AN INVESTIGATION OF THE ROTATOR CUFF IN MALE ROCK CLIMBERS AND KAYAKERS

A Thesis

by

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ABSTRACT

AN INVESTIGATION OF THE ROTATOR CUFF IN MALE ROCK CLIMBERS AND KAYAKERS. (August 2003)

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The purpose of this research was to determine if rock climbers and kayakers would have a greater difference in strength between internal rotation and external rotation of the rotator cuff of the shoulder when compared with a control group. The measurement of the internal rotation: external rotation ratio was achieved by performing manual muscle testing of the shoulder with a Nicholas Lafayette hand held dynamometer which determined peak force of internal rotation, external rotation and abduction in the shoulder. Twenty-five male rock climbers closely matched in age (mid-20's), height (approximately 180 cm), and weight (72-80 kg average) with 25 male kayakers and 25 male controls were tested. The rock climbers and kayakers were required to perform at or above an intermediate level in their respective sports. The rock climbing group was found to have a significantly greater internal rotation range of motion for the right and left hands than the control or kayaking groups. The kayakers were also significantly lower than the controls. For right hand external rotation range of motion, rock climbers were significantly higher than kayakers and controls. This suggests an increased laxity in the range of motion of the rock climbers in comparison to the control and kayaking groups. There was no significant difference in range of motion between any group for the left hand. Manual muscle testing of peak force of the right and left hand internal rotation demonstrated that the kayaking group was significantly lower than the rock climbing and control groups. Also, there were no differences found in the manual muscle testing for external rotation in the right and left hands. This suggests that there is a noticeable weakness in the internal rotation of the kayaking group in comparison to the control and rock climbing groups. Right hand internal rotation: external rotation ratio produced significant differences in all three groups. The rock climbing group had a significantly higher ratio than both the control and kayaking groups. The kayaking group had a significantly lower ratio than both the rock climbing and control groups. For the left hand internal rotation to external rotation ratio, the kayaking group was significantly lower than the rock climbing and the control groups and there was no significant difference between the rock climbing and controls groups. These results demonstrate an increased laxity in the range of motion of rock climbers. In addition, rock climbers have an increased shoulder strength ratio than kayakers and controls. Kayakers, however, appear to have a lower shoulder strength ratio than rock climbers and controls.

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Chapter 1

Introduction

Over the past ten years, the popularity of alternative sports has increased, including whitewater kayaking and rock climbing. With this increase in popularity comes an increase in participation. These sports are no longer enjoyed only by small numbers. The general population is now looking to these extreme sports as alternative methods of maintaining fitness. There have been few investigations into the possibility that with the increase in participation in these sports there also might be an increase in specific muscular development for rock climbing and kayaking. This may result in a change in strength balance, which may predispose one to injury. Rock climbing and kayaking are shoulder-intensive activities, creating the possibility of a change in this joint's balance of strength. Shoulder strength balance has been predominantly studied with respect to baseball, swimming, water polo and tennis (McMaster, Long & Caiozzo, 1991; Codine, Bernard, Pocholle, Behaim, & Brun, 1997; and Donatelli et al., 2000), all overhead intensive sports, but there has been no research conducted on rock climbing or kayaking. For this reason, it is becoming necessary for research to be aimed towards these alternative sports.

Statement of Problem

Shoulder injuries occur due to traumatic stress, repetitive stress, and poor mechanics during activities. (Haas & Meyers 1995) The more stress that an individual places on his or her shoulder, the more likely he/she are to injure it. Muscular strengthening can occur through continued activities, but repetitive force can be detrimental to shoulder function by lending itself to shoulder strength imbalance. Participation in a sport requires the learning of that particular sport's mechanics, which when not applied correctly, may lead to shoulder injury.

The shoulder is utilized in the majority of daily activities and can function freely in all three degrees of motion, flexion/extension, abduction/adduction and internal/external rotation (Starkey & Ryan, 1996). Due to the large range of motion that the glenohumeral joint has, stability has been sacrificed (Starkey & Ryan, 1996). Thus much of the support and stabilization of this joint is relegated to the surrounding musculature (Starkey & Ryan, 1996). As a unit, the rotator cuff muscles are responsible for the dynamic stabilization of the humeral head in the glenoid fossa (Starkey & Ryan, 1996).

Due to the multiple functional demands that are placed on the shoulder, objective and reliable evaluation of strength to determine imbalance within the rotator cuff is important (May, Burnham, & Streadward, 1997). Sirota, Malanga, Eischen, & Laskowski, (1997), suggest that the repetitive eccentric loading of the shoulder could lead to the tearing of connective tissue as well as chronic inflammation, contributing to the relative weakness of external rotation in comparison to internal rotation.

The enthusiasm for the sport of rock climbing among many of its participants often leads to their climbing with acute injuries and developing habits of overtraining which may lead to overstress conditions (Shea, Shea, & Meals, 1992). Stabilization of the glenohumeral joint while the scapular surface is in motion is a common demand in rock climbing (Haas & Meyers, 1995). Bollen, (1988), Rooks, (1997), and Haas & Meyers, (1995), agree that injuries involving impingement and rotator cuff tears are not surprising due to the fact that a climber spends many hours with his/her arms at or above shoulder height during a climb. The steeper the climbing route, the greater weight and forces placed on the upper extremities, increasing the risk of shoulder injuries (Maitland, 1992). Other upper extremity injuries are more likely to occur under steep climbing conditions as well.

A kayaker with correct form uses his/her torso and lower extremity to produce much of the force applied to the paddle to control steering and propulsion (Fiore & Houston, 2001). Therefore, when incorrect technique is used or an unforeseen problem occurs, any unexpected and sudden force against the paddle can result in stress on the upper extremity, in particular, the shoulders (Fiore & Houston, 2001). Burrell & Burrell, (1982), suggest that shoulder dislocations and subluxations are two of the four major injuries sustained during paddling. Kizer (1987) states that improper technique is a common cause of dislocation, particularly during the attempt of a high brace. During a high brace, the shoulder is forced into hyperabduction and external rotation, which causes the humeral head to lever from the glenoid fossa, resulting in either a dislocation or subluxation of the shoulder (Burrell & Burrell, 1982).

Research Hypothesis

It is hypothesized that due to the stresses encountered while tackling their sports, both rock climbers and kayakers will have a greater difference in strength between internal rotation and external rotation when compared with a control group. Also, the internal rotation : external rotation ratio for rock climbers and kayakers should be similar to those ratios found in previous studies of athletes involved in overhead-intensive sports.

<u>Operational Definitions</u>

Manual muscle testing: The testing of muscle function by placing a given body part into a specific position, and the subject maintains that position while a firm constant resistance is applied by the examiner. (Kent, 1994)

Repetitive stress injury: An injury that occurs due to repeated use of the body under physically stressful conditions. Also known as an overuse injury. (Kent, 1994)

Traumatic stress injury: An injury with a rapid onset that results in physical damage. (Kent, 1994)

High brace: A high brace involves the shoulder being hyperabducted and extended while the water forces the paddle to lever the humeral head out of the glenoid fossa (Kizer, 1987).

Internal rotation: The rotation of the humerus towards the body.

External rotation: The rotation of the humerus away from the body

Glenohumeral joint: The point of articulation between the head of the humerus and the glenoid fossa.

Glenoid fossa: A shallow cavity in the scapula in which the humeral head is inserted. (Kent, 1994)

Supraspinatus: A rotator cuff muscle which makes up the posterior portion of the rotator cuff and lies on the posterior scapula, superior to the scapular spine. It is responsible for abduction of the humerus.

Subscapularis: A rotator cuff muscle that forms the anterior portion of the rotator cuff and is responsible for internal rotation of the humerus

Infraspinatus: A rotator cuff muscle which makes up the posterior portion of the rotator cuff and lies on the posterior scapula, inferior to the scapular spine. It is responsible for external rotation.

Teres Minor: A rotator cuff muscle that makes up the posterior portion of the rotator cuff and aids the infraspinatus in external rotation.

Ape Index: A term used to describe the difference between arm span and height (arm span – height)

Basic Assumptions

Only subjects who had not had a shoulder injury in the past 6 months or shoulder surgery in the past year, or who had been free of any other injury, such as injury to the neck, in the past year that could have altered their shoulder function. Also subjects were asked to report honestly any shoulder rehabilitation or strengthening exercises they might perform, as well as the level at which they perform their sport, by the rating scales for their respective sports (Appendices D & E).

Delimitations

Rock climbers were classified by their ability to climb grades of ≥ V5 or 5.12 (Appendix D) and/or by having climbed consistently for at least 5 years. Kayakers were selected by their ability to paddle the level of grade 3 or above (Appendix E) and/or having paddled consistently for 5 years or more. To be in the control group, participants could never have been involved in either rock climbing or kayaking, and could not have been involved in an overhead-intensive sport for the past 6 years. Athletes were asked if they participated in any other sports and if they had been involved in any other overhead activities. If they responded positively, they were not asked to participate in the study. In addition, any participants who had had an injury to their shoulders in the six months prior to testing, or who had had surgery on their shoulders within the year prior to this testing, were excluded from the study.

All tests on each subject were performed by the same individual using the same equipment and the same protocol.

Limitations

In this study the use of questionnaires, anthropometric measures and physical testing of shoulder strength and range of motion were utilized and applied uniformly across the three groups. There were, however, several limitations that must be considered when analyzing the data. First, though attempts were made to enroll individuals of similar ages for all three groups of participants, the ages of participants varied considerably. Secondly, all testing was done in the field and the athletes may have been involved in moderate athletic activity prior to the testing. Thirdly, since all of the research on both rock climbers and kayakers was performed in the field, test sites and environments vary. Finally, the testing performed was largely isometric manual muscle testing, which is only representative of one type of demand out of the many that rock climbers and kayakers place on their shoulders during their respective activities.

Significance to the Field

Shoulder strength assessment has not been performed on rock climbers or kayakers previously. There have been many studies of the frequency of injuries done for both rock climbers and kayakers, but little or none of this research has involved shoulder strength specifically (Bollen, 1988; Burrell & Burrell, 1982; Haas & Meyers, 1995; and Kizer, 1987). This research described herein will add shoulder strength ratios and a background on the strength of the shoulder to the small pool of literature that is available on rock climbers and kayakers. This could possibly provide background for the prevention and treatment of shoulder injuries among these athlete

Chapter 2

Review of Literature

Shoulder

Anatomy and Mechanics:

The shoulder is utilized in the majority of daily activities and can function in all three degrees of motion, using flexion/extension, abduction/adduction and internal/external rotation freely (Starkey & Ryan, 1996). The relationship between the glenohumeral joint and the scapular thoracic joint allows for the humerus to be positioned in 16,000 distinct positions (Starkey & Ryan, 1996). Due to the large range of motion of the glenohumeral joint, stability may be sacrificed (Starkey & Ryan, 1996). The glenohumeral joint is a ball and socket joint in which only one-third of the head of the humerus (the ball) articulates with the glenoid fossa (the socket), the remainder of the articulation depends on the labrum, which is a thick, circular band of fibrocartilage attached to the rim of the glenoid (Heinrichs, 1991). Thus, much of the support and stabilization of this joint is relegated to the surrounding musculature (Starkey & Ryan, 1996). As a unit, the rotator cuff muscles are responsible for the dynamic stabilization of the humeral head in the glenoid fossa (Starkey & Ryan, 1996). Each rotator cuff muscle aids in the performance of shoulder motion. The supraspinatus is responsible for the abduction of the arm along with the deltoid (Starkey & Ryan, 1996). The subscapularis is responsible for internal rotation and the infraspinatus and teres minor rotate the humerus externally (Starkey & Ryan, 1996.)

Range of Motion:

There has been much research done on the range of motion of the shoulder joint. Primarily, the focus of these studies has been baseball pitchers of elite status. In the dominant shoulder of professional baseball pitchers, humeral head retroversion and glenoid retroversion were increased when compared to the nondominant shoulders (Crockett et al., 2002). Also, external rotation at 90° was significantly increased in the dominant shoulders compared with the nondominant shoulders (Crockett et al., 2002; Ellenbecker, Roetert, Bailie, Davies, & Brown, 2002, Ellenbecker, Mattalino, Elam, & Caplinger, 2000; Osbahr, Cannon, & Speer, 2002). There was a significantly greater internal rotation at 90° found in the nondominant shoulder when compared with the dominant shoulder (Crockett et al., 2002; Ellenbecker, et al, 2002). This is consistent with the anterior laxity and posterior tightening of the capsule that has been found in overhead sports. When comparing throwing (baseball pitchers) to non-throwing groups, there was a significantly greater humeral head retroversion for the dominant shoulders (Crockett et al., 2002). For both shoulders there was a significant increase in total shoulder motion, and external rotation at 90° in throwers as compared with non-throwers (Crockett et al., 2002).

The range of motion of the shoulder is considered a key part in the balance between the mobility and dynamic stability that are required in the shoulder (Crockett et al. 2002). The coordination between muscular activity, ligaments and capsular restraints create the dynamic stabilization of the glenohumeral joint (Crockett et al., 2002). This balance is an integral part of the performance of the shoulder during athletic activities. The performance of the shoulder in athletes who throw, e.g. baseball, is at the extremes of glenohumeral motion. It has been noted that when there is a disruption to this balance, it may result in shoulder instability and secondary impingement (Crockett et al. 2002). When repetitive microtrauma occurs in an overhead activity such as baseball, it can lead to the stretching of the anterior capsule and the tightening of the posterior capsule (Bigliani, et al. 1997; Crockett et al. 2002). The increase in anterior translation in the humeral head in the throwing arm has been attributed to the anterior capsular laxity that occurs (Ellenbecker et al., 2000). These capsular changes contribute to the tendency for instability and secondary impingement in the stressed shoulder (Bigliani et al., 1997; Crockett et al., 2002; Ellenbecker et al., 2002). Also, a relationship is considered to exist between glenohumeral joint instability and rotator cuff abnormalities (Ellenbecker et al., 2000). Glenohumeral joint instability, is affected by the range of motion of the shoulder. Overuse has also been considered a contributing factor to the contracture of the posterior capsule and the stretching of the anterior capsule on the dominant shoulder of baseball pitchers (Osbahr et al., 2002). These capsular changes are considered to lead to a tendency towards anterior glenohumeral subluxation (Osbahr et al., 2002).

Manual Muscle Testing:

Manual muscle testing (MMT) is considered an integral portion of the examination of the shoulder joint (Kelly, Kadrmas, & Speer, 1996). The correct application of MMT techniques can provide an examiner with a variety of information about the ability of the muscle to support and stabilize, as well as function properly in motion (Kelly et al., 1996). Considering that the infraspinatus and teres minor are primary contributors in the production of external rotation (ER) and the subscapularis is the main contributor to internal rotation (IR), it is logical to focus on these muscles during manual muscle testing. Jenp, Malanga, Growney, & An (1996), stated that it is difficult to isolate the teres minor from the infraspinatus, and since they produce the same action, they are typically tested together. Jenp, et al., (1996), suggested that the positioning of the arm in the sagittal plane with half external rotation provides the best isolation of the infraspinatus and the teres minor. Similarly, Kelly et al., (1996), consider external rotation at 0° of scapular elevation and –45° of humeral rotation to be optimal MMT positioning for the infraspinatus. For the isolation of the subscapularis from the pectoralis and latissimus muscles, the Gerber push with force test has been recommended (Kelly et al., 1996). Through electromyography (EMG) testing it has been determined with that the subscapularis can also be isolated from the pectoralis major in the scapular plane with 90° of elevation and neutral rotation (Jenp et al., 1996).

Ratios of Internal Rotation vs. External Rotation:

Due to the multiple functional demands that are placed on the shoulder, objective and reliable evaluation of strength within the rotator cuff to determine imbalance is important (May et al., 1997). One way of evaluating rotator cuff strength is through the use of internal rotation (IR) and external rotation (ER) strength ratios. There is an established a relationship between IR:ER ratios and abnormalities in the normal shoulder (Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1990). Though it should be noted that according to Kramer & Ng, (1996), when using IR:ER data for research purposes, a greater sample size may be required to attain correct power levels.

In all of the following of studies, isokinetic dynamometers were used to determine the IR:ER strength ratios. A ratio of 1.5 between IR and ER has been determined as normal for subjects in three separate studies (Scoville, Arciero, Taylor, & Stoneman, 1997; Ivey, Calhoun, Rusche, & Bierschenk, 1985; and Aldernick & Kuck, 1986). The IR:ER ratios in baseball players, tennis players, runners and nonathletes were compared; nonathletes and runners had ratios of 1.3 to 1.5, tennis players had ratios of 1.54 to 1.68 and baseball players had ratios that were approximately 2.0 (Codine et al., 1997). Codine et al., (1997), stated that there was an increase in the IR:ER ratio to near 2.0 when the subject was involved in internal rotation intensive activities. McMaster, Long, & Caiozzo, (1991) determined that the IR:ER ratio was between 1.7 and 1.9 in water polo players, compared to the controls (1.35 to 1.5). Though the ER of the water polo players was not as close in strength to their IR when compared to the control group, the overall strength of the water polo players was greater (McMaster et al., 1991). Sirota et al., (1997), suggested, on the basis of their studies with baseball players, that the repetitive eccentric loading of the shoulder could lead to the tearing of connective tissue as well as chronic inflammation, contributing to the relative weakness of ER in comparison to IR.

In a more recent study, a Lafayette Nicholas hand-held dynamometer was used to test the IR:ER ratios in baseball pitchers. Professional pitchers produced IR:ER ratios of 1.5 in the pitching arm and 1.3 in the non-pitching arm (Donatelli et al., 2000). This suggested that the method of testing may have had an effect on the absolute ratio, but the pattern remained consistent.

Rock Climbing

Basics:

There are three main styles of natural rock climbing, sport climbing, traditional climbing and bouldering. Sport climbing consists of climbing a distinct path in a vertical direction, in which permanent fixed bolts appear in regular intervals along the route. The lead climbers are tied to one end of a rope by a harness worn by the climber. The lead climber clips the other end of the rope to the fixed bolts with two carabiners linked together with webbing called a quick draw. At the top of the route are fixed anchors to allow the lead climber to descend and later, allow others to climb the route on the same rope. This is referred to as top roping, in which the climber does not carry the rope, but instead follows it. Traditional climbing requires the placement of removable gear in the features of the rock. These protective pieces (pro) include active camming devices and passive stoppers, nuts and hexs. The lead climber places the pro and then attaches a quick draw and the rope.

Bouldering is quite different. It involves no use of ropes, only spotters and crash pads (foam pads to absorb the forces of falling). Bouldering typically occurs on large rocks or boulders and climbers rarely reach heights of more than 20 to 25 feet. Bouldering often involves more difficult moves closer to the ground. This was once a form of climbing used only as training for the other forms, but has now evolved into a viable counterpart to traditional and sport climbing. A fourth type is called gym climbing, which can be done in the form of sport or bouldering. It is performed indoors on artificial walls with artificial holds that mimic the natural rock.

Rock climbing is a sport that requires the body to be placed in difficult positions. The stresses that are placed on the joints of the body are repetitive and involve large amounts of load and torque (Haas & Meyers, 1995). The shoulder, considered the most mobile joint in the body, can be moved in three planes of motion (Arnheim & Prentice, 1997), and all three of these planes are used in the sport of rock climbing. As strength in the shoulder builds, there is the possibility for traumatic injuries due to excessive rotation of the shoulder. The shoulder mechanics of rock climbing are best described through the use of instructional manuals such as Garth Hattingh's Rock and Wall Climbing: Essential guide to equipment and techniques (2000). The most basic motions of climbing described involve moving from approximately 180 degrees of abduction and external rotation to adduction (Hattingh, 2000). All ranges of motion, including internal rotation, external rotation, horizontal abduction and adduction, are involved in rock climbing. There are specific techniques that require the climber's body weight to be supported at full extension by the shoulder (Hattingh, 2000).

Injuries:

Climbing, as well as training, place a large amount of stress on the upper extremities and may result in injuries to the upper extremities (Haas & Meyers, 1995). In a study of 86 climbers, 16 shoulder injuries were reported. Of the 16 shoulder injuries, the majority involved some degree of rotator cuff tear, though a specific number was not given, and two reported impingement syndromes (Bollen, 1988). In a survey involving 460 rock climbers, it was noted that 61% of injuries among elite climbers are shoulder and elbow injuries (Haas & Meyers, 1995). Combination injuries of shoulder-elbow are also known to occur (Haas & Meyers, 1995). These combination injuries could be the result of the distribution of forces that are carried through the anatomical linkages of the upper limb (Maitland, 1992).

Common shoulder injuries specific to climbers are rotator cuff tendonitis, subacromial impingement, and muscle strains of the rotator cuff, rhomboid, latissimus dorsi or trapezius (Rooks, 1997). The stabilization of the glenohumeral joint while the scapular surface is in motion is a common demand in rock climbing (Haas & Meyers, 1995). Increased stress is often transferred to the shoulder tendons due to the frequency of climbers supporting their body weight with fingertip strength and arm extension (Haas & Meyers, 1995). This could lead to damaging the tendon of the long head of the biceps at the shoulder (Haas & Meyers, 1995). Considering the fact that climbers spend a large portion of time with their arms flexed high above their heads, it is not surprising that the risk to the rotator cuff, secondary to mechanical impingement of the rotator cuff tendons against the acromion process is increased(Rooks, 1997, Bollen, 1988). Difficulty is often associated with the steepness of a climbing route or problem. As steepness increases, greater weight and forces are placed on the upper extremities, and this increases the risk of shoulder injuries and other upper extremity injuries (Maitland, 1992).

<u>Kayaking</u>

Basics:

There are several different forms of whitewater kayaking that can be participated in aside from the basic form of running a river. There is playboating as well as several forms of competitions. Playboating is a form of kayaking that involves trick moves, including drops, catching air and other precision maneuvers (Ford, 1995). An advanced form of this is squirt boating which involves the use of a much smaller playboat, one that is barely able to float (Ford, 1995). Acrobatic moves such as cartwheels, and an underwater move known as a mystery maneuver, are feasible in these boats (Ford, 1995). There are competitions called rodeos in which these skills are performed.

Other competitions in kayaking include slalom and wild-water racing. Slalom involves up to 25 numbered and color-coded gates that must be run in a sequential order (Ford, 1995). The color coding determines whether the gate should be run upstream or downstream (Ford, 1995). Scoring is based on timing in seconds, and penalties for missed or incorrectly run gates increases the time for the run (Ford, 1995). Some kayakers prefer to enhance their fine-motor whitewater skills through the running of slaloms as opposed to the running of more difficult whitewater (Ford, 1995). Wildwater racing is strictly a race. The race occurs over approximately 8 kilometers of whitewater and usually takes 20 minutes (Ford, 1995). The only scoring for these races is time from start to finish, with no penalties or technical rules (Ford, 1995).

The sport of kayaking also places extreme demands on the shoulder. The shoulder is required to move in primarily in the transverse plane during the basic motion of paddling (Shepard, 1987). Over time this builds shoulder strength, primarily in the trapezius and rhomboid muscles, with less emphasis on the rotator cuff. The strength is less balanced and thus when the body is placed in a more compromised position, the shoulder muscles are less adept at handling the stresses of other planes. Also, because the mechanics of kayaking are primarily in one plane, there is less variation and thus more risk for an overuse injury. In the shoulder mechanics of kayaking, the shoulder moves in the transverse plane. In this plane the stroke motion is limited to between 45 degrees horizontal abduction and 45 degrees horizontal adduction, with only slight internal and external rotation applied (Guillion, 1987). A brace technique is also used which adds abduction to the above motions (Guillion, 1987). This bracing technique applies to the shoulder added stress that is not as consistent a part of the paddling mechanics as the stroke. Thus shoulder positioning and muscular contractions are involved that the shoulder is unaccustomed to and muscularly weaker in its execution.

Injuries:

In kayaking, correct form is key to preventing shoulder injuries. A kayaker with correct form uses his/her torso and lower extremity to produce much of the force applied to the paddle to control steering and propulsion (Fiore & Houston, 2001). Because of this, when incorrect technique is used, any unexpected and sudden force against the paddle may result in stress on the upper extremity, in particular, the shoulders (Fiore & Houston, 2001). If stress occurs, it creates an eccentric loading of the subscapularis. Of the 242 injuries reported in a study by Fiore & Houston, (2001), 61% were upper extremity injures, and of those, approximately half were shoulder injuries, including 56 dislocations. Kizer (1987), reported that out of 211 survey participants, 45% of injuries were classified as muscle strains, of which, 72% were in the shoulders or upper back. In the same study, it was determined that four percent of all injuries recorded were shoulder dislocations (Kizer, 1987). Burrell & Burrell (1982) considered shoulder dislocations and subluxations two of the four major injuries that can be sustained during paddling. Fiore & Houston (2001) stated that paddling instructors consider technique as being crucial in the prevention or minimizing of upper extremity injuries particularly tendonitis and shoulder dislocations. Further, both Kizer (1987) and Burrell & Burrell (1982) reported that improper technique is a common cause of dislocation or subluxation of the shoulder, particularly during the attempt of a high brace. A high brace involves hyperabduction and external rotation of the shoulder while the water forces the paddle to lever the humeral head out of the glenoid fossa (Kizer, 1987). Severe abduction is considered one of the most common causes of shoulder injuries in kayaking. Usually excessive abduction is caused by inaccurate techniques in such mechanics as bracing (Walsh 1985).

Hand-Held Dynamometer(HHD)

Reliability:

The use of the HHD as a reliable and valid way to measure and compare muscular strength has been investigated a great deal in the past 15 years. Sullivan et al.(1988) confirmed the reliability ($r = 0.986$) of HHD even when there is an interval of one week between the test and retest, allowing the retest to be free from carry-over for external rotation manual muscle test (MMT). Byl, Richards, & Astuias (1988) found good HHD reliability for measuring shoulder flexion and abduction when the same tester measured the same subject on the same day. The lowest r value for deltoid strength without stabilization was 0.83 and the highest r value for biceps strength with stabilization was 0.96. The reliability for multiple forces was good for day-to-day ($r = 0.87$ for HHD A and $r = 0.85$ for HHD B) as well as for trial-to-trial ($r = 0.98$ for HHD A and $r = 0.97$ for HHD B) (Trudelle-Jackson et al. 1994). Kilmer et al. (1997), testing for shoulder flexion, extension and abduction, found that the reliability for both interrater testing ($r = 0.97$) and intrarater testing ($r = 0.97$) was high. With elbow extension, interrater testing ($r = 0.98$) and intrarater testing ($r = 0.99$) were also very high (Surburg, Suomi, & Poppy, 1992).

Many of these studies involved the use of the Nicholas HHD, which is identical to the device used in the current study.

Validity:

Isokinetic dynamometers (ID) such as Cybex and KinCom, both popular name-brand ID's, have been used in previous studies of shoulder strength testing. A good correlation was found between the Cybex ID and the HHD ($r = 0.78$ for two day testing) (Sullivan et al., 1988). Surburg et al. (1992), also found no significant difference between the measurements taken by the Cybex ID and the Nicholas HHD. May et al. (1997), comparing internal and external rotation strengths found a high correlation between the HHD (IR $r = 0.96$ and ER $r = 0.94$) and the Cybex (ID) (IR $r = 0.88$ and ER $r = 0.86$). In addition, Stratford & Balsor (1994) determined that the reliability coefficients for the HHD test ($r = 0.97$) did not differ significantly from the reliability coefficients for the KinCom (ID) ($r = 0.95$).

On the basis of these studies, it can be concluded that the HHD is a valid testing method. Thus, researchers can do the measurements in the field, going to where the subjects are. This permits the testing of greater numbers of subjects. In order to maximize reliability and validity, it however, was necessary to develop a specific protocol for positioning and stabilization so that testing would be consistent among all subjects.

Positioning and Stabilization:

The correct positioning of the HHD on the arm is crucial to performing the test efficiently, effectively and consistently. It should be placed approximately 2cm proximal to the styloid process of the wrist, and perpendicular to the limb segment being tested

(Sullivan, Chesley, Herbert, McFaull, & Scullion, 1988; Wilkholm & Bohannon, 1991; Byl et al., 1988; and May et al., 1997). Bly et al., (1988), determined that the correct position of the HHD involves by matching the force exerted by the subject with the tester's force.

The stabilization of the subject during testing is important to prevent the compensation for weakness in one muscle group with strength in another muscle group. Reliability coefficients have been enhanced in the past by the incorporation of stabilization techniques (Surburg et al., 1992). Byl et al., (1988), had determined earlier that increased stability could be added through the trunk if the subject was in the supine position. Some traditional manual muscle testing has been performed in a seated position. When Bly et al. (1988) compared deltoid strength with and without stabilization using the HHD, the r value was lower withoutstabilization r=0.83-0.88 compared to r = 0.92-0.94. Wilkholm, & Bohannon, (1991), also used a supine position as well as manual stabilization in their testing. Reed et al. (1993) and Kilmer et al. (1997) used manual stabilization to the upper arm in a supine position as well, though no comparison was made to non-supine positioning.

Summary:

Data in the literature would seem to indicate that participants in overhead intensive sports have higher IR:ER ratios than nonathletes and controls involved in non-overhead intensive sports. There is evidence that both rock climbing and kayaking, because of the mechanics of motion involved, place stresses on the shoulder similar to those for overhead intensive sports. Also there is a relatively high frequency of shoulder injuries among athletes in rock climbers and kayakers. There is however no literature on the actual IR:ER ratios that occur in durning these sports. Since the HHD appears to be both reliable and valid as a means of testing manual muscle strength and for deriving the IR:ER ratio, we investigated shoulder strength and determined IR:ER ratios of rock climbers and kayakers.

Chapter 3

Methods

Subjects:

Twenty-five adult males between the ages of 19 and 35 with at least 5 years of rock climbing experience and/or with the ability to climb at or above grade V5 or 5.12 (Appendix D) were recruited from the community and during climbing competitions. Twenty-five adult males between the ages of 19 and 35 with at least 5 years of white-water kayaking experience and/or the ability to paddle at or above grade III (Appendix E) were recruited from popular rivers, competitions, and rodeos. Twenty-five adult males of the same age range, with no background in rock climbing, kayaking, or any sport designated as an overhead intensive activity (such as baseball, tennis, swimming and water polo) were recruited from local college campuses and the community as controls. All subjects met the criteria of having no shoulder injuries in the past six months or shoulder-related surgeries in the past year. All the subjects were required to be free of any neck injury that might alter testing results as well. Participants gave written informed consent prior to their participation in this study (Appendix A). The study had been approved by the Appalachian State University's Institutional Review Board on 12/27/2002 (Appendix G).

Research Design:

Rock climbing and kayaking subjects were tested in field settings whereas control subjects were tested in the Appalachian State University human performance laboratory. Subjects completed a questionnaire (Appendix B), which included questions about level of ability, years of experience, any previous shoulder injuries or surgeries, and if they participate in any shoulder-strengthening programs. The answers to the questions were used to determine the subject's eligibility for the study. Once the questionnaire was completed and approved, the subjects' height (cm), weight (kg), body composition, and arm span (cm) were measured to the nearest tenth of a unit. Body composition and weight were assessed using bioelectrical impedance (BIA) (Tanita Corporation, Arlington Heights, Ill). Bilateral passive range of motion for internal rotation, external rotation, extension, and abduction were assessed through goniometric measurements. Internal rotation and external rotation range of motion measurements were taken with the subject in a supine position, and extension and abduction were recorded with the subject standing. Goniometric measurements were taken three times and the average calculated (Donatelli et al., 2000). Shoulder strength was measured bilaterally with the Lafayette Nicholas Manual Muscle Test (MMT) system, a hand-held dynamometer. As suggested by previous studies, the HHD was placed approximately 2cm proximal to the styloid process of the wrist, and perpendicular to the limb segment that was tested (Sullivan et al., 1988; Wilkholm & Bohannon, 1991; Byl et al., 1988; and May et al., 1997). Subjects were tested in a supine position to provide added stability during the MMT (Kilmer et al., 1997; May et al., 1997). The supine position provided stability by limiting the motion of the scapula, and provided posterior support to the glenohumeral joint.

Internal and external rotation MMT testing was performed with the subject in the supine position in the scapular plane with 90° of elevation and neutral rotation (Jenp et al., 1996). Abduction MMT was tested in a neutral position of the humerus and 90° flexion of the elbow with the subject in a supine position. Each manual muscle test was performed three times with a short rest between each and the average of the force in kilograms (kg) was determined, as well as the average time to peak force, and total time. All results were recorded on a data sheet (Appendix C).

Statistics:

For statistical analysis, a) the average force in kg was converted to Newtons (N = kg * 9.81), b) peak force was normalized to body mass by dividing the peak force (N) by the body weight (kg) of each subject, and c) peak force for internal rotation was divided by peak force for external rotation to produce the IR:ER ratio. Data are presented as mean $\pm$ SEM. Comparisons between the three groups were done using a one-way ANOVA. The Tukey HSD post-hoc test was used to determine significance. Significance was set at $p \leq 0.05$. Comparisons, using the same statistical requirements were run with and without those subjects who had sustained shoulder injuries that were diagnosed by a physician, but still eligible for the study. Ape index (cm) was determined by the subtraction of the arm span in cm by the height in cm. Percentages for the responses to the questions addressed in the questionnaire were determined. The coefficient of variance (CV) was determined for the peak force results to assess if there were any significant differences between any of the groups or tests.

Chapter 4

Results

Anthropometric data are summarized in Table 1. Average age was significantly higher for the kayaking group in comparison to the rock climbing and control groups, but there were no significant differences in age between the rock climbing and control groups. No significant difference was found in the heights of the subjects, measured arm span, or in the calculated ape index. The rock climbing group had a significantly lower body weight than the kayaking group, but not the control group, and there was no significant difference between the control and kayaking groups. For BIA, the rock climbing group was significantly lower that the control group, but not the kayaking group, and there was no significant difference between the kayaking and control groups. Rock climbers were significantly lower in body mass index than the kayakers, but not the controls, and there was no significant difference between the controls and kayakers.

The descriptive data obtained from the questionnaire is given in Table 2. For the dominant hand, 84% of the rock climbers, 96% of the kayakers and 88% of the controls were right handed. Forty-four percent of the rock climbers had sustained shoulder injuries, compared to 64% of the kayakers, and 36% of the controls. One out of 11 rock climbers sustained shoulder injuries resulting in surgery, whereas only 1 out of 16 shoulder injuries in kayaking resulted in surgery. The control group sustained no injuries

Table 1: Anthropometric data gathered on the three subject groups. Ape index is the arm span in cm minus the height in cm. BIA is body fat percent analyzed using a Tanita body fat analyzer. BMI is body mass index. * mean significantly different from the rock climbing group, # means significantly different from the kayaking group, and ^ means significantly different from the control group.

	Rock Climbers	Kayakers	Controls
Age (years)	$23.5 \pm 0.8^{\#}$	28.7 ± 0.7*^	$24.3 \pm 0.6^{\#}$
Height (cm)	178.2 ± 1.4	180.3 ± 1.5	178.3 ± 1.4
Weight (kg)	$71.6 \pm 1.5^{\#}$	80.1 ± 2.3*	75.8 ± 2.4
Arm Span (cm)	182.7 ± 1.5	184.3 ± 1.9	182.4 ± 1.35
Ape Index (cm)	4.5 ± 0.8	4.01 ± 0.8	4.01 ± 0.92
BIA (%)	8.6 ± 0.5^	11.3 ± 1.1	13.9 ± 1.2*
BMI (kg/m^2)	$22.5 \pm 0.3^{\#}$	24.5 ± 0.5*	23.8 ± 0.7

Table 2: Questionnaire results provided by the three subject groups. Handed represents the dominant hand of the subject. Dislocations, impingements, tendonitis, and subluxations are all types of injuries that have occurred in the shoulders of subjects.

	Rock Climbers	Kayakers	Controls
Dominant Hand	4 left 21 right	1 left 24 right	3 left 22 right
	Positive/Total	Positive/Total	Positive/Total
Shoulder Injuries	11/25	16/25	9/25
Surgery Due to Injury	1/11	1/16	0/9
Dislocation	2/11	5/16	1/9
Impingement	1/11	3/16	1/9
Tendonitis	3/11	2/16	1/9
Subluxation	5/11	6/16	6/9

resulting in surgery. Seven of the 11 shoulder injuries in rock climbers were diagnosed by a doctor, the remainder were self-diagnosed. Seven of the 16 kayaking shoulder injuries diagnosed by a doctor, as were four injuries in the control group. It should also be noted that 66.6% of the shoulder injuries among kayakers were reported as either subluxations or dislocations of the glenohumeral joint.

Range of motion testing is summarized in Tables 3 and 4. The rock climbing group was significantly higher in right- and left-hand internal rotation range of motion than both the kayaking and control groups. Also the kayaking group was significantly lower than both the rock climbing and control groups (Table 3). When subjects with shoulder injuries diagnosed by a physician were removed, the right-hand internal rotation range of motion only showed a significant difference between the rock climbers and the kayakers. Rock climbers were notably higher than the control group ($p = 0.079$), however. Moreover, if the left-hand internal rotation range of motion for injured subjects removed, there was no significant difference between the control and the kayaking groups (Table 4). Right external rotation range of motion was significantly higher for the rock climbing group than both the kayaking and control groups, there was no significant difference found between the control and kayaking groups (Table 3). There were no significant differences determined for the left-hand external rotation range of motion across all groups (Table 3). For right and left-hand extension range of motion, the rock climbing and kayaking groups were significantly higher than the control group, but there was no significant difference between the rock climbers and kayakers (Table 3). When the subjects with physician diagnosed injuries were removed, there however, was no longer a significance found for right- or left-hand extension range of motion between the

Table 3: Mean range of motion in degrees of the shoulder measured goniometrocally for all subjects. R stands for right shoulder, L stands for left shoulder. ROM stands for range of motion. IR is internal rotation, ER is external rotation, EXT is extension, and ABD is abduction. * Mean significantly different from the rock climbing group, # means significantly different from the kayaking group, and ^ means significantly different from the control group. All data presented as means ± SEM.

	Rock Climbers	Kayakers	Controls
R ROM IR	90.68 ± 3.3^#	72.4 ± 2.4*^	81.5 ± 2.0*#
L ROM IR	92.6 ± 3.5^#	70.0 ± 2.2*^	83.5 ± 1.9*#
R ROM ER	99.5 ± 2.3^#	88.28 ± 1.3*	91.5 ± 1.2*
L ROM ER	97.7 ± 2.8	90.9 ± 1.5	90.3 ± 2.1
R ROM EXT	170.2 ± 3.0^	167.2 ± 1.9^	153.2 ± 4.4*#
L ROM EXT	173.1 ± 2.9^	168.9 ± 2.8^	157.5 ± 2.6*#
R ROM ABD	138.3 ± 1.6^#	127.9 ± 2.4*	122.2 ± 2.8*
L ROM ABD	142.1 ± 2.8^	133.3 ± 2.1	125.9 ± 3.3*

Table 4: Mean range of motion in degrees of the shoulder measured goniometrocally for subjects not diagnosed by a physician with a shoulder injury. R stands for right shoulder, L stands for left shoulder. ROM stands for range of motion. IR is internal rotation, ER is external rotation, EXT is extension, and ABD is abduction. * Mean significantly different from the rock climbing group, # means significantly different from the kayaking group, and ^ means significantly different from the control group. All data presented as means ± SEM.

	Rock Climbers	Kayakers	Controls
R ROM IR	90.78 ± 4.0#	74.2 ± 2.5*	81.4 ± 2.4
L ROM IR	95.2 ± 3.8^#	73.1 ± 2.5*	81.9 ± 1.8*
R ROM ER	97.9 ± 2.2^#	88.50 ± 1.5*	91.1 ± 1.4*
L ROM ER	97.6 ± 3.0	90.8 ± 1.5	89.6 ± 2.5
R ROM EXT	170.9 ± 3.1^	164.1 ± 1.9	151.7 ± 5.5*
L ROM EXT	174.0 ± 3.5^	166.3 ± 3.3	158.5 ± 3.2*
R ROM ABD	138.5 ± 2.1^	129.7 ± 3.0*	122.1 ± 3.2*
L ROM ABD	141.6 ± 3.3^	135.2 ± 2.7	126.8 ± 3.8*

control group and the kayaking group (Table 4). For right- and left-hand abduction range of motion, the rock climbers were significantly higher than both the kayakers and controls, but there was no significant difference between the kayakers and controls (Table 3). When the subjects with doctor-diagnosed shoulder injuries were removed, there was no significant difference between the kayaking and rock climbing groups for right- or left-hand abduction range of motion (Table 4).

Time to peak force and total time are depicted in Table 5. There was no significant difference for internal rotation, external rotation and abduction time to peak force or total time among the three groups for right or left hands.

Peak force of manual muscle testing is summarized in Tables 6 and 7. Repeatability was tested by determining the coefficient of variance (CV). The CV was less than 10 for all groups and there were no significant differences found among any of the groups or tests for peak force. Right-hand manual muscle testing for internal rotation showed that the rock climbing group and the control group were significantly stronger than the kayaking group, but not significantly different from each other (Table 6). The control group, however, was not found to be significantly higher than the kayaking group for right-hand MMT for internal rotation when the subjects with physician-diagnosed shoulder injuries were removed from the analysis ($p = 0.083$) (Table 7). In this elimination testing, though the rock climbing group was not significantly higher, it was notably increased ($p = 0.098$) (Table 7). Left-hand MMT for internal rotation produced significantly greater results in rock climbers and controls compared to kayakers (Table 6), but only the rock climbing group was found to be significantly higher than the kayaking group when the subjects with physician-diagnosed shoulder injuries were

Table 5: Time to peak force (TPF) and total time (TT) for all three groups measured in seconds. Measurements taken from the Nicholas Lafayette hand held dynamometer. R stands for right shoulder, L stands for left shoulder. IR is internal rotation, ER is external rotation, and ABD is abduction. All data presented as means ± SEM.

	Rock Climbers	Kayakers	Controls
R TPF IR	1.96 ± 0.17	1.89 ± 0.13	1.85 ± 0.1
L TPF IR	1.87 ± 0.14	1.69 ± 0.17	1.79 ± 0.14
R TPF ER	1.75 ± 0.14	1.48 ± 0.11	1.58 ± 0.1
L TPF ER	1.77 ± 0.11	1.58 ± 0.1	1.51 ± 0.08
R TPF ABD	1.54 ± 0.1	1.53 ± 0.08	1.54 ± 0.09
L TPF ABD	1.61 ± 0.13	1.58 ± 0.08	1.55 ± 0.08
R TT IR	3.11 ± 0.21	2.7 ± 0.13	2.8 ± 0.12
L TT IR	2.8 ± 0.17	2.6 ± 0.11	2.8 ± 0.15
R TT ER	2.7 ± 0.16	2.6 ± 0.11	2.6 ± 0.11
L TT ER	2.77 ± 0.2	2.3 ± 0.07	2.4 ± 0.08
R TT ABD	2.5 ± 0.13	2.36 ± 0.14	2.4 ± 0.11
L TT ABD	5.5 ± 2.85	2.41 ± 0.11	2.48 ± 0.09

Table 6: Peak force determined with the Nicholas Lafayette hand-held dynamometer for all three subject groups. R stands for right shoulder, L stands for left shoulder. MMT stands for manual muscle testing. IR is internal rotation, ER is external rotation, and ABD is abduction. * Mean significantly different from the rock climbing group, # means significantly different from the kayaking group, and ^ means significantly different from the control group. All data presented as means ± SEM.

	Rock Climbers	Kayakers	Controls
R MMT IR (N/kg)	1.93 ± 0.09#	1.45 ± 0.05*^	1.8 ± 0.06#
L MMT IR (N/kg)	1.9 ± 0.08#	1.5 ± 0.04*^	1.78 ± 0.06#
R MMT ER (N/kg)	1.6 ± 0.06	1.61 ± 0.05	1.68 ± 0.05
L MMT ER (N/kg)	1.67 ± 0.07	1.62 ± 0.05	1.67 ± 0.06
R MMT ABD (N/kg)	1.3 ± 0.07	1.25 ± 0.03	1.35 ± 0.06
L MMT ABD (N/kg)	1.46 ± 0.07#	1.2 ± 0.03*^	1.38 ± 0.06#

Table 7: Peak force taken with the Nicholas Lafayette hand-held dynamometer for subjects without physician-diagnosed shoulder injuries. R stands for right shoulder, L stands for left shoulder. MMT stands for manual muscle testing. IR is internal rotation, ER is external rotation, and ABD is abduction. * Mean significantly different from the rock climbing group, # means significantly different from the kayaking group, and ^ means significantly different from the control group. All data presented as means ± SEM.

	Rock Climbers	Kayakers	Controls
R MMT IR (N/kg)	1.97 ± 0.1#	1.5 ± 0.06*	1.7 ± 0.06
L MMT IR (N/kg)	1.91 ± 0.1#	1.5 ± 0.05*	1.77 ± 0.08
R MMT ER (N/kg)	1.63 ± 0.05	1.64 ± 0.06	1.67 ± 0.05
L MMT ER (N/kg)	1.73 ± 0.08	1.63 ± 0.06	1.67 ± 0.07
R MMT ABD (N/kg)	1.37± 0.09	1.27 ± 0.04	1.36 ± 0.08
L MMT ABD (N/kg)	1.54 ± 0.08#	1.2 ± 0.04*	1.36 ± 0.07

removed. There was, however, a notable decrease in rotation in kayakers when compared to the controls ($p = 0.062$) (Table 7). In the right-hand MMT for external rotation and left-hand MMT for external rotation, there were no significant differences found (Table 6). There were no significant differences for right-hand MMT for abduction between any groups. Both the rock climbers and the controls were significantly higher than the kayakers for left-hand abduction, but there was no significant difference found between rock climber and control groups (Table 6). When physician-diagnosed shoulder injuries were removed form the analysis, however, a significant difference in the left-hand MMT for abduction occurred between the rock climbing and kayaking groups (Table 7).

The internal : external rotation ratios are depicted in Figures 1, 2, 3, and 4. For the right-hand internal rotation: external rotation ratio (Figure 1), the rock climbing group had a significantly higher ratio than both the control and kayaking groups. The kayaking group had a significantly lower ratio than both the rock climbing and control groups. For left-hand internal rotation to external rotation ratio (Figure 3), the kayaking group was significantly lower than the rock climbing and control groups. There was no significant difference found between the rock climbing and control groups for the left-hand ratio ($p = 0.096$). When the subjects with physician-diagnosed shoulder injuries were removed, the only changes that occurred in the statistics were in the right-hand ratio; the kayaking group was not significantly lower than the control group, but was still lower ($p = 0.069$) (Figure 2). There was no change in the left-hand data with the removal of subjects with doctor-diagnosed shoulder injuries (Figure 4).

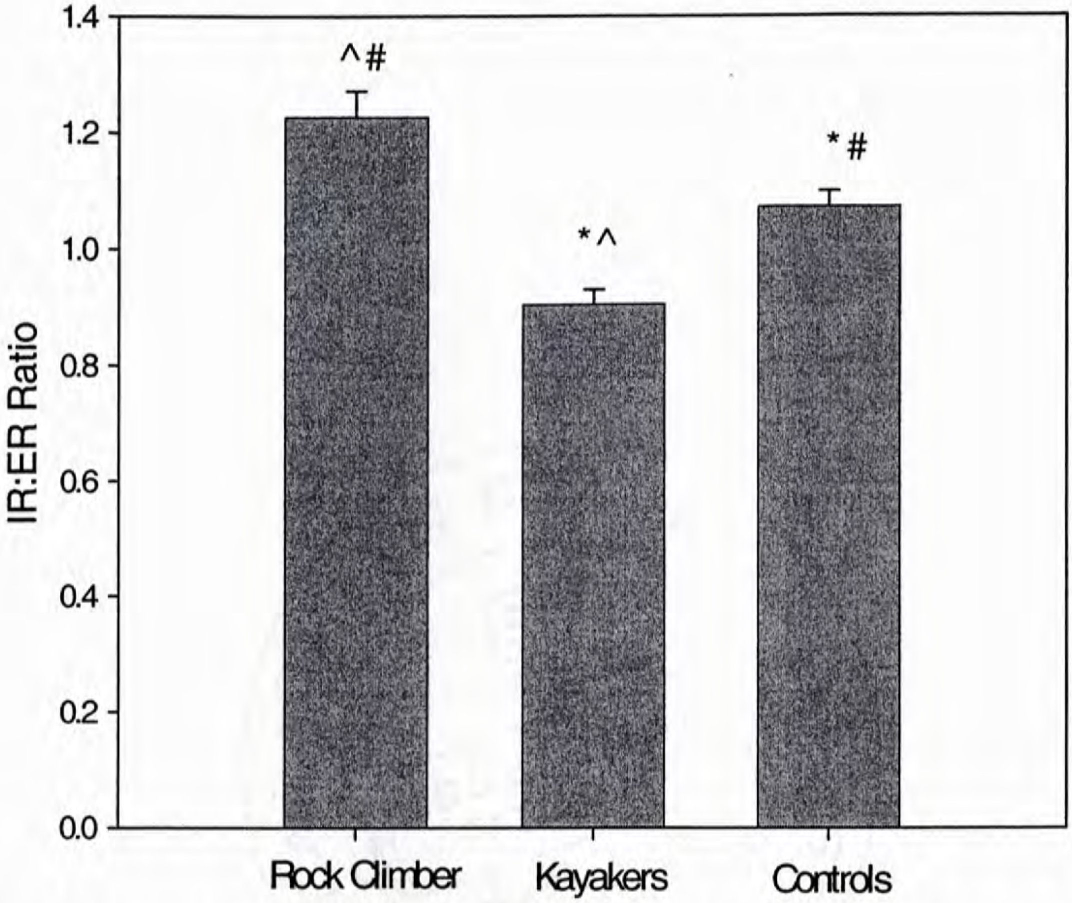

Figure 1: Ratio of internal rotation to external rotation in the right hand. *Means significantly different from the rock climbing group, # means significantly different from the kayaking group, and ^ means significantly different from the control group. All data presented as means ± SEM.

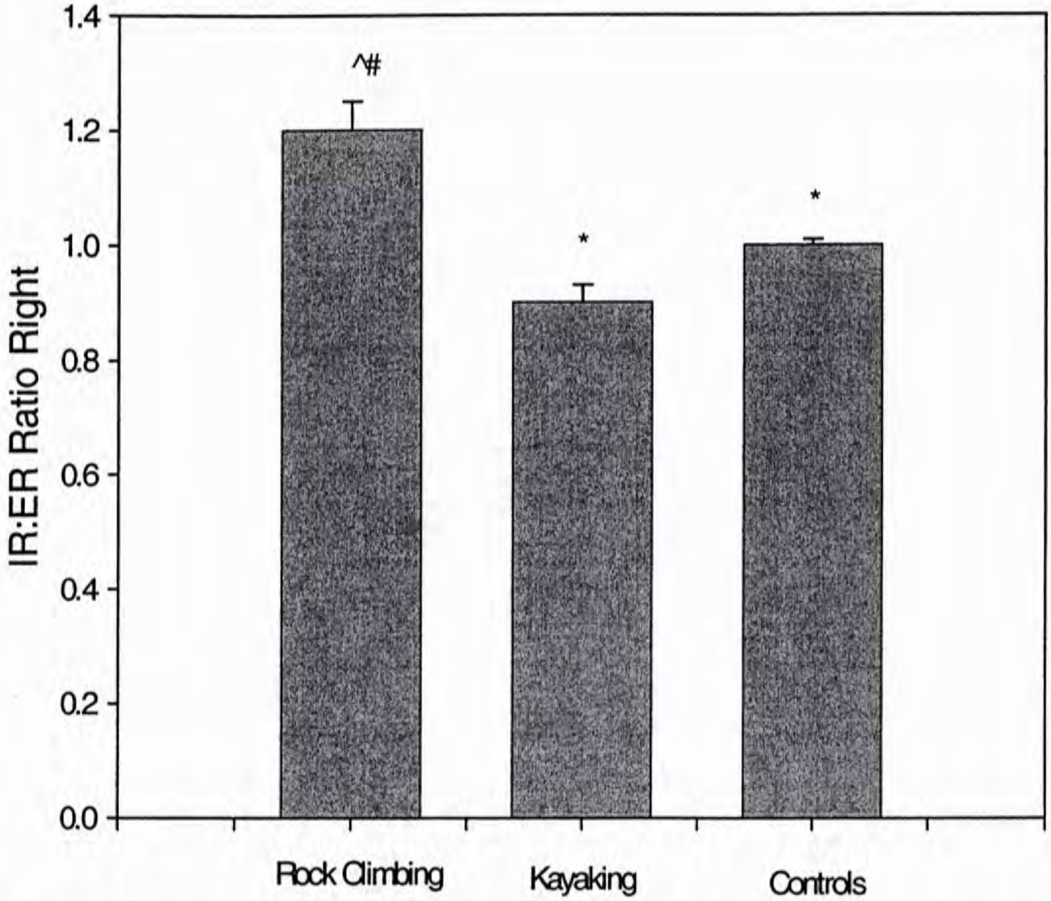

Figure 2: Ratio of internal rotation to external rotation in the right hand without subjects with physician diagnosed shoulder injuries. *Means significantly different from the rock climbing group, # means significantly different from the kayaking group, and ^ means significantly different from the control group. All data presented as means ± SEM.

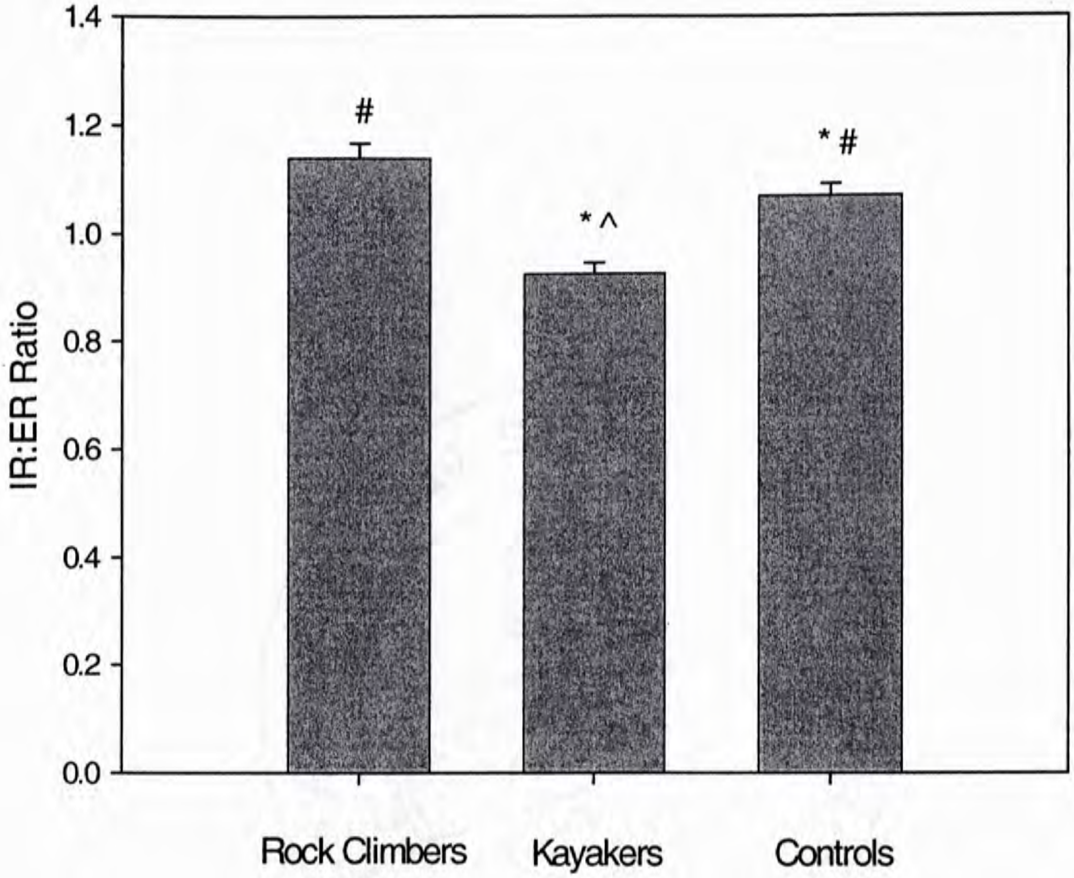

Figure 3: Ratio of internal rotation to external rotation in the left hand. * Means significantly different from the rock climbing group, # means significantly different from the kayaking group, and ^ means significantly different from the control group. All data presented as means ± SEM.

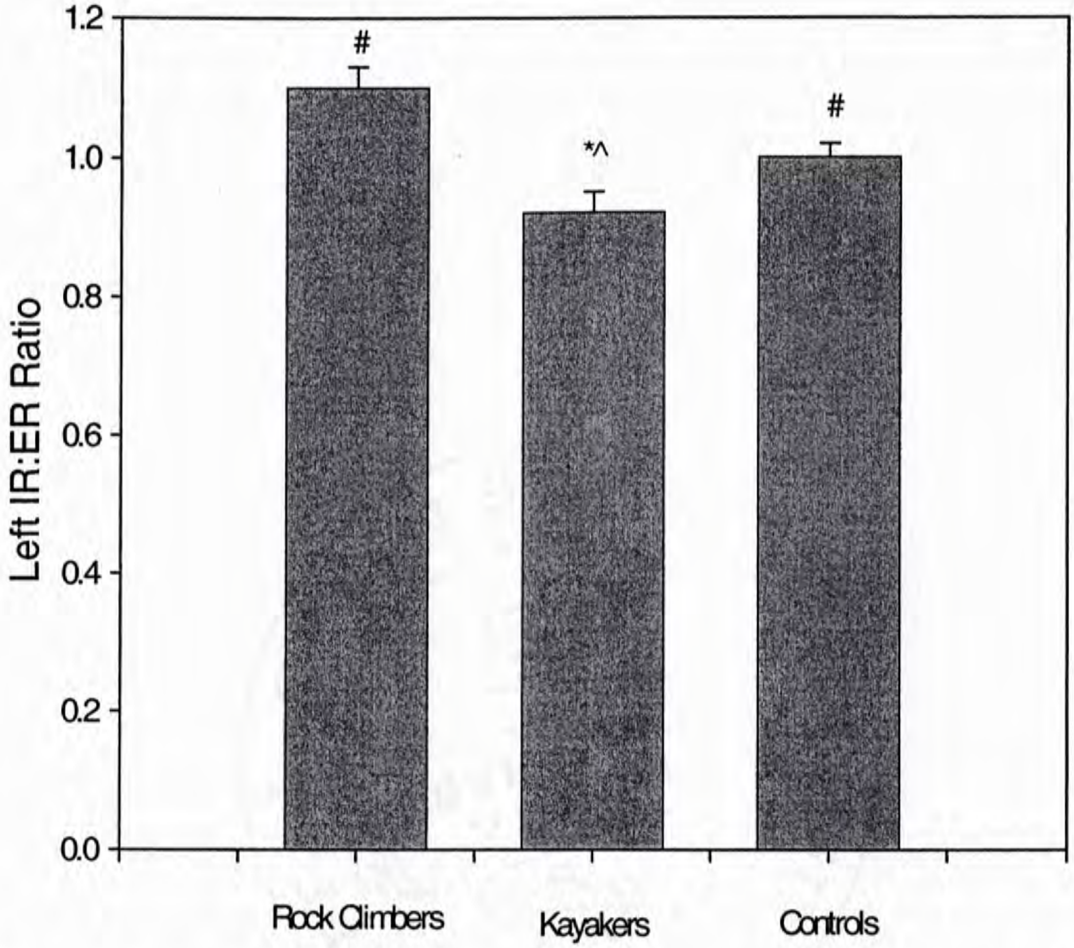

Figure 4: Ratio of internal rotation to external rotation in the left hand wherein subjects with physician-diagnosed shoulder injuries were excluded. * Means significantly different from the rock climbing group, # means significantly different from the kayaking group, and ^ means significantly different from the control group. All data presented as means ± SEM.

Chapter 5

Discussion

The results of this study examining the rotator cuff in rock climbers, kayakers and controls indicate that there are significant differences in the range of motion, peak force and internal rotation to external rotation ratios among these groups.

The rock climbing group has a greater range of motion overall than the control group. This suggests that there is increased motion in the shoulder of the rock climber compared to the control group. The kayaking group was only significantly different than the control group in left and right internal rotation. Crockett et al., (2002); Donatelli et al., (2000); Ellenbecker et al., (2002), Ellenbecker et al., (2000); & Osbahr et al., (2002) did report that there were significant differences between the passive ROM in dominant and non-dominant arms for internal rotation and external rotation for professional baseball pitchers. The pitching arm was found to have a significantly higher external rotation and a significantly lower internal rotation ROM than the non-pitching arm (Crockett et al., 2002; Donatelli et al., 2000; Ellenbecker et al., 2002, Ellenbecker et al., 2000; Osbahr et al., 2002).

When repetitive microtrauma occurs in an overhead activity such as baseball it can lead to the stretching of the anterior capsule and the tightening of the posterior capsule (Bigliani, et al. 1997; Crockett et al. 2002; Osbahr et al., 2002). The increase in anterior translation in the humeral head in the throwing arm has been attributed to the anterior capsular laxity that occurs (Ellenbecker et al., 2000). These capsular changes contribute to the tendency for instability and secondary impingement and anterior glenohumeral subluxation in the stressed shoulder (Bigliani et al., 1997; Crockett et al., 2002; Ellenbecker et al., 2002 Osbahr et al., 2002). Also, a relationship is considered to exist between glenohumeral joint instability and rotator cuff abnormalities (Ellenbecker et al., 2000).

There is a possibility that the capsular changes that occur due to overstressing the shoulder may be occurring in the shoulders of rock climbers in a similar fashion to those which occur in the shoulders of individuals involved in sports in which objects are thrown. The propensity of instability, impingement and anterior subluxation that accompany this laxity might increase the risk of shoulder injury in rock climbers due to their increased external rotation. The decrease in internal rotation that occurred in the kayaking group may result in similar injuries, since it has also been shown that there is a decrease in internal rotation range of motion for throwers as well. These changes in range of motion however, may be secondary to the eccentric loading's effect on the rotator cuff muscle.

The observations with respect to peak force were not as hypothesized. It had been hypothesized that the rock climbing and kayaking groups would have an overall higher peak force when compared to the control group. There was, however, considerable variation in the control group peak force. This could be due to the greater variety of subjects used in the control group compared to the homogeneity for the kayaking and rock climbing groups. The kayaking group was weaker in internal rotation than both the rock climbing and the control groups and there were no differences in strength found for external rotation for any group. These data are compatible with the eccentric loading of internal rotation that occurs in kayaking moves such as the high brace, and they could lead to the weakening of the subscapularis (Burrell & Burrell, 1982; Sirota et al., 1997).

There was a significant difference in the IR:ER ratios that were found in the kayakers in comparison to both the control and the rock climbing groups. On the right-hand side, the rock climbers had a significantly higher ratio as compared to the control and kayaking groups. The left-hand side produced ratios that were not considered significant between the rock climbing and control groups, although a significant difference did occur between the rock climbing and kayaking groups. However, there was a trend for internal rotation to external rotation ratio for the left-hand in rock climbers to differ from controls ($p = 0.096$). These data suggest that although a statistical significance could not be demonstrated, rock climbers may actually have higher ratios. Considering the number of right-hand dominant subjects, 84% of rock climbers, 96% of kayakers and 88% of controls, it can be determined that the right hand ratios are those of the dominant hand. In a study performed using the same HHD, professional pitchers produced IR:ER ratios of 1.5 in the pitching arm and 1.3 in the non-pitching arm (Donatelli et al., 2000). These similar ratios suggest that it may now be possible to categorize rock climbing with other overhead sports such as baseball, tennis, and water polo.

Other studies using isokinetic dynamometry have produced increased internal rotation :external rotation ratios in overhead sports. In McMaster et al., (1991), the IR:ER ratio was between 1.7 and 1.9 in water polo players, compared to IR:ER ratios of 1.35 to 1.5 for a control group. The IR:ER ratios for a study that included baseball players, tennis players, runners and nonathletes were as follows: nonathletes and runners had ratios of 1.3 to 1.5, tennis players had ratios of 1.54 to 1.68 and baseball players had ratios that were approximately 2.0 (Codine et al., 1997). The training that occurs in rock climbing appears to have a similar effect on shoulder strength as these other overhead sports.

Elevated internal rotation :external rotation ratios have been linked to a possible predisposition to shoulder injury. A relationship has been noted between IR:ER ratios and abnormalities in the normal shoulder (Warner et al., 1990) and in professional baseball pitchers by (Wilk, Andrews, Arrigo, Keirns, & Erber, 1993). Sirota et al. (1997) suggested that the repetitive eccentric loading of the shoulder could lead to the tearing of connective tissue, as well as to chronic inflammation, both of which could contribute to the relative weakness of ER in comparison to IR. For this reason, it is possible that the elevated internal rotation to external rotation ratios found for rock climbers in this study might be an expression of either a predisposition to shoulder abnormalities or an underlying abnormality. Thus, the possibility should be considered rock climbers are at increased risk for shoulder injuries.

The kayaking group produced IR:ER ratios of less than 1.0. I have been unable to find any population with a ration this low. IR:ER ratios have not been determined for kayakers previously. A ratio of below 1.0 indicates that the internal rotation of the shoulder is weaker than the external rotation of the shoulder. This could be attributed to the persistent motion of the shoulder in the transverse plane. Also, the eccentric loading of the subscapularis in an externally rotated position. It has been suggested that the repetitive eccentric loading of the shoulder could lead to the tearing of connective tissue as well as chronic inflammation (Sirota et al., 1997). In kayakers this may contribute to the relative weakness in internal rotation in comparison to external rotation. The high numbers of glenohumeral dislocations and subluxations could be attributed to the weakened internal rotation. In comparison to the controls, kayakers had significantly lower IR:ER ratios for both the right and left hands. The kayaker group IR:ER ratios were also significantly lower than the rock climbing group. This isolates the kayaking group from more traditional overhead intensive sports such as baseball, tennis and water polo, which all have ratios of above 1.0.

Conclusion:

In conclusion, there may be a commonality, not in mechanics but in the eccentric loading of the shoulder between rock climbers and other athletes participating in overhead sports, such as baseball pitchers, tennis players, and water polo players. This similar imbalance appears to be occurring with both range of motion and IR:ER ratios. Moreover, it appears that the eccentric loading of the subscapularis in kayakers may be creating weakness in the internal rotation that has created an IR:ER ratio of less than 1.0. This indicates that a sport that is shoulder-intensive and requires the motion of the shoulder in an overhead position can result in measurements that are different from those in athletes in other overhead sports.

Further research could include more studies on the IR:ER ratios on rock climbers and kayakers, including testing in which females were compared to males. A large scale frequency-of-injury study for both rock climbing and kayaking would be invaluable in determining if the ratios found in both rock climbers and kayakers in the current study are linked to shoulder abnormalities or injuries.

A greater biomechanical understanding of both rock climbing and kayaking motions involving the shoulder could improve the understanding of how these sports specifically develop shoulder strength. This would aid in a greater understanding of the development of strength in the shoulder, as well as provide information for the possible development of preventative measures for shoulder injuries. This could lead to a greater understanding of the mechanism of shoulder injuries in both rock climbers and kayakers, as it has yet to determined if an improvement in the IR:ER ratios would aid in the prevention of injuries in rock climbing and kayaking.

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APPENDIX A

Informed Consent

CONSENT FORM: ROCK CLIMBING AND KAYAKING SHOULDER STUDY

Thank you for your time, your participation is greatly appreciated. Please take the time to fill out the following questionnaire and participate in short measurement process of this study. The measurement process with include 5 tests of your shoulder range of motion and 3 manual muscle tests with a hand held dynamometer to test strength. Each manual muscle test will require your arm to be placed at specific angles and you will be asked to resist against the hand held dynamometer. Positions should not cause pain at any time, there is however a slight chance of muscle soreness the following day. The purpose of this study is to analyze the strength of the rotator cuff muscles in rock climbers and kayakers. This study will aid in the development of procedures to help identify the potential risks of injuries in kayaking and rock climbing. It will assist in the creation of measures to prevent the likelihood of shoulder injuries in these sports, as well as aid in the development of rehabilitation protocols that would be more sport specific to the sports of rock climbing and kayaking. Whether you have experienced a shoulder injury during these activities or not, the information that you provide us will be vital.

Please answer the questionnaire as honestly as possible and pay full attention to the direction given in the short battery of tests that follows. Your confidentiality will be assured by the use of subject identification numbers which will be used in the data analysis, thus your name will not be associated with all data.

STATEMENT OF INFORMED CONSENT

As a participant in this study, I acknowledge that the information that I provide during this questionnaire and following measurements will aid in providing a greater understanding of the shoulder as it is affected by kayaking and rock climbing. I understand that if I do not wish to continue in the study at any point in time, I can discontinue participation and will not be expected to continue against my will. It is also clear that my refusal to participate will involve no penalties to me.

I have been informed that if I wish to contact an impartial third party not associated with this study regarding any complaint I may have about the study, I may contact Dr. Vaughn Christian, Chairman of the Department of Health, Leisure and Exercise Science, Appalachian State University, Boone, NC 28608, phone (828) 262-3140 for information and assistance. I may contact the Appalachian State University Institutional Review Board at the following address and telephone number at any time during this study if I feel my rights have been violated: Dr. Robert Johnson, Graduate Studies and Research, Dougherty Administration Building, Appalachian State University, Boone, NC 28608 (828)262-2692

I understand that my personal information will be held confidential and thus not disclosed in any published documents of this study. I acknowledge that this will be accomplished through the use of subject numbers assigned for the processing of data.

I have read the above explanation of the study and understand that in signing this document, I am consenting to participate in this experiment. All questions concerning this study have been answered within my satisfaction. I hereby give voluntary consent to participate in this study.

____

Signature of subject date

____

Signature of witness date

____

Signature of primary investigator date

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APPENDIX B

Questionnaire

Shoulder Injury Survey

Please answer the following questions as completely and honestly as possible, there are no correct or incorrect answers. Please participate whether or not you have experienced a shoulder injury, all data collected will be valuable to this study.

1. Name ____________________________
2. Age__________
3. Dominant hand Left Right
4. Years of experience_________________
5. Level of expertise, please list the highest consistent grade or class you perform at. ______

   ____
6. How many times per week do you participate in kayaking/climbing?

   1 2 3 4 5 6 7
7. How many hours per session do you kayak/climb?

   1-2 3-4 5-6 7+
8. Have you ever sustained a shoulder injury? Yes No
9. If yes, when was it injured and which shoulder?

   Date / / Left Right
10. If yes, was the shoulder injury a result of kayaking/climbing? Yes No
11. What type of injury? Dislocation Impingement Tendonitis
12. If yes, was your injury diagnosed by a physician? Yes No
13. Have you had surgery for your shoulder injury and if so, when?

    Yes No Date / /
14. Do you participate in any training other than kayaking/climbing? Yes No
15. Does this training involve shoulder strengthening exercises? Yes No
16. If yes, how often and what types of shoulder exercises?

____

____

____

APPENDIX C

Data Sheet

Data Sheet

Measurements

Right	Trial 1			Left	Trial 1		
Height cm				Height cm			
Weight kg				Weight kg			
Body Fat %				Body Fat %			
Wing Span cm				Wing Span cm			
Ape Index cm				Ape Index cm			

ROM

Right	Trial 1	Trial 2	Trial 3	Left	Trial 1	Trial 2	Trial 3
External Rotation				External Rotation			
Internal Rotation				Internal Rotation			
Extension				Extension			
Flexion				Flexion			
Abduction				Abduction			

Manual Muscle Testing

Force in KG

Right	Trial 1	Trial 2	Trial 3	Left	Trial 1	Trial 2	Trial 3
IR 90° abd				IR 90° abd			
ER 90° abd				ER 90° abd			
Abduction				Abduction			

Time to Peak Force

Right	Trial 1	Trial 2	Trial 3	Left	Trial 1	Trial 2	Trial 3
IR 90° abd				IR 90° abd			
ER 90° abd				ER 90° abd			
Abduction				Abduciton			

Total Time

Right	Trial 1	Trial 2	Trial 3	Left	Trial 1	Trial 2	Trial 3
IR 90° abd				IR 90° abd			
ER 90° abd				ER 90° abd			
Abduction				Abduction			

APPENDIX D

Rock Climbing Difficulty Ratings

Rock Climbing Rating Scale

5.0-5.6 Various sizes of available holds with straightforward moves

5.7-5.9 Moves are more complex steeper terrain and smaller holds

5.10a-d Has some missing holds requiring training to make moves

5.11a-d Majority of moves made with tiny or missing holds, need problem solving skills, on steep to overhanging terrain.

5.12 a-d Increasingly difficult to problem solve and harder moves. Extremely tiny and limited holds On steep terrain or a few decent Holds on near horizontal terrain.

5.13 a-d Increase the difficulty from 5.12 climbs. Requires specific training.

5.14 a-d Steep or overhanging terrain with few to no noticeable holds.

(Watts, 1996)

Verman (Bouldering)	Yosemite Decimal	
	Class 1-4	
	Class 5.0	Technical Climbing
	5.1	
	5.2	
	5,3	
	5.4	
	5.5	
	5.6	
	5.7	
	5.8	
	5.9	
V0 - V1	5.10	
V2 - V4	5.11	
V5 - V7	5.12	
V8 - V9	5.13	
V10 - V14	5.14	

APPENDIX E

Whitewater Kayaking Difficulty Ratings

Whitewater Classifications

Class I: Easy. Has fast moving water with small waves. There are a few obvious obstructions. Low risk to swimmers and self-rescue is easy.

Class II: Novice. Rapids are straightforward and have wide, clear channels that do not require scouting. Maneuvering may occasionally be required, but trained paddlers will find no trouble in avoiding rocks and medium-sized waves. Still low risk to swimmers, and though assistance can be helpful, though it is not necessary, self-rescue is easy.

Class III: Intermediate. Rapids have moderate and irregular waves and can be difficult to avoid. It is often required for the kayaker to perform complex maneuvers in fast current and have good boat control in tight passages and around ledges. There is the possibility of large waves or strainers, which can easily be avoided. Strong eddies and powerful currents can also occur, typically on high volume rivers. Scouting is advised. Self-rescue is still considered easy, but assistance could prevent a long swim.

Class IV: Advanced. Intense and powerful rapids occur, but are predictable and require precise boat handling in turbulent water. River can have large unavoidable waves and holes or constricted passages that will require fast maneuvers. Must be able to perform reliably fast eddy turns to initiate some maneuvers. Upstream moves may be necessary. Scouting is necessary for first runs. Risk of injury to swimmers is moderate to high, and self-rescue is difficult. Assisted rescues are often needed and skill should be practiced. A strong roll is also recommended.

Class V: Expert. Long, obstructed or very violent rapids that can place a paddler in above average danger. Drops with large unavoidable waves and holes, congested chutes with complex and demanding routes can occur. Rapids can continue for extended distances between pools. Eddies are typically small, turbulent and difficult to reach. Scouting is mandatory but often difficult. Swimming is dangerous and rescues are difficult even for the experienced.

Class VI: Extreme. Reach the extremes in difficulty, unpredictability, and danger. Errors have severe consequences and rescue may not be possible. For teams of experts only.

(Ford, 1995)

APPENDIX F

Review of Literature Matrix

Table 1. Range of Motion

Author	Research Design	Results
Crockettt et al. 2002	25 professional baseball pitchers,25 nonthrowing subjects, dominant and nondominant shoulders, ROM and laxity for glenohumeral joint tested	Significant increase in throwing vs. nonthrowing shoulders for humeral head retroversion, glenoid retroversion, ER. IR decreased. Total ROM and glenohumeral laxity were bilaterally equal. In a comparison to control, ER and humeral head retroversion were significantly greater in the throwers.
Ellenbecker et al. 2002	117 male junior tennis players, 46 male baseball pitchers, measured glenohumeral joint IR, ER and abduction.	No significant difference between extremities for total ROM in pitchers, dominant was significantly less for total ROM in tennis players.
Ellenbecker et al. 2000	20 professional baseball pitchers, bilateral manual anterior humeral head translations and stress radiographic tests	No significant difference between extremities for the amount of anterior translation or stress tests. No significant correlation between stress tests and anterior translations.
Osbar et al. 2002	19 male college baseball pitchers, ROM for IR and ER were measured	Increased ER and IR at 90 degrees of abduction and a greater humeral retroversion occurred in the dominant arm. There was a significant correlation between ER and humeral retroversion.

Table 2. Manual Muscle Testing		
Jenp et al. 1996	Twenty healthy subjects tested in 29 shoulder positions with a Cybex ID and EMG	Determined that the best isolation of the subscapularis was in the scapular plane with 90 degrees of shoulder elevation, of the infraspinatus-teres minor was in the sagittal plane with 90 degrees of shoulder elevation
Kelly et al. 1996	11 healthy male subjects tested in 29 shoulder positions using a Isobex ID and EMG	Subscapularis was best tested at 90 degrees of shoulder elevation and 45 degrees of ER, infraspinatus was best at 45 degrees of IR, and the subscapularis best tested with the Gerber push test.

Table 3. Internal Rotation to External Rotation Ratios		
Author	Research Methods	Results
Codine et al. 1997	12 nonathletes, 12 runners, 15 tennis players, and 12 baseball players. Tested for rotator cuff ratios with ID	Produced IR:ER ratios for nonathletes and runners (1.3-1.5), tennis players (1.5-1.6) and baseball players, (1.6-2.2)
Donatelli et al. 2000	39 male professional baseball pitchers tested IR:ER ratio with HHD bilaterally	Produced ratios of 1.5 in the pitching arm and 1.3 in the non-pitching arm.
McMaster et al. 1991	15 male waterpolo players and 10 controls tested IR:ER ratio with Cybex ID	Ratios for water polo players was found to be between 1.7 and 1.9 and for the control group 1.3 to 1.5
Scoville et al. 1997	75 college aged males tested with KinCom ID	A IR:ER ratio of 1.5 was found for normal male subjects
Sirota et al. 1997	25 professional baseball pitchers tested IR and ER concentric and eccentric with KinCom ID	Found no difference between dominant and non dominant hands for internal roation or external rotation. Suggested that repetitive eccentric loading of the shoulder could contribute to relative ER weakness in comparison to IR

Table 4. Rock Climbing		
Author	Research Design	Results
Bollen 1988	71 male and 11 female rock climbers, responded to questionnaire	Total of 115 injuries lasting 10 or more days, 54 occurred during training.16 shoulder injuries were reported, 2 were impingement syndromes.
Maitland 1992	148 male and female rock climbers, responded to questionnaire	49 respondents sustained 124 injuries in the past year. Shoulder injuries made up 8%, Shoulder-elbow combinations made up 23% of injuries.

Table 5. Kayaking		
Author	Research Design	Results
Fiore & Houston 2001	392 kayaker respondants to questionnaire	219 subjects suffered 282 distinct injuries, 242 injuries (61%) were upper extremity, of which half were to the shoulder, of which 56 were dislocations

Table 6. Hand Held Dynomometer		
Author	Research Design	Results
Byl et al. 1988	27 normal subjets, 2 physical therapy examiners. Measured elbow flexion and shoulder abduction for inrarater and interrater reliability.	Interrater and intrarater were highest with additional stabilization r = 0.957, r = 0.941
Kilmer et al. 1997	10 experimental subjects, 11 controls HHD measurements of flexion and extension in the shoulder, elbow, wrist and knee, shoulder abduction, and ankle dorsiflexion.	Intratester intraclass correlation was high (r = 0.82, r = 0.96) for HHD and fixed dynamometry. Intertester reliability was good for the HHD (r = 0.72, 0.97)

May et al. 1997	25 spinal cord patients tested with HHD and Cybex ID, for IR and ER strength	Intraclass correlations for intrarater reliability r = 0.89, r = 0.96. There was variability in ID strength values at lower strength levels.
Reed et al. 1993	16 males and 16 females considered to be healthy, tested elbow and knee flexion and extension with HHD and Lido ID.	Correlations between techniques was good, r = 0.72, r = 0.85.
Stratford & Balsor 1994	32 healthy female subjects, tested elbow flexor strength with HHD and KinCom	The HHD and ID produced comparable reliability coefficients.
Sullivan et al. 1988	14 healthy male subjects, tested ER of the shoulder with HHD and Cybex ID	Interrater reliability was established for HHD (r = 0.98) for the ID (r = 0.99).
Surburg et al. 1992	10 adults with mild to moderate mental retardation, tested elbow flexion and knee extension with HHD and Cybex ID	HHD intrarater correlation was high at r = 0.99, the HHD and ID produced good reliability at r =0.76.
Trudelle-Jackson et al. 1992	30 healthy female subjects tested with HHD and KinCom ID for hamstring strength	The HHD and ID produced comparable reliability (r = 0.85, r 0.83)
Wang et al. 2002	41 community-dwelling elderly fallers, tested with HHD for 8 lower-extremity muscle groups.	Test-retest correlations were high r = 0.99 for trial 1 and r = 1.0 for trial 2
Wilkholm & Bohannon 1991	27 healthy adults tested shoulder ER, elbow flexion and knee extension, with HHD.	Interrater/intrasession testing was good (r = 0.93).

APPERNDIX G

IRB Approval Letter

Appalachian
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TO: Ms. Kasie Ann Richards,
HLES
Dr. Charles Dumke
HLES

FROM: Robert L. Johnson, Chair
Institutional Review Board

DATE: January 2, 2003

SUBJECT: Institutional Review Board
Request for Human Subjects Research

REFERENCE: *"An Investigation of Rotator Cuff Strength in Rock Climbers and Kayakers"*

IRB Reference #03-63

Initial Approval Date - December 27, 2002
End of Approval Period – December 27, 2003

Your request for Review of Human Subjects Research has been approved.

OHRP Guidelines stipulate that projects may be approved for a maximum of one (1) year. During this period, you should contact this office to:

1. report any unanticipated problems involving risks to subjects or others,
2. request modification in the approved protocol,
3. request an Extension beyond the one (1) approval, and/or
4. inform the IRB of the completion of the project.

Best wishes with your research.

RLJ/lab

VITA

Kasie Ann Richards was born on September 17, 1978 in Birmingham, Alabama. She attended grade school in Wilmington, NC and graduated from John T. Hoggard High School in 1996. In the fall of 1996, she entered the University of North Carolina at Chapel Hill to study sports medicine and athletic training. She was awarded a bachelors of arts degree in exercise science in May of 2000 and became a nationally board certified athletic trainer in April of 2000.

In the summer of 2000 she worked as the head athletic trainer for a team in the coastal plains premier collegiate wooden bat baseball league. In the fall of 2000 to the summer of 2001 she worked as an ATC in an orthopedic clinic and with high school outreach in Asheville, NC.

In the fall of 2001, she entered Appalachian State University and began working towards her masters of science in exercise science, focusing on research, and strength and conditioning. During the fall of 2001, she was also a graduate assistant trainer in charge of men's and women's varsity soccer. In November of 2002 she became a nationally certified strength and conditioning specialis