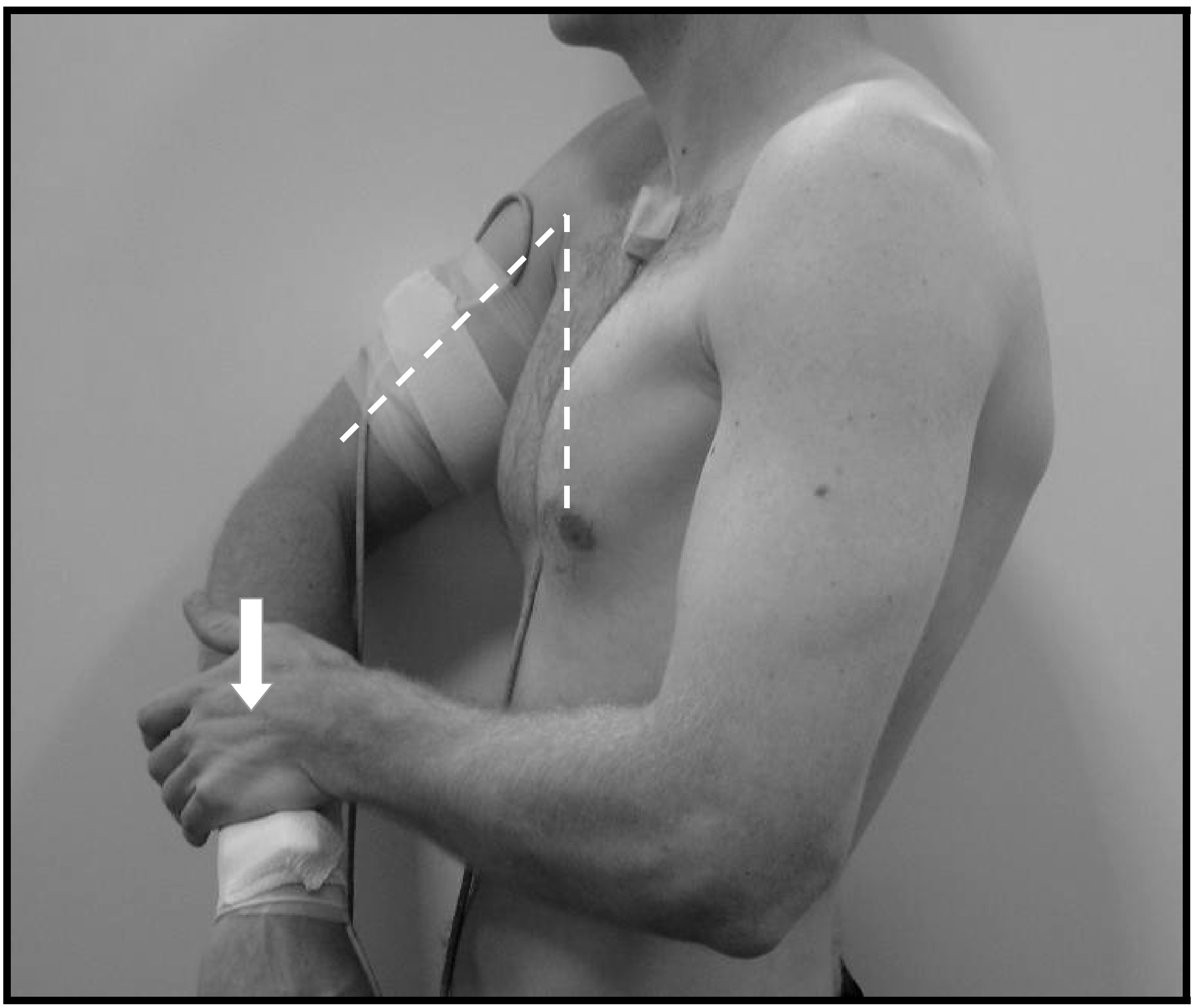
FIGURE 4: Standing Sleeper Stretch at 90º



Standing Sleeper Stretch at 45º

The subject stood with their dominant shoulder against the wall and flexed at 45º and elbow in 90º of flexion **(FIGURE 5).** The subject leaned against the wall applying pressure to the lateral border of the scapula. Their head and neck remained in neutral position, looking straight ahead. The scapula remained pressed against the wall while the dominant shoulder was moved into IR by having the non-dominant hand slowly press the forearm closer to the opposite hip.

FIGURE 5: Standing Sleeper Stretch at 45˚



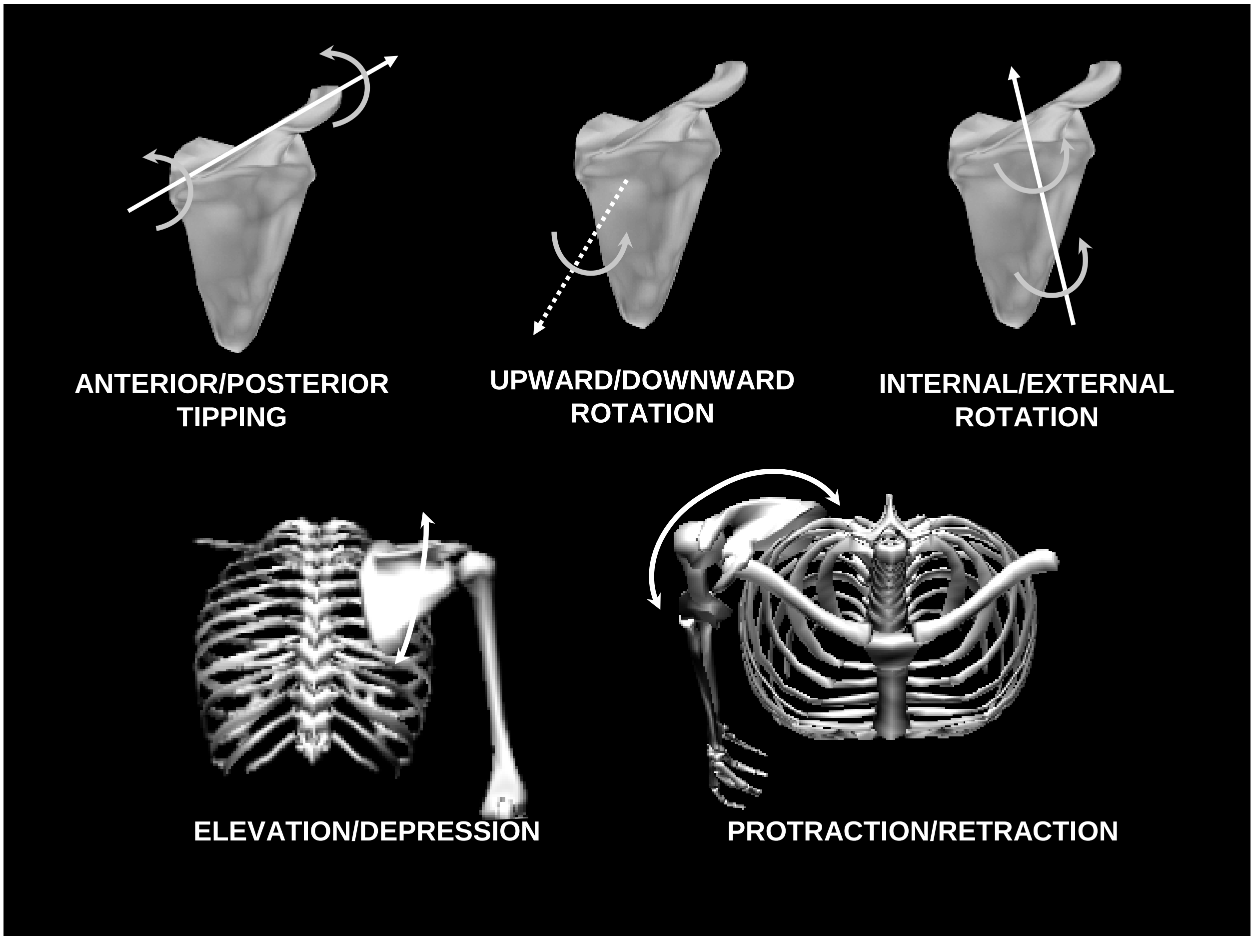
2.4 DATA REDUCTION & ANALYSIS

Raw scapular kinematic data was filtered with a low-pass filter with a cut-off frequency of 10 Hz. Receiver position and orientation data of the thoracic, scapular, humeral, and wrist receivers was transformed into a local coordinate system for each of the respective segments.[75] The coordinate system used was in accordance with recommendations from the International Shoulder Group of the International Society of Biomechanics[74]. When the subject stood in anatomical position, the coordinate system for each segment is vertical (y-axis), horizontal to the right (x-axis), and posterior (z-axis). Euler angle decompositions were used to determine the scapular and humeral orientation with respect to the thorax. Orientation of the scapula was determined as rotation about the y-axis of the scapular (internal/external rotation), rotation about the z-axis of the scapula (upward/downward rotation), and rotation about the x-axis of the scapula (anterior/posterior tipping). Humeral orientation was determined as rotation about the y-axis of the humerus (plane of elevation), rotation about the z-axis (elevation), and rotation about the y-axis (axial rotation) (**FIGURE 6**). The rotation sequence of the Euler angle was chosen based on the recommendation of the International Shoulder Group[74]. The position of the scapula can be described by 2 degrees of freedom, as if in spherical space, by both elevation/depression and protraction/retraction.[75]

A one-way analysis of variance (ANOVA) was used to determine the differences in the five scapular kinematic variables during three posterior shoulder stretches. Kinematic values from each posterior shoulder stretch were compared to determine the stretch with the least amount of scapular movement. Scapular movement values were recorded throughout the 30 seconds of each posterior shoulder stretch.

The mean values for shoulder IR, ER ROM and PST were presented. An alpha level of .05 was established. A paired t-test was performed to determine bilateral differences for each variable of IR and ER ROM and supine and side lying PST. A repeated-measures ANOVA was performed on the IR, ER ROM, and PST data to determine between stretch differences and main effects of each stretch on the dominant arm. A Tukey post-hoc test was performed following any significant differences that arose. SPSS version 13.0 was utilized for statistical analysis. Variables were calculated and processed using Matlab 12 (The MathWorks inc., Natick, Massachusetts).

FIGURE 6: Scapular Position and Orientation Assessed in the current study



3.0 RESULTS

3.1 GLENOHUMERAL FLEXIBILITY CHARACTERISTICS OF BASEBALL PITCHERS

Bilateral shoulder characteristics are presented in **TABLE 6**. The baseball pitchers who participated in this study exhibited significantly greater internal rotation ROM in their dominant throwing shoulder compared to their non-dominant shoulder (p<0.0001). There was no side-to-side differences for external rotation ROM (p=0.174). PST was significantly greater on the dominant throwing shoulder for the supine assessment (p=0.001), however, there was no significant difference between limbs for the side lying PST assessment (p=0.774).

TABLE 6: Bilateral Shoulder Characteristics

	Dominant		**Non- Dominant**		**Difference**		**p**
	Mean	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	
Internal Rotation (deg)	34.46	13.11	50.17	13.17	-15.71	13.43	<0.0001*
External Rotation (deg)	119.62	6.46	117.16	8.59	2.47	6.67	0.174
Supine PST (deg)	95.93	3.76	98.82	4.87	-2.89	2.81	0.001*
Side Lying PST (cm)	35.90	2.68	35.58	3.54	0.32	4.27	0.774

*Significant limb difference

3.2 ACUTE EFFECTS OF INTERNAL ROTATION RANGE OF MOTION

The pre and post stretch manual measurement results are presented in **TABLE 7.** There was no significant stretch x test interaction for IR ROM [F(2,28)=0.085; p=0.919] (**FIGURE 7**). There was a significant main effect for IR ROM [F(1,14)= 24.749; p<0.0001] (**FIGURE 8**). Glenohumeral IR ROM significantly increased following stretching.

FIGURE 7: Internal Rotation Range of Motion Pre and Post Stretch

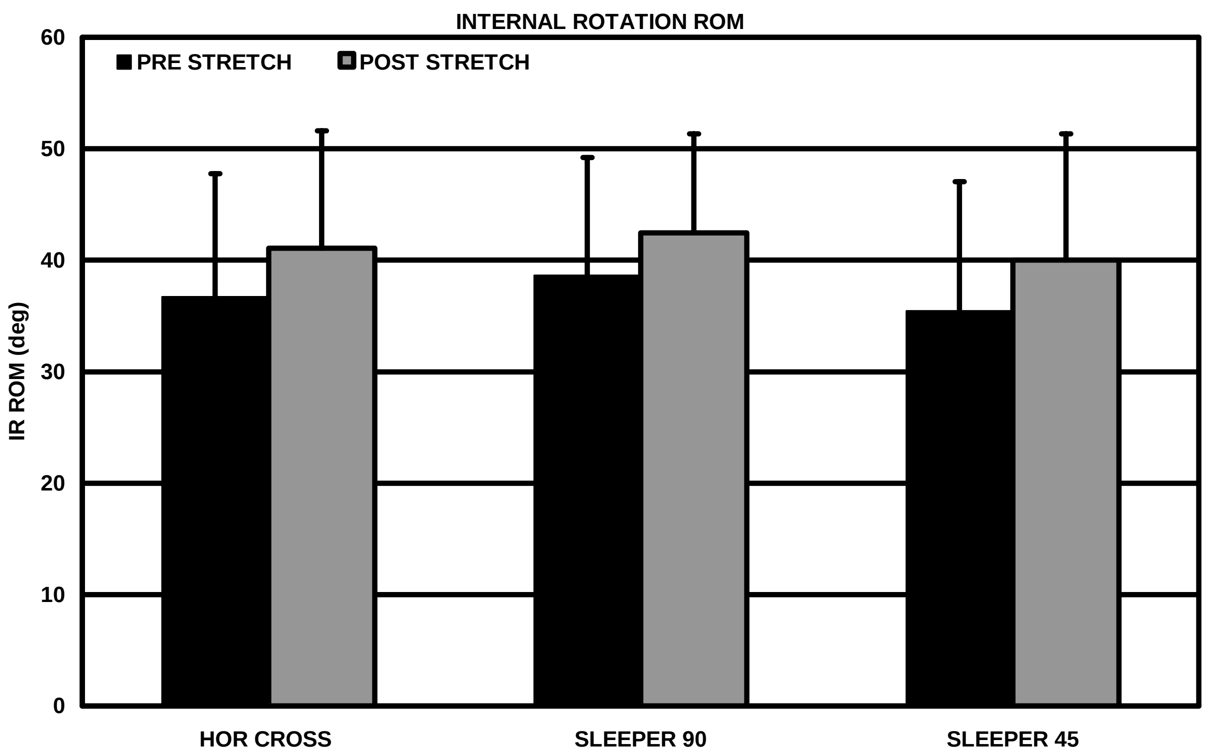


FIGURE 8: Internal Rotation Range of Motion Group Means

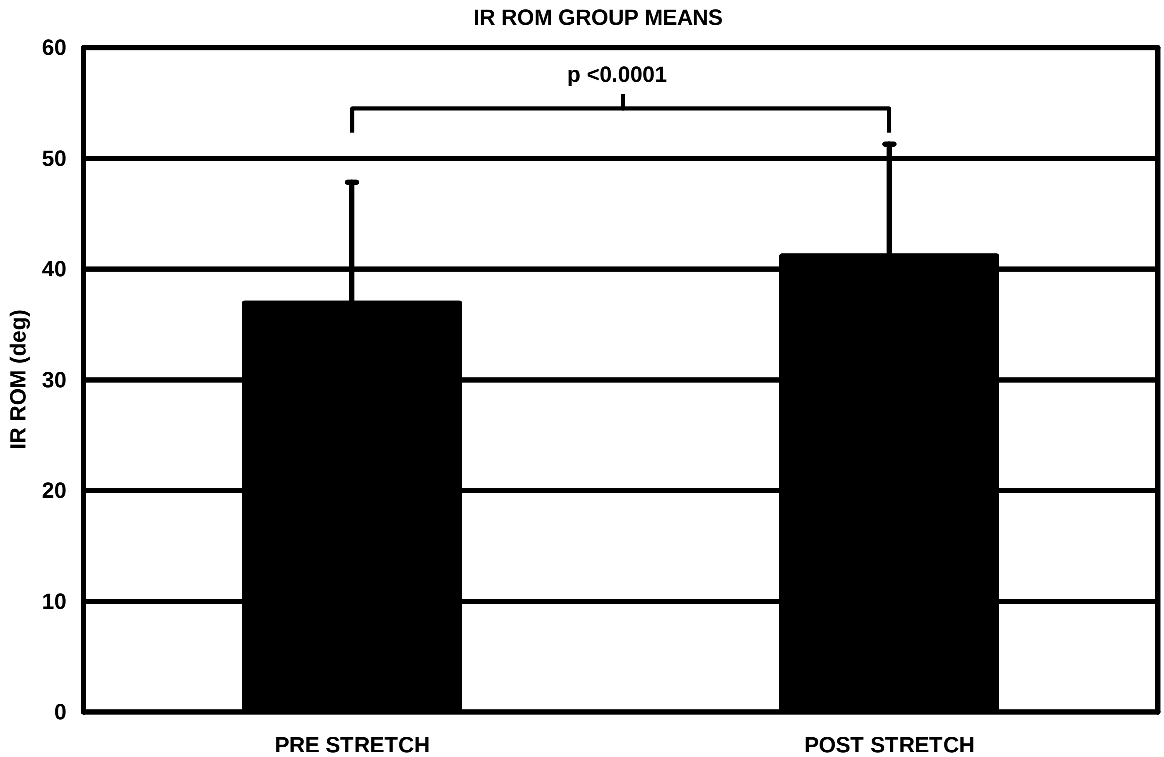


TABLE 7: Internal Rotation Range of Motion Measurements

	Pre Stretch		Post Stretch		Difference		P
	Mean	**±SD**	**Mean**	**± SD**	**Mean**	**±SD**	
Internal Rotation(◦)							0.919
Horizontal Cross Arm	36.71	11.06	41.09	10.55	4.38	5.60	
Sleeper Stretch 90º	38.64	10.59	42.47	8.88	3.82	4.80	
Sleeper Stretch 45º	35.44	11.61	40.00	11.35	4.56	5.51	
Group Means	36.93	10.91	41.18	10.12	4.25	5.20	<0.0001*

*Significant main effect of stretching

3.3 ACUTE EFFECTS OF EXTERNAL ROTATION RANGE OF MOTION

The pre and post stretch manual measurement results are presented in **TABLE 8.** There was no significant stretch x test interaction for ER ROM [F(2,28)=0.724; p=0.494]. The main effect for ER ROM was not significantly different following stretching [F(1,14)=0.001;p=0.971] (**FIGURE 9**).

FIGURE 9: External Rotation Range of Motion Pre and Post Stretch

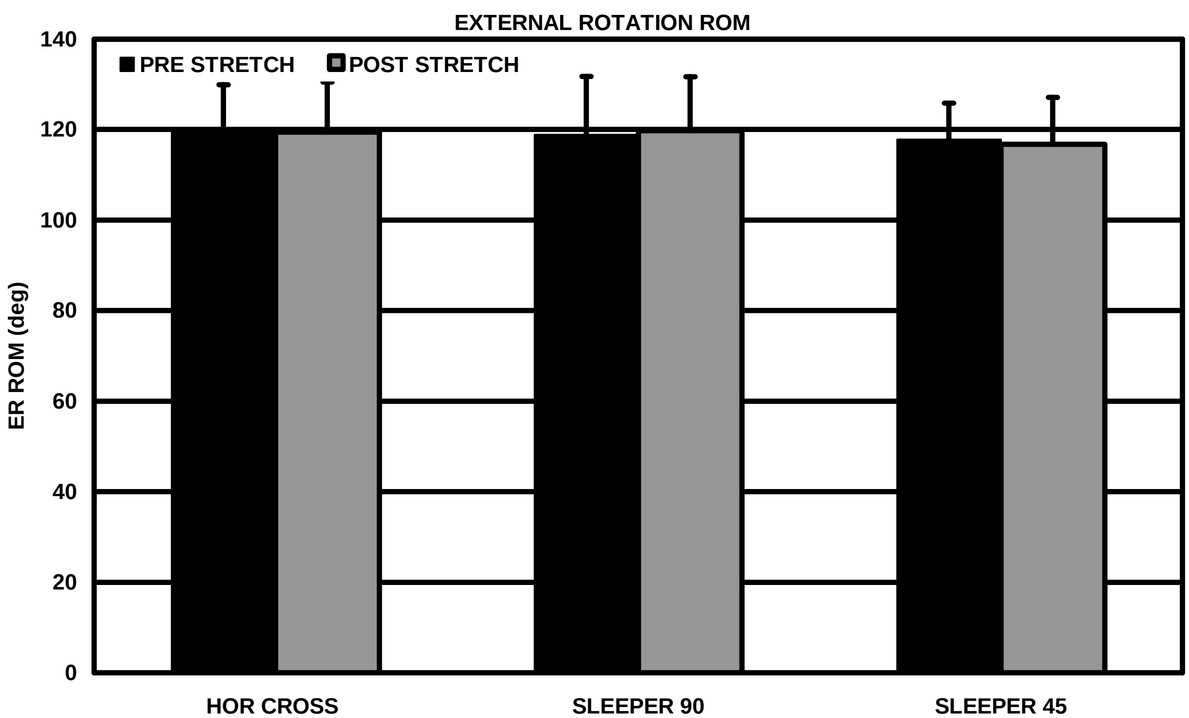


TABLE 8: External Rotation Range of Motion Measurements

	Pre Stretch		Post Stretch		Difference		P
	Mean	**±SD**	**Mean**	**± SD**	**Mean**	**±SD**	
External Rotation(◦)							0.494
Horizontal Cross Arm	119.38	10.56	119.47	11.06	0.09	4.92	
Sleeper Stretch 90º	118.84	12.88	119.78	11.91	0.93	3.50	
Sleeper Stretch 45º	117.84	7.98	116.75	10.33	-1.09	5.02	
Group Means	118.68	10.43	118.66	10.95	-0.02	4.50	0.971

3.4 ACUTE EFFECTS OF SUPINE POSTERIOR SHOULDER TIGHTNESS

The pre and post stretch manual measurement results are presented in **TABLE 9.** There was no significant stretch x test interaction for the manual supine PST measurement [F(2,28)= 0.637; p=0.536] (**FIGURE 10)**. There was a significant main effect for supine PST following each stretch [F(1,14)= 20.343; p<0.0001] (**FIGURE 11**). Supine posterior shoulder tightness significantly decreased following stretching.

The instrumental PST data is presented in **TABLE 11.** There was no significant stretch x test interaction for the instrumental supine PST assessment [F(2,28)= 0.594; p=0.559]. The main effect for supine PST was not significantly different following each stretch [F(1,14)= 1.161; p=0.299]. There were no significant improvements following stretching.

FIGURE 10: Manual Supine Posterior Shoulder Tightness Pre and Post Stretch

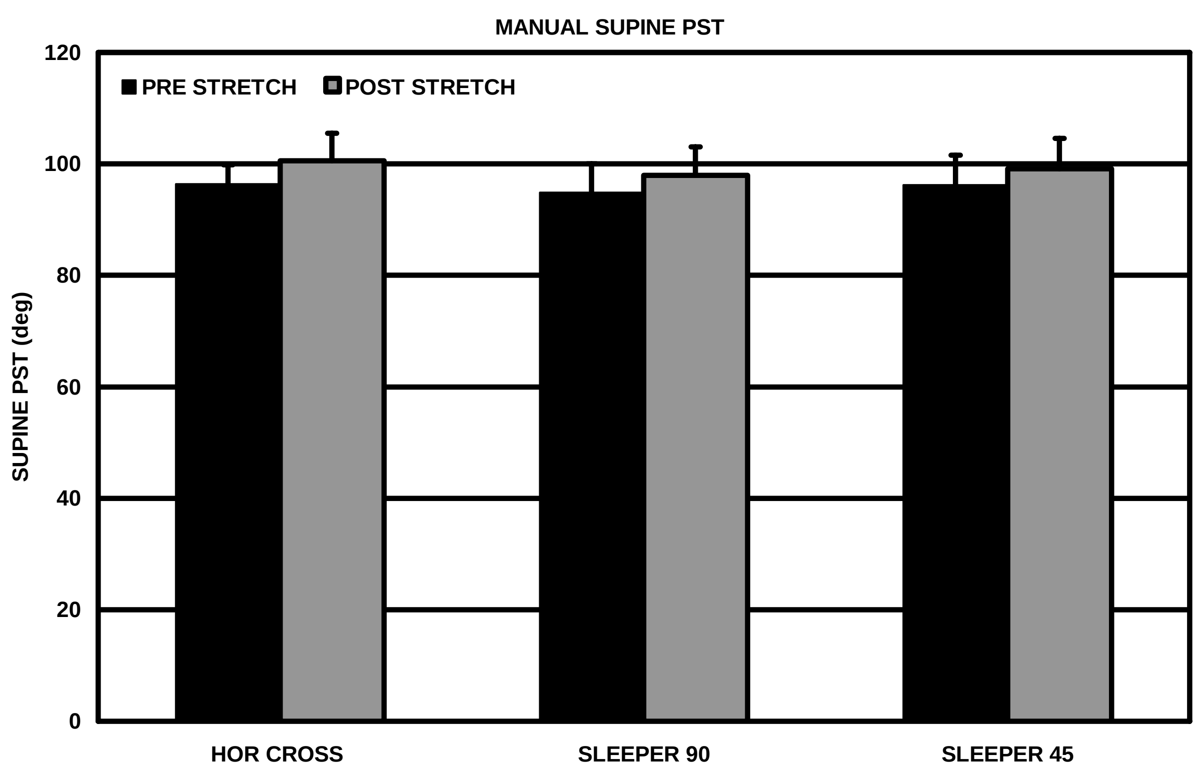


FIGURE 11: Manual Supine Posterior Shoulder Tightness Group Means

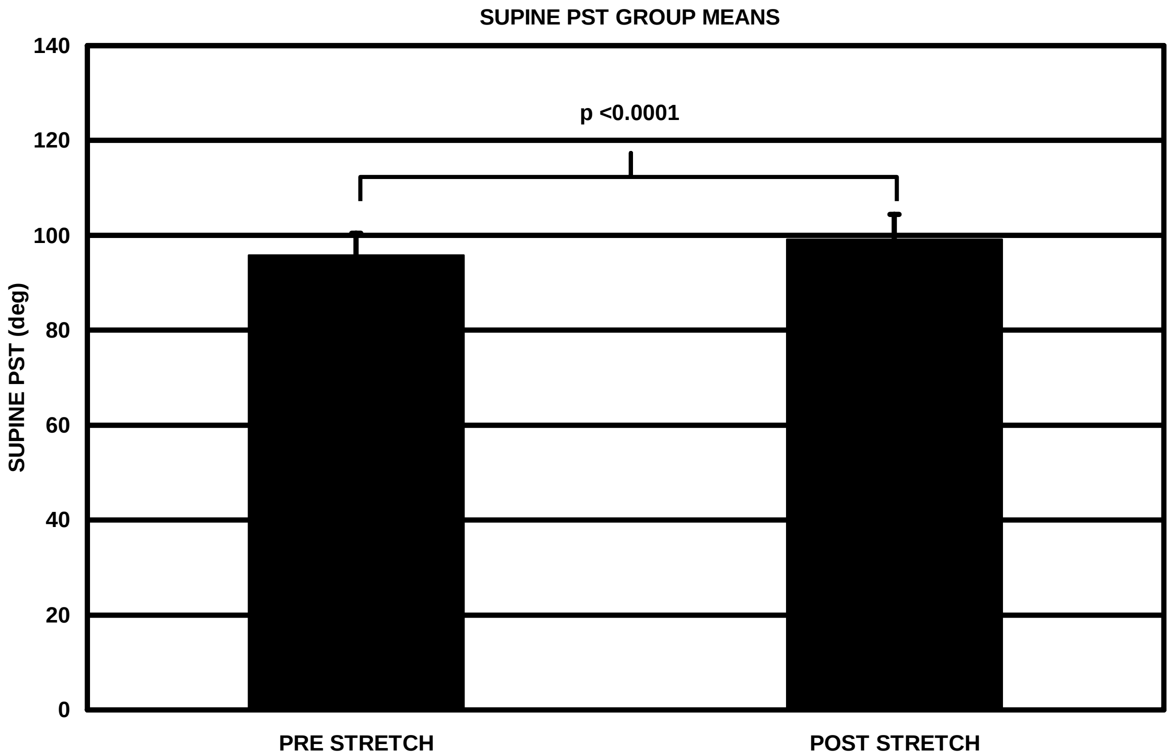


TABLE 9: Supine Posterior Shoulder Tightness Measurements

	Pre Stretch		Post Stretch		Difference		P
	Mean	**±SD**	**Mean**	**± SD**	**Mean**	**±SD**	
Supine PST(◦)							0.536
Horizontal Cross Arm	96.36	3.47	100.56	4.97	4.20	3.37	
Sleeper Stretch 90º	94.87	5.15	97.96	5.14	3.09	4.37	
Sleeper Stretch 45º	96.22	5.33	99.11	5.45	2.88	4.30	
Group Means	95.81	4.66	99.20	5.18	3.39	3.99	<0.0001*

*Significant main effect of stretching

3.5 ACUTE EFFECTS OF SIDE LYING POSTERIOR SHOULDER TIGHTNESS

The pre and post stretch manual measurement results are presented in **TABLE 10.** There was no significant stretch x test interaction for the manual side lying measurement [F(2,28)= 1.845; p=0.177] (**FIGURE 12**). There was a significant main effect for side lying PST following each stretch [F(1,14)=8.265; p=0.012] (**FIGURE 13).** Side lying PST significantly decreased following stretching.

The instrumental side lying PST data is presented in **TABLE 11.** There was no significant stretch x test interaction for the instrumental side lying PST assessment [F(2,28)= 1.955; p=0.160]. The main effect for side lying PST was significantly different following each stretch [F(1,14)= 9.982; p=0.007]. Side lying PST significantly decreased following stretching.

FIGURE 12: Manual Side Lying Posterior Shoulder Tightness Pre and Post Stretch

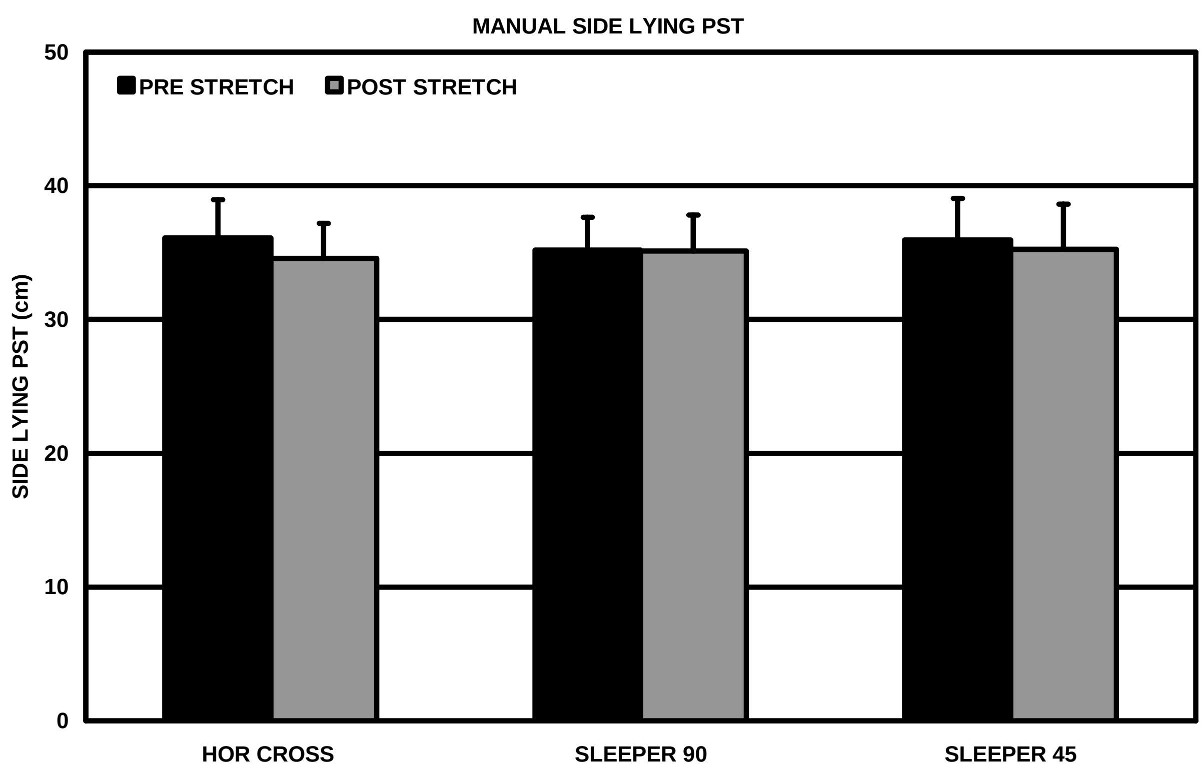


FIGURE 13: Manual Side Lying Posterior Shoulder Tightness Group Means

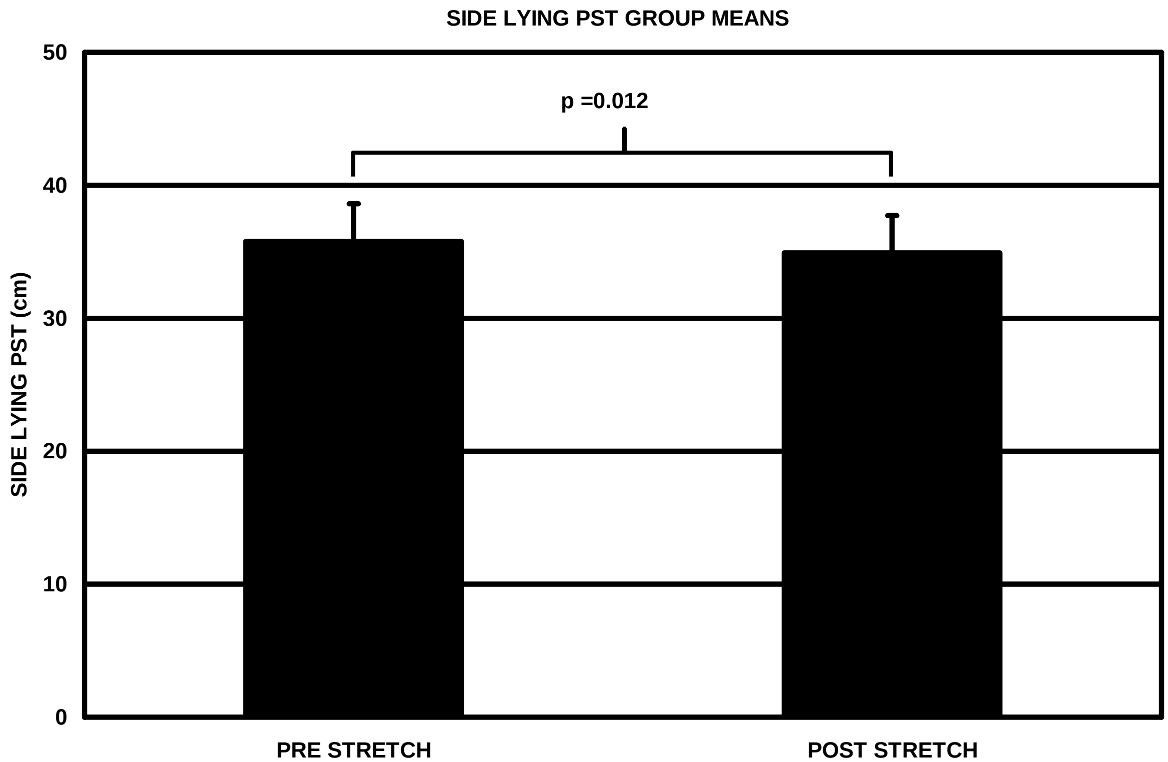


TABLE 10: Side Lying Posterior Shoulder Tightness Measurements

	Pre Stretch		Post Stretch		Difference		P
	Mean	**±SD**	**Mean**	**± SD**	**Mean**	**±SD**	
Side Lying PST(cm)							0.177
Horizontal Cross Arm	36.10	2.87	34.56	2.62	-1.54	2.04	
Sleeper Stretch 90º	35.32	2.66	35.01	2.45	-0.31	1.24	
Sleeper Stretch 45º	35.94	3.12	35.25	3.38	-0.70	2.17	
Group Means	35.78	2.84	34.93	2.79	-0.85	1.89	0.012*

*Significant main effect of stretching

TABLE 11: Instrumented PST Assessments Pre & Post Stretch

	Pre Stretch Mean	± SD	Post Stretch Mean	± SD	Difference Mean	± SD	P
Supine PST(°)							0.559
Horizontal Cross Arm	100.28	4.76	100.41	4.51	0.13	3.29	
Sleeper Stretch 90º	98.46	3.55	100.00	4.87	1.53	3.96	
Sleeper Stretch 45º	98.82	4.91	99.42	4.42	0.61	4.59	
Group Means	99.18	4.41	99.94	4.51	0.75	3.93	0.299
Side Lying PST(cm)							0.160
Horizontal Cross Arm	35.27	2.70	33.84	2.49	-1.43	1.68	
Sleeper Stretch 90º	34.27	3.18	33.98	2.84	-0.28	1.32	
Sleeper Stretch 45º	35.13	3.22	34.60	3.27	-0.53	1.86	
Group Means	34.88	3.01	34.14	2.82	-0.74	1.67	0.007*

*Significant main effect of stretching

3.6 SCAPULAR KINEMATICS DURING STRETCHES

The scapular kinematic data are presented in **TABLE 12**. There were no significant differences between stretch for each of the five scapular kinematic variables, upward rotation (p=0.066), external rotation (p=0.077), posterior tilt (p=0.101), protraction (p=0.221), elevation (p=0.228).

TABLE 12: Scapular Kinematics Data During Stretches

	Mean	±SD	p
Upward/downward rotation			0.066
Horizontal Cross Arm Stretch	1.96	1.10	
Sleeper Stretch 90º	3.14	1.96	
Sleeper Stretch 45º	3.04	2.20	
External/internal rotation			0.077
Horizontal Cross Arm Stretch	2.81	1.58	
Sleeper Stretch 90º	2.91	1.36	
Sleeper Stretch 45º	4.12	3.27	
Posterior/anterior tilt			0.101
Horizontal Cross Arm Stretch	2.71	1.46	
Sleeper Stretch 90º	4.58	3.35	
Sleeper Stretch 45º	4.42	4.02	
Protraction/retraction			0.221
Horizontal Cross Arm Stretch	2.20	1.55	
Sleeper Stretch 90º	2.31	1.37	
Sleeper Stretch 45º	3.13	3.35	
Elevation/depression			0.228
Horizontal Cross Arm Stretch	1.50	1.13	
Sleeper Stretch 90º	1.74	0.73	
Sleeper Stretch 45º	2.18	1.78	

4.0 DISCUSSION

The purpose of this study was to determine the most effective posterior shoulder stretch that acutely increases glenohumeral IR ROM and decreases PST while minimizing scapular movement among baseball pitchers. Due to high pitching velocities and ballistic shoulder rotations, baseball pitchers are known to have both osseous and soft tissue adaptations that result in an increase in ER ROM, a decrease in IR ROM, and an increase in PST[1]. The baseball pitchers in this study presented with a 15.7º mean deficit of IR ROM in their throwing shoulder compared to their non-dominant shoulder. This characteristic is consistent with Burkhart et al[6] who states that baseball pitchers can display as much as 15º less IR ROM and 9º more ER ROM in their throwing shoulder. The greater amount of IR ROM has been extensively reported in previous studies as a normal characteristic for healthy active baseball pitchers[2, 71]. However, the decreases in IR ROM and increases in PST have been associated with injury[6, 19, 28, 76]. For baseball pitchers to maximize their performance and reduce the risk of injury, it may be beneficial to include posterior shoulder stretches into a warm-up program. This study demonstrates that the act of stretching the posterior shoulder resulted in significant acute increases in glenohumeral IR ROM and improvements in PST.

4.1 ACUTE CHANGES IN RANGE OF MOTION

The results of this study demonstrated significant increases in GH IR ROM following stretching, regardless of the stretch performed. It was hypothesized that the standing sleeper stretch at 90º and 45º would create the greatest increase in GH IR ROM, however, all stretches resulted in significant increases in GH IR ROM after stretching.

Although the exact mechanisms behind the acute effects of stretching on performance are not fully understood, a decrease in muscle-tendon unit stiffness after acute stretching has been proposed[77]. Tissue stiffness is the ability of a tissue to resist change in length and is represented by a change in force per change in length[78]. A stiffer tissue would require more force to stretch to a given length[78]. Riemann et al[79] categorized muscle stiffness into intrinsic and extrinsic (reflex) components. The intrinsic components consist of several noncontractile tissues (tendon, fascia) that contain high amounts of collagen. The components therefore, exhibit the properties of elasticity and viscosity when stretched[79]. Because biological tissues are viscoelastic, if the muscle-tendon unit is stretched and then held at a constant length, the passive force at that length gradually declines; the effect known as stress relaxation[80]. In addition, the viscoelastic materials of the muscle-tendon unit produce a variation in the load-deformation relationship that takes place between the loading and unloading curves[81]. Stretching is beneficial for acutely reducing the viscosity and/or stiffness of the muscle-tendon unit, which would be a factor to increase the joint range of motion[80]. Kubo et al[80] suggested that the existence of the viscoelastic changes in muscle-tendon units will depend on the duration rather than the number of stretches.

The extrinsic contribution of muscle stiffness arises from the increased reflexive neural activation of the muscle[79]. This is largely determined by the excitability of the motor-neuron pool, which in itself is largely dependent upon the sensitivity of muscle spindle afferents eliciting reflexes, as well as descending neural commands[79]. The peripheral regions of intrafusal muscle fibers, which are primarily sensitive to changes in velocity, contain contractile elements innervated by gamma motorneurons. The activation level of these gamma motor-neurons directly influences the muscle spindle sensitivity. The muscle spindle functions mainly as a stretch receptor, and the afferent signals from the spindles are hypothesized to be a function of muscle length changes superimposed on the integrated peripheral receptor and descending pathway[79]. The golgi tendon unit, which is sensitive to tension, is located at the origin and insertion at the myotendinous junction[81]. Upon activation, impulses are sent to the spinal cord, causing an inhibition of the alpha motor-neurons of the contracting muscle and its synergists. This in return allows relaxation of the muscle being stretched and changes in muscle length to occur.

Previous studies have demonstrated, however, that lengthening and stretching a muscle decreases activation through the use of surface and fine-wire EMG[82]. Avela et al[83] found decreases in motor-unit recruitment (EMG amplitude) and firing frequency (zero crossing rate) after repeated passive stretches of the plantar flexors. They stated that passive stretching of a muscle could lead to a direct decrease in force.

Changes in muscle-tendon unit stiffness, may therefore, affect the transmission of forces, the rate of force transmission and the rate at which changes in muscle length or tension are detected[84]. This indicates that the decreased muscle stiffness resulting in increased ROM following stretching may result in less energy transfer to the contractile component, and force output.

There are many controversial results regarding the acute effect of stretching on various lower extremity tasks. Some previous studies have demonstrated an acute decrease in vertical jump height and strength output following pre-event static stretching,[54-60], while others have demonstrated no decrease in vertical jump height[44, 57, 85, 86]. While there has been a considerable amount of research devoted to the effects of static stretching on parameters related to the lower extremity, there have been far less devoted to the upper extremity. Knudson et al[61] evaluated upper extremity stretching on tennis serve velocity in tennis players. They found no significant differences in average ball speed following a traditional 5-minute warm-up with static stretching. However, they performed several upper and lower body stretches and did not measure ROM after stretching.

Few studies have evaluated acute ROM increases and force output following stretching in the upper extremity. The baseball pitch is a highly dynamic skill requiring coordinated action of the lower and upper extremity for the GH joint to achieve angular velocities as high as 7000º/s[87]. This study focused on stretching of the posterior shoulder, which is responsible for decelerating the arm in the follow-through phase of overhand throwing[13]. During this phase, a simultaneous contraction of all muscle groups occurs with an eccentric contraction of the posterior shoulder to decelerate the arm[17], and the adducted, internally rotated position places the humeral head posteriorly within the glenoid, generating high posterior stresses[88]. Therefore, it seems unlikely that the posterior shoulder stretches shoulder affect ball velocity, however, further investigation is needed.

The increases of GH IR ROM that results from acute stretching of the posterior shoulder can be beneficial for the overhead athlete. The increase in ROM can potentially provide a greater region over which the forces associated with follow-through are dissipated, thus a greater impulse. Theoretically, by increasing the area over which forces are applied, it will result in less stresses placed on the posterior shoulder. This, in return, may help lessen the onset of fatigue, decrease the risk of injury, and may lead to extended innings pitched.

This study demonstrated an increase in GH IR of 3-4° following stretching. To our knowledge, this is the first study to evaluate acute changes in GH ROM and PST. Previous literature has stated that stretching immediately prior to an event, may be necessary to ensure maximum ROM[89]. Whatman et al[89] evaluated knee joint ROM post stretch and found similar ROM increases. The immediate post-stretch change in ROM they found represents the likelihood (91%) of a clinically useful increase (an increase greater than 2.7º). Passive stiffness was also evaluated in their study. For stretch conditions it is likely (92%) the decrease is a small clinically useful change immediately post-stretch[89].

The literature supports that a static stretch of 30 seconds at a frequency of 3 repeated stretches per single session is sufficient to increase muscle length[46]. Whatman et al[89] showed that ROM increases can occur when performing stretches 4 times 20 seconds, for a total of 80 seconds of stretching. We showed similar ROM increases when stretches were performed 3 times 30 seconds, for a total of 90 seconds of stretching. Our results are consistent with previous literature that supports 3 times 30 seconds for increasing ROM[46]. Previous studies that have used other protocols such as 2 times 15 seconds have shown no increase in ROM[90].

This study demonstrated that the act of stretching the posterior shoulder resulted in increases in GH IR ROM. We hypothesized that there would be differences among stretches due to the positioning of the arm and the direction of joint motion while stretching. The sleeper stretch at 90º is designed to stabilize the scapula while stretching the posterior rotator cuff muscles and the posterior inferior capsule/GH ligament in the shoulder[53]. The sleeper stretch at 45º is performed when there is pain with the 90º position. This stretch is performed the same way, however the stretching sensation is felt lower in the posterior shoulder and there is more triceps involvement[91]. The horizontal cross arm stretch primarily stretches the posterior musculature to a greater degree than the posterior inferior capsule[6] while the arm is horizontally adducted across the chest. Although these stretches might focus on slightly different portions of the posterior shoulder due to joint position, they all were shown increase GH IR ROM.

ER ROM of the shoulder was measured before and after stretching as well. There were no significant differences in GH ER ROM following stretching. We did not expect changes in ER because all the posterior shoulder stretches were focused on increasing IR of the shoulder.

4.2 ACUTE CHANGES IN POSTERIOR SHOULDER TIGHTNESS

The results of this study demonstrated significant decreases in posterior shoulder tightness after stretching with both the supine and the side lying assessments. We hypothesized that the standing horizontal cross arm stretch would create the greatest improvement in PST following stretching. The standing horizontal cross arm stretch is believed to primarily stretch the posterior musculature to a greater degree when the scapula is stabilized[6]. However, these results show that no matter which posterior shoulder stretch is performed, PST will improve.

The stretches chosen for this study focused on stretching the posterior shoulder which consists of posterior rotator cuff muscles and the posterior deltoid. These muscles are responsible for glenohumeral ER ROM, however, they limit glenohumeral IR ROM when contracted. Our results found an increase in glenohumeral IR ROM after stretching because of stretching the posterior shoulder. In addition, stretching the posterior shoulder created a decrease in PST.

In this study we used two methods of measurement for PST. We measured manual side lying PST using an antropometer, supine PST using a digital inclinometer and both using an electromagnetic tracking device. The PST assessments were measured with the electromagnetic tracking device simultaneously with the manual measurement for better precision because small measurement differences were expected.

The side lying PST assessment, as described by Tyler et al[2], is a measurement of the distance of the medial epicondyle of the humerus to the top of the treatment table while the examiner stabilizes the scapula. The medial epicondyle is easily palpable for a simultaneous measurement with the anthropometer and the electromagnetic tracking device. Although the side lying method has been shown to be reliable, it is difficult to make comparisons among patients due to different body structures and shoulder widths. Results of this study demonstrated significant improvements in side lying PST following stretching when measured with both the anthropometer and the electromagnetic tracking device.

The supine PST assessment is a measurement of the angle formed between the humerus and the horizontal plane from the superior aspect of the shoulder. This measurement requires the clinician to align the inclinometer along the humerus while estimating the GH joint center and elbow joint center. These values are estimated in the electromagnetic tracking device by digitizing the anatomical landmarks prior to testing. Our results showed only significant improvements in supine PST with the inclinometer following stretching. The disagreement between the manual and electromagnetic tracking device results maybe due to human error with the inclinometer or possibly from the movement of the scapular receiver due to the skin movement when the humerus is horizontally abducted. The assessment of the scapular kinematics during a humeral elevation task using an electromagnetic tracking device has only been validated below the humeral elevation angle of 120 deg due to an increased error from excess skin movement.

Recent studies have shown PST to be a contributing factor to shoulder pathologies in the overhead athlete[1, 2, 4, 6, 8, 27, 69]. It has been documented that tightness in the posterior shoulder structures tend to shift the GH joint center postero-superiorly during maximal ER[92]. This change in position increases the risk of developing labral pathologies such as SLAP lesions in overhead athletes[6].

PST has also been associated and correlated with loss of GH IR ROM[10 4, 76]. Tyler et al[4] found a significant correlation between IR ROM losses and increased PST in patients with shoulder impingement. Based on their data, they stated that clinicians can expect 1cm of PST for every 4º of IR ROM lost. In the current study, the IR ROM was increased by approximately 4º (4.25±5.20deg) and the side-lying PST decreased by approximately 1cm (0.85 ±1.89cm) immediately following the stretch.

Pappas et al[3] assessed PST in baseball pitchers by goniometrically measuring subjects in a supine position with manual stabilization of the scapula. Recently, Laudner et al[76] documented the reliability and validity of measuring GH joint horizontal adduction using a digital inclinometer. Using the digital inclinometer significantly reduced the number of subjective estimations needed by the examiner and allowed for easy, reproducible, and accurate measurements[76]. Similar to a correlation that Tyler et al[4] found with PST and IR , Laudner et al[76] documented a moderate to good relationship between decreased IR and decreased posterior shoulder motion of the dominant arm in healthy individuals. The results of this study demonstrate similar relationships following stretching.

As stated previously, the stretches performed in this study focused on stretching the posterior shoulder. Although the stretches may have slightly affected different components of the posterior shoulder due to arm position and joint motion, all stretches improved PST following stretching.

4.3 SCAPULAR KINEMATICS

This is the first study to evaluate the amount of scapular motion that occurs during the standing sleeper stretch at 90º and 45º, and the standing horizontal cross arm stretch. It is important to minimize scapular motion during stretching for better isolation of the glenohumeral joint. When the scapula is stabilized, stretching can occur at the glenohumeral joint resulting in increased ROM.

It was hypothesized that the horizontal cross arm stretch would provide the most scapular stabilization and that the standing sleeper stretch at 45º would provide the least amount of scapular stabilization. These hypothesizes were developed based on the relative position of the scapula to the wall while stretching. The horizontal cross arm stretch allows for easy location of the scapular border for stabilization against a wall, while the sleeper stretch at 45º provides minimal exposure to the lateral border of the scapula for stabilization. However, the results of this study showed no differences in the amount of scapular motion that occurred during any of the stretches performed.

The main variable of interest when evaluating the scapular motion of each stretch was protraction/retraction. The goal of the posterior shoulder stretches is to isolate the GH joint and allow stretching to occur in the posterior shoulder. If there is excessive protraction of the scapula, stretching may occur at the scapulothoracic articulation rather than the posterior shoulder. Kibler[13] believes that if stretching occurs at the scapulothoracic articulation, it will increase rather than alleviate the biomechanical problem by allowing too much scapular protraction. There were, however, no significant differences between each stretch and protraction/retraction, suggesting that all three posterior shoulder stretches properly stabilized the scapula allowing for a potential isolation of the posterior shoulder during stretching.

The stretches chosen for this study were based on the ability to be performed independently on-the-field, without the help of a clinician to provide scapular stabilization. Previous literature describes various stretching techniques with the help of a clinician to manually provide scapular stabilization[8, 41, 64, 65]. Despite the importance of stabilizing the scapula when stretching the posterior shoulder, there are no studies to our knowledge that compare assisted to non-assisted stretches evaluating the efficacy of scapular stabilization.

The chosen stretches were all performed while standing against a wall support. This was to stimulate a dug-out wall that could be used to perform the stretches on-the-field in an activity warm-up setting. The side lying sleeper stretches are known for their ability to stabilize the scapula while lying on a table[6]. This position, however, does not allow pitchers to perform these stretches on-the-field. This study has determined that the standing sleeper stretches and standing horizontal cross arm stretch are very appropriate for an on-the-field warm-up, when performed properly.

With proper instruction and position of the scapula, these stretches demonstrated acute ROM changes after stretching. All subjects were given consistent instructions for proper positioning against the wall support. First, the subject was positioned with their dominant shoulder perpendicular to the wall. They then raised their arm and focused on placing their lateral scapula border against the wall. They were instructed to lean against the wall using their body weight to stabilize the scapula. Once proper positioning of the scapula was achieved, the arm was moved into the position of stretch, either 90º of GH flexion, 45º GH flexion, or adducted across the chest. The subjects remained in that position for 30 seconds during the stretching.

4.4 CLINICAL SIGNIFICANCE

Our data suggests that the standing sleeper stretch at 90º, the standing sleeper stretch at 45º, and the horizontal cross arm stretch effectively increased GH ROM when performed 3 times for 30 seconds. With proper positioning for scapular stabilization, baseball pitchers can perform these stretches independently. Clinicians and baseball coaches may instruct the pitchers and players to perform these stretches as part of the on-the-field warm up routine, or between innings for the maintenance of their posterior shoulder flexibility. In addition, these stretches can be performed independently off the field to enhance ROM, reduce muscle soreness, and decrease the onset of injury.

4.5 LIMITATIONS OF THE STUDY

One of the main limitations of this study was that all subjects were assumed to be healthy based on absence of shoulder pain or history of shoulder injury. No physical exam, x-rays or magnetic resonance imaging (MRI) were performed to rule out pathology. There is a possibility that some subjects may have had underlying pathology that had yet to become symptomatic.

Another limitation is due to the influence of pitching. All subjects were tested during the off season, however, some subjects were tested after pitching at practice that day. A few subjects complained of soreness that may have influenced their full GH ROM. An additional limitation in this study was that GH ROM and PST was not repeatedly measured after the stretch to know how long the effects of each stretch lasted. Only immediate effects were measured following stretching, thus, the duration of the stretch effects could not be determined. In addition, force output and ball velocity was not measured in this study as well. These measures would determine any force deficits or decreases in ball velocity that might occur due to stretching prior to pitching.

4.6 FUTURE DIRECTIONS

Further research is needed to determine the lasting stretch effects of the posterior shoulder stretches, force output, and ball velocity after stretching. The effects of pre-event stretching need to last long enough to be considered as a possible mechanism to reduce the risk of injury and enhance performance during an activity. Previous studies has shown no clear evidence that increases in ROM last longer than 5-15 minutes[89, 90]. Limited studies have focused on upper extremity force output and ball velocity following static stretching. That information is important to determine the timing of these stretches prior to an event. Once the duration of the stretch effects, force output, and ball velocity are determined, more effective stretching protocols can be established. Until then, it is still unknown as to which posterior shoulder stretches to perform, when to perform the stretches, and for how long to stretch prior to an event.

Studies comparing different types of stretching are also needed in the upper extremity. This study did not evaluate PNF stretching, assisted stretching, or dynamic warm up procedures. Comparisons of these stretches will help develop the most appropriate stretching protocol for overhead athletes with the goal of reducing the risk of injury without compromising performance.

Although it is commonly documented that baseball pitchers present with increased PST and decreased GH IR ROM, this study did not involve other overhead athletes. It is speculated, however, that other highly dynamic overhead sport athletes develop similar shoulder adaptations as well. The results of this study are very applicable to all overhead athletes and future studies should evaluate other overhead athletes to compare acute ROM increases.

4.7 CONCLUSIONS

This study has demonstrated that performing a posterior shoulder stretch for a single session of 3 repeated 30 seconds is adequate to significantly increase acute GH IR ROM and decrease PST. Sufficient scapular stabilization can be achieved when the standing sleeper stretch at 90º, standing sleeper stretch at 45º, and the standing horizontal cross arm stretch are performed correctly. Despite our hypotheses, this study found that regardless of the posterior shoulder stretch that is performed, an increase in GH IR ROM and decrease in PST will occur. These stretches are very beneficial to overhead athletes and can be performed during an on-the-field warm up session.

BIBLIOGRAPHY

1. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med.*2006;34(3):385-391.

2. Tyler TF, Roy T, Nicholas SJ, Gleim GW. Reliability and validity of a new method of measuring posterior shoulder tightness. *J Orthop Sports Phys Ther.*1999;29(5):262-269; discussion 270-264.

3. Pappas AM, Zawacki RM, McCarthy CF. Rehabilitation of the pitching shoulder. *Am J Sports Med.*1985;13(4):223-235.

4. Tyler TF, Nicholas SJ, Roy T, Gleim GW. Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. *Am J Sports Med.*2000;28(5):668-673.

5. Awan R, Smith J, Boon AJ. Measuring shoulder internal rotation range of motion: a comparison of 3 techniques. *Arch Phys Med Rehabil.*2002;83(9):1229-1234.

6. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. *Arthroscopy.*2003;19(4):404-420.

7. Brown LP, Niehues SL, Harrah A, Yavorsky P, Hirshman HP. Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. *Am J Sports Med.*1988;16(6):577-585.

8. Wilk KE, Meister K, Andrews JR. Current concepts in the rehabilitation of the overhead throwing athlete. *Am J Sports Med.*2002;30(1):136-151.

9. Meister K, Day T, Horodyski M, Kaminski TW, Wasik MP, Tillman S. Rotational motion changes in the glenohumeral joint of the adolescent/Little League baseball player. *Am J Sports Med.*2005;33(5):693-698.

10. Borsa PA, Wilk KE, Jacobson JA, et al. Correlation of range of motion and glenohumeral translation in professional baseball pitchers. *Am J Sports Med.*2005;33(9):1392-1399.

11. Reagan KM, Meister K, Horodyski MB, Werner DW, Carruthers C, Wilk K. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. *Am J Sports Med.*2002;30(3):354-360.

12. Borsa PA, Dover GC, Wilk KE, Reinold MM. Glenohumeral range of motion and stiffness in professional baseball pitchers. *Med Sci Sports Exerc.*2006;38(1):21-26.

13. Kibler WB. The role of the scapula in athletic shoulder function. *Am J Sports Med.*1998;26(2):325-337.

14. Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis upon shoulder kinematics. *J Orthop Sports Phys Ther.*1993;18(2):402-408.

15. Ellenbecker TS, Roetert EP, Bailie DS, Davies GJ, Brown SW. Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. *Medicine & Science in Sports & Exercise.*2002;34:2052-2056.

16. Osbahr DC, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. *Am J Sports Med.*2002;30(3):347-353.

17. Crawford SD, Sauers EL. Glenohumeral joint laxity and stiffness in the functional throwing position of high school baseball pitchers. *J Athl Train.*2006;41(1):52-59.

18. Crockett HC, Gross LB, Wilk KE, et al. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med.*2002;30(1):20-26.

19. Meister K. Injuries to the shoulder in the throwing athlete. Part one: Biomechanics/pathophysiology/classification of injury. *Am J Sports Med.*2000;28(2):265-275.

20. Jobe CM, Iannotti JP. Limits imposed on glenohumeral motion by joint geometry. *J Shoulder Elbow Surg.*1995;4(4):281-285.

21. Lorenz D. The Importance of the Posterior Capsule of the Shoulder in Overhead Athletes. *National Strength and Conditioning Association.*2005;27(4):60-62.

22. Bigliani LU, Codd TP, Connor PM, Levine WN, Littlefield MA, Hershon SJ. Shoulder motion and laxity in the professional baseball player. *Am J Sports Med.*1997;25(5):609-613.

23. Werner SL, Gill TJ, Murray TA, Cook TD, Hawkins RJ. Relationships between throwing mechanics and shoulder distraction in professional baseball pitchers. *Am J Sports Med.*2001;29(3):354-358.

24. Levine WN, Flatow EL. The pathophysiology of shoulder instability. *Am J Sports Med.*2000;28(6):910-917.

25. Bigliani LU, Kelkar R, Flatow EL, Pollock RG, Mow VC. Glenohumeral stability. Biomechanical properties of passive and active stabilizers. *Clin Orthop Relat Res.*1996(330):13-30.

26. Cain PR, Mutschler TA, Fu FH, Lee SK. Anterior stability of the glenohumeral joint. A dynamic model. *Am J Sports Med.*1987;15(2):144-148.

27. Downar JM, Sauers EL. Clinical Measures of Shoulder Mobility in the Professional Baseball Player. *J Athl Train.*2005;40(1):23-29.

28. Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. *J Am Acad Orthop Surg.*2003;11(2):142-151.

29. Thigpen CA, Padua DA, Morgan N, Kreps C, Karas SG. Scapular kinematics during supraspinatus rehabilitation exercise: a comparison of full-can versus empty-can techniques. *Am J Sports Med.*2006;34(4):644-652.

30. Dome DC, Kibler WB. Evaluation and Management of Scapulothoracic Disorders. *Current Opinion in Orthopaedics.*2006;17:321-324.

31. Laudner KG, Myers JB, Pasquale MR, Bradley JP, Lephart SM. Scapular dysfunction in throwers with pathologic internal impingement. *J Orthop Sports Phys Ther.*2006;36(7):485-494.

32. Krahl VE. The torsion of the humerus: Its localization, cause, and duration in man. *Am J Anat.*1947;80:275-319.

33. Pieper HG. Humeral torsion in the throwing arm of handball players. *Am J Sports Med.*1998;26:247-253.

34. Axe MJ. Recommendations for Protecting Youth Baseball Pitchers. *Sports Medicine and Arthroscopy Review.*2001;9:147-153.
35. Sabick MB, Kim YK, Torry MR, Keirns MA, Hawkins RJ. Biomechanics of the shoulder in youth baseball pitchers: implications for the development of proximal humeral epiphysiolysis and humeral retrotorsion. *Am J Sports Med.*2005;33(11):1716-1722.
36. Ludewig PM, Cook TM. Translations of the humerus in persons with shoulder impingement symptoms. *J Orthop Sports Phys Ther.*2002;32(6):248-259.
37. Warner JJ, Micheli LJ, Arslanian LE, Kennedy J, Kennedy R. Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. *Am J Sports Med.*1990;18(4):366-375.
38. Davidson PA, Elattrache NS, Jobe CM, Jobe FW. Rotator cuff and posterior-superior glenoid labrum injury associated with increased glenohumeral motion: a new site of impingement. *J Shoulder Elbow Surg.*1995;4(5):384-390.
39. Schmitt L, Snyder-Mackler L. Role of scapular stabilizers in etiology and treatment of impingement syndrome. *J Orthop Sports Phys Ther.*1999;29:31-38.
40. Cavallo R, Speer K. Shoulder instability and impingement in throwing athletes. *Med Sci Sports Exerc.*1998;30(4):18-25.
41. Boon AJ, Smith J. Manual scapular stabilization: its effect on shoulder rotational range of motion. *Arch Phys Med Rehabil.*2000;81(7):978-983.
42. Kibler WB, McQueen C, Uhl T. Fitness Evaluations and Fitness Findings in Competitive Junior Tennis Players. *Clin Sports Med.*1988;7:403-416.
43. Litchfield R, Hawkins R, Dillman CJ, Atkins J, Hagerman G. Rehabilitation for the overhead athlete. *J Orthop Sports Phys Ther.*1993;18(2):433-441.
44. Knudson D, Bennett K, Corn R, Leick D, Smith C. Acute Effects of Stretching are not Evident in the Kinematics of the Vertical Jump. *J Strength Cond Res.*2001;15(1):98-101.
45. Smith CA. The warm-up procedure: to stretch or not to stretch. A brief review. *J Orthop Sports Phys Ther.*1994;19(1):12-17.
46. de Weijer VC, Gorniak GC, Shamus E. The effect of static stretch and warm-up exercise on hamstring length over the course of 24 hours. *J Orthop Sports Phys Ther.*2003;33(12):727-733.
47. Williford HN, East JB, Smith FH, Burry LA. Evaluation of warm-up for improvement in flexibility. *Am J Sports Med.*1986;14(4):316-319.
48. Cramer JT, Housh TJ, Johnson GO, Miller JM, Coburn JW, Beck TW. Acute effects of static stretching on peak torque in women. *J Strength Cond Res.*2004;18(2):236-241.
49. Halbertsma JP, van Bolhuis AI, Goeken LN. Sport stretching: effect on passive muscle stiffness of short hamstrings. *Arch Phys Med Rehabil.*1996;77(7):688-692.
50. Andersen JC. Stretching Before and After Exercise: Effect on Muscle Sorenes and Injury Risk. *J Athl Train.*2005;40(3):218-220.
51. Evetovich TK, Nauman NJ, Conley DS, Todd JB. Effect of static stretching of the biceps brachii on torque, electromyography, and mechanomyography during concentric isokinetic muscle actions. *J Strength Cond Res.*2003;17(3):484-488.
52. Kibler WB. The relationship of glenohumeral internal rotation deficit to shoulder and elbow injuries in tennis players: A prospective elvaluation of posterior capsular stretching. Paper presented at: Presented at the Annual closed meeting of the American Shoulder and Elbow Surgeons, October 1998; New York.

53. The relationship Between Glenohumeral Internal Rotation and Shoulder and Elbow Pain. *PBATS Newsletter*.2002;15(2).

54. Nelson AG, Allen JD, Cornwell A, Kokkonen J. Inhibition of maximal voluntary isometric torque production by acute stretching is joint-angle specific. *Res Q Exerc Sport.*2001;72(1):68-70.

55. Nelson AG, Kokkonen J. Acute ballistic muscle stretching inhibits maximal strength performance. *Res Q Exerc Sport.*2001;72(4):415-419.

56. Kokkonen J, Nelson AG, Cornwell A. Acute muscle stretching inhibits maximal strength performance. *Res Q Exerc Sport.*1998;69(4):411-415.

57. Unick J, Kieffer HS, Cheesman W, Feeney A. The acute effects of static and ballistic stretching on vertical jump performance in trained women. *J Strength Cond Res.*2005;19(1):206-212.

58. Laur DJ, Anderson T, Geddes G, Crandall A, Pincivero DM. The effects of acute stretching on hamstring muscle fatigue and perceived exertion. *J Sports Sci.*2003;21(3):163-170.

59. Cornwell A, Nelson AG, Sidaway B. Acute effects of stretching on the neuromechanical properties of the triceps surae muscle complex. *Eur J Appl Physiol.*2002;86(5):428-434.

60. Yamaguchi T, Ishii K, Yamanaka M, Yasuda K. Acute effect of static stretching on power output during concentric dynamic constant external resistance leg extension. *J Strength Cond Res.*2006;20(4):804-810.

61. Knudson D, Noffal GJ, Bahamonde RE, Bauer JA, Blackwell JR. Stretching has no effect on tennis serve performance. *J Strength Cond Res.*2004;18(3):654-656.

62. Beaulieu JE. Developing a Stretching Program. *Phys Sportsmed.*1981;9:59-69.

63. Myers JB, Pasquale MR, Laudner KG, Sell TC, Bradley JP, Lephart SM. On-the-Field Resistance-Tubing Exercises for Throwers: An Electromyographic Analysis. *J Athl Train.*2005;40(1):15-22.

64. Johansen RL, Callis M, Potts J, Shall LM. A modified internal rotation stretching technique for overhand and throwing athletes. *J Orthop Sports Phys Ther.*1995;21(4):216-219.

65. Mullaney MJ, Nicholas SJ. Rehabilitation for the Post Surgical Bankart Lesion. *Current Concepts in the Examination and Treatment of the Shoulder*. New York; 2005.

66. Ninos J. Posterior Shoulder Stretches. *Strength and Conditioning.*1997(2):18-19.

67. Meister K. Injuries to the shoulder in the throwing athlete. Part two: evaluation/treatment. *Am J Sports Med.*2000;28(4):587-601.

68. Williams D. Posterior Capsule Stretching. *Strength and Conditioning.*1998(4):11-12.

69. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part III: The SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy*.2003;19(6):641-661.

70. Myers JB, Jolly JT, Nagai T, Lephart SM. Reliability and Precision of in Vivo Scapular Kinematic Measurements Using an Electromagnetic Tracking Device. *J Sport Rehabil.*2006;15:125-143.

71. Myers JB, Wassinger CA, Oyama S, Jolly JT, Ricci RD, Lephart SM. Accuracy of two common clinical assessments of posterior shoulder tightness. Paper presented at: National Athletic Trainers' Association, 2006; Atlanta, GA.

72. Myers JB, Oyama S, Wassinger CA, et al. Reliability, Precision, Accuracy, and Validity of Posterior Shoulder Tightness Assessment in Overhead Athletes. *Am J Sports Med (In Press).*2007.
73. Norkin CC, White DJ. *Measurement of Joint Motion: A Guide to Goniometry*. Philadelphia: F. A. Davis Company; 1995.
74. Wu G, van der Helm FC, Veeger HE, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand. *J Biomech.*2005;38(5):981-992.
75. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Scapular Postion and Orientation in Throwing Athletes. *Am J Sports Med.*2005;33(2):263-271.
76. Laudner KG, Stanek JM, Meister K. Assessing posterior shoulder contracture: the reliability and validity of measuring glenohumeral joint horizontal adduction. *J Athl Train.*2006;41(4):375-380.
77. Bjorklund M, Djupsjobacka M, Crenshaw AG. Acute muscle stretching and shoulder position sense. *J Athl Train.*2006;41(3):270-274.
78. Stone M, O'Bryant H, Ayers C, Sands W. Stretching: Acute and Chronic? The Potential Consequences. *Strength and Conditioning Journal.*2006;28(6):66-74.
79. Riemann BL, Lephart SM. The Sensorimotor System, Part II: The Role of Proprioception in Motor Control and Functional Joint Stability. *J Athl Train.*2002;37(1):80-84.
80. Kubo K, Kanehisa H, Kawakami Y, Fukunaga T. Influence of static stretching on viscoelastic properties of human tendon structures in vivo. *J Appl Physiol.*2001; 90(2):520-527.
81. Wilk KE, Voight ML, Keirns MA, Gambetta V, Andrews JR, Dillman CJ. Stretch-shortening drills for the upper extremities: theory and clinical application. *J Orthop Sports Phys Ther.*1993;17(5):225-239.
82. Marek SM, Cramer JT, Fincher AL, et al. Acute Effects of Static and Proprioceptive Neuromuscular Facilitation Stretching on Muscle Strength and Power Output. *J Athl Train.*2005;40(2):94-103.
83. Avela J, Kyrolainen H, Komi PV. Altered reflex sensitivity after repeated and prolonged passive muscle stretching. *J Appl Physiol.*1999;86(4):1283-1291.
84. Behm DG, Bambury A, Cahill F, Power K. Effect of acute static stretching on force, balance, reaction time, and movement time. *Med Sci Sports Exerc.*2004;36(8):1397-1402.
85. Woolstenhulme MT, Griffiths CM, Woolstenhulme EM, Parcell AC. Ballistic stretching increases flexibility and acute vertical jump height when combined with basketball activity. *J Strength Cond Res.*2006;20(4):799-803.
86. Church JB, Wiggins MS, Moode FM, Crist R. Effect of warm-up and flexibility treatments on vertical jump performance. *J Strength Cond Res.*2001;15(3):332-336.
87. Mullaney MJ, McHugh MP, Donofrio TM, Nicholas SJ. Upper and lower extremity muscle fatigue after a baseball pitching performance. *Am J Sports Med.*2005;33(1):108-113.
88. Pepe M, Rodosky M. Nonoperative Treatment of Common Shoulder Injuries in Athletes. *Sports Medicine and Arthroscopy Review.*2001;9:96-104.
89. Whatman C, Knappstein A, Hume P. Acute changes in passive stiffness and range of motion post-stretching. *Physical Therapy in Sport.*2006;7:195-200.

90. Zito M, Driver D, Parker C, Bohannon R. Lasting effects of one bout of two 15-second passive stretches on ankle dorsiflexion range of motion. *J Orthop Sports Phys Ther.*1997;26(4):214-221.

91. Donley P, Verna C, Morgan C, Cooper J. Managing Glenohumeral Internal Rotation Deficit: Seattle Mariners Organiation; 1991.

92. Harryman DT, 2nd, Sidles JA, Clark JM, McQuade KJ, Gibb TD, Matsen FA, 3rd. Translation of the humeral head on the glenoid with passive glenohumeral motion. *J Bone Joint Surg Am.*1990;72(9):1334-1343.