Comparison of the Proprioceptive and Motion Reduction Effects of Shoulder Braces in Individuals With and Without Anterior Shoulder Dislocations: A Pilot Study

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COMPARISON OF THE PROPRIOCEPTIVE AND MOTION REDUCTION EFFECTS OF SHOULDER BRACES IN INDIVIDUALS WITH AND WITHOUT ANTERIOR SHOULDER DISLOCATIONS: A PILOT STUDY

by
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April 5, 2012

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

BACKGROUND AND PURPOSE: In individuals with a history of anterior shoulder dislocation, research has shown that proprioception can become impaired. Conservative intervention often includes the use of a shoulder brace for activities. There is currently no research that compares the efficacy of shoulder braces in limiting range of motion (ROM) and providing proprioceptive feedback of the shoulder. The purpose of this pilot study was to investigate the effects of various shoulder braces on glenohumeral ROM and proprioception in individuals with a history of anterior shoulder dislocation. Subjects without a history of dislocation were also recruited to assess the feasibility of the methodology utilized in this study.

METHODS: Eight subjects’ maximal ROM and proprioception were tested in three conditions: 1) no brace; 2) Duke Wyre; and 3) Sully. Kinematic data for both proprioception and ROM was collected using an electromagnetic 3-dimensional motion capture system. Humeral motions tested were: 1) abduction; 2) maximal external rotation at 90° of abduction; and 3) combined motion. Proprioception was tested using active replication of three standardized external rotation (ER) positions of the shoulder. Outcome measures included motion restriction compared to the no brace condition and the relative error in active replication at each of the three ER positions.

RESULTS: ANOVA’s were run for each ROM and proprioception condition and if significant, post-hoc, independent t-tests were performed. Significance for all tests was set at 0.05. Statistically significant findings between all brace conditions were found with glenohumeral ER and abduction. Significant differences in combined ranges of motion were found between the no-brace condition and braced conditions. Proprioceptive testing revealed statistically significant findings between the no-brace condition and the Sully, and between the Sully and Duke Wyre at 10 degrees of ER. Ten degrees short of maximal ER revealed statistical significance between the Sully and other two conditions.

CONCLUSION: Both the Duke Wyre and the Sully shoulder braces limit glenohumeral ROM. The Sully increased shoulder proprioception in positions vulnerable to dislocation. The study design and methods performed will enable future research to expand upon the data gathered in order to benefit both the clinician and athletic populations.
The undersigned certify that they have read, and recommended approval of the research project entitled...

COMPARISON OF THE PROPRIOSPECTIVE AND MOTION REDUCTION EFFECTS OF SHOULDER BRACES IN INDIVIDUALS WITH AND WITHOUT ANTERIOR SHOULDER DISLOCATIONS: A PILOT STUDY

Submitted by
Evan Boldt
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In partial fulfillment of the requirements for the Doctor of Physical Therapy Program

Primary Advisory: Cort J. Cieminski, PT, PhD, ATR

Date: 4-5-2012
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CHAPTER I
INTRODUCTION

The glenohumeral joint is the most mobile joint in the human body. As a result of that mobility, the shoulder is also the most unstable joint in the human body.

Glenohumeral instability can present in a wide spectrum from minor subluxations to full dislocations.\(^1\) Shoulder dislocations involve the displacement of the humeral head from its normal position in the glenoid fossa, often leading to separation of the articular surfaces and causing further injury to the surrounding joint capsule and ligamentous structures.\(^2\) The glenohumeral joint has the highest rate of dislocation of any joint in the human body, with studies showing shoulder dislocations occurring at a rate of 1-2% in the general population, and a shoulder dislocation rate as high as 7% in the athletic population.

Traumatic anterior shoulder dislocations involve the proximal humerus being forced anteriorly through the glenohumeral joint capsule. Traumatic anterior shoulder dislocations account for 96% of all shoulder dislocations and are most commonly caused by forced external rotation and abduction of the humerus.\(^1,2\) Once an anterior shoulder dislocation has occurred, there is a high probability of recurrence. Studies have shown that the mean dislocation rate for all ages is 67%, with patients under 30 years of age having a dislocation rate as high as 92%.\(^3\)
**Glenohumeral anatomy**

The glenohumeral joint, or more commonly referred to as the shoulder joint, involves the bony articulation between the head of the humerus and the glenoid fossa of the scapula. This joint is considered a ball and socket joint, with the convex head of the humerus being the ball, and the concave portion of the glenoid serving as the socket. The glenohumeral joint is stabilized by many different structures which are commonly divided up into two groups; dynamic and static stabilizers. Dynamic stabilizers include the four tendons of the rotator cuff as well as the long head of the biceps, which function mainly during active motion. Static restraints to dislocation include the glenoid labrum, the glenohumeral ligaments, the bony glenoid architecture, and the joint capsule. Proper stabilization of the glenohumeral joint requires an intricate balance of the static and dynamic stabilizers, which can be disrupted in an anterior shoulder dislocation.

**Proprioception**

Proper shoulder stability requires not only the intact static and dynamic stabilizers, but it also requires intact proprioception. Proprioception is the sense of joint and limb movement and position caused by the depolarization of nerve endings called mechanoreceptors.\(^1-^3\) Mechanoreceptors depolarize when tissues such as tendons, muscle, or skin change position and cause the tissue to become deformed.\(^1\) The extent of depolarization of the mechanoreceptors depends on the amount of tissue deformation.\(^1\) The more mechanoreceptors the body has in a particular area increases the ability to receive information about the position of the body or limb.\(^1\) It has been found that
receptors in the joint are most likely to be active at end ranges of motion. Proprioception can serve as a protective mechanism against any excessive strain placed on the joint. It has been shown that this joint position sense can be damaged with an anterior shoulder dislocation, thus impairing the body’s ability to avoid vulnerable positions that may lead to recurrent subluxation or dislocation.

There are several methods in which proprioception can be evaluated. One way in which proprioception in a limb can be measured is by active repositioning. In this method, a subject’s limb can be passively placed in a target angle of motion. The subject’s limb is then placed back to a resting position and they are asked to replicate the target angle of motion actively.

Another method to evaluate proprioception of a joint is by passive repositioning. In this method, a subject’s limb can be passively placed to a target angle of motion. The subject’s limb is then placed back to a resting position and then they are moved passively either by a researcher or machine in the same direction of motion and verbalize when they think their limb is in the same position as it was placed originally.

Additionally, a subject’s proprioception can be evaluated using a dynamic tracking task, where their opposite limb is moved passively to a target angle, and the subject is asked to actively replicate the movement with the limb being tested.

A study done by Herrington et al assessed the effect on proprioceptive acuity of a neoprene brace on the knee in healthy subjects. The study also examined the relationships between three different methods of testing proprioception (active tracking, active reproduction, and perceived angle tests). Subjects’ proprioceptive acuity was tested
with all three methods with the presence of a neoprene brace or without a neoprene brace. All three tests showed that the neoprene brace significantly improved the degree of error.\textsuperscript{5} The study concluded that due to the weak relationship between the findings of the tests, it appears that the different tests measure different aspects of proprioception such as joint, muscle and cutaneous receptors, or visual feedback.\textsuperscript{6}

\textit{Bracing}

Treatment for an anteriorly dislocated shoulder often begins with the reduction of the acute dislocation. Approaches to the care of a shoulder after it has been reduced involve the two main choices of operative or non-operative treatment. Operative treatment involves varying approaches, all with the common goal of restoring the anatomic stability of the injured glenohumeral joint to ensure optimal healing. Non-operative treatment typically involves a period of immobilization in a sling, followed by therapeutic exercises with a focus on increasing the stability and proprioception of the glenohumeral joint.

Regardless of whether an injury is treated surgically or conservatively, further precautions may be necessary upon return to activity or sport. Glenohumeral joint braces are designed with the intention of limiting glenohumeral motion to help prevent recurrent shoulder dislocation and to offer stability to the joint. Several glenohumeral joint braces are available with varying containment methods, construction, comfort and costs. Braces provide support to the glenohumeral joint after anterior shoulder dislocation by three methods: restricting excessive abduction, extension and external rotation; supplying an
indirect force to the humeral head; or providing a direct stabilizing force to the humeral head.

Two commonly utilized shoulder braces for glenohumeral instability are the Duke Wyre Shoulder Vest (Duke Wyre) (C.D. Denison Orthopaedic Appliance Corporation, Baltimore, Maryland) and the DonJoy Sully Shoulder Stabilizer® (Sully) (The Saunders Group Inc, Chaska, MN). The Duke Wyre is comprised of canvas and leather with adjustable shoestrings that allow for static control of abduction and extension motions, but is not designed to limit external rotation. The Sully is made of neoprene and has an adjustable hook and loop fastener. The Sully is designed to limit abduction and apply an indirect posterior force to the humeral head for support. The Sully allows external rotation and extension.\(^7\)

**Purpose and hypothesis of the study**

Currently, there are research studies that have investigated types of shoulder braces and their possible limitations on active and/or passive ranges of motion. These studies have involved athletic participants who either have or have not had a history of shoulder injuries, dislocations in particular. The braces typically used within the research focusing on range of motion are a type of brace constructed with a rigid material such as canvas. On the other end of the spectrum there are research studies that investigate the effects that shoulder bracing has on proprioception. The studies in our literature search used subjects that had both stable and unstable shoulders. The brace that appears to be most commonly selected is a neoprene based sleeve with or without straps. During the
search of the literature, no studies were found that compared various materials and styles of shoulder braces in both active range of motion and proprioceptive feedback. Therefore the purpose of this study was threefold: 1) to determine the feasibility of the methodology used; 2) to investigate the effect that a sturdy canvas brace and a neoprene strapped brace have on glenohumeral maximal active planar and combined ranges of motion; and 3) to determine the effects that a sturdy canvas brace and a neoprene strapped brace have on glenohumeral proprioception. The null hypotheses of this study include no difference between the no-brace condition and braced conditions for range of motion restrictions, and no difference between the no-brace condition and the braced conditions on proprioception. The hypothesis of this investigation is that the canvas shoulder brace will have the greatest effect on restricting active glenohumeral planar and combined motions, while the neoprene brace will have the greatest effect on increasing proprioceptive feedback. It is also hypothesized that the methods utilized will be feasible and reliable to use in order to conduct other research studies.
CHAPTER II
REVIEW OF RELATED LITERATURE

Etiology of Anterior Shoulder Dislocation

Anatomy

Anterior shoulder dislocations account for 94% to 98% of all shoulder dislocations.\textsuperscript{2,6,8} An anterior shoulder dislocation involves displacement of the humeral head from its normal position in the glenohumeral (GH) joint in an anterior direction. There are many structures involved in the stability of the glenohumeral joint, commonly divided into dynamic and static stabilizers. Dynamic stabilizers include the four tendons of the rotator cuff as well as the long head of the biceps, which function mainly during active motion. In the middle range of humeral abduction, the rotator cuff provides stability by compressing the humeral head into the glenoid. The supraspinatus contributes to the compression at lower degrees of humeral abduction. The long head of the biceps contributes stability to the humeral head at the more extremes of the range of motion; specifically resisting excessive external rotary forces that occur in the abducted and externally rotated position. Pagnani et al found that the biceps tendon was an anterior stabilizer with the arm in internal rotation and a posterior stabilizer with the arm in external rotation.\textsuperscript{5,6,9}

The dynamic stabilizers, as the name implies, act to provide stability to the glenohumeral joint while the joint is in motion. The rotator cuff is positioned to provide compression throughout the glenohumeral range of motion. Studies have shown that
displacement of the humeral head increased with an increase in the size of rotator cuff tear. The glenohumeral ligaments have been shown to be lax during the mid range of shoulder motion, indicating the importance of the rotator cuff at this point in the motion.\textsuperscript{9}

Static restraints to dislocation include the glenoid labrum, the glenohumeral ligaments, the bony glenoid architecture, the rotator interval, and the joint capsule. The labrum functions to increase the depth of the glenohumeral joint and to decrease joint translation. The major glenohumeral ligaments consist of three distinct thickenings of the joint capsule- the superior (SGHL), middle (MGHL), and inferior glenohumeral ligament (IGHL). The IGHL is the strongest of the glenohumeral ligaments and consists of three portions: the anterior band, the axillary pouch, and the posterior band.\textsuperscript{6,9,10}

The glenoid labrum is a bumper made of fibrocartilage that is attached circumferentially to the glenoid rim. It is loosely attached superiorly, and firmly attached to the anterior and inferior aspects of the glenoid. The labrum contributes to the stability of the glenohumeral joint by deepening the concavity of the joint, increasing the contact surface area for the humeral head, and serving as a fibro-cartilaginous ring for the glenohumeral ligaments to attach.

The superior glenohumeral ligament, with help from the coracohumeral ligament, limits inferior translation and external rotation of the adducted shoulder as well as posterior translation of the flexed, adducted, internally rotated shoulder. The middle glenohumeral ligament functions to limit anterior translation of the humeral head when the arm is abducted between sixty and ninety degrees. The IGHL is multi functional and
serves to limit inferior translation in abduction, posterior translation while in internal rotation, and anterior translation in external rotation.

The rotator interval is a triangular shaped area that is formed by the anterior border of the supraspinatus tendon superiorly, the subscapularis tendon inferiorly, and the base of the coracoid process laterally. Increases in humeral head translation have been shown in the anterior, posterior, and inferior direction after damage to the rotator interval.¹

Patho-anatomy

With so many structures involved in the stability of the shoulder and specifically the glenohumeral joint, there are many potential complications in these structures as a result of anterior dislocations. Bankhart lesions and Hill-Sachs lesions are among the most prevalent complications, while numerous others may also occur depending on the specific incident.¹ A Bankhart lesion occurs when the anterior capsule and labrum are separated from the glenoid rim.¹,⁸ This tear affects the attachment of the IGHL which greatly impacts anterior shoulder instability. The Bankhart lesion is sometimes referred to as the “essential lesion” in a dislocation and occurs in 80% to 97% of all anterior shoulder dislocations.⁸ A Hill-Sachs lesion is a bony lesion, caused by the impact of the posterior-lateral portion of the humeral head colliding with the glenoid rim. Hill-Sachs lesions are also fairly common in anterior shoulder dislocations, occurring 80% of the time.
Traumatic shoulder dislocations were studied in a prospective study conducted by Owens with 4,141 military cadets being followed for one year.\textsuperscript{11} Of the patient population, 38 sustained a first time traumatic anterior glenohumeral dislocation. Of the 27 eligible patients that obtained magnetic resonance imagining, Bankhart lesions were noted in 26 of the 27 patients, and Hill-Sachs lesions were discovered in 25 of the 27 patients.

\textit{Mechanism of Injury}

The major cause of first-time anterior shoulder dislocations is traumatic injury. Hayes et al reported that nearly 95\% of primary shoulder dislocations result from a traumatic injury, and subsequently only 5\% of primary anterior shoulder dislocations result from a non-traumatic origin.\textsuperscript{6} Hayes et al stated the most common mechanism for traumatic anterior shoulder dislocation is depicted as forced external rotation and abduction of the humerus.\textsuperscript{2,6} Other less common traumatic mechanisms include a fall onto an elevated out-stretched arm and direct force application to the posterior portion of the humeral head.\textsuperscript{6} Owens et al reported the most common mechanisms of injury in their study with cadets were tackling (involving forced external rotation and horizontal abduction of the shoulder), falls, and missed punches while boxing.\textsuperscript{11}

Zacchilli et al performed an epidemiological study using a computer tracking system in hospitals around the United States.\textsuperscript{12} They recorded 8,940 shoulder dislocations during a five year period and found that falls (58.8\%, n=4,047) and direct blows (8.9\%, n=626) were the most common mechanism of injury in the 6,881 incidents that reported a mechanism. Sports or recreational activities accounted for 48.3\% (n=4,303) of all of the
dislocations, with football and basketball being responsible for 34% of that population. Sileo et al found patients will often subjectively report mechanisms involving abduction and external rotation such as during an “arm tackle” or being hit while in the motion of throwing the ball.\textsuperscript{10}

**Treatment of anterior shoulder dislocations**

There have been varying opinions and approaches to the treatment of anterior shoulder dislocation over time. The main approaches involve either a conservative non-operative approach, or an operative approach involving one of many varying surgical procedures. The effectiveness of various surgical techniques is not a primary focus of this study and thus is not covered in detail in this review of literature.

*Conservative Treatment*

Typical conservative treatment for an anterior shoulder dislocation involves the manual reduction of the shoulder, a period of immobilization in a sling, followed by therapeutic exercises. The type of reduction that is performed depends on the preference of the physician or employee performing the procedure, and is often done with the use of sedation and/or analgesics.\textsuperscript{10}

*Immobilization*

Immobilization typically occurs in both conservative and operative treatments of anterior shoulder dislocations, but the length of immobilization and the best position for immobilization are areas of debate among clinicians. A Kim et al study in 2003 randomized 62 patients into either an early mobilization group which started physical
therapy one day post surgery, or an immobilization group that was in a standard internal rotation sling for three weeks. Subjects in the early mobilization group experienced earlier return of functional range of motion and returned to play sooner. Ultimately, at approximately 31 months post-operation, there was no significant difference in return to play, pain scores, or range of motion between the two groups. There were also no recurrent dislocations or subluxations noted in either group. These results led the authors to conclude that due to non-significant differences at follow-up, early mobilization provides an opportunity for earlier return of functional motion and earlier return to play, and is thus the more favorable outcome.

The traditional position for immobilization of the glenohumeral joint following anterior shoulder dislocation is with the arm in an adducted and internally rotated position. However, there is growing evidence and opinion that immobilization should be performed in external rotation as opposed to the traditional internal rotation. Itoi et al performed a study on 19 shoulders in 18 patients who had experienced Bankhart Lesions along with their anterior shoulder dislocation. Magnetic resonance imaging was used to measure the displacement and separation of the labrum in positions with an average of 29° internal rotation for one, and 35° external rotation for the other. The researchers found there was significantly less displacement and separation of the labrum in the externally rotated position, leading the authors to conclude immobilization in external rotation provides better approximation for shoulders with a Bankhart lesion.

To follow up the initial findings, Itoi et al performed a small clinical study assigning patients with first time anterior shoulder dislocations to either be immobilized
in internal rotation (n=20) or external rotation (n=20). They found a zero percent recurrence rate in the external rotation group compared to 30% for the internal rotation group at a follow up of fifteen months. Itoi et al then performed a large randomized-control trial of 198 patients to find once again that the group of immobilization in external rotation resulted in significantly lower recurrence rates at two years post injury. Although there is some evidence for immobilization in external rotation, patients have greater difficulty functioning with an arm braced in external rotation and thus this practice has been slow to gain acceptance.

Despite the recent trend of immobilization in external rotation, studies have also shown there is no difference between immobilization in the internal and external rotation positions. Finestone et al studied fifty-one males who were between the ages of 17 and 27, and randomized 24 to be immobilized in internal rotation and 27 to be immobilized in external rotation following traumatic anterior shoulder dislocation. Follow-up occurred between 24 to 48 months and the authors found ten subjects from each group had experienced a recurrent dislocation, a non-statistically significant difference.

Conservative versus Surgical management

A considerable number of studies have compared the effectiveness of conservative versus surgical management for anterior shoulder dislocations. Numerous studies have reported the high recurrence rates for shoulder dislocations, especially for younger populations. In a large prospective study of 252 patients, Robinson et al found that 150 of the patients experienced a recurrent dislocation at a rate of 52% for the 15 to
21 years age group and 21% for the 31 to 35 years age group. This finding has been reported in other studies, leading some to conclude that age is a prognostic indicator for rate of recurrent dislocations. This high level of recurrence is one of the main reasons that this topic is extensively studied in an attempt to decrease recurrence rates at much as possible.

The long-term effects of anterior shoulder dislocation, specifically recurrence rate, were studied in a randomized control trial published by Jakobsen et al in 2008. Participants had a diagnosis of a first time traumatic anterior shoulder dislocation and were randomized to either a conservative treatment group consisting of one week of immobilization in internal rotation followed by a rehabilitation program, or to the surgical group consisting of an open repair of the shoulder followed by a similar rehabilitation program. There were 76 patients total, 37 in the conservative group and 39 in the surgical treatment group. At two years follow-up, 21 of the 37 patients in the conservative group had experienced a recurrence, where only one of the 39 in the surgical group had experienced a recurrent dislocation.

The results published by Jakobsen et al were reinforced in a Cochrane review article by Handoll et al, looking specifically at success of surgical versus conservative treatment. The authors performed a comprehensive review of the current literature using MEDLINE and EMBASE and found four studies that met their criteria. The total number of patients from the studies came out to 163, with the average ages of the participants of the four studies being 22, 22, 24, and between 14 and 30 years of age for
the last study where the average age was not reported. All four of the trials included patients that experienced a first-time traumatic anterior shoulder dislocation.

The primary outcome measures assessed in each of the four studies were return to prior level of function/activity and recurrence rates. Pooled results of the four studies revealed subsequent instability, meaning either recurrent dislocation or subluxation, was found to be statistically significantly less frequent in the surgical group as compared to the conservatively managed group. In the four studies, various subjective patient satisfaction measures were also obtained and found the surgical group scored significantly better at all times the tests were administered with one exception in which the surgical group still scored higher but the results were no longer significant. The authors of this review thus concluded surgery for first time anterior shoulder dislocations is more effective than traditional conservative treatment.

**Bracing**

Reuss et al offer a guideline for choosing a functional brace for anterior shoulder instability. The study did not scientifically test the different braces for function; rather it was a subjective assessment of brace application completed by one male and one female athlete. Ideally, a brace would stabilize the shoulder while still allowing full range of motion without impeding function. Other factors that are important in selecting a brace are the cost, comfort, durability, and ease of use. Additionally, the athlete’s age, arm dominance, skill, and sport requirements should contribute to the brace decision. The Reuss study categorizes braces for shoulder instability into three different types. Type A braces restrict shoulder abduction, extension, and external rotation – the arm position
associated with instability and dislocation. Type A braces may be advised for patients with more severe instability; however, they also pose the threat of over-restricting motion. Type A braces examined in the Reuss study include: Cadlow Shoulder Stabilizer, Curtis Shoulder Cuff, Duke Wyre Shoulder Vest, Shoulder Stabilizer, SAWA Shoulder Stabilizer, Shoulder Subluxator Inhibitor, Simple Stable Shoulder, and Sully. Type B and type C braces apply stabilizing support via a posterior force on the humeral head indirectly or directly, respectively. Due to the design of type B and type C braces, they may interfere with respiration, scapulothoracic motion or muscular excursion, ultimately compromising athletic function. The following braces, according to the Reuss study, are Type B braces: Acro Comfort, Omo Train, Shoulder Stability Brace, and Universal Shoulder Support. Type C braces include: Acro Comfort, Shoulder Controller, and Shoulder Stability Brace. Reuss included the above thirteen different braces that were analyzed for containment method, construction, comfort, cosmesis, convenience of application, and cost. Several concerns were exposed surrounding difficulty of application, discomfort, fitting issues, material breathability, and inadequate control of shoulder motion. Through this study, specific recommendations for selecting a brace cannot be made, as it needs to be done on a case-by-case basis, although guidelines are presented for the decision making process.

A study by DeCarlo et al examined three different types of shoulder instability braces and their ability to maintain a predetermined range of motion limit in a controlled, nonathletic environment after isokinetic exercises. The braces compared were the Duke Wyre Shoulder Vest, the Sawa Shoulder Orthosis, and the Shoulder Subluxation Inhibitor
(SSI). Ten healthy male recreational athletes (average age = 27.2 ± 2.82 years) who reported no history of previous glenohumeral joint instability served as subjects in the study. Each subject wore all three braces in a random order and completed 10 repetitions of flexion/extension and abduction/adduction exercises at isokinetic speeds of 120° and 180° per second using the Cybex® II isokinetic dynamometer. Maximum active range of motion measurements of flexion, abduction, and external rotation were taken without the brace, and pre- and post-exercises with each brace. All three braces allowed statistically significantly more motion post exercise in the flexion motion according to a paired t-test. Only the Sawa brace allowed significant (p< .05) change in motion from pre- to post-test for shoulder abduction. For external rotation, no significant differences were found in any of the braces pre- to post-test. A two-way analysis of variance indicated the three braces did not differ significantly from one another in their pre to post range of motion measurements for all three motions. All three braces did undergo a loosening effect for the three motions measured and statistically there was no significant difference between the pre to post range of motion measurements comparing the three braces. Limitations of this study include: the use of healthy subjects instead of those who have glenohumeral joint instability as the braces were designed for; testing in a controlled environment, performing the exercises in supine rather than a sport specific position; using isokinetic exercises in straight planes; and it does not take into account fatigue effect as only a small amount of repetition of movements were performed.

In another study comparing glenohumeral joint stability braces, Weise et al compared the Denison and Duke Wyre harness and the Sawa shoulder brace for their
ability to limit motion. The subjects of the study included fifteen male Division I football players (19.9 ± 1.37 years) with no history of right shoulder injury within twelve months of the study, no previous experience with glenohumeral joint stability braces, or prior right shoulder surgery. The study was performed after a five-week spring practice season. All participants completed an Injury History Questionnaire and received a clinical assessment by the primary investigator including the anterior apprehension, posterior apprehension, and sulcus sign tests to establish any pre-existing shoulder instability. All participants had a minimum range of passive motion of 180° of shoulder abduction and 90° of shoulder external rotation of their right dominant arm assessed by goniometric measurements using Norkin and White protocols. Weise measured passive and active shoulder abduction and external rotation range of motion of the participant in both the Duke and the Sawa braces. Reflective markers were strategically placed on the participant’s thorax and right upper extremity to allow for the measurement of angular displacement at the glenohumeral joint in conjunction with the Peak Motus Motion Analysis System. The primary investigator properly fitted the subjects with the braces, following the manufactures’ recommendations and limiting abduction to 45°, confirmed by passive goniometric measurement. Three practice trials were completed for shoulder abduction with submaximal intensity. Three recorded abduction trials were performed starting with the arm at the side and then abducting until limited. Passive trials were completed with twenty-pounds of force measured by a handheld dynamometer applied to the medial epicondyle of the humerus. The same parameters were used to measure external rotation both actively and passively. The start position for the external rotation
trials was shoulder abduction of 45° and elbow flexion to 90° with the upper arm and forearm resting on a foam wedge in internal rotation. The upper arm was to stay resting on the foam wedge during external rotation. The average of the three trials was used for the results. Neither brace maintained the preset 45° limit of abduction during active or passive motion. The Duke brace allowed an average increase for abduction of 23.0° actively and 28.0° passively, while the Sawa allowed 11.8° actively and 14.6° passively. For external rotation, the Duke permitted an average of 76.3° and 93.9° for active and passive motion, respectively, while the Sawa averaged 71.6° actively and 85.2° passively. The Sawa shoulder brace significantly limited motion more effectively than the Denison and Duke Wyre harness for all of the test conditions. Neither brace limited motion to the pre-set limit, which may be due to loosening/slippage of the braces, decomposition of the material of the brace, and/or slippage between the brace and the cotton T-shirt worn by the participants as recommended by the manufacturers. Using subjects that have shoulder instability, testing in a more functional and athletic position, increasing the repetition of movement, and employing a non-braced condition may have improved this study.

**Proprioception**

Proprioception is the sense of joint and limb movement and position caused by the depolarization of nerve endings called mechanoreceptors. Mechanoreceptors depolarize when tissues such as tendons, muscle, or skin change position and cause the tissue to become deformed. The extent of depolarization of the mechanoreceptors depends on the amount of tissue deformation. The more mechanoreceptors the body has
in a particular area increases the ability to receive information about the position of the body or limb. \(^{23}\) It has been found that receptors in the joint are most likely to be active at end ranges of motion. \(^{25}\) The location and function of mechanoreceptors varies throughout the body. \(^{23}\) Several authors have studied proprioception in the upper and lower extremities and its relationship to joint position sense. Joint position sense is determined by five different inputs: joint receptors, muscle receptors, visual input, vestibular input, and cutaneous input. \(^{23}\)

Many researchers have studied joint reposition sense and how to determine joint reposition sense by using different devices. A study done by Allegrucci et al looked at differences in threshold to detection of passive motion between dominant and non-dominant shoulders in healthy athletes who participated in upper extremity sports. \(^{25}\) Athletes were tested in two positions: 0° and 75° of external rotation. Passive shoulder range of motion was measured with a standard goniometer at 90° of shoulder abduction. Measurements were taken while the subject was in supine with the scapula stabilized by the underlying table. Measurements were taken before proprioceptive testing. The study used a proprioceptive testing device with a motor driven goniometer that moved the shoulder passively at a speed of 0.5° per second through internal and external rotation. The device measured threshold to detection of passive movement. While in the proprioceptive testing device, subjects were positioned in supine with their shoulder in 90° of abduction and 90° of elbow flexion. The ipsilateral forearm was placed in a compression splint and was attached to the device that moved the shoulder through passive range of motion. The two starting positions used were neutral and 75° of external
rotation. Before testing, subjects were given a hand held switch for the contralateral hand and instructed to place their thumb on the button. Subjects wore headphones with white noise, and were also blindfolded to prevent visual and auditory input during the trials. Subjects were tapped to inform them when the trial was beginning. The subject turned off the device when they felt movement. Both shoulders were tested in each subject three times in both internal and external rotation, for both testing positions (0° and 75° of external rotation). Intraclass correlation coefficients (ICC) were calculated for external rotation at 0° and an ICC of 0.82 was revealed. External rotation at 75° was calculated and an ICC of 0.87 was revealed. Internal rotation at 0° was calculated and an ICC of 0.86 was revealed. Internal rotation at 75° was calculated and an ICC of 0.92 was revealed.

A study done by Chu et al compared the effects of shoulder bracing on active joint reposition sense in subjects with stable and unstable shoulders.26 The study used the Cybex® II isokinetic dynamometer to test active joint reposition sense. The subjects were positioned in supine on a table with the shoulder joint axis aligned with the axis of rotation of the Cybex®. The shoulder was placed in 90° of abduction, the elbow was placed at 90° of flexion, and the forearm was pronated. The contralateral arm was strapped into the testing device with an elastic wrap placed around the forearm and wrist, which decreased cutaneous input. Subjects were blindfolded and had on headphones that played white noise in order to decrease visual and audio input. External rotation was measured in subjects prior to testing by having the subject actively externally rotate the shoulder while in supine on a table. The preset angle was determined by subtracting 10°
from full external rotation. Active joint reposition sense was tested by instructing the subject to move the shoulder from neutral rotation of 90° of shoulder abduction and 0° of internal/external rotation to a preset angle set at 10° from full external rotation, 30° of external rotation, or 30° of internal rotation. The subject was placed in each of these target angles for ten seconds. The subject was asked to actively return the shoulder to the starting position that stopped mechanically at 0° of external rotation. The subject then moved the shoulder actively to the previous target angle and said, “stop” when they felt that they had reached the target angle. The degree of error was determined by subtracting the angle at which the subject stopped from the preset angle. Three trials were conducted and the degree of error used for the statistical analysis was determined by taking an average of the absolute value of the three errors. This study by Chu et al revealed when a neoprene shoulder stabilizer was used, the braced condition, when compared with the non-braced condition, had significant improvements in active joint reposition sense at 10° from full external rotation in the unstable group (persons who had a self reported history of one or more anterior glenohumeral shoulder dislocations).26

Many researchers have indicated bracing, taping, and the use of elastic bandages have been shown to increase joint position sense in the lower extremity.26 In a study done by Ulkar et al, shoulder joint positioning sense was examined with the application of a neoprene brace.27 The neoprene brace was used in order to examine the role of cutaneous receptors in passive position sense. A significant difference was found between the braced and without brace conditions. A lower overall mean (standard deviation) deficit
score was found in measurements with the brace. Analysis of variance for brace application had a significant main effect measured in degrees (160.40°, p<0.001).

A study done by McNair et al examined the effects of a knee sleeve brace on proprioception in subjects with healthy knees during a dynamic tracking task. Subjects were blindfolded and the lower extremity was attached to a dynamometer and moved passively by the dynamometer. The subjects used their other lower extremity to follow the movement as closely as possible (tracking). There was an 11% improvement found in tracking when subjects wore the knee brace (p< .05). Similarly, in a study done by Perlau et al, it was shown that an elastic knee bandage improved joint position sense significantly in uninjured knees by 25% and improvement of joint position sense was lost when the bandage was removed. Furthermore, a study done by Barrett et al found that using an elastic bandage on subjects with poor position sense due to a knee replacement or osteoarthritis improved accuracy of joint reposition by 40%.

A study done by Beynnon et al examined the effect chronic anterior cruciate ligament disruption, functional bracing, and a neoprene sleeve on knee proprioception. No significant improvements in the threshold to detection of passive motion for the anterior cruciate ligament deficient knee were found when a brace (1.30° ± 0.50°, p=0.18) or sleeve (1.37° ± 0.58°, p=0.26) were used.

A study done by Hartsell observed active joint position sense awareness, effects of bracing, and differences between flexible and semi-rigid braces in chronically unstable ankles. When compared to un-braced or flexible braced ankles, it was found the semi-rigid brace was significantly more effective in reproducing joint position sense. Another
study done by Heit et al examined the effect of ankle bracing and taping on joint position sense in the stable ankle.\(^{33}\) Plantar flexion and inversion were tested using an electric goniometer. The taped condition significantly improved joint position sense for both motions of inversion and plantar flexion when compared to the control condition. The braced condition showed improvement in joint position sense for plantar flexion motion, but not inversion.

A study done by Herrington et al assessed the effect on proprioceptive acuity of a neoprene brace on the knee in healthy subjects.\(^4\) The study also examined the relationships between three different methods of testing proprioception (active tracking, active reproduction, and perceived angle tests). Subjects’ proprioceptive acuity was tested with all three methods with the presence of a neoprene brace or without a neoprene brace. All three tests showed the neoprene brace significantly improved the degree of error.\(^4\) A Pearson’s Product Moment Correlation was used to assess the relationship between error scores of the three proprioceptive tests and revealed a non-significant, low correlation.\(^4\) The study concluded that due to the weak relationship between the findings of the tests, it appears the different tests measure different aspects of proprioception.\(^{33}\)

*Proprioception following injury*

One of the contributing factors thought to be responsible for the high level of recurrence in anterior shoulder dislocations is the loss of proprioceptive input following a dislocation. Studies have been done in an attempt to determine whether this is truly a contributing factor and if there is a method of repairing the proprioceptive input.
A study performed by Lephart et al looked at three different groups: healthy controls, subjects with chronic shoulder instability, and subjects with an anterior shoulder dislocation who had surgical intervention and subsequent physical therapy. All subjects underwent proprioceptive testing for threshold to detection of passive motion (TTDPM) and reproduction of passive positioning (RPP). The healthy control group had no difference between dominant and non-dominant shoulders. The chronically instable group showed significantly longer TTDPM compared to the normal contra-lateral shoulder and also found the injured shoulder to be significantly less accurate for RPP compared to the stable shoulder. The third group who underwent surgical repair was found to have no statistical differences between the repaired and the contra-lateral normal shoulder. Group three also showed no statistical significance compared to group one, the healthy controls. These findings led the researchers to hypothesize injury to the soft tissue structures of the shoulder disrupt the normal proprioceptive mechanism, and surgical repair may be able to repair the mechanism.

The authors of this study hypothesized that the restoration of normal proprioceptive ability may be due to a combination of factors. The mechanoreceptors in the joint capsule and glenohumeral ligaments that are thought to provide the main input for joint position sense and require deformation in order to transmit any information to the central nervous system. Surgical repair may be effective in restoring the tissue tension required to send adequate signals. The authors also state this normalized joint position sense may have been influenced by the rehabilitation program following surgery which focused on exercises to emphasize joint proprioception. Studies are lacking on the exact
mechanism of how proprioceptive input may be affected by surgical repair in the shoulder.\textsuperscript{34}

Edmonds et al conducted a study to compare the proprioception in anteriorly dislocated shoulders that were repaired by either immobilization with rehabilitation or arthroscopic surgery and rehabilitation, specifically looking at participants following their primary dislocation.\textsuperscript{3} Participants were randomized into either group, with the surgical group receiving repair within four weeks of the initial injury. The average age of the participants was 21.4-years-old, with 21 of the 24 participants being male. All participants in each group were immobilized in a sling for three weeks, either immediately following the reduction for the conservative group or following surgery for the operative group. Both groups then received the same course of rehabilitation, which included active assisted range of motion and scapular exercises at weeks 4-6, with active range of motion and isometrics at 7-8 weeks, progressing to isotonic exercises at 9-12 weeks. Researchers were blinded and subjects were tested for TTDPM and RPP at an average of 19 months post-treatment. There was no statistically significant difference between the two groups for either condition tested. The study led the authors to conclude proprioception and the proprioceptive mechanisms can heal equally with surgical correction and immobilization in addition to rehab. It is important to note data from three subjects of the immobilization group and one subject of the surgical repair group was excluded due to recurrent dislocation prior to final proprioceptive testing. Also there was no follow-up done on the long term recurrence rates of the individuals following the proprioceptive testing.
The study by Edmonds et al contradicts the results given in the earlier study of Lephart et al. It is important to note that although both studies utilized the same methods for assessing proprioception, Edmonds et al tested both TTDPM and RPP at 30° and 60° of external rotation, while Lephart et al tested at neutral and 30° of external rotation. This may be significant as a previous study by Blaiser et al showed that as the limit of external rotation is reached, i.e. the greater the angle of external rotation, an individual’s ability to detect movement becomes significantly more sensitive.3,23,35

Review of Three-Dimensional Kinematics

Three-dimensional kinematics is a vastly growing field. Its applications range from surgical procedures to motion analysis to biomechanics in sport. There are several types of motion trackers including spatial linkage systems, ultrasonic tracking systems, optical systems, and electromagnetic systems.36 The two most common systems are optical and electromagnetic. Both optical and electromagnetic systems have their advantages and disadvantages. This review of the literature will focus on studies concerning the validity and reliability of electromagnetic systems, followed by studies concerning optical systems, and finally comparative studies of these two systems.

Electromagnetic Tracking Systems

Electromagnetic systems are considered to be active systems, requiring wires to connect the sensors of the instrument to the transmitter. This tethered system limits the capture volume, as it is only allowed to capture motion within its reach. The capture
volume of data collected is usually limited to either side of the y-z plane, implying that motions involving greater than 180° in a transverse plane may be difficult to accomplish while being tethered to the transmitter. There are a handful of electromagnetic systems that are considered to be passive, in that they are wireless and utilize the transmission of radiofrequencies. Passive systems are generally limited to very small capture volumes and are in the process of being further developed. They will not be addressed in this review. Active electromagnetic systems are highly accurate, measuring positional and rotational components within 0.25 mm and 0.10° of the true angle. The transmitter to sensor distance, surrounding metals in the environment, the frequency at which the data is collected, and skin artifacts can all affect the accuracy of active electromagnetic systems. The following studies address each of these areas.

Metal within a testing environment can cause disturbances, or noise, during data collection if using an electromagnetic system. Metals create secondary magnetic fields that interfere with the transmitter through eddy currents. LaScazza et al completed a study in 2002 with the purpose of determining the effects of sampling rates with an electromagnetic system in steel and aluminum metal environments. The system selected for this study was the Flock of Birds by Ascension Technology. The size and field of view for this transmitter was not specified. Six sensors were rigidly attached to a premeasured metal board. The three scenarios tested were air, steel, and aluminum. Sampling rates were measured at 20, 60, 100, and 140 hertz (Hz). Three measures at each frequency were taken at each of the six locations in a random order for each scenario. The averages of the three measures were then compared with the gold standard, or known
measured distances. The metal samples were 5 x 5 x 15 cm blocks and were placed 15 cm away from the transmitter in the direction of the sensors. LaScalza et al found that interference from aluminum is increased as the frequency increases. Aluminum has low magnetic permeability and therefore forms eddy currents that quickly diminish. This explains why aluminum environments allow more accurate data collection when collection is done at lower frequencies. A lower frequency gives time for the eddy current to fade before the next sample is taken. Steel, on the other hand, had less of an effect on accuracy at higher frequencies despite it having a greater effect overall. Steel has high magnetic permeability resulting in sustained eddy currents creating a secondary magnetic field. Errors found with metal environments were statistically significant in the $x$ direction ($p<0.0001$), $y$ direction ($p<0.0001$), and $z$ direction ($p<0.0016$). Limitations to this study included only testing two types of metal and using static conditions.$^{39}$

The purpose of a study done by Stone et al was to determine acceptable distances between sensors and transmitters in both a metal-free environment and in a heavy metal environment.$^{40}$ Stone’s study used the Flock of Birds electromagnetic tracking system (Ascension Technology Corp). It utilized a direct current transmitter, with unspecified size and field of view, along with four sensors. The sensors were rigidly mounted to a board in order to keep translation and rotation distances between two sensors constant. This board was tested in a static and a dynamic position. Due to the set-up of the electromagnetic system, the sensor located closest to the transmitter will determine the strength of the magnetic field emitted by the transmitter. This is because of receiver saturation from the closest sensor, creating a reduced signal at the farthest sensor. The
unbalanced signals received between sensors can be reduced if all sensors are farther away than a predetermined distance of 241.3 mm from the particular transmitter used in Stone’s study. When the test was performed in a metal-free environment the translational and angular accuracies were excellent, matching the manufacture’s expectations. As for interference from a heavy metal environment, it was found that balancing the sensors at maximal distances between all metal disturbances enabled the best outcome. The type of metal tested was not specified. Samples were collected at rates of 144, 80, 40 and 20 Hz. Samples taken at 144, 80, or 20 Hz were not found to be acceptable due to inaccuracies. A sampling rate of 40 Hz had the most accurate results. As for distances between the transmitter and sensor 14, 20.3, or 30.5 cm were acceptable for static conditions. A distance of 47.5 cm away from the transmitter was too noisy to yield accurate results. In dynamic conditions, a distance of 30.5 cm for larger joints and 20.3 cm for smaller joints produced accurate results. These reported distances create parameters to use when working in a metal environment. However, the size of the transmitter used was not clearly specified and therefore recommended distances may not be transferable to other laboratory set-ups.

Milne et al looked at the positional and rotation accuracy and resolution of a direct current electromagnetic tracking system. The effects of various metals were also studied to simulate the interference possibly created from orthotic implants. Flock of Birds electromagnetic system was used. The size of the transmitter was not specified. Positional accuracy was determined using a custom-manufactured board with 25 mm markings measured to the 0.005 mm. Measurements taken ranged from 15 to 85 cm and
the average of ten measurements was recorded at each location. Positional resolution was recorded by taking measurements at various increments on a 60 cm Delrin boom arm moved along an axial translation. Rotational accuracy was evaluated by rotating a boom arm through known increments. Transmitter to receiver distance was maintained at 35 ± 1.5 cm. Ten samples were taken at increments of 1, 2, 3, 4, 5, 10, 15, and 20°. Rotational resolution was completed with recording rotational increments of 0.1° and 0.8°. Metal interference was observed by placing a 12 mm diameter by 125 mm long sample of aluminum, cobalt, chrome alloy, mild steel, stainless steel, or titanium alloy in the path of the transmitter and receiver. Results revealed an optimal range for transmitter and receiver separation to be between 22.5 cm to 64 cm. In this zone the ten sample mean error was 0.5 mm. Among the ranges of rotation observed, a 1.6% error of the rotational increment was found. The system was able to sense increments as small as 0.25 mm or 0.1°. Out of the metals tested only mild steel produced significant interference (p<0.001), producing significant positional differences of 5.26 mm and 9.75°.

The accuracy of an electromagnetic tracking system using a stylus tipped sensor was explored by Meskers et al. The purpose of the study was to look at the accuracy of taking measurements using a stylus point. The electromagnetic system allows for fast and simultaneous data collection with regards to multiple landmarks. These landmarks and stylus reference points are found via palpation techniques. The Flock of Birds electromagnetic system with an extended range transmitter was utilized. One wired sensor was placed on the end of a stylus point and was used to identify twelve bony landmarks. Other receivers were attached to the thorax and upper arm. Patients were
seated on a wooden platform one meter above the ground due to the possibility of metal interference from steel reinforced concrete. Measurements at each landmark were taken five times while increasing arm flexion by 18° increments. Results revealed that calibration is necessary for accuracy. It was found that with calibration and removing the measurements closest to the ground, errors were generally less than two degrees throughout all tested positions.

Skin based methods for tracking kinematic movement are most commonly used, however they also have an inherent error built in them from skin artifacts. A study done by Karduna et al in 2001 simultaneously compared two skin-tracking methods with a bone pin method. The following four motions were measured, with multiple trials each: shoulder elevation in the sagittal plane, scapular plane elevation, horizontal adduction, and internal to external rotation at 90° elevation. An electromagnetic tracking system was utilized consisting of the transmitter, four receivers, and a digitizer. Receivers were located on the posterior thorax at the level of T3, the distal humerus with a cuff, and two on the scapula (one for each method performed). Skin methods utilized were the acromial method where the sensor is attached to the posterior-lateral border of the acromion, and the tracker method using a custom made tracker to fit over the spine of scapula. These skin methods were compared with two bone pins that were placed in the lateral scapular spine. The root-mean-square (RMS) errors between the bone pin method and each skin method. Both skin methods increased in the amount of error as the elevation exceeded 120°. The acromial method tended to overestimate the range of motion with scapular upward rotation, while the tracker method underestimated the degree of scapular upward
Skin methods of data collection are performed with respect to the movement of bones underneath. Therefore, errors or differences in data collections may be attributed to the skin artifacts. Keeping this in mind, it may be important to consider the body composition of subjects, as an increased level of adipose over the area of sensor placement could possibly contribute to an increase in skin artifact.

**Optical Tracking Systems**

Optical systems are camera-calibrated systems used for motion analysis, topographic mapping, sports analysis and architecture. There are both passive and active systems. Active optical systems include infrared light-emitting diodes to act as trackers. They are rigidly fixed to the object or patient. The camera then captures the light emitted from the diodes and calculates the trackers position. Passive systems use either specially printed or reflective markers. These markers are placed in clusters of three on the tracker and then attached to the object or patient. These systems are generally cable free. Single or multiple camera systems are available. The major disadvantage of optical systems is that in order to collect data the trackers must be in line of sight of the cameras and with rotation the viewing angle of the transmitter may be skewed resulting in inaccurate data. The following studies will describe some of the advantages and disadvantages of optical systems.

The purpose of a study done by Vander Linden et al was to determine the accuracy and reproducibility of an optical system measuring angles. The system used was the Motion Analysis Expert Vision that can use up to six cameras and thirty
individual retroreflective markers. Both static and dynamic angles were measured. Reflective markers were placed on the end of three goniometers, with the stationary arm fixed in a vice. Each goniometer was located at a different height, one of which was also rotated 45° away from the cameras. The two cameras were placed 237 cm away from each other and in a 58° angle from the experimental set-up. Under static conditions the goniometers were rotated in 10° increments between the angles of 20° and 180°. Dynamic conditions were tested with markers rigidly fixed onto a wooden dowel that was randomly placed within the designated coordinate system. The dowel was then attached to the lateral aspect of a test subject who transitioned from sit to stand and short durations of gait. The system was able to constantly calculate the tracker angles with intraclass correlation coefficients of 0.99 or higher. However, for the angled goniometer the calculation of the angle was overestimated by roughly 1° for angles 110° to 160°. For all three locations there was an overestimation of up to 2.4° for the 180° angle. In the dynamic scenarios the with-in trial variability ranged from 1.39 mm to 3.04 mm with the wooden dowel, and 2.16 mm to 2.58 mm for gait and sit to stand. Overall there was greater accuracy with static conditions with this optical system, as angled markers can skew data collection.

Accuracy and precision of optical systems was analyzed by Scholts and Millford. A two-camera optical system from PEAK Performance Technologies was used. Each camera had a floodlight attached to it to ensure adequate lighting during the procedure. The optical axes of the cameras were set so the centers formed a 60° angle with each other. A 115.5 cm metal shelving bracket was loosely anchored to a wooden
board. It was allowed to freely swing as a pendulum, but also had slight forward and backward sway. On this bracket were 17 reflective markers and a C-clamp to add some weight. The first block of trials was with the board head on, the second with the board rotated counter-clockwise 30°, and the third with the board rotated clockwise 30°. Ten trials were run at each position for roughly 6.5 cycles of the pendulum. The precision of angle measurements for both upper and lower halves was excellent with an ICC of 0.99 for all pendulum orientations. Intertrial standard deviations were greatest for the clockwise orientation but never exceeded 0.11°. Significant effects were found between orientations (p<0.001) and trials (p<0.001). Ninety-four percent of trials’ standard deviations fell below 0.5°. Overall the inaccuracy fell between 0.0° and 1.2° for head on and counter-clockwise orientation, and ranged from 37° to 95° for clockwise orientation. This implies accuracy is dependent upon tracker orientation to the cameras. One possible shortcoming for the Scholts’ study can be found within the supplies used. Black electrical tape was used to cover the metal bracket and adhere the reflective markers. This tape can be reflective itself which may have been picked up by the tracking system.

Reflective markers need to be in the line of sight by all cameras in order to triangulate positions in space for motion analysis. This could be a potential limitation with optical systems. In a study done by Maletsky, Sun, and Morton, an Optotrak 3020 infrared system was used to determine the rotational and translational accuracy of two rigid bodies in space.45 Rigid bodies, with six infrared diodes each, were mounted onto a rotary table and were rotated at 10° increments and translated in 10 mm increments. Data was sampled at 30 Hz. The camera positioning ranged from 1.75 meters to 4.75 meters.
The mean differences and standard deviations for rotation and translation generally increased as camera distance increased. A 10° rotation showed an average difference of 0.05°, standard deviation of 0.24°, and repeatability limits of 0.67°. Translational distances of 10 mm showed mean differences of 0.03 mm, standard deviations of 0.10 mm, and repeatability limits of 0.29 mm. Accuracy was shown to improve near camera distances of 3.25 meters. Distances beyond this point reach beyond the camera’s focus point and should not be used as they were shown to decrease the system’s precision and accuracy, particularly rotational measurements.

*Comparisons Between Electromagnetic and Optical Systems*

The selection of an electromagnetic system versus an optical system should be made specific to the experimental design, weighing the advantages and disadvantages for each tracking system. To help with this process, articles that directly compared electromagnetic and optical systems were reviewed.

A reliability study comparing optical and electromagnetic systems on upper extremity motion was performed by Hassain, Jenkyn, and Duning. A mechanical articulator was used to mimic the motions of the elbow. It was constructed to move in three planes of motion – flexion-extension, varus-valgus, and internal-external rotation. The gold standard comparison was computer-generated markings upon the device itself. The electromagnetic system used was the Flock of Birds with a standard range transmitter, and the optical system was 8-camera Eagle System. While analyzing data it was noted that to use an electromagnetic system, data first went through a series of
calculations to smooth out noise from metal interference, velocity of motion was controlled due to the sequential collection of data, and motion was limited in size due to the transmitter wires. The optical system worked well for large volume capture, but was limited to line of sight collections, and again, least-squares calculations and post-hoc analysis was performed to smooth data. When looking at the results, comparing the two systems, the mean differences were -0.30° with limits of -1.55° and 0.94°. The difference between systems was variable depending upon joint position with 21 out of 528 samples exceeding the limits of agreement (all of which were smaller flexion angles). When looking at each system in isolation with the gold standard, both tended to underestimate the actual measure. The optical averaged values were -0.92° (limits of agreement: -1.46°, -0.37°), and the electromagnetic averaged values were -1.09° with limits of agreement of -1.75° and -0.43°. Both systems were found acceptable as measurements fell within the limits of agreement. However, because values were most underestimated at smaller angles of measure, neither of these systems may be truly reliable with small angle measurements.

A comparison study of multiple optical systems and one electromagnetic system was performed by Richards to determine their ability to generate basic coordinate data. The optical systems were Arial, Motion Analysis’ HiRes system, Peak Performance’s Motus system, Qualisys’ ProReflex system, BTS’s ElitePlus system, and Vicon’s 370 system. Six cameras were used for each system, except five cameras were used for the Ariel system. Skill Techonology’s 6D Research magnetic based system was also tested. All systems were calibrated prior to testing. A rigid bar with various reflective markers
was mounted on top of a rotating horizontal axis was used for optical testing. On one end was a set of three markers in a triangular position set perpendicular to the first bar. This setup allowed for both passive and active measurements to take place. Six trials were performed for four seconds each at a sampling rate of 60 Hz. Between each trial, markers were moved one centimeter closer. All system operators were permitted to change any tracking control parameters and to use all editing techniques desired. As for the electromagnetic system, trackers were placed along a meter stick and it was rotated along the vertical axis due to the tethered sensors. Samples were taken at 60 Hz for ten seconds at each location. Distances and angles from known fixed markers were recorded along with the RMS of the average measured distance and the actual measured distance.

Four of the optical systems were able to determine distances between markers within one millimeter, with the largest reported deviation of two millimeters. Variation between trials was within one millimeter. Moving, or active, markers were found to have RMS values of less than three millimeters for six out of seven systems, with the largest reported error around one centimeter. As for angular measures, all systems were within 1.5° of the actual values. Error tended to increase as distance between markers decreased. Maximum error associated with each of the systems was quite considerable with the largest error approaching 20°.

All but one system confused the stationary and moving markers when their paths were within one centimeter of each other. The electromagnetic system reported an average distance of 41.28 cm between markers (actual was 40 cm). Errors during motion were larger than those with static tracking. Variability of tracking took anywhere from 2
to 5 seconds per trial to 1.5 hours per trial. The amount of time it took to edit each trial was also variable from 2 to 20 minutes being most common. Skill Technologies 6D Research system produced positional information faster, but its capture volume was limited to a hemisphere on either side of the y-z plane and the sensors distance from the transmitter. The electromagnetic system was also very susceptible to metal interference.
CHAPTER III

METHODS

Participants

Participants were recruited from the St. Catherine University Doctor of Physical Therapy Program and members of the surrounding community that fit within the inclusion criteria. Subject demographics can be found in Table 3.1. Subjects who participated in this study included those with a history of right shoulder anterior dislocation without surgical intervention, as well as an unimpaired population. The inclusion criteria for this study consisted of being between the ages of 18-50, having pain-free shoulder motion, and no reports of a dislocation episode within four weeks of participating in the study. Participants were excluded from the study if shoulder range of motion was painful, had suffered a dislocation within the past four weeks, or had a history of right side shoulder surgery.

This study was approved by the St. Catherine University Institutional Review Board, and participants read and signed an informed consent form (Appendix A). Participants were tested on their right shoulder using various bracing conditions. Upon acceptance of informed consent and meeting inclusion criteria, participants completed a subjective questionnaire in regards to their shoulder and underwent a clinical exam. The health status of the participant was collected from a subjective questionnaire. Example questions include general demographics such as height and weight, skin sensitivity to adhesives, activity level, types of shoulder injuries, most recent dislocation episode and current symptoms such as pain, surgical interventions, and types of treatment (Appendix
B). The questionnaire was completed by the participant prior to data collection. The clinical assessment consisted of the apprehension-relocation test along with the load and shift test. These tests were selected to examine the integrity of the shoulder joint and determine the presence of any hypermobility within subjects. The assessment was performed once per subject by the primary investigator, who is a licensed physical therapist.

**Instrumentation**

Kinematic data was collected with Model 800 Trakstar sensors and a mid-range transmitter (Ascension Technology Corporation, Burlington, VT, USA). The Trakstar can track up to six degrees of freedom with a reported static accuracy of 1.4 mm root-mean-square (RMS) for position and 0.5° RMS for orientation. The sensors were of minimal size, 8.0 mm x 20.0 mm, with a 3.3 m cable. The small size of sensors minimizes the potential of skin motion artifact that accompanies kinematic analysis of active shoulder motions. An orthogonal axis system is embedded within each sensor that has an independent data collection rate of 420 updates/second. Kinematic data was gathered at 120 Hz and processed with Motion Monitor software (Innovative Sports Training, Chicago, IL, USA).

This three-dimensional electromagnetic tracking system consisted of a transmitter, three sensors, and a digitizer stylus. It was used to measure maximal, planar shoulder motions of abduction, external rotation at 90° abduction, along with a combined motion to mimic a throwing motion. This system was also used to measure the accuracy
of joint position sense at various degrees of shoulder external rotation with the arm in a position of 90° shoulder abduction and 90° elbow flexion.

A bubble inclinometer was used during maximal external rotation for an immediate estimation of joint range of motion to use in the joint position sense protocol. The inclinometer was used to estimate the placement of the right upper extremity for each location of joint position due to the lack of instantaneous feedback with the electromagnetic system. The tracking system was able to determine if the subject is able to accurately reproduce the joint placement.

Shoulder Braces

Two type A shoulder braces were used during the study: the Denison and Duke Wyre Shoulder Vest and the DonJoy Sully Shoulder Stabilizer (Figures 3.1 and 3.2). The Duke Wyre was designed to physically restrain the individual’s allowed range of motion, restricting them from reaching end range of abduction and extension where chances of dislocation increase. The Duke Wyre was not designed to restrain external rotation. The body of the brace is composed of canvas, grommets are found on strips of leather along the borders of the brace, and it is laced together with a leather shoestring. The Duke Wyre brace was slightly modified in order to increase the validity and reliability of the electromagnetic tracking system. There are roughly seventy metal grommets per Duke Wyre brace that would significantly interfere with data collection. Therefore, the grommets were safely removed without damaging the rest of the brace structure, and the leather shoestring was fed through the existing holes.
The Sully brace is comprised of neoprene and is designed to allow more motion than the Duke Wyre. It has a series of Velcro® adjustable neoprene straps that can be used to individualize the limitations of motion for each individual. It primarily limits abduction while still allowing external rotation and extension. In order to ease the process of donning and doffing the brace over a tracking sensor, a small one inch slit was cut on the distal and lateral aspect of the Sully under-sleeve.

Procedure

Upon obtaining informed consent and completion of the subjective questionnaire and clinical assessment, data collection began with donning of the motion analysis sensors. The first sensor was attached to the thorax, just inferior to the sternal notch; the second sensor was placed onto the posterior acromion (sensor placement, Figure 3.3 and Figure 3.4). Both sensors were secured to the skin with double-sided adhesive tape. When necessary, the anterior chest area was shaved to promote adherence of the sensor. The third sensor was mounted onto a thermoplastic molded cuff that was secured with Velcro straps to the distal right humerus proximal to the humeral condyles. Bony anatomical landmarks were then digitized according to the International Society of Biomechanics protocol. Subjects were shirtless when wearing both the Duke Wyre and the Sully braces. Participants stood on a designated mark with feet shoulder width apart throughout data collection. The Duke Wyre brace was cinched in place according to manufactures directions with the arm at subject’s side. The Sully brace straps were applied according to the manufacture’s instructions.
Testing began with an unbraced condition followed by randomly assigning the order of the two braced conditions, the Duke Wyre and Sully. Within each condition the participant completed a range of motion protocol and a proprioception protocol before switching to the next condition. The following motions were each demonstrated by a researcher and then were performed by the subject within the subjects’ available range in a randomized order: 1) abduction in the frontal plane, 2) external rotation with the shoulder at 90° of abduction, and 3) a combined motion to simulate the cocking phase of throwing, consisting of shoulder abduction, external rotation, and horizontal abduction. The subject was asked to replicate this motion as if they were throwing a ball. If the brace restricted shoulder abduction motion to less than 90°, the subject was tested at their maximum available abduction range of motion. The randomized order of motions was kept consistent between the braced conditions for each subject. For each condition maximal humeral external rotation while in 90° of abduction was also measured with a bubble inclinometer to allow the investigators to have an estimate of their maximal range of motion in order to select the appropriate proprioception positions for subsequent testing. The inclinometer was placed on the distal dorsal surface of the forearm. All test motions were repeated three times.

The second phase of testing within each condition was proprioception, or position sense. The subjects remained standing in the same position as noted for range of motion. Subjects were blindfolded and had headphones placed on them in order to decrease proprioceptive input from other body systems. The right shoulder was placed at 0° of external rotation and 90° of abduction, if possible, according to the bubble inclinometer.
The right elbow was passively placed at 90° of flexion. Three positions of external rotation were tested in a randomized order. The positions were: 1) 10° less than the participant’s maximal external rotation ROM, as measured during the previous ROM testing, 2) 50% of this maximal external rotation ROM, and 3) 10° of external rotation. The investigators passively placed the participants in one of these three positions according to a bubble inclinometer. The participant was held in this position by the primary investigator for three seconds and then the arm was passively lowered to their side. The participant was then asked to actively replicate that position as best as they could for two trials. This position was held for three seconds each time, during which time data for the humeral position relative to the thorax was collected. This procedure was repeated for each of the three external rotation ranges. The procedure remained the same for all braced conditions, however, the available range of motion varied between the braces, as the braces restricted range of motion to differing degrees.

After the proprioception protocol was completed, the next condition was then set-up and performed in the same manner. Range of motion and proprioception data collections continued until all three conditions were tested, or until the participant requested to stop testing.

*Data Reduction*

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

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

**Statistical Analysis**

Data was collected at 120 frames per second. Using Motion Monitor software (Innovative Sports Training Inc., Chicago, IL, USA) data was able to be viewed frame by frame and a marker was inserted for each maximal motion obtained – such as abduction/adduction, and internal/external rotation - during ROM testing. Humerus orientation relative to the thorax could then be determined at each of these maximal
points. All processed motion files were exported into an Excel spreadsheet. For all proprioceptive data, the amount of humeral external rotation was determined by using the last frame of each trial’s motion file. Averages of the three repetitions of range of motion and two trials of proprioception were calculated and Number Cruncher Statistical Software (Kaysville, UT) was utilized to analyze the data. The critical value for all statistical tests was set a priori at 0.05.

A one-way, repeated measures analysis of variance (ANOVA) was used to analyze the independent variable of brace condition for each of the three test motions and each of the three proprioception positions, with humeral motion being the dependent variable. For any ANOVA that was statistically significant, a post-hoc analysis was performed using an independent t-test, with a Bonferroni correction applied to each t-test.
CHAPTER IV

RESULTS

Range of Motion Testing: External Rotation in 90°

The average maximum external range of motion for the no brace condition was 82.9°, 54.5° for the Duke Wyre, and 30.3° for the Sully. The Sully had the greatest restriction of external rotation range of motion. A repeated measures ANOVA revealed a significant difference in external rotation range of motion afforded by the braces. Post-hoc t-tests revealed the no brace condition was significantly different from the Duke Wyre and Sully conditions. Likewise, there was a significant difference between the Duke Wyre and Sully, with the Sully brace limiting external rotation ROM to the greatest extent (Table 4.1).

Range of Motion Testing: Abduction

The average maximal abduction range of motion for the no brace condition was 144.4°, 72.5° for the Duke Wyre and 117.4° for the Sully. A repeated measures ANOVA revealed a significant difference in abduction range of motion afforded by the braces. Post-hoc t-tests revealed there was a statistically significant difference between all three brace conditions. The Duke Wyre allowed significantly less abduction range of motion when compared to the other two conditions. Both the Duke Wyre and Sully allowed significantly less abduction than the no brace condition (Table 4.2).

Range of Motion Testing: Combined Motion

For the combined range of motion test the external rotation component was specifically examined. The average external range of motion for the no brace condition
was 79.8°, 45.9° for the Duke Wyre, and 29.4° for the Sully. A repeated measures ANOVA revealed the combined motion averages yielded statistically significant differences. Post-hoc t-tests revealed the Duke Wyre and Sully braces allowed significantly less external rotation ROM compared to the no brace condition. While there was no statistically significant difference between the Duke Wyre and Sully, a trend revealed that the Sully allowed less external rotation ROM that the Duke Wyre (Table 4.3).

**Proprioception: 10° of External Rotation**

The average error from the target angle for the no brace condition was 5.2°, 7.8° for the Duke, and 28.8° for the Sully. A repeated measures ANOVA revealed a significant difference in proprioception afforded by the braces, as determined by the amount of external rotation, in degrees. Post-hoc t-tests revealed that there was a statistically significant difference between the no braced condition and the Sully, and a statistically significant difference between the Sully and the Duke Wyre, with the Duke Wyre providing more proprioception at 10° of external rotation. No difference was noted between the Duke Wyre and no braced conditions (Table 4.4).

**Proprioception: Fifty Percent of Maximum External Rotation**

The average error from the target angle for the no brace condition was 15.7°, 15.8° for the Duke Wyre and 9.0° for the Sully. A repeated measures ANOVA revealed a significant difference in proprioception afforded by the braces, as determined by the amount of external rotation, in degrees. Post-hoc t-tests, however, failed to reveal any
statistically significant difference between the no braced condition and either of the braces, due to the p value being set to a lower value of 0.017 with Bonferroni correction. However, there was a trend in the data that the Sully provided more proprioception due to a smaller absolute error in external rotation ROM at 50 percent of maximum external rotation (Table 4.5).

**Proprioception: 10° From Maximum External Rotation**

The average error from the target angle for the no brace condition was 20.1°, 17.2° for the Duke, and 3.2° for the Sully. A repeated measures ANOVA revealed a significant difference in proprioception afforded by the braces, as determined by the amount of external rotation, in degrees. Post-hoc t-tests determined that there was a statistically significant difference between the Sully and the two other conditions, with the Sully providing increased proprioception at a position of 10° from maximal external rotation. The Duke Wyre and no brace conditions, however, were not significantly different from one another (Table 4.6).
CHAPTER V
DISCUSSION

The primary focus of this pilot study was to investigate the overall integrity and feasibility of the methods. The procedure was well understood and easily followed by each of the subjects as evidenced by the active replication portion of the procedure that was used for proprioceptive testing. The data was not filled with artifacts that could potentially skew the study results. This indicates that the sensors were not likely disturbed or moved during the donning and doffing of each of the brace conditions and that they were properly adhered to bony landmarks. Being that the methods are feasible and easily replicated the primary intention of the study was achieved, and allows these methods to be used in further research endeavors.

In terms of using a brace as part of the conservative treatment for return to play, ideally one should look for a brace that can stabilize the shoulder while still allowing the athlete to have the range of motion necessary for a given sport. Both the Sully and Duke Wyre braces limit range of motion in general when compared to the no-brace condition. The Duke Wyre is best at limiting abduction motions while the Sully is best at limiting external rotation. The range of motion limitations found within this study coincide with the clinical description of Reuss and the limitations found with DeCarlo et al. Our results of increased accuracy with position sense and the neoprene brace also coincide with studies done by Ulkar, Chu, McNair, and Perlau. These factors should be taken into consideration when selecting a brace for an athlete.
The proprioceptive comparison between each brace condition also revealed statistical significance. The Sully brace is best able to reduce the amount of error subjects experienced in actively reaching the target position. This reduction in error is mainly found near the end range of external rotation, as one begins to reach a vulnerable position for dislocation.

Proprioception is the ability to integrate information from the skin, muscles, and joints in order to determine static limb position and kinesthetic movement. Although cutaneous receptors are not typically defined as proprioceptors, they play an integral role in kinesthetic movement due to the increase in stretch and pressure on the skin with joint movement. Mechanoreceptors within the actual joint are primarily influential in static limb positioning. Therefore, the process replicating a target position includes the processing of neural information from the stretching of muscles, the increasing tension in tendons, and the position of joint receptors. Within this paper, however, the term proprioception was made with specific reference to joint mechanoreceptors for ease of understanding.

It could be hypothesized that the Sully brace may enhance an individual’s proprioceptive capabilities by providing increased tactile input regarding joint position in space. This assumption is based on the fact that the further into external rotation the subject moves, the greater the amount of friction between the rubber brace and the subject’s skin and the greater the pressure exerted under the anchoring strips. These components could lead to an increase in firing of mechanoreceptors, whether located within the dermis or the joint capsule. The increase in neuron firing may lead to an
increased kinesthetic awareness and an enhanced ability to replicate a given
glenohumeral and scapular position.

This neurological assumption aligns with the common clinical practice that
physical therapists employ within the therapeutic setting to “sense” or heighten the
understanding or application of proper technique or a given exercise by using tactile cues.
In this sense, the Sully brace may be able to heighten the subject’s ability to sense joint
direction to a greater extent by providing increased sensory input.

It is unclear at this point in our research whether the brace is increasing cutaneous
somatosensory input, increasing compression to the joint mechanoreceptors, or adding
tension and stretch to tendons and muscles, and/or a combination of these aspects. The
active motion of replicating a target position would suggest an increase in cutaneous
neuron firing, as this is when cutaneous neurons are most active. However, it should not
be forgotten that the test position was given to the subjects passively, indicating joint
receptor involvement. It is likely a combination of receptors located in the skin, muscles,
and tendons that are influenced by the Sully brace and may be contributing to the
increased accuracy in proprioception. The investigators cannot be certain how much
influence each aspect of proprioception is involved, but simply that the ability to replicate
a target position was improved.

The results from this study can assist in clinical decision making in regards on
how to select a brace for a given athlete. In general, some considerations for selecting a
brace include the cost of the brace, ease of use, brace durability, age of athlete, arm
dominance, athletic skill level, and the specific sport requirements. For example, a
football defensive lineman has had an anterior shoulder dislocation and has been cleared to return to play. However, he is requesting something that can provide him with extra stability and limit his range of motion, specifically abduction. The Duke Wyre brace would best limit the range of motion requested while providing general stability against internal and external forces. Another example is of either a football wide receiver or basketball player. If both of these athletes were to sustain an anterior shoulder dislocation they may also require something to assist in stabilizing their shoulders particularly in external rotation. However, with both of these positions, they will need to occasionally reach overhead as part of their specific sport and position. The Sully brace would allow these athletes to have the ability reach overhead while stabilizing in the direction of external rotation. The additional advantage of the Sully brace is that as the athlete is reaching end range external rotation they are receiving increased proprioceptive input that assist them in being able to actively avoid a position vulnerable to dislocation.

Limitations

One limitation of this study is the overall small sample size, along with the small clinical population sample size of two individuals. There are several factors that may have contributed to such a small sample. Recruiting a clinical population can always be a challenge, as was with this study. The test itself took potentially up to seventy-five minutes which can be a significant time commitment without being able to offer compensation to the participants. There were limited responses from other practitioners on the availability of potential subjects who had not gone on to have surgical correction. The facility utilized for this study was recently built and had difficulty with equipment
installation which was needed for data collection as well. The small sample size limits the ability of the study to detect significant changes between brace conditions and between populations. Therefore, it is difficult to infer generalizable and clinically relevant information.

Another limitation that is inherently built into our study is motion artifacts, or skin slip error. With the use of electromagnetic systems there is the option of using skin surface sensors or bone pins. This study utilized skin surface sensors. Using sensors that are placed on the skin can cause excess artifacts due to the skin gliding over bony prominences. The motion artifacts were minimally controlled with placement directly over the most prominent bony protrusion and not over muscle bellies or excessive adipose tissue.

**Future Research**

Future research can take place, utilizing these methods, in order to expand the sample size to include a greater number of individuals with and without anterior shoulder dislocations. The increase in number of subjects will increase the strength of our results and will allow for increased generalizeability to both clinical and healthy populations.

Another aspect of future research can include looking further into the impact shoulder braces may have on scapular kinematics. The investigators have begun to look into extra data gathered on scapular movements that were collected during the study, though not reported here. There are trends that have shown potential limitations of scapular upward rotation and posterior tipping while wearing a brace. This may
predispose athletes who use these braces to secondary injuries such as subacromial impingement.
CHAPTER VI

CONCLUSION

The Duke Wyre and the Sully shoulder braces are statistically different than the no brace condition. They both, in general, limit glenohumeral range of motion when compared to the no brace condition, while the Sully brace can increase position sense of an individual as they approach positions vulnerable to dislocation. The study design and methods performed in this study will enable future research to expand upon the data gathered here in order to benefit both the clinician and the athletic populations.
REFERENCES


**TABLES**

**Table 3.1.** Subject Demographics.

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Age (years)</th>
<th>Height (inches)</th>
<th>Weight (pounds)</th>
<th>History of Dislocation</th>
<th>Shoulder Examination Findings</th>
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<td>1</td>
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<td>71</td>
<td>205</td>
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<td>23</td>
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<td>185</td>
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<td>175</td>
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<td>6</td>
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<td>Averages:</td>
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<td>186.86</td>
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Table 4.1 - Range of Motion Results: External Rotation at 90° of Abduction.

<table>
<thead>
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<th>Brace Condition</th>
<th>External Rotation (°)</th>
<th>Standard Error (°)</th>
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<tr>
<td>No brace</td>
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<td>54.5</td>
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<tr>
<td>Sully</td>
<td>30.3</td>
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*p-value of 0.000005

Table 4.2 - Range of Motion Results: Abduction.

<table>
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<th>Brace Condition</th>
<th>Abduction (°)</th>
<th>Standard Error (°)</th>
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<td>No brace</td>
<td>144.4</td>
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<td>Duke</td>
<td>72.5</td>
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<tr>
<td>Sully</td>
<td>117.4</td>
<td>6.4</td>
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*p-value of 0.000000

Table 4.3 - Range of Motion Results: Combined Motion.

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<th>Brace Condition</th>
<th>Combined Motion – External Rotation (°)</th>
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<tr>
<td>Duke</td>
<td>45.9</td>
<td>5.0</td>
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<tr>
<td>Sully</td>
<td>29.4</td>
<td>4.6</td>
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*p-value of 0.000001
Table 4.4 - Proprioception Results: 10° of External Rotation.

<table>
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<th>Brace Condition</th>
<th>Average Error from Target Position (°)</th>
<th>Standard Error (°)</th>
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*p-value of 0.000000

Table 4.5 - Proprioception Results: Fifty Percent of Maximal External Rotation.

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*p-value of 0.0471

Table 4.6 - Proprioception Results: 10° from Maximal External Rotation.

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<th>Average Error from Target Position (°)</th>
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<td>Sully</td>
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*p-value of 0.000008
FIGURES

**Figure 3.1** - Subject wearing Duke Wyre Shoulder Vest.

**Figure 3.2** - Subject wearing Sully Shoulder Stabilizer.
**Figure 3.3** - Sensor Placement: Scapular and humeral sensors.

**Figure 3.4** - Sensor Placement: Thorax sensor.
APPENDIX A

COMPARISON OF SHOULDER BRACES IN LIMITING RANGE OF MOTION AND JOINT POSITION SENSE IN INDIVIDUALS WITH HISTORY OF SHOULDER DISLOCATION

RESEARCH INFORMATION AND CONSENT FORM

Introduction:
You are invited to participate in a research study investigating how various type of shoulder braces affect the range of motion and the ability to sense the position of your shoulder as you move through your range of motion. This study is being conducted by Dr. Cort Cieminski, faculty member in the Doctor of Physical Therapy (DPT) Program at St. Catherine University, along with four 2nd year DPT students: Evan Boldt, Lana Prokop, Marci Burg, and Leah Jackson. You were selected as a possible participant because you may have a past history of shoulder dislocation(s). You are also between the ages of 18-50, have pain-free shoulder motion, and have not had a shoulder dislocation episode in the past 4 weeks. You will be excluded from participation in the study if you have painful range of motion of your shoulder, have suffered a shoulder dislocation within the past 4 weeks, or have a history of shoulder surgery. Please read this form and ask questions before you decide whether to participate in the study.

Background Information:
Shoulder dislocation is a fairly common orthopedic condition that is treated conservatively, in part, with the use of a brace. Very little evidence, however, currently exists for the ability of various types of shoulder braces to limit range of motion of the shoulder or for increasing the sense of awareness of where the shoulder is in space for individuals who have a history of shoulder dislocation. This study will compare two commonly used shoulder braces in individuals who have a history of shoulder dislocation and the study will attempt to see how much range of motion is restricted in each of these braces, as well as how much shoulder position awareness is provided by each of these braces. Approximately 6-8 people are expected to participate in this research.

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

1. Shoulder questionnaire: The researcher will give you a brief questionnaire asking about your history of shoulder dislocation(s).

1. Clinical shoulder examination: The researcher will perform two clinical tests on your shoulder to determine any degree of looseness that may be present due to your history of shoulder dislocation(s).
Shoulder range of motion and position sense testing:

Two motion sensors (each approximately 1/2 square inch in size) will be taped to your skin, one over your upper trunk just below your neck and one over the lower portion of your upper arm bone on the side of your shoulder dislocation(s). These sensors will detect the amount of movement of the shoulder that occurs during the testing motions. If you have excessive hair over the upper trunk sensor location you will be asked to gently shave a two square inch area to allow for proper adhesion of the sensor. With you standing, several bony locations on your trunk, shoulder blade and upper arm bone will then be located by the researcher using their finger tips.

You will then be asked to raise your arm out to the side to 90 degrees and perform two active motions of your shoulder: 1) inward rotation, and 2) outward rotation. You will perform three repetitions of each motion. Next, you will be asked to close your eyes and a researcher will slowly move your shoulder to three positions of inward and outward rotation. Your shoulder will not be forced into a position where you would feel your shoulder wanting to dislocate. You will then be asked to actively place your shoulder as close to those three positions as possible. You will perform three repetitions of this activity.

After completing this sequence without a brace, you will then repeat this same sequence of testing activities once which wearing an elastic shoulder brace and once while wearing a canvas shoulder brace. All testing will take place at the Women’s Health and Integrative Research Center on the St. Paul campus of St. Catherine University and will take about one hour to complete.

Risks and Benefits:

You may experience temporary minor skin irritation due to shaving of the upper chest sensor location or to the use of the adhesive tape that is used to attach the sensors to the skin. All adhesive tape residue will be removed with alcohol before you leave the testing session. Minor muscle soreness may also be experienced after completing the shoulder motions. The use of ice packs, gentle stretching and/or possible rest from activity for a brief period of time after your testing session will minimize potential soreness. There are no direct benefits to you for participating in this research.

Confidentiality:

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

We will keep the research results in a password protected computer and in a locked file cabinet in the Women’s Health and Integrative Research Center on the St. Paul campus of St. Catherine University and only the researcher(s) named in this form will have access to the records while we work on this project. We will finish analyzing the data by
December 2012. We will then destroy all original reports and identifying information that can be linked back to you.

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

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

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

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

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

______________________________________________
I consent to participate in the study.

Signature of Participant Date

______________________________________________
Signature of Researcher Date
APPENDIX B

Subject ID# ______

GENERAL INFORMATION
Shoulder Dislocation Questionnaire

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

Do you have a history of skin sensitivity or skin allergies, especially with tape?
Y/N

Do you consider yourself left or right-handed?
L/R

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

Have you ever injured your shoulder(s)?
Y/N
If yes, what type of injury:

Shoulder dislocation Y/N L/R
Labral tear Y/N L/R
AC or SC joint instability Y/N L/R
what if any stabilization was performed? _____________________________
what if any displacement was noted? ______________________________

Fracture:
collarbone (clavicle) Y/N L/R
upper arm (humerus) Y/N L/R
shoulder blade (scapula) Y/N L/R
shoulder tendonitis Y/N L/R
shoulder impingement Y/N L/R
rotator cuff tear Y/N L/R
shoulder bursitis Y/N L/R
scoliosis Y/N L/R
shoulder strain Y/N L/R
Other:

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

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

When was your last episode of shoulder dislocation ____________________________

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

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

Have you ever been given a brace to wear to reduce your risk for shoulder dislocation?
   Y/N
   If so, what brace(s) have you used? ___________________

How long have you used the brace? __________________________

Shoulder examination findings

1. Anterior apprehension sign + or -
   If positive, relocation sign + or -

2. Anterior load shift test + or -
APPENDIX C

Establishment and Definitions of Local Anatomic Coordinate Systems.\textsuperscript{48}

For a right scapula and humerus assumption:

\textit{Scapula}

The XS axis is defined by an approximately horizontally-directed vector created by subtracting the point at the root of the spine of the scapula from the point at the posteriolateral angle (PLA) of the acromion process. Calculation of the unit vector will create an axis oriented to the right in the plane of the scapula.

The YS axis is defined by establishing an inferiorly oriented intermediate vector by subtracting the point at the root of the spine of the scapula from the point at the inferior angle of the scapula. The cross product of this inferior intermediate vector and the horizontal XS vector is calculated to create a vector oriented perpendicular to the plane of the scapula. The unit vector of this is calculated to define the YS axis.

The ZS axis is defined by calculating the cross product of the XS unit vector and the YS unit vector. This axis will be oriented roughly vertically, orthogonal to both the XS axis and YS axis.

The origin of the scapular coordinate system is located at the AC joint.

\textit{Humerus}

The ZH axis is defined by a vertically oriented vector established by subtracting the point on the distal humeral cuff from the estimated humeral head center. The estimated humeral head center is derived from a least squares algorithm for the point on the humeral head that moves the least during short arc humeral motions. A unit vector was then calculated.
The YH axis is defined by first subtracting the medial epicondyle point from the lateral epicondyle point to create a laterally directed vector. The cross product of this lateral vector and the ZH vector will create an anteriorly oriented vector. Calculating the unit vector produces YH.

The cross product of ZH and YH unit vectors will define XH, a horizontal axis directed to the right.

The origin of the humeral system is located at the medial epicondyle.

_Thorax_

The ZT axis is defined by a vertically oriented vector established by subtracting the point that bisects the T8 spinous process to the xyphoid process line from the point that bisects the C7 spinous process to suprasternal notch line and calculating the unit vector.

The XT axis is defined by a horizontally oriented vector established by creating a posteriorly-directed intermediate vector using the xyphoid process to T8 spinous process line and calculating the cross product of this posterior vector and the vertical vector. Calculation of the unit vector will create an axis oriented to the right.

APPENDIX D

Vector Calculations

Cross product multiplication is performed on two positional vectors lying in the same plane. The result of this calculation is a third vector mutually perpendicular to the first two. The cross product equation is:

\[ \mathbf{A} \times \mathbf{B} = (A_jB_k - A_kB_j) \mathbf{i} + (A_kB_i - A_iB_k) \mathbf{j} + (A_iB_j - A_jB_i) \mathbf{k} \]

Where \( \mathbf{A} \) and \( \mathbf{B} \) are positional vectors and \( i, j, k \) represent the \( x, y, z \) coordinates of each vector.

A unit vector is calculated by determining the magnitude of the positional vector and dividing the positional vector coordinates by the magnitude:

\[ \sqrt{x^2 + y^2 + z^2} \mathbf{i} = \text{vector magnitude} \]

\[ \frac{x + y + z}{\text{magnitude}} = \text{Unit Vector} \]