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Shoulder proprioception in male and female athletes

Zachary Lloyd Sutton

To the Graduate Council:

I am submitting herewith a thesis written by Zachary Lloyd Sutton entitled "Shoulder proprioception in male and female athletes." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Human Performance and Sport.

Wendell Liemohn, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Karen Goss

Greg Mathien

Accepted for the Council:

Vice Provost and Dean
Of Graduate Studies

SHOULDER PROPRIOCEPTION IN MALE AND FEMALE ATHLETES

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Zachary Lloyd Sutton
May 2003

DEDICATION

To my wife, Margaret, and my parents, Ann and Greg.

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ABSTRACT

The objective of this study was to examine the relationship between male and female athletes and shoulder proprioception. This includes the interaction of gender, overhand sports activity, fatiguing exercise, and proprioception. Clarifying these relationships may present insight to injury prevention and performance gains.

Fifty-six subjects (30 males and 26 female) volunteered to participate. The participants did not have a history of shoulder surgery, shoulder injury in the past three months, or a disease affecting the neuromuscular system. The subjects were divided into two groups: (1) varsity athletes and (2) non-athletes.

Group I was comprised of 16 subjects who performed Active Reproduction of Active Positioning (ARAP) and Passive Reproduction of Active Positioning (PRAP) at three target angles of 30 degrees of external rotation, 20 degrees of internal rotation, and 75 degrees of external rotation. All testing was done on a Biodex multi-joint dynamometer; subjects performed three trials at each angle. Next, participants performed a fatiguing exercise consisting of continual internal and external rotations of the shoulder at 180 degrees per second until the peak torque of the external rotator muscles dropped below 50 percent of the maximal torque production three rotations in a row. After exercises, the ARAP and PRAP tests were repeated. Participants performed all testing and exercises on both dominant and non-dominant arms.

Group I, made up of 40 subjects (20 male and 20 female), performed a setof three trials of the ARAP test with the target angle set at 40 degrees of external rotation.

For each condition, means, standard deviations, and a 3x2x2 with gender between subjects ANOVA was calculated using SPSS (Chicago, IL) statistical package; the

significance level was set at $p < 0.05$. Group I and Group II were compared by a paired samples t-test with the significance level at ($p < 0.05$).

The results of this study suggest that there is a difference in proprioceptive abilities between overhand collegiate athletes and the general population. Athletes exhibited less joint position sense in the middle range of shoulder motion than the general population ($p < 0.05$). The athletes did not demonstrate any differences between the dominant and non-dominant shoulder. These finding suggest that athletes' proprioception abilities may not be affected by sport activity as much as generalized joint laxity that may be exhibited in both shoulders. Intense, short duration exercise did not affect the participants' proprioceptive abilities. There was not a significant relationship between gender and proprioceptive deficits.

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LIST OF ABBREVIATIONS

20	20 degrees of internal rotation at the shoulder
-30	30 degrees of external rotation at the shoulder
-40	40 degrees of external rotation at the shoulder
-75	75 degrees of external rotation at the shoulder
ARAP	active reproduction of active positioning
ARPP	active reproduction of passive positioning
DAA	dominant arm, after fatigue exercise, ARAP test
DAP	dominant arm, after fatigue exercise, PRAP test
DBA	dominant arm, before fatigue exercise, ARAP test
DBP	dominant arm, before fatigue exercise, PRAP test
DND	dominant vs. non-dominant arm
GTOs	Golgi tendon organs
NAA	non-dominant arm, after fatigue exercise, ARAP test
NAP	non-dominant arm, after fatigue exercise, PRAP test
NBA	non-dominant arm, before fatigue exercise, ARAP test
NBP	non-dominant arm, before fatigue exercise, PRAP test
PRAP	passive reproduction of active position
RAP	reproduction of active positioning
ROM	range of motion
RPP	reproduction of passive positioning
TIME	before exercise vs. after exercise
TTDPM	threshold to detection of passive motion
YIA	year in academics
YIE	year in eligibility
YOC	number of years of competition
YOP	number of years of participation

CHAPTER I

INTRODUCTION

Borsa et al.[1] defined proprioception as "a specialized variation of the sensory modality of touch which encompasses the dynamic and static sensations of joint motion and position, respectively." Proprioception refers to the awareness of the position of a joint. Afferent receptors that surround the joint respond to stimuli in muscles, tendons, and joints. Neuromuscular control is the motor efferent response to the proprioceptive afferent input. Decreases in proprioceptive ability can reduce coordination at a joint, increase the incidence of injury, and can decrease performance ability. Stability at the shoulder is maintained primarily by the ligaments and muscles that surround the joint with little support from bony constraints. Without bony stability, such as seen in the hip, the shoulder exhibits a high incidence of trauma.[2-8] Proprioception is the integral information system that directs the neuromuscular system in providing the joint with the most stability possible in any given position.

Active and dynamic components and passive and static components contribute to proprioceptive abilities. Both dynamic and static components of a joint experience changes due to activity; ligaments increase in laxity while muscles experience fatigue. Therefore, the influence of activity on proprioception is crucial.

Muscle fatigue is believed to affect proprioception and diminish neuromuscular control.[9-16] Muscle fatigue acutely impairs motor performance and can increase the risk of injury since it appears to deleteriously affect the ability to initiate and communicate proprioceptive feedback and thus motor control.[17, 18] As fatigue sets in there is an increase in the perceived effort necessary to exert force and an eventual inability to produce that force.[19, 20] If fatigue is present the muscle spindle threshold is desensitized; this affects joint position sense and neuromuscular responses vital to joint stability. Researchers define muscle fatigue as the inability to maintain force output that results in decreased neuromuscular capabilities within the muscle; this can predispose the joint to injury and decrease athletic performance.[15, 21, 22]

Many investigators have demonstrated that females tend to have greater flexibility than males[23-29] and thatathletes of both genders demonstrate more laxity in the shoulder joint than non-athletes.[30-34] Athletes in general and females in particular may be predisposed to decreased stability at the glenohumeral humeral joint and perform while fatigued; for this reason proprioception can be crucial for preventing injury. Therefore, assessment of proprioception can be valuable for (a) identifying proprioceptive and neuromuscular deficits that may decrease performance ability or increase risk of injury and (b) planning training and rehabilitation programs.

Statement of Purpose

Many investigators have provided evidence that proprioception is crucial to proper shoulder joint functioning and that muscle fatigue has a major effect on the abilities of these afferent receptors of the glenohumeral joint. Although some investigators tested male and females,[13, 14, 22, 35] none have drawn a direct relationship between gender and shoulder proprioception. Therefore, the purpose of this investigation is to clarify the effects of gender, sports activity, and fatigue on shoulder proprioception.

Hypotheses

The following hypotheses were tested:

1. There will be no difference in proprioceptive acuity between non-fatigued and fatigued shoulders.
2. There will be no difference in shoulder proprioception between genders.
3. There will be no difference of proprioception between the dominantand non-dominant shoulders in athletes.
4. There will be no difference in shoulder proprioception between Group I (athletes) and Group II (general population).

Delimitations

The study was conducted within the following delimitations:

1. Group I consisted 16 active and healthy subjects (10 males and 6 females), ages 18 – 25 years, selected from the varsity athlete population at The University of Tennessee. Group II consisted of 40 active and healthy subjects (20 males and 20 females), ages 18 – 35, selected from the general population at The University of Tennessee. All subjects met the inclusion criteria as defined in the methods section.
2. Group I. Two proprioception tests, both with three target angles (20, -30, -75), were conducted before and after fatiguing exercise on dominant and non-dominant shoulders. Group II. One proprioceptive test, with one target angle (-40), was conducted on the subject's non-dominant shoulder.
3. Collection of data for each subject was completed in one session.

Limitations

The study was limited by the following factors:

1. Group I subjects were limited to the "over-handed athletic population" at The University of Tennessee, Knoxville. Group II, subjects were limited to the general population at The University of Tennessee, Knoxville.
2. Subject motivation may vary when attempting to duplicate the target angle position and accuracy to complete tasks can be variable. All subjects voluntarily participated and a detailed explanation was given stressing the importance of trying to achieve the target angle.
3. A learning curve with the dynamometer may be present. The investigator demonstrated the tests and gave the participants a practice trial to become familiar with the equipment and test protocol.
4. The environment was variable. The majority of subjects were tested in the morning to lessen the effect of time of day and major activity in the clinic. In addition, every attempt was made to control the environment by providing the subjects with limited visual and auditory cues by using goggles and headphones. However, since testing took place in a physical therapy clinic, not every aspect of the environment could be controlled.
5. Joint position sense is conscious and voluntary. This may not truly reflect the spinal reflex abilities necessary to prevent injury when a destructive stress is applied to a joint.

Assumptions

The following assumptions were made for this study:

1. The dynamometer used and associated software used could produce valid and reliable data.
2. All subjects met the inclusion criteria: a) no history of shoulder surgery, b) no shoulder pain in the past three months, and c) no disease that effects the neuromuscular system.
3. The performance of the subjects was an accurate representation of their true proprioceptive abilities and not influenced by a lack of motivation to accurately attempt the target angle.

CHAPTER II

REVIEW OF LITERATURE

Anatomy and Structure of the Shoulder

The shoulder is a multi-axial joint that involves the articulation of three bones (i.e., clavicle, scapula, and humerus) and four joints (i.e., glenohumeral, acromioclavicular, sternoclavicular, and scapulothoracic). The glenohumeral joint is the principal articulation of the shoulder and allows for large ranges of motion due to minimal articular constraints. Therefore, active muscle forces play a significant role in shoulder joint stability[36-38] by providing a dynamic and mechanical restriction on excessive translation with compression of the humeral head into the glenohumeral fossa.[36-38] Normal kinematics at the shoulder depend on several variables including bony surfaces, surrounding capsule, ligaments, muscles, and nervous system. When muscle imbalances and/or laxity in the capsule and ligaments becomes excessive, the shoulder joint may become unstable and at greater risk of injury.

Shoulder Instability

Stone et al.[39] identified three causes of recurrent joint instability: 1) capsular or ligamentous laxity, 2) muscular weakness, and 3) lack of proprioception. Capsular and ligamentous laxity results in the joint being mechanically unstable due to lack of functional supporting structures. Muscular weakness can cause mechanical instability since the musculature crossing the joint cannot create enough compression to hold the joint in position. A lack of proprioceptive feedback causes functional instability and dysfunctional muscular response to action at the joint.

Several studies suggested that glenohumeral hyperlaxity and generalized joint hypermobility are contributing factors for glenohumeral instability.[2, 23, 29, 40] Smith and Brunolli[41] and Lephart et al.[42] demonstrated that subjects with glenohumeral instability had decreased proprioceptive input.

Physiological and Epidemiological Gender Differences

Recent research themes have emphasized the anatomical, physiological, and neuromuscular differences between males and females. Title IX has dramatically increased the number of female sports teams and female participation in sports. Because of the increase in the number of female athletes and an increase in the number of injuries to this population, some investigators believe that women are more susceptible to sports injuries than men.[35, 43, 44] Investigators have also suggested that neural, mechanical, and hormonal factors may play a role in proprioceptive deficits and injury to the female athlete.[16, 27, 45, 46]

Sallis et al.[47] refuted much of the prior documentation on the relationship of gender and injury incidence. In this study a certified athletic trainer compiled male and female athlete injury reports at a NCAA division III college between the years of 1980 and 1995. They found that there was a statistically significant gender difference in injury incidence for swimming. Female swimmers reported more back, neck, shoulder, hip, knee, and foot injuries than their male teammates. When evaluating all sports, female athletes reported a higher rate of hip, lower-leg, and shoulder injuries.

Rozzi et al.[48] measured knee joint laxity and proprioception in 34 collegiate-level athletes who played soccer or basketball. They found that women inherently possess significantly greater knee joint laxity and exhibit increased latencies to detect knee joint motion. They concluded that excessive joint laxity of women appeared to contribute to diminished joint proprioception.[48]

Similar to the knee, joint laxity in the shoulder may play a major part in female injury occurrence. McFarland et al.[29] observed that females have greater posterior shoulder joint laxity compared to male subjects; this could logically increase the chances of posteriorly subluxating the shoulder. Borsa et al.[23] found that healthy women have significantly more anterior shoulder joint laxity and less anterior shoulder joint stiffness than men. These findings were consistent with knee studies that revealed greater joint laxity and decreased joint stiffness in women than imen .[25, 27] Borsa et al.[23] observed a significant difference between gender for generalized joint hypermobility.[23] Using the Beighton Mobility Score, Borsa et al.[23] determined that women have significantly more joint mobility than men; this is consistent with some earlier studies.[24, 26]

Pedersen et al.[35] showed that movement sense acuity was lower for women than men. They suggested that proprioceptive training with females maybe necessary to increase proprioceptive sensitivity and acuity to reduce incidence of injury and increase performance.

Sport Participation and Effect on Shoulder Joint Structure

Many studies have shown that athletes demonstrate increased structural joint laxity compared to non-athletes;[2, 3, 28, 40, 49] this can lead to hypermobility of joints.[50, 51]

Although there is a genetic aspect to joint laxity, some studies suggest that athletic activity may also contribute to joint laxity.[2, 40, 49]

Athletes also tend to show significant difference in range of motion (ROM) patterns. The typical upper extremity athlete has excessive external rotation and compromised internal rotation.[30-34] Excessive external rotation in overhand athletes may be the result of the repetitive stress and microtrauma to the anterior and inferior capsule and ligaments during the throwing, swimming, or serving motion. Throwing athletes are especially at risk because of the high forces required during the cocking and follow-through phases. These forces may cause shortening and scarring of the posterior capsule and rotator cuff muscle tendons that result in limited internal rotation of the shoulder joint.[34] These capsule and ligament changes may also cause proprioceptive changes that lead to further damage due to poor feedback from afferent joint receptors.

Athletes often exhibit increased ligamentous laxity while exercising.[15] During cyclical loading, in exercise such as swimming or pitching, viscoelastic changes could decrease the stiffness properties of the ligament surrounding the shoulder.[52] Decreased stiffness and increased laxity of ligamentous and capsular structures may result in athletes becoming more dependent on proprioceptive abilities and at greater risk for injury than non-athletes.

Proprioreceptors in the Shoulder

Shoulder proprioception is mediated by peripheral receptors in articular, muscular, and cutaneous structures. In cadaver studies investigators have established the neurological anatomy of the glenohumeral joint. They found that there were at least three different afferent receptors in the shoulder joint.[42, 53-55] There are Ruffini-like endings in the glenohumeral joint capsule, Pacinian corpuscles in the glenohumeral ligaments, and nociceptive free nerve endings in the glenohumeral labrum. Vangsness et al.[55] further described the sensory innervation of the glenohumeral ligaments, glenoid labrum, and subacromial bursa. They found Pacinian corpuscles, two types of Ruffini end organs, and free nerve endings within all of the shoulder ligaments (i.e., coracoclavicular, coracoacromial, acromioclavicular, and superior, middle, inferior and posterior glenohumeral ligaments). They found no evidence of any mechanoreceptors in the labrum, although they noted free nerve endings in all of the surrounding tissue.

Pacinian Corpuscles are found around joints and are stimulated by pressure of surrounding structures when movement occurs in the joints.[9] Although these receptors are best activated by local compression stimuli and are also responsive to tensile loading of the joint capsule, they onlysignal jo int movement and do not give information regarding the final joint position. They are fast-adapting and sensitive to acceleration, vibration, and deformation. There are two types of slow adapting Ruffini end organs, the classic and the GTO-like. The classical has a low threshold and is stimulated by slight changes in tension in the ligament; this slow adaptability allows for constant input from the afferent receptor about the ligament's tension.[55] The other is a Ruffini-like end organ that looks like a GTO but performs similar functions to the Ruffini receptor. Although very common in the knee, fast adapting Pacinian corpuscles are not as common in the shoulder.[55]

Vangsness et al.[55] reported that due to the shoulder joint's extensive ROM and multi-axial movement, it requires more receptors that sense position and thus relies more on the slow adapting afferent receptors. Capsular receptors only respond at the end range of motion, compression, distraction, or deep pressure.[1] Interestingly, Barrack et al.'s[56] ballet dancers demonstrated enhanced ability with Threshold to Detection of Passive Motion (TTDPM), but significantly worse acuity when reproducing a reference angle than the control group. Therefore, training appears to have an effect on only some joint proprioception. TTDPM relies more on proprioceptors found in ligaments and the joint capsule since the movement is passive and does not involve muscle proprioceptors until the muscle is stretched or contracted. However, active reproduction of a reference angle relies on muscle activation which should fire Golgi tendon organs and muscle spindles in skeletal muscle tissue. [9]

The capsuloligamentous structures are the primary static restraints and prevent excessive translation and rotation at the glenohumeral joint. Since static restraints function at the extremes of motion, they may only provide afferent feedback about joint position that contributes to muscle stabilization of the joint in the end ranges of motion.[42] This feedback mechanism is necessary for normal biomechanical functioning. Neurological feedback not only coordinates shoulder muscle activation, but also provides protection from excessive strain for the capsule and ligaments.[42]

Mechanoreceptors act as transducers converting mechanical energy of physical deformation of tissueinto electrical energy of a nerve action potential .[55] The greater the stimulus, the more rapid the rate of neural firing from the receptor. The central nervous system uses the rate and frequency of the receptor's impulses to analyze the position of the joint. Adaptation, a characteristic of mechanoreceptors, is the intrinsic ability of the receptor to decrease the frequency of impulses with a continued unchanging stimulus. A rapidly adapting receptor identifies change in the tension of a ligament, but quickly decreases its impulses once more tension becomes constant. With this ability, mechanoreceptors can detect acceleration and deceleration of ligament tension.[55] Voight et al.[22] demonstrated that muscle mechanoreceptors best function as informers of conscious awareness of joint position sense in the shoulder.

Golgi tendon organs (GTOs), located in the musculotendinous junction, are stimulated by tension that occurs when muscle is stretched or contracted. Since the amount of stretch at a tendon is proportional to amount of stretch or force created by the muscle, these types of afferent receptors are able to relay information on muscle force, joint position, and joint movement. GTOs fire more rapidly as the tension on the tendon becomes greater, especially when there is danger of it being injured. GTOs register direction of movement and joint position and are slow adapting and have a high threshold.[9] In skeletal muscle, muscle spindles are stimulated when muscle is stretched or shortened. Tensing the muscles around a joint increases the stretch sensitivity of muscle spindles and can drastically enhance proprioception at the joint.[57] Excitation of muscle afferents delivers acknowledgement of joint movement and position sense to the central nervous system.[58] Similar to GTOs, muscle spindles give information about muscle length and movement of the muscle.

Shoulder Proprioception Investigations

To enhance reliance on proprioceptive senses, most proprioceptive investigations utilized a pneumatic air splint,[14, 34, 41] a blindfold,[13, 14, 22, 34, 35, 41, 42, 59, 60] and headphones or music[13, 14, 34, 35, 41, 42, 59, 60] to eliminate tactile, visual, and auditory cues.

Many investigators used variations of Reproduction of Passive Positioning (RPP) and Reproduction of Active Positioning (RAP) as assessment tests to measure joint position sense. With these tests, angle positions were given passively, then the subject reproduced the angle, both passively and actively in order to evaluate all neural mechanisms involved with proprioception. These tests challenged afferent receptors to relay information about joint position sense to the central nervous system. RAP was a more functional assessment of afferent pathways since it stimulates both joint and muscle mechanoreceptors.[61]

Other investigators used Threshold to Detection of Passive Motion (TTDPM) for proprioceptive testing.[13, 34, 41, 42, 60] Blasier et al.[60] confirmed a capsular mechanism for the detection of rotation sensitivity. With this type of test, the subject signaled the computer when they first detected passive movement of the joint. Speed for passive velocity placement of shoulder was usually tested between .5 degrees per second to two degrees per second. TTDPM largely depends on the rate of angular motion; therefore, this must be a consistent throughout testing. [62]

Smith and Brunolli[41] studied eight subjects with a history of unilateral anterior shoulder dislocation and 10 healthy subjects. The subjects performed three proprioceptive tests including accuracy of angle reproduction, threshold to sensation of movement, and end-range reproduction. The angle reproduction was also known as active reproduction of passive positioning or ARPP. Threshold to sensation of movement was also known as TTDPM and was tested at 1.5 degrees per second. The end-range reproduction test, similar to the passive reproduction of passive positioning or PRPP, involved the investigators moving the subject's shoulder to the end-range of motion.

After 30 seconds in that position, the shoulder was passively returned to starting position. Smith and Brunolli used a motor-driven shoulder wheel apparatus with a large compass that passively took the shoulder to the end-range position at which the subjects were supposed to signal. Subjects were tested lying supine with 90 degrees of abduction, 90 degrees of elbow flexion, and 45 degrees of external humeral rotation. Smith and Brunolli[41] reported significant kinesthesia deficits of both TTDPM and RPP in shoulders after anterior dislocation compared to the uninvolved shoulder.

Lephart et al.[42] tested a total of 90 subjects, dividing them into three groups: (1) normal control of 40 college-age students, (2) 30 athletically active men with chronic, recurrent, traumatic anterior shoulder dislocation or subluxation, and (3) 20 subjects who underwent surgical repair and rehabilitation. The subjects performed TTDPM in the supine position with the arm positioned at 90 degrees of shoulder abduction and 90 degrees of elbow flexion. There were two starting points for this study, neutral and 30 degrees of external rotation. Order of dominant or uninvolved shoulder, start position, and movement direction were all randomized. Movement began at a random point over 10 seconds. The movement occurred at a constant angular velocity of 0.5 degrees per second. Three trials were performed from each starting point, moving into both internal and external rotation. RPP was also performed to assess joint position sense. For the non-athlete, non-injured group, there were no significant differences in TTDPM between the non-dominant and dominant arm for any test conditions, which was consistent with Smith and Brunolli's results.[41] The injured athletes with unstable shoulders demonstrated significantly longer TTDPM for the condition involving a neutral starting position and moving into internal and external rotation compared with the normal contralateral shoulder. The injured shoulder also demonstrated significantly less acuity with the RPP test in the starting position of 30 degrees of external rotation and in reproducing angles in internal and external ranges of motion compared to the uninjured contralateral shoulder. The surgically repaired group showed no significant difference between the repaired shoulder and the uninjured shoulder. The investigators supported that injury increases proprioceptive deficits.

Similarly, Lephart et al.[63] observed significant kinesthetic deficits at zero and 30 degrees of external rotation for TTDPM and at zero degrees for reproduction of passive positioning testing in subjects with unilateral, traumatic or recurrent, anterior shoulder instability. They also tested dominant and non-dominant effects in healthy shoulders, but no significant differences were found. Although not statistically significant, subjects who exhibited generalized joint laxity tended to show diminished kinesthesia.

Blasier et al.[60] tested varying positions of humeral rotation for TTDPM on 29 subjects witlnormal and generalized joint laxity effected shoulders. These positions included 60 and 90 degrees of external rotation, zero degrees of humeral rotation, and 45 degrees of internal rotation. The subjects performed the tests sitting with 90 degrees of shoulder abduction, 90 degrees of elbow flexion, and the testing degree of humeral rotation; all angles were measured with an electrogoniometer. They found that neither gender nor arm dominance made any significant difference in proprioceptive ability. However, they did confirm a capsular mechanism for the detection of rotation sensitivity. First, the perception of shoulder rotation was more sensitive in the direction that tends to tighten the capsule; in other words, it was more sensitive in the external rotation direction (the direction capsular tightness) especially as the end point is approached. Second, this perception was less sensitive in subjects with generalized joint laxity.

Allegrucci et al.[34] recruited 20 collegiate male overhand athletes as subjects to perform TTDPM positioned in supine with 90 degrees of shoulder abduction and 90 degrees of elbow flexion, and either zero or 75 degrees of external humeral rotation. After testing the dominant and non-dominant arms, they also found that the non-dominant arm exhibited a significantly enhanced ability to detect motion for internal and external rotation at the starting positions of neutral and 75 degrees of external rotation. They found that the difference between non-dominant and dominant arm is more pronounced at the neutral position than at 75 degrees of external rotation when moving into internal rotation. Therefore, they suggest that as internal rotation of the shoulder increases, threshold to detection of passive motion decreases. This observation of the non-dominant arms enhanced ability to detect motion is not in agreement with the findings in other bilateral arm studies.[22, 41, 42, 63]

The Effect of Fatigue on Proprioception

Originally Lumex, Inc, manufactures of Cybex and Orthotron instrumentation, attempted to quantify fatigue.[64] They suggested that muscle fatigue occurred when a torque of a give contraction is one-half that of the initial torque produced. In further research, Patton et al. [65] determined that the isokinetic fatigue curve is curvilinear, independent of gender, and a function of initial strength.

Using the fatigue protocol foundation and some evidence of proprioceptive deficits at fatigued joints, other studies have specifically addressed the effects of muscle fatigue on shoulder proprioception.[13, 14, 22, 35, 59, 66]

Voight et al.[22] studied the effects of muscle fatigue and the relationship of arm dominance to shoulder proprioception. Thirty-seven males and 43 females of college age complete the tests and a fatigue protocol while seated with the shoulder positioned in 90 degrees of shoulder abduction, 90 degrees of elbow flexion, and neutral pronation/supination. Subjects performed RPP and RAP proprioceptive tests and a fatigue protocol on a multi-joint isokinetic dynamometer. For the fatigue protocol, the subjects performed isokinetic internal and external rotation at 180 degrees per second until peak torque output of the external rotators dropped below 50 percent of the initial or maximal values for three consecutive repetitions.

Voight et al. found that glenohumeral active and passive repositioning ability was significantly decreased after the fatigue activity. They suggested that dysfunctional mechanoreceptors may be a reason why passive repositioning acuity diminished as well as active repositioning acuity after muscle fatigue. By taking the joint to the end range of motion in external rotation during the fatigue protocol, the muscle mechanoreceptors sensitive to muscle tension may have been desensitized and accommodated the stimuli.[22] Actively, the fatigued muscle becomes dysfunctional, decreasing the ability to detect change in muscle tension. Since this demonstrated that muscle fatigue plays a role in the decreased proprioceptive abilities, Voight et al.[22] suggested increasing muscular endurance to produce a more fatigue resistant muscle, which would not only benefit a rehabilitation protocol, but also a performance protocol. Dominant and non-dominant arm exhibited no significant difference.

Carpenter et al.[13] used threshold to detection of passive movement (TTDPM) to determine how fatigue affects the proprioception of the shoulder. They tested 20 subjects, 11 male and nine female, with no shoulder abnormalities, who completed the same proprioceptive protocol as Blasier.[60] In their study, without warning of initiation, the dynamometer internally or externally rotated in a random order at one degree per second. The subjects completed the study in the seated position with the shoulder positioned at 90 degrees of abduction, 90 degrees of elbow flexion, 90 degrees of external rotation, and in the plane of scapulation (30 degrees in front of the frontal plane). This position attempted to simulate the abducted, externally rotated position of the shoulder used in most overhand sports, specifically in the cocking phase of throwing or serving.

In their fatigue protocol, Carpenter et al.[13] had a similar fatigue protocol to Voight et al.[22], however, they based the fatigue on the peak torque of the internal rotators rather than the external rotators. After the fatigue protocol, TTDPM was retested. The repeated test after fatigue demonstrated a decrease in proprioception. Specifically, detection latency increased 171 percent for internal rotation and 179 percent for external rotation.[13] They concluded that fatigue affects sensation of joint movement, decreases athletic performance, and increases fatigued-related shoulder dysfunction.

Sterner et al.[59] included 20 college-aged and recreationally active subjects in their study. The subjects performed a variety of proprioceptive tests before and after a muscle fatigue protocol including an Active Reproduction of Active Positioning test (ARAP), an

Active Reproduction of Passive Positioning test (ARPP), a Reproduction of Passive Positioning test (RPP), and a Threshold to Detect Passive Motion (TTDPM). These investigators did randomly divided the subjects into equal groups to form a fatigue group and a control group. This study used a similar protocol to Voight et al.,[22] but the subjects performed four sessions of continuous maximal concentric contractions at 180 degrees per second until external rotation peak torque decreased below 50 percent of the individual's MVC. In between the sessions a 30-second rest period was given, and the initial three external rotation contractions for the second and fourth sessions reestablished the MVC so that fatigue recovery during the rest period was nullified.

Sterner et al. observed no significant difference between the control group and the fatigue group for ARAP, ARPP, RPP, and TTDPM in either external or internal rotation. These findings show little correlation to other proprioceptive studies on the shoulder. The investigators noted that the fatigue protocol that emphasized short duration, high intensity muscular fatigue did not impair shoulder proprioception within the midranges of external and internal rotation.[59] Therefore, they concluded that this type of fatigue may not have provided a prolonged fatigue effect.

Myers et al.[14] recruited 32 college-aged, male and female subjects to performed two proprioceptive tests before and after fatigue. First, subjects performed an Active Angle Reproduction Test (AAR) on an isokinetic dynamometer, which measured proprioceptive feedback using active reproduction of a specific joint position. This test used three reference angles: (1) 30 degrees of internal rotation, (2) 30 degrees external rotation, or (3) 75 degrees of external rotation; this represented both directions of humeral rotation including mid-range and end-range of motion points. They used varying speeds between one and five degrees per second of placement to help decrease the chance of anticipation. After the testing angle was obtained and held for 10 seconds, the shoulder was passively returned to zero degrees of rotation at the same speed. Subjects then actively attempted to reproduce the reference angle.

Myers et al.'s[14] fatigue protocol utilized the external rotation's initial peak torque as the MVC and involved only one bout. The subjects performed continual concentric repetitions until their peak torque fell below 50 percent for three consecutive repetitions. This study did include a control group that did not perform the fatigue exercise.

Myers et al.[14] found a significant difference between the pre-test and post test values for the experimental group, but not for the control group. They found a decreased ability to actively reproduce joint position in both mid and end ranges of motion. Therefore, they suggest that fatigue inhibits afferent proprioception and thereby affects neuromuscular control.

CHAPTER III

RESEARCH METHODS

Subjects

In this study 56 volunteers were recruited at the University of Tennessee in Knoxville and divided into two groups, (1) athletes and (2) general population. In order to participate, subjects were required to meet criteria thatincluded no history of shoulder surgery, no shoulder injury that required a visitation to a medical doctor or medication in the past three months, or a disease affecting the neuromuscular system. Prior to their participation, the nature of the study (purpose, procedures, risks, and benefits) was explained in detail and the participants were encouraged to ask questions to clarify any aspects of the study. All subjects signed an informed consent form approved by the Institutional Review Board at the University of Tennessee prior to their participation (Appendix IV). [1]

Group I, consisted of 16 subjects (10 male and 6 female) from varsity overhand sports at the University of Tennessee, a NCAA Division I school. Subject information is provided in Appendix I.

Group II, consisted of 40 subjects (20 male and 20 female) between the ages of 18 and 35 from the general population at The University of Tennessee, Knoxville.

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[1] All figures and tables are located in the Appendix.

Instrumentation

All testing was conducted in the Physical Therapy Room, 117A Neyland-Thompson Sports Center at the University of Tennessee. The instrumentation included a Biodex multi-joint dynamometer, attached computer, and Biodex System 3 Advantage Software (Version 3.2) (Biodex Medical Systems, Inc., Shirley, NY, USA) (Figure 2).

Dynamometer

The dynamometer was used with an arm attachment moved to align the subject's shoulder at 90 degrees of shoulder abduction and 90 degrees of elbow flexion (Figure 3). The subject placed their elbow in the corner of the arm attachment, so that the axis of rotation went through the shaft of the humerus. The wrist piece was adjusted to comfort. The subject used an attached trigger to signal the computer to stop.

Experimental Protocol

Group I

The principal investigator outlined the purpose and procedures of the study for each subject prior to their participation. Subjects were further informed about the purpose, the number of conditions, the number of repetitions, and the performance requirements on the day of the testing. The testing session was completed in approximately 1.5 hours.

The testing session included two parts. The subject for both parts was in the seated position and the use of a Biodex multi-joint dynamometer and attached computer.

Part One included two proprioceptive tests called Active Reproduction of Active Positioning (ARAP) and Passive Reproduction of Active Positioning (PRAP). For these tests, the subjects were seated in an upright position with 90 degrees of shoulder abduction, 90 degrees of elbow flexion, and zero degrees of shoulder rotation. All movement occurred in a sagittal plane arc around the axis of the humerus and glenohumeral joint. For the ARAP part of the session, the subjects slowly moved their shoulder to a test position, held for ten seconds, and returned the arm to the starting position. The subject attempted to return his/herarm to the test position. For the PRAP part of the session, the subjects slowly moved their shoulder to a test position, held for ten seconds, and returned their arms to the starting position. As the dynamometer returned the subjects' arms toward the test position, the subjects pressed the stop button at the point they believed was the reproduction of the original angle. Both ARAP and PRAP tested three target angles: -30 (30 degrees of external rotation, 20 (20 degrees of internal rotation), and -75 (75 degrees of external rotation). Subjects wee given three trials at each target angle, for a total of nine trials per tests. Each trial included a practice to determine target angle and a test to determine ability to reproduce the target angle. All three trials were given consecutively for each target angle with no randomization. Because visual and auditory cues could influence the results of these tests, the participants were blindfolded and listened to music and instructions through headphones.

Part Two included response after fatiguing exercise. The participants performed continual isokinetic internal and external rotations of the shoulder at 180 degrees per second until the peak torque of the rotator cuff muscles or external rotators, monitored by the computer, dropped below 50 percent of the maximal torque production three rotations in a row. Prior shoulder investigators and studies have determined this as a reliable quantitative assessment of fatigue.[13, 14, 22, 59] There were no adverse long-term effects of this exercise reported in the literature; and some studies demonstrated recovery from this type of exercise to be within six minutes.[67, 68]

After both test parts were administered, Part One was repeated. After all tests were completed with the dominant shoulder, the machine was arranged and adjusted for the non-dominant. The non-dominant arm servd as a control to compare the dominant arm performance for the overhand sporting activity.

Group II

The principal investigator outlined the purpose and procedures of the study for the subjects prior to their participation. Subjects were further informed about the purpose, the number of trials and performance requirements on the day of the testing. The testing session was completed in approximately thirty minutes. The testing session included three trials, each with a practice and a test. This part of the study only tested the subject's non-dominant arm.

Subjects' proprioception with Active Reproduction of Active Positioning (ARAP) was tested. This test allowed sagittal plane movement to occur in an arc around the axis of the humerus and glenohumeral joint. With ARAP, the subject slowly moved their shoulder to the target position of -40 (40 degrees of external rotation), held for five seconds, and returned the arm to the starting position of 90 degrees of shoulder abduction, 90 of elbow flexion, and zero degrees of shoulder rotation. Zero degrees of shoulder rotation being defined as horizontal to the ground. Because visual and auditory cues can influence the results of these tests, the subjects were blindfolded with blacked-out goggles and listened to music through headphones.

Data Processing

For both groups, the software documented the number of degrees away from the target angle for each condition, but did not distinguish whether the angle was greater or less than the target angle.

Statistical Analysis

Group I. For each condition, means and standard deviations were calculated. A 3x2x2 (Angle x Arm x Time) with gender between subjects, repeated measures analysis of variance (ANOVA) using Wilkes Lambda test for significance was computed using SPSS (SPSS Inc., Chicago, Illinois, USA) statistical package. Significance level was set at $p < 0.05$.

Group II. Means and standard deviations were calculated for the three trials. An analysis of variance (ANOVA) with gender between subjects for each set was used to test significance. SPSS (SPSS Inc., Chicago, Illinois, USA) statistical package was used for all statistical computations. Significance level was set at $p < 0.05$.

Group I and Group II were compared with a paired samples t-test to determine significance between the two groups for differences due to athletic participation. Significance level was set at ($p < 0.05$).

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of this study was to investigate the relationship between gender, sport activity specific to overhand athletes, and muscle fatigue to proprioception at the glenohumeral joint. Data were collected on 56 subjects. Group I consisted of 16 subjects who were from a population of varsity athletes at the University of Tennessee Knoxville Campus. Tables 1 and 2 display their athletic and academic background information. Group II consisted of 40 subjects who were from the general student population at the University of Tennessee Knoxville Campus. The proprioceptive results specific to sport activity, muscle fatigue, and gender are presented and discussed in the following chapter.

Sport Activity and Proprioception

A comparison was made between overhand sports activity and the general population by testing 16 dominant, athletic shoulders, 16 contralateral, non-dominant shoulders, and 40 non-dominant shoulders from the general population. No significant difference was demonstrated between the dominant and non-dominant shoulder for the athletic groups for any condition (Table 9). These results are similar to other studies conducted on both dominant and non-dominant shoulders.[22, 60] Although many unilateral athletes exhibit increased structural joint laxity in the dominant shoulder, we found no resultant deficits in proprioception.

Many studies have shown that athletes demonstrate increased structural joint laxity compared to non-athletes;[2, 3, 28, 40, 49] this can lead to hypermobility of joints.[50, 51]

Although there is a genetic aspect to joint laxity, some studies have suggested that athletic activity may also contribute to joint laxity.[2, 40, 49]

To address whether joint laxity found in certain athletes effects proprioception abilities, we compared Group I, the athletes, to Group II, the general population. We found that the athletes exhibited significantly less joint position sense than the general population at middle range of motion at the shoulder ($p < 0.05$).

All of the subjects in Group I of this study participated in NCAA Division I athletics. While the dominant shoulders of the athletic participants did not exhibit any proprioceptive deficits compared to the contralateral non-dominant shoulder, their training to become elite athletes may have benefited their proprioceptive sense. Their training included sport specific training on the field and court, strength training in the weight room, and often injury preventative exercises designated by the athletic trainer. Both sport-specific and strengthen training enhances stability as well as proprioception. Increasing the strength of muscles that cross the shoulder joint creates dynamic and mechanical stability in the shoulder by compressing the humerus into the glenohumeral fossa. We suggestthat dynamic stability may compensate for generalized static laxity associated with overhand sports activity. Further, genetic generalized joint laxity may account for no difference between the dominant and non-dominant shoulders of the athletes.

Despite the lack of significant difference in the dominant shoulder compared to the non-dominant shoulder, sport activity demands, such as overhand throwing, do change the dynamic involvement of a joint's proprioceptive ability since proprioceptive sense is dependent on joint angle. In this study, the position of the target angle showed significantly greater accuracy at the middle range of motion targets, 20 degrees of internal rotation and 30 degrees of external rotation, than the target closer to end range of motion, 75 degrees of external rotation ($p < 0.01$)(Tables 9, 11, 12). In general, athletic shoulders exhibit joint laxity with increased external rotation and decreased internal rotation ROM. They also exhibit anterior shoulder muscular tightness, such as the pectoralis major and the latissimus dorsi. Anterior muscles are responsible for generating the power and force for a serve, throw, or stroke. Our results are in contrast to the finding of Blasier et al[60] and Allegrucci et al.[34]; however, they performed Threshold to Detection of Passive Motion (TTDPM) which focuses primarily on static receptors. Therefore, this contrast between dynamic and static receptor testing suggests that these types of receptors have different roles within the ranges of motion. Specifically, Ruffini end organs in static shoulder structures work more during the end range of motion and Golgi tendon organs and muscle spindles work less with the shoulder in the end of external range of motion, when there is less tension on the rotator cuff muscles and they receptors do not fire rapidly.

Unlike Smith and Brunolli, [69] who reported significant proprioceptive deficits with traumatic shoulder injuries, we studied the effect of athletic use on proprioception. Like Smith and Brunoll, Lephart et al.[42] also suggested that unstable shoulders that experience recurrent subluxation exhibit decreased proprioception sense. While wedid not examine the degree of shoulder instability, it was assumed that the participants demonstrated generalized laxity due to their history of athletic participation but no current history of major trauma such as a dislocation that may create instability. Another variation that must be taken into account with this investigation is the type of proprioceptive tests administered. Allegrucci et al.[34] found significant differences between dominant and non-dominant shoulders. They used Threshold to Detection of Passive Motion (TTDPM) and tested primarily static receptors, while this investigation examined the dynamic and static receptors with Active Reproduction of Active Positioning (ARAP) and Passive Reproduction of Active Positioning (PRAP).

This study suggests that athletes exhibit less proprioceptive acuity than non-athletes. No difference was found between the athletes' dominant and non-dominant shoulders.

Muscle Fatigue and Proprioception

The interaction of muscle fatigue and proprioception is an integral component to an athlete's ability to maintain shoulder stability. Since athletes often exhibit ligamentous laxity in their shoulders, shoulder stability is predominantly maintained by joint muscular compression from neuromuscular feedback. We tested collegiate throwing and overhand athletes, but did not find statistical difference between the proprioceptive tests before a fatiguing exercise compared to proprioceptive tests after a fatiguing exercise (Table 9). Tables 5-8 show each participant's performance and the overall performance for each condition. The fatigue protocol emphasized short duration, high intensity muscular fatigue, much like that in the sports of tennis, baseball, and track, which emphasize quick and explosive overhand actions. This type of fatigue protocol may not have provided a prolonged fatigue effect. Sterner et al.[59] used a similar fatigue protocol and found similar results. Therefore, in practice situations, where an athlete may continually perform numerous serves in a row or many repetitions of javelin throwing without rest unlike match situations, the athlete may become muscularly fatigued and decreased proprioceptive sense. Many investigators demonstrated that proprioreceptors in the shoulder were affected by muscle fatigue and thus shoulder stability may be compromised in fatiguing situations.[13, 14, 22, 35, 59, 66]

The subjects for this study participated in NCAA Division I athletics and dedicated time to sport-specific training, but also strength and conditioning. They often encountered fatigue in the weight room and on the practice field. Strength and sport-specific training in competition and fatigue-like conditions may decrease the effects of muscle fatigue on afferent and neuromuscular feedback.[70] These athletes probably also had better access to National Athletic Trainers' Association board-certified athletic trainers, Certified Strength and Conditioning Specialists, and equipment resources than other athletes.

Gender and Proprioception

It is important that sports medicine practitioners, such as athletic trainers and physical therapists, do not assume that all populations of athletes share the same characteristics. Overlooking gender differences may mean overlooking preventative treatments. This statement on gender differences is not in reference to ability, but differences in anatomical, physiological, and histological structure. The major purpose of this study was to define any proprioceptive differences between males and females in order to create better preventative and awareness programs. In Group I, gender between subjects did not differ in means (Table 9, 10). Since our athlete population was small, Group II was examined to confirm any finding with gender similarities. Forty subjects

(20 male and 20 female) volunteered to test their non-dominant arm at three target angles with the ARAP test. The mean and standard deviation are given in Table 14. We did not find any significant difference between the males and females of Group Two (Table 14). A stem-leaf plot demonstrates the relative consistency between the two gender groups in Figure 1. These results concur with Blasier et al.[60] that gender does not influence proprioceptive ability at the glenohumeral joint.

Recent research has focused on the differences between gender in the lower extremity, determining that female athletes more commonly demonstrate proprioception deficits, imbalances in strength, timing of activation, and recruitment of the lower extremity muscles.[71] We suggest that the upper extremity, specifically the shoulder joint, does not share the same gender specific characteristics as the lower extremity.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

In this investigation, there were no differences in proprioception between males and females. Therefore hypermobility common in females does not appear to cause decreased proprioception. Nor do the results support that athletic overhand shoulders are at risk to proprioceptive deficits compared to non-dominant shoulders; however, they are at greater risk compared to the general population. This statement supports the hypothesis that generalized joint laxity in athletes results in decreased shoulder joint position sense. This study does not support the finding that muscle fatigue that is intense, but short in duration, decreases proprioception in the shoulder.

Future studies should consider testing sessions more akin to the practice environments to investigate the effects of muscle fatigue on proprioception. Most practice situations are often of moderate intensity, but are much longer in duration and consist of numerous repetitive motions. A larger comparison of athletes may be needed to demonstrate that there areno significant difference s between male and female overhand athletes. Subsequent testing on gender differences specific to the shoulder and athletes should also look at different throwing techniques and strength programs that may be gender specific. Future investigators may find proprioceptive differences if cohesive groups of athletes are compared rather than merely comparing a generalized group of unilateral, overhand athletes.

Future research also needs to focus on the relationship between joint position sense testing and injury preventing reflexes. Time is an essential component to injury prevention. It takes 35 - 90 milliseconds between ligament loading and ligament rupture.[72] Joint position sense tests the cerebral cortex's ability to produce voluntary muscle contraction; however, this pathway takes more than 150 milliseconds for the resulting contraction to occur.[72] It is important to know whether or not cerebral cortex abilities parallel the spinal reflex and brainstem motor functioning, which take between 40 – 80 milliseconds between ligament loading and the initiation of a ligamento-muscular reflex. Future studies should incorporate this understanding of the spinal reflex into their proprioception study. If there is a strong correlation between joint position sense testing and lower reflex abilities, clinicians would be able to determine the spinal reflex abilities in a simple and reproducible joint position test.

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APPENDICES

APPENDIX I

SUBJECT INFORMATION

Table 1. Male Athletes' Information

Males	Age	YOP	YOC	YIE	YIA	Sport	#Px/wk	hrs/wk
1	21	3	1	2	3	track	6	18
2	21	4	4	4	4	track	6	27
3	22	18	16	5	5	tennis	6	18
4	21	3	3	3	3	track	6	24
5	20	2	2	3	3	track	6	18
6	21	17	13	3	3	baseball	6	20
7	21	14	14	3	3	track	6	12
8	21	7	6	3	3	track	5	10
9	23	15	12	3.5	4	tennis	10	25
10	21	11	11	3	3	tennis	6	12
AVG:	**21.2**	**9.4**	**8.2**	**3.25**	**3.4**		**6.3**	**18.4**

Table 2. Female Athletes' Information

Females	Age	YOP	YOC	YIE	YIA	Sport	#Px/wk	hrs/wk
11	21	8	7	3	3	track	9	18
12	19	8	8	2	2	track	5	15
13	20	8	7	3	4	track	8	12
14	24	11	11	5	5	softball	10	28
15	19	13	13	1	1	softball	6	30
16	19	10	10	1	2	track	9	18
AVG:	**20.333**	**9.666667**	**9.333333**	**2.5**	**2.833333**		**7.833333**	**20.16667**

KEY
YOP: Years of Participation
YOC: Years of Competition
YIE: Year in Eligibility
YIA: Year in Academics
(1 = Freshman, 5 = Fifth Year)

APPENDIX II

RESULTS

Table 3. Within-Subjects Factors

Within-Subjects Factors		
ARM	**TIME**	**TARGET ANGLE**
DOMINANT SHOULDER	**BEFORE EXERCISE**	**-30**
		20
		-75
	AFTER EXERCISE	**-30**
		20
		-75
NON-DOMINANT SHOULDER	**BEFORE EXERCISE**	**-30**
		20
		-75
	AFTER EXERCISE	**-30**
		20
		-75

Table 4. Between- Subjects Factors

Between-Subjects Factors			
		Value Label	**N**
GENDER	**1.00**	FEMALES	6
	2.00	MALES	10

Table 5. Subject Results for Dominant Arm before Exercise

		DBA			DBP		
	Angle:	-30	20	-75	-30	20	-75
Males:	1	4.7	2	12	4.3	3.7	0
	2	4	4.3	7	8.7	8.7	6
	3	6.3	2	8	9	13.3	7.7
	4	4.3	4	8.3	2.3	4.3	11
	5	3.7	4.3	6	4.7	8.3	5.7
	6	4.7	3	9	3.3	5.7	15.3
	7	5.3	3.3	8.3	4.7	12.7	12.7
	8	3	4	5	4.3	4.7	8.3
	9	3.3	2.7	3	2.7	3.3	3.7
	10	7	5	3.3	6.7	1.3	6.7
	Mean:	**4.63**	**3.46**	**6.99**	**5.07**	**6.6**	**7.71**
Females:	11	3.7	3.3	6.3	4.7	8.3	13.7
	12	3.7	0.3	3.7	1	2.7	3
	13	6.3	3.7	4	3.3	5.3	8
	14	3.7	8	1	5	7.7	3
	15	12.7	2.7	8.3	2.7	6.7	13
	16	7.3	7.3	8.3	3.3	8.3	9
	Mean:	**6.233333**	**4.216667**	**5.266667**	**3.333333**	**6.5**	**8.283333**

Table 6. Subject Results for Dominant Arm after Exercise

		DAA			DAP		
	Angle:	-30	20	-75	-30	20	-75
Males:	1	8.3	2.3	11.7	4	1	2.3
	2	9	5.7	7.3	8.3	6.3	4.3
	3	4	1.7	6.3	4	9.7	4
	4	3.7	1	11	4.7	4	6
	5	1.3	4	4	6	7.7	6.7
	6	3.7	8	4.7	2.7	5.7	7.3
	7	9.7	11.7	7.7	11.3	15	12.7
	8	12.7	3.3	4.7	7.7	12	4
	9	3.3	2.3	10	5.3	2	9.3
	10	6.3	2.3	3	6.3	1	4.7
	Average:	**6.2**	**4.23**	**7.04**	**6.03**	**6.44**	**6.13**
Females:	11	3	4.3	9.3	4	1.7	10.3
	12	1.3	0.7	3	1.3	2	6.7
	13	6	3	3.7	4	3	4.3
	14	5	5.3	3.3	4.3	8.3	4.7
	15	4	1.3	6.3	4	3.7	6.7
	16	6	10	6.7	4.3	7.7	12
	Average:	**4.216667**	**4.1**	**5.383333**	**3.65**	**4.4**	**7.45**

Table 7. Subject Results for Non-Dominant Arm before Exercise

		NBA			NBP		
	Angle:	-30	20	-75	-30	20	-75
Males:	1	4	2.7	11.3	3.7	4.3	5.3
	2	7.3	5.3	5.3	7	7	2.7
	3	5.7	5	6.7	2.7	8	8.7
	4	1.7	3.7	10	7	4.3	10.7
	5	4.7	3.3	6.7	4	6.7	2.7
	6	1.7	2.3	9	4.7	4	7.3
	7	3	7.7	9.3	15.3	20.3	3.3
	8	6.7	6	6.7	2.7	8.3	3
	9	3	4.7	7.3	2.7	1.7	7.3
	10	4.7	5	2	5	1	6.3
	Average:	**4.25**	**4.57**	**7.43**	**5.48**	**6.56**	**5.73**
Females:	11	6.3	2	3.3	5.7	7.3	15.7
	12	4.3	1	5.3	1	3	6.7
	13	7.3	4.3	4.3	4.7	3.7	1.3
	14	7	3.3	2.3	0.3	7	4.7
	15	4	5.7	8.7	2	2.7	10.7
	16	7.7	2.7	3.7	9.7	2.3	5
	Average:	**6.1**	**3.166667**	**4.6**	**3.9**	**4.333333**	**7.35**

Table 8. Subject Results for Non-Dominant Arm after Exercise

		NAA			NAP		
	Angle:	-30	20	-75	-30	20	-75
Males:	1	11	1	6.3	4.3	4.7	5.3
	2	9	5.3	9.3	11.3	7.7	4
	3	3.7	9.7	4	3.7	7.3	6.3
	4	2.3	2.3	12	9.7	5	14.7
	5	2.7	2.3	5.3	1.7	5.7	2
	6	3.3	2	10.7	11	5.7	3.7
	7	3.3	13	14	11.3	22.7	8.3
	8	8.7	6	12	3.7	8.3	5.7
	9	3	0.3	4	1.7	4.7	5.3
	10	3.3	5.7	3.3	1.7	2.7	5
	Average:	**5.03**	**4.76**	**8.09**	**6.01**	**7.45**	**6.03**
Females:	11	5.7	2	4	2	3.7	4.3
	12	3.7	2.7	3.7	4	3.7	7
	13	3.7	0.7	3.7	1.7	7.3	3
	14	3.7	8.3	1.7	7.3	8.7	2.3
	15	0.7	0.7	8.3	3	3	8.3
	16	8.7	4	6.7	11	2.7	4.7
	Average:	**4.366667**	**3.066667**	**4.683333**	**4.833333**	**4.85**	**4.933333**

Table 9. Multivariate Tests[*1,*2]

Effect	Value	F	Hypothesis df	Error df	Sig.
DND	0.99	0.16	1	14	0.69
DND * GENDER	0.99	0.17	1	14	0.68
TIME	0.99	0.21	1	14	0.65
TIME*GENDER	0.99	0.27	1	14	0.61
ROM	0.43	8.54	2	13	**0.0043**
ROM*GENDER	0.36	11.32	2	13	**0.0014**
DND * TIME	0.88	2.00	1	14	0.18
DND * TIME * GENDER	0.97	0.39	1	14	0.54
DND * ROM	0.90	0.70	2	13	0.52
DND * ROM * GENDER	0.99	0.039	2	13	0.96
TIME * ROM	0.75	2.12	2	13	0.16
TIME * ROM * GENDER	0.75	2.12	2	13	0.16
DND * TIME * ROM	0.87	0.99	2	13	0.40
DND * TIME * ROM * GENDER	0.88	0.86	2	13	0.45

*1) Wilkes Lambda used to determine significance.
*2) Design: Intercept+GENDER; Within Subjects Design: DND+TIME+ROM+DND*TIME+DND*ROM+TIME*ROM+DND*TIME*ROM.

Table 10. Tests of Between-Subjects Effects

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	68.419	1	68.419	1.875	.192
GENDER	1.296	1	1.296	.036	.853
Error	510.800	14	36.486		

Table 11. Target Angle Position and Reproduction Ability

Paired Samples Statistics

	Mean	N	Std. Deviation	Std. Error Mean
ROM30	4.9583	8	.42667	.15085
ROM20	4.9190	8	1.10561	.39089
ROM75	6.4438	8	.73744	.26073

Table 12. T-test Results to Determine Target Angle's Effect on Proprioception

Paired Samples Test

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
ROM30 - ROM20	.0394	1.35713	.47982	-1.0952	1.1740	.082	7	.937
ROM30 - ROM75	-1.4854	1.13559	.40149	-2.4348	-.5360	-3.700	7	.008
ROM20 - ROM75	-1.5248	1.01210	.35783	-2.3709	-.6787	-4.261	7	.004

Table 13. Analysis of Variance Test for Significance within Gender

ANOVA
TABLE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.4	1	4.4	0.973	0.33
Within Groups	170.1	38	4.5		
Total	174.5	39			

Table 14. Paired Samples t-test comparing Athletes and General Population

Paired Samples t-Test
Athletes vs General Population

		Athletes	Gen. Pop.
Females	Mean	6.23	3.8
	N	6	20
	SD	3.53	1.91
Males	Mean	4.63	3.5
	N	10	20
	SD	1.78	2.10
Total	Mean	5.23	3.65
	N	16	40
	SD	2.4	1.99
	t-test		0.0285

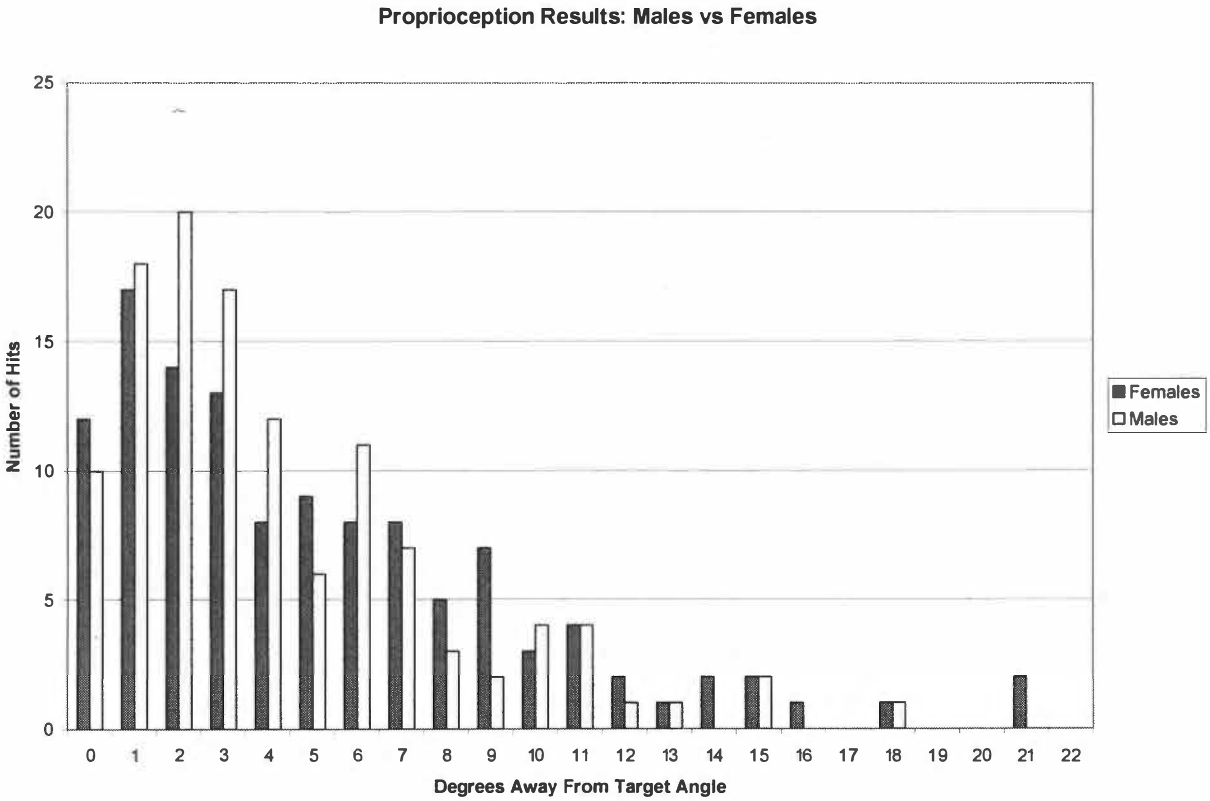

Figure 1. Stem-Leaf Plot of Male and Female Target Attempts

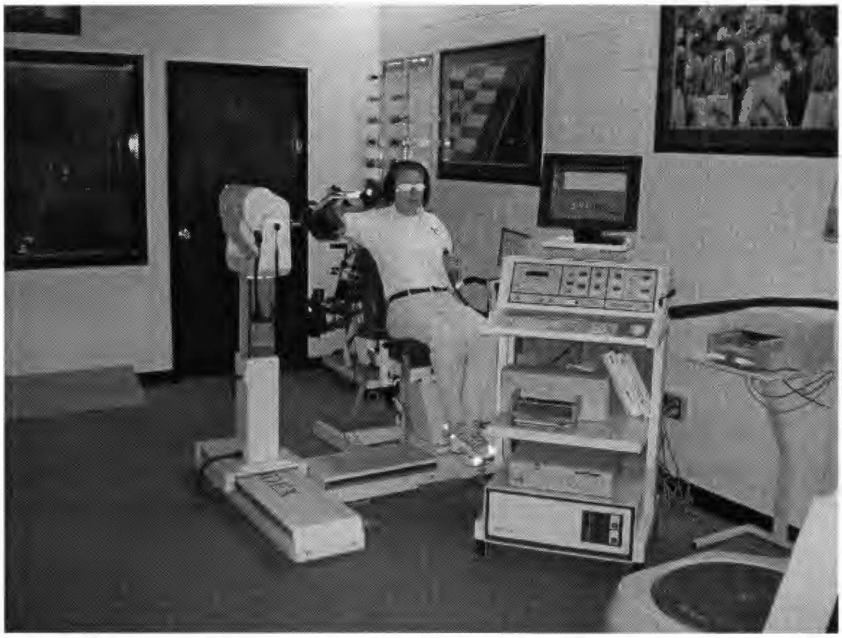

Figure 2. Picture of Biodex Dynamometer

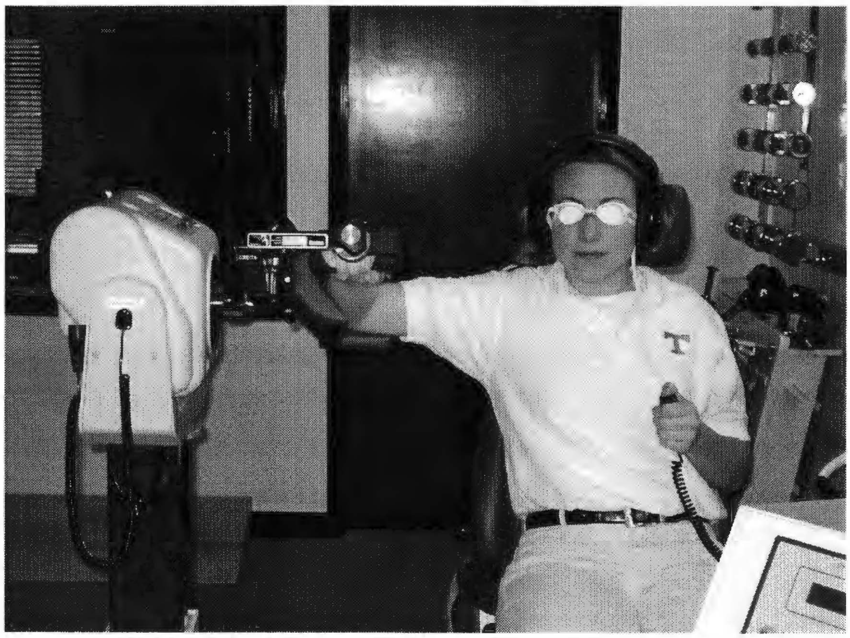

Figure 3. Picture of Subject Positioning

APPENDIX III

GROUP I
INFORMED CONSENT FORM

Title of Study: The relationship of gender, sport activity, and muscle fatigue to shoulder proprioception.

Investigator: Zach Sutton

Lab Address: 117A Neyland-Thompson Sports Complex
1704 Johnny Majors Drive
Knoxville, TN 37996

Depart. Address: Department of Health, Safety, and Exercise Science
322 H.P.E.R. Building
The University of Tennessee
1914 Andy Holt Avenue
Knoxville, TN 37996-2700

Phone: 865-207-4179 Zach Sutton, Researcher
865-974-1276 Dr. Liemohn, Research Advisor

1) Purpose and Explanation of the Tests

The study will consist of one testing session that should require no more than two hours. During this session, there will be two parts for each shoulder.

Part One includes two proprioceptive tests called Active Reproduction of Active Positioning (ARAP) and Passive Reproduction of Active Positioning (PRAP). With ARAP, you will slowly move your arm to a position, hold for ten seconds, and return the arm to the original set position. Then you will attempt return your arm to that exact position. With PRAP, you will slowly move your shoulder to a position, hold for ten seconds, and return your arm to the original set position. Then, as the dynamometer returns your arm toward the test position, press the stop button at the point that you believe is the reproduction of the original angle. These test both require the wearing of a blindfold and headphones, and one upper limb attached to the testing machine.

Part Two. This includes a fatigue exercise. You will perform continual isokinetic, which means at the same speed, internal and external rotations of the shoulder at 180 degrees per second until the peak torque of the rotator cuff muscles or external rotators, monitored by the computer, drops below 50 percent of the maximal torque production. By using the computer for this exercise, the tester can monitor your performance for accuracy and safety. After explanation of procedures, shoulder range of motion of internal and external rotation will be determined and testing conditions will begin.

After the two parts are complete, there will be a repeat of Part One. After the parts are completed with one limb, the machine will be arranged and adjusted for the opposite limb.

The equipment that will be used in this study is the Biodex Multi-Joint Dynamometer. This machine and computer allow for the measurement collection of neuromuscular data and torque that are pertinent to this study.

Initial:______

2) Attendant Risks and Discomforts

Risks involved in this study are minimal, but some discomforts such as muscle fatigue and soreness may occur, however recovery from this type of exercise is thought to be less than ten minutes. Every effort will be made to ensure that your safety is maximized. The investigator, a licensed Emergency Medical Technician-Intermediate, will perform all tests should any problems arise. In the event of physical injury due to your participation in the study, the University of Tennessee does not automatically provide reimbursement for medical care or other compensation.

3) Benefits to be Expected

The results obtained from this study will provide insight to injury prevention, specifically related to shoulder injuries that result due to the presence of fatigue. Benefits to you include knowledge of your proproceptive ability before and after fatigue.

4) Inquiries

Any questions about the procedures used in the tests of this study or the results of your tests are encouraged. If you have any concerns or questions, please ask for further explanation at any time.

5) Use of Medical and Research Records

The information that is obtained during this study will be treated as privileged and confidential. The information obtained will not be released to any other persons except with your written consent. These records will be securely kept in the office of the P.I. for the duration of the project and then in the office of his faculty advisor for up to three years before being destroyed.

6) Freedom of Consent

I hereby consent to voluntarily engage in this study. My permission to perform tests related to this study is given voluntarily. I understand that I am free to stop the test at any point if I so desire.

I have read this form and I understand the test procedures that I will perform and the attendant risks and discomforts. Knowing these risks and discomforts, and having had an opportunity to ask questions that have been answered to my satisfaction, I consent to participate in this test.

Signature ______________________________ Date__________________

Witness ______________________________ Date__________________

APPENDIX IV

GROUP II
INFORMED CONSENT FORM

Title of Study:	The relationship between gender and joint position sense in the shoulder.
Investigators:	Zach Sutton Kevin Lehmann
Lab Address:	117A Neyland-Thompson Sports Complex 1704 Johnny Majors Drive Knoxville, TN 37996
Phone:	865-207-4179 Zach Sutton, Researcher 865-382-9570 Kevin Lehmann, Researcher 865-974-1276 Dr. Liemohn, Research Advisor

1) Purpose and Explanation of the Tests

The study will consist of one testing session that should require no more than thirty minutes. All testing involves you in the seated position and the use of a Biodex multi-joint dynamometer and attached computer. You will perform a proprioceptive test called Active Reproduction of Active Positioning (ARAP) with your non-dominant arm.

With ARAP, you will slowly move your non-dominant shoulder to a test position, hold for five seconds, and return the arm to the starting position. Then you will attempt to return your arm to the test position. The start position is defined as 90 degrees of shoulder abduction (away from the body) and 90 degrees of elbow flexion. You will complete six trials at one test angle. You will wear goggles and headphones to limit auditory and visual cues during the test.

The equipment that will be used in this study is the Biodex Multi-Joint Dynamometer. This machine and computer allow for the measurement collection of neuromuscular data that are pertinent to this study.

2) Attendant Risks and Discomforts

Risks involved in this study are negligible; however, every effort will be made to ensure that your safety is maximized. Furthermore, you should not participate if you have had surgery on your non-dominant shoulder, an injury to your non-dominant shoulder seen by a doctor in the past 3 months, or a disease that affects the neuromuscular system. The investigators have extensive experience with the equipment and testing protocol. In the event of physical injury due to your participation in the study, the University of Tennessee does not automatically provide reimbursement for medical care or other compensation.

3) Benefits to be Expected

Benefits to you include knowledge of your proproceptive ability.

Initial:______

4) Inquiries

Any questions about the procedures used in the tests of this study or the results of your tests are encouraged. If you have any concerns or questions, please ask for further explanation at any time.

5) Use of Medical and Research Records

The information that is obtained during this study may be presented in written or verbal form, but will maintain your anonymity. Your results will be kept confidential with the assignment of a number that will be used to reference the information. These records will be securely kept in the investigators' office for the duration of the project and then in the office of his faculty advisor for three years and then destroyed.

6) Freedom of Consent

I hereby consent to voluntarily engage in this study. My permission to perform tests related to this study is given voluntarily. I understand that I am free to stop the test at any point if I so desire.

I have read this form and I understand the test procedures that I will perform and the attendant risks and discomforts. Knowing the potential risks and discomforts, and having had an opportunity to ask questions that have been answered to my satisfaction, I consent to participate in this test.

Signature ________________________________ Date__________________

Witness ________________________________ Date__________________

VITA

Zachary Lloyd Sutton was born in Alexandria, VA on the 2nd of April in 1978. After graduating from St. James School in Hagerstown, MD, he attended the University of the South in Sewanee, TN, where he received his Bachelors of Arts in American Studies in 2000. While also at Sewanee, he earned his certification and license as an Intermediate Emergency Medical Technician. In August of 2000, he began as a non-degree graduate student at The University of Tennessee, Knoxville. In August of 2001, he began his graduate studies in Exercise Science with a concentration in Sports Medicine and Biomechanics. While at UT, he worked as a graduate assistant athletic trainer for Men's Athletics and the Department of Sports Medicine. In 2002, he certified as an athletic trainer with the Board of Certification of The National Athletic Trainers' Association. After completing his thesis, he received the Master of Science degree in Human Performance and Sports Studies in May of 2003.