BIOMECHANICAL AND PHYSICAL CHARACTERISTICS OF WHITEWATER KAYAKERS WITH AND WITHOUT SHOULDER PAIN

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Participation in whitewater kayaking is growing faster than any other outdoor recreational pursuit. With increases in participation, an increase in the number of injuries associated with whitewater kayaking may also become apparent. Overuse injuries are the most prevalent type of injury found in whitewater kayakers. Due the large range of motion and forces that occur through the shoulder while kayaking, the most common injury location is the shoulder. Little scientific inquiry has been performed assessing the kinematics of kayaking and the musculoskeletal attributes of these athletes.

Sixteen whitewater kayakers with shoulder pain and sixteen whitewater kayakers without shoulder pain participated in this study. Each subject underwent kinematic and electromyographic analysis of the forward kayak stroke. Additionally, participants underwent clinical examination of shoulder injury, clinical assessment of shoulder and torso range of motion, posterior shoulder tightness assessment, isokinetic strength testing at the shoulder, and a scapular kinematic evaluation during a standardized humeral elevation task.

The most common type of injury found was related to overuse. Statistical comparisons occurred between the involved and uninvolved limb in the shoulder pain group and between the involved and uninvolved and matching shoulders in the control group, respectively. Significant differences were found between in involved and uninvolved shoulder for shoulder internal rotation and abduction range of motion. Additional differences were found for these variables between the involved shoulder in the pain group and the matching shoulder in the control group.

Kayakers with shoulder pain present with decreased shoulder range of motion on their involved shoulder. Assessment of the specific types of injuries seen in whitewater kayakers should be further evaluated. Additionally, the role of increasing range of motion through injury prevention programs in whitewater kayakers with shoulder pain should be investigated.

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PREFACE

Completion of a doctoral degree is a cumulative effort of many people's labors and teamwork. I was fortunate to have compiled a talented team. Special thanks go out my dissertation committee members that helped guide me through the process. Dr. Scott Lephart, Dr. Tim Sell, and Dr. Elaine Rubinstein all contributed to my dissertation with distinct and valuable insight. Many thanks go out to my dissertation committee chair, Dr. Joseph Myers, whose efforts and guidance were exemplary and during all phases of my doctoral education. I would also like to recognize some of my colleagues who supported me in various ways throughout my doctoral career, Takashi Nagai, Saki Oyama, Dr. James Smoliga, Dr. Kenneth Learman, Dr. John Abt, Dr. Yung-Shen Tsai, John Jolly, Kristie Howard, Gordon Huang, and Anna Benjamnise. Finally, I would like to recognize my family and friends who provided unwavering encouragement and understanding throughout my education.

1.0 INTRODUCTION

According to the American Canoe Association (ACA), it is estimated that 22.6 million people participated in some form of paddling (canoe or kayak) in 1999, compared to 16.7 million in 1994-95.[1] In fact, kayaking is growing faster than any other outdoor activity, whether on land or water.[1] According to outdoor recreation market participation surveys, kayaking participation increased 37% from 2000 to 2001.[2] Canoeing has increased 33% over this same time period.[2] The total estimated number of people participating in some sort of paddle sport (kayaking, canoeing, or whitewater rafting) in 2001 was 47.6 million people.[2] This constituted approximately 16% of the United States population.

These large numbers of participants along with the uncommon nature of upper extremity exertion has the potential to lead to many injuries of the upper extremity. If the number of participants continues to increase, it is likely that so too will the number of injuries. With the tremendous growth in the popularity of kayaking, it is important to understand the injuries that occur, as well as the mechanisms that may be underlying them. One of the unique aspects of kayaking is the large amount of repetitions that occur in the upper extremity during participation, yet few studies exist detailing this.[3, 4] There have been many biomechanical studies on overhead athletes, especially pitchers, yet pitchers rarely throw greater than 150 pitches during a baseball game, while Wilson et al[4] found that kayakers can take up to 8,000 paddle strokes in a two-hour distance race. Kayakers' paddle strokes may even be greater than swimmers strokes, who take up to 18,000 swimming strokes per week while training 8,000 to 12,000 meters per day.[5] For a swimmer, this equates to approximately 3,000 swimming strokes per day.[5] Considering the large numbers of strokes taken while kayaking, it is imperative to understand the upper extremity kinematics associated with the kayak forward paddle stroke, as this may lead to an understanding of the injuries involved in kayaking.

1.1 SHOULDER INJURIES IN KAYAKERS

There are a limited number of studies detailing the prevalence and incidence of whitewater kayaking injuries. Krupnick et al[6] reported whitewater kayaking injuries in United States Olympic trials athletes (n=271) in 1996 and found sprains and strains to be the most common type of injury, followed by tendonitis. They also report the most common injury site is the torso, followed by the shoulder.[6] Kameyama et al[9] reported similar location of injuries in competitive Japanese canoeists (n=417) with the shoulder as the second most common injury site next to the low back. Schoen and Stano[7] used the internet as well as local paddling clubs to assess injuries in recreational and competitive athletes (n=319). They broke injuries into two categories, acute and chronic. For both acute and chronic injuries the shoulder was the most common injury location followed by the wrist/hand.[7] In a study of marathon kayakers, Hagemann et al[3] reported the greatest percentage of injuries during kayaking as shoulder injuries, namely rotator cuff injury, shoulder bursitis, and biceps tendonitis. While these studies are limited in number, they clearly show that the upper extremity, particularly the shoulder, is a very common site of injury. It is important to recognize that these studies are limited to self-reported instruments and pertain mostly to competitive athletes versus recreational participants. It should be noted that competitive athletes most likely spend much more time training and kayaking than recreational participants, and thus competitive athletes are subsequently more susceptible to overuse injuries such as the ones described. It is clear, however, that investigation into the motion occurring during a forward kayak stroke is necessary to glean knowledge as to what potential mechanisms contribute to the injuries described above.

Kayakers are susceptible to many orthopedic injuries at the shoulder.[3, 7, 8] Examples of injuries often seen in kayakers include subacromial impingement, rotator cuff tendonitis, bursitis, and biceps tendonitis.[3, 7, 9] Faulty kinematics, particularly significant asymmetry may contribute to the repetitive use injuries seen in kayakers' shoulders.[10] Additionally sub-optimal physical characteristics may augment the pathological kinematics contributing to shoulder pain in kayakers. Although the majority of injuries reported in kayakers' upper extremities are related to overuse, it has been reported in marathon kayak racers that age, number of years kayaking, and number of distance races completed do not relate to symptoms of pathology as noted on magnetic resonance imagining (MRI) or to clinical tests of instability, impingement, or tendonitis.[3] Heeding the findings of this study, faulty kayaking kinematics and sub-optimal physical characteristics may be substantial contributors to shoulder pain in kayakers. No study to date has performed an assessment of shoulder and torso kinematics and physical characteristics between kayakers with shoulder pain and those who are pain free.

1.2 ANALYSIS OF THE KAYAK STROKE

1.2.1 The Forward Kayak Stroke

There is little information describing the forward kayak stroke available in scientific literature. Mann and Kearney[11] describe the stroke as occurring with a draw side (the side paddle is entering the water) and a thrust side (the side paddle is in the air). At the initiation of the stroke, when the paddle enters the water, the draw shoulder is in front of the thrust shoulder (Figure 1, position A).[11] This shoulder position results in torso rotation away from the side of paddle entry (rotation to the right when the paddle enters on the left and vice versa). The draw elbow is extended and the draw shoulder is flexed in attempt to place the paddle in the water as far toward the front of the boat as possible (Figure 1, position A).[11] The thrust shoulder is abducted and the thrust elbow is flexed at the same time to help facilitate forward paddle entry (Figure 1, Position A).[11]

Propulsion of the kayak occurs in two phases; a push phase and a pull phase.[11] From the time paddle enters the water (paddle-water association) until the paddle shaft is vertical (paddle shaft vertical) (Figure 1, position A to position B) pushing (horizontal adduction of the thrust shoulder with extension of the elbow) with the thrust segments should be emphasized. From paddle shaft vertical until the blade exits the water (paddle-water dissociation), pulling (extension of the draw shoulder with slight flexion of the elbow) with the draw segments should be emphasized (Figure 1, position B to position C).[11] Torso rotation toward the side of the draw segment should occur at the same time as the upper extremity movement to maximize energy transfer up the kinetic chain. (Figure 1, position A to position C).[11] Mann and Kearney[11] refer to this “push-pull sequence” as ideal for forward boat propulsion. This account is a description of the stroke in Olympic flatwater kayakers. Considering the elite level of these kayakers, this description was considered proper technique, and deviation from this as faulty mechanics. Anecdotally, common faults during the kayak stroke are the lack of push phase (initiating the propulsion phase by the pulling motion on the draw side) and weak or noncontributory torso rotation.[12]

A. Paddle Water Association B. Paddle Shaft Vertical C. Paddle Water Dissociation

Figure 1. The Forward Stroke

1.2.2 Bilateral Comparison

The forward kayak stroke is used to propel the kayak in a straight direction and the most effective means to accomplish this is through symmetric bilateral motion. However, it has been reported that kinematic and force asymmetries occur in healthy kayakers when comparing strokes bilaterally.[10, 11] Bilateral differences have been shown for percentage of stroke duration in water, time from paddle water entry to paddle vertical, time from paddle vertical to paddle water exit, peak force, and force-impulse. The paddle blades are not aligned with one another but are offset. In kayak racing the blades are offset by 90°.[11] The motion of the arm used to properly place the offset blade in the water has been hypothesized to contribute to the bilateral asymetry.[11] The motion required to change the blade position requires a "control" hand and an "off" hand. The control hand maintains grip of the paddle the entire stroke while the off hand loosens the grip to allow rotation of the paddle for proper blade placement in the water.[11] To date no published research has measured muscle activity while kayaking as a means to compare the control hand versus the off hand. Information regarding the activation of shoulder muscles along with kinematics in healthy and shoulder injured kayakers will add to the small knowledge base assessing kayaking biomechanics.

A pilot study was performed to assess the kinematics and muscle activation at the shoulder during the kayak stroke using an electromagnetic tracking device and electromyography (EMG). Scapular and humeral motions and muscle activity were assessed at several time points during the kayak stroke as described above. Expert whitewater kayakers (n=12) without recent history of shoulder pathology participated in the study. No differences were noted for humeral or scapular kinematics comparing control and off arm at any time point during the stroke. Additionally, no difference in mean activation of shoulder and scapular muscles was noted upon bilateral comparison for the time while the paddle was in the water. The muscles analyzed were lower trapezius, serratus anterior, latisimus dorsi, triceps, anterior deltoid, and posterior deltoid. Muscle activity was compared using the six time points during the stroke during four phases while the paddle was in the water.

In kayakers who have shoulder pain, a significant asymmetry has been shown in force variables in bilateral comparison.[10] Kayakers with shoulder injury exhibit significantly greater asymmetry compared to uninjured kayakers in peak force as measured on a kayak ergometer.[10] Additionally, kayakers with torso injury exhibit greater asymmetry in bilateral comparison when assessing peak force and force-impulse on a kayak ergometer. However, this difference failed to reach statistical significance.[10] With evidence showing a bilateral difference in force measures in injured participants and conflicting evidence whether or not kinematic asymmetry exists in healthy kayakers, investigation into the kinematics and muscle activation during the kayak stroke is warranted.

1.3 PHYSICAL CHARACTERISTICS

1.3.1 Shoulder Strength

Kayaking is a bilateral sport.[3, 10, 11] Propulsion of a kayak uses coordinated contractions of the muscles of the torso and shoulder complex. To facilitate propulsion of the kayak it would be expected that kayakers would exhibit equal strength bilaterally.

Scapular muscle strength and coordinated scapulohumeral movement is vital to efficient movement of the upper extremity as the scapula acts as a base for humeral movement.[13] If strength imbalances are present around the scapula, humeral motions may be altered leading to pathology.[14-16] Scapular protraction:retraction strength ratios have been assessed in a limited number of studies.[15, 16] Cools et al[15] report that for healthy shoulders in non-overhead athletes a ratio of around one (protraction:retraction) is to be expected. In participants with shoulder pathology (clinical signs of impingement) the ratio decreases to less than one (0.84-0.94) which was due to decreased protraction strength.[16]

The main function of the rotator cuff muscles is to act synergistically to compress the humeral head into the glenoid for stability and control. Rotator cuff strength is often measured and compared as a ratio of external:internal rotation strength.[17-21] Commonly, external rotation strength is less than internal with a ratio of 0.67-0.77 in non-athletic populations.[18] Baseball players ratios have been reported to be between 0.61 and 0.70.[17, 19-21] These studies show that this ratio is lower due to increases in internal rotation strength. Swimmers' strength ratios have been shown to have values between 0.53-0.65 external:internal rotation.[22] Tennis players tend not to differ greatly from non-athletic populations with strength ratios between 0.67-0.77.[18] As is apparent from the above findings, comparing external:internal rotation strength ratios are sport and demand specific and no data is available assessing kayakers for either external:internal rotation or protraction:retraction strength ratios. Comparison between kayakers with and without shoulder pathology may allow insight into shoulder strength differences associated with shoulder pathology in kayakers.

1.3.2 Torso and Shoulder Flexibility and Posterior Shoulder Tightness

Torso rotation is a crucial component to kayak propulsion during the forward stroke.[4, 10, 11] Deficits in torso rotation range of motion have the potential to contribute to injury if the shoulder is functioning through a greater range of motion than usual to compensate for torso rotation range of motion deficits.[23] Flexibility assessment of torso rotation range of motion will aid in determining if range of motion deficits proximally are associated with shoulder pain in kayakers.

Alterations in shoulder flexibility have been linked to shoulder pathology in many athletic populations.[17, 24, 25] Specifically humeral rotation range of motion plays a large role in injuries of the glenohumeral joint.[24, 26] Deficits in range of motion stemming from capsular contracture may lead to an altered point of contact between the humerus and glenoid thus creating altered force distribution and pain with repeated use.[27] As the glenohumeral joint capsule adapts to demands placed upon it, specific alterations in shoulder range of motion may manifest.[14, 28, 29] Flexibility assessment of all motions at the shoulder may be beneficial in determining the relationship between shoulder pain in kayakers and alterations in range of motion.

Posterior shoulder tightness has been connected with decreases in humeral internal rotation range of motion and has been implicated in several pathologies.[14] Specifically, overhead athletes with internal impingement and individuals with subacromial impingement have significant increases in posterior shoulder tightness.[14, 24, 25] During humeral elevation in all planes, participants with posterior shoulder tightness have also been identified as having increased superior and anterior humeral head position.[30] This suboptimal position has been associated with subacromial impingement.[30-32] Assessment of posterior shoulder tightness in a group of kayakers may lead to a greater understanding of the stresses involved with the shoulder pathologies seen in this sport.

1.3.3 Scapulohumeral Kinematics during an Elevation Task

The relationship between scapular and humeral motion has been described in detail in several populations.[32-40] Some pathological populations that have undergone evaluation include participants with rotator cuff tears, subacromial impingement, internal impingement, and shoulder instability.[32, 36, 38, 39, 41, 42] Additionally participants have been tested under various conditions of fatigue and in different seated postures.[34, 35, 40, 43] This wealth of information has provided a large body of knowledge regarding normal and abnormal scapulohumeral kinematics. Overhead athletes have received attention as sport specific movements have resulted in alterations in scapulohumeral kinematics during elevation tasks.[37] It was found that in healthy throwers scapular protraction, upward rotation, and internal rotation were different than compared to control participants during a standardized task. It is hypothesized that these changes are specific to throwers and are a natural adaptation to the sport demands.[37] Assessment of scapulohumeral kinematics in kayakers with and without shoulder pain will allow an understanding of the scapular motions present in this group.

1.4 ERGOMETRY

Ergometers are widely used as a means for training and research when environmental conditions prohibit specific equipment use. Examples of sports that use ergometers for training include cycling, running, rowing, swimming, cross-country skiing, and kayaking. Several studies have compared the ergometer performance to the actual physical performance for both biomechanical and physiological variables.[44-47] All of these studies have concluded that ergometers provide both a biomechanical and physiologic representation of the sports performance studied (rowing, kayaking, and cycling).

There has been little investigation assessing kayaking performances on water versus an ergometer. Van Someren et al[47] focused on physiological variables and showed no significant differences between the kayak ergometer and flatwater kayaking on water performance for VO_2 max, peak work, distance traveled, heart rate, and respiration rate. Begon et al[48] investigated phase duration, pelvic rotation, and upper torso rotation between a kayak ergometer and while kayaking on the water at a constant rate. These authors found no significant difference between the two conditions. They do not report any kinematic difference yet state that, obvious unchangeable differences will exist, such as boat instability on the water and visual displacement perception.[48]

1.5 SUMMARY

Improper forward stroke kinematics have been implicated in shoulder pathology in kayakers.[3] Sub-optimal physical characteristics have also been considered to be associated with injuries in many overhead athletes and therefore may contribute to injuries in kayakers. Kayaking with faulty mechanics may produce undue stress to the soft tissues and joints while kayaking. The combination of improper stroke mechanics with altered strength and flexibility while kayaking may lead to shoulder pain in kayakers. Thus, the current study proposes to investigate kayak forward stroke mechanics and physical characteristics in kayakers with and without shoulder pain to gain insight into potential contributors to injury in kayakers who have shoulder pain.

1.6 STATEMENT OF PURPOSE

The current study proposed to investigate 3D torso and scapulohumeral kinematics and muscle activation patterns of the kayak forward stroke while kayaking on a kayaking ergometer. Scapulohumeral kinematics during a standardized elevation task, shoulder and scapular strength, shoulder and torso flexibility, and posterior shoulder tightness were assessed. Thirty-two (32) kayakers participated in this study, 16 kayakers with shoulder pain were compared to 16 kayakers without shoulder pain, matched on gender and ability. Intra-participant comparisons also took place between the involved and uninvolved shoulder in the 16 injured participants.

1.7 SPECIFIC AIMS AND HYPOTHESIS

Specific Aim 1: Determine if alterations in humeral and scapular position and orientation exist at various time points during the paddle stroke in 32 whitewater kayakers with and without shoulder pain. Comparisons were made between 16 whitewater kayakers with shoulder pain and 16 kayakers without shoulder pain, using a 3D motion analysis system. Comparisons were also made between the involved and uninvolved side. The time points that were assessed during the paddle stroke were paddle water association, paddle shaft vertical, paddle water dissociation during the water and the air phase of the stroke.

Hypothesis 1: It was hypothesized that kayakers with shoulder pain would exhibit altered humeral and scapular positions and orientations. Specifically, participants with shoulder pain would exhibit decreased humeral elevation, scapular upward rotation, posterior tilting, and protraction, during paddle shaft vertical on the top hand when compared bilaterally and to control participants. It was also hypothesized that no differences would exist between the uninvolved shoulder in the pain group and the matched shoulder.

Specific Aim 2: Determine if differences in torso kinematics exist at various time points during the paddle stroke in 32 whitewater kayakers with and without shoulder pain. Comparisons were made between 16 whitewater kayakers with shoulder pain and 16 kayakers without shoulder pain, using a 3D motion analysis system. Comparisons were also made between the involved and uninvolved side. The time points assessed were paddle water association, paddle shaft vertical, paddle water dissociation during the water and the air phase of the stroke.

Hypothesis 2: It was hypothesized that kayakers with shoulder pain would exhibit decreased torso rotation during paddle water association and paddle water dissociation when compared bilaterally and to control participants. It was also hypothesized that no differences would exist between the uninvolved side in the pain group and the matched side.

Specific Aim 3: Determine if muscle activity, as determined by mean amplitude of EMG during four phases of the kayak stroke, is different in 32 whitewater kayakers with and without shoulder pain. Comparisons were made between 16 whitewater kayakers with shoulder pain and 16 kayakers without shoulder pain, using a portable EMG unit. Comparisons were also made between the involved and uninvolved side. The muscles tested were triceps, anterior deltoid, posterior deltoid, serratus anterior, latisimus dorsi, and lower trapezius.

Hypothesis 3: It was hypothesized that kayakers with shoulder pain would exhibit decreased activation of the triceps, serratus anterior, lower trapezius, and anterior deltoid bilaterally with increased activation of posterior deltoid and latisimus dorsi bilaterally during the push portion of the stroke compared to control participants. It was also hypothesized that no differences would exist between the uninvolved shoulder in the pain group and the matched shoulder.

Specific Aim 4: Determine if differences in scapulohumeral kinematics exist during a standardized elevation task in the scapular plane in 32 whitewater kayakers with and without shoulder pain. Comparisons were made between 16 whitewater kayakers with shoulder pain and 16 kayakers without shoulder pain, using a 3D motion analysis system. Comparisons were also made between the involved and uninvolved side in the pain group, between the involved shoulder and control match, and the uninvolved shoulder and control match.

Hypothesis 4: It was hypothesized that kayakers with shoulder pain would exhibit altered scapulohumeral kinematics. Specifically, kayakers with shoulder pain would have decreased scapular upward rotation and posterior tilting at 0°, 30°, 60°, 90° and 120° of elevation compared bilaterally and to control participants. It was also hypothesized that no differences would exist between the uninvolved shoulder in the pain group and the matched shoulder.

Specific Aim 5: Determine if alterations in humeral external:internal strength ratios exist between 32 whitewater kayakers with and without shoulder pain. Comparisons were made between 16 whitewater kayakers with shoulder pain and 16 kayakers without shoulder pain, using an isokinetic strength testing device. Comparisons were also made between the involved and uninvolved side in the pain group, between the involved shoulder and control match, and the uninvolved shoulder and control match.

Hypothesis 5: It was hypothesized that the kayakers with shoulder pain would exhibit lower external:internal rotation strength ratios on the involved side when compared bilaterally and to control participants, resulting from of decreased external rotation strength. It was also hypothesized that no differences would exist between the uninvolved shoulder in the pain group and the matched shoulder.

Specific Aim 6: Determine if alterations in scapular protraction:retraction strength ratios exist between 32 whitewater kayakers with and without shoulder pain. Comparisons were made between 16 whitewater kayakers with shoulder pain and 16 kayakers without shoulder pain, using an isokinetic strength testing device. Comparisons were also made between the involved and uninvolved side in the pain group, between the involved shoulder and control match, and the uninvolved shoulder and control match.

Hypothesis 6: It was hypothesized that the kayakers with shoulder pain would exhibit lower protraction:retraction strength ratios on the involved side when compared bilaterally and to control participants, resulting from decreased protraction strength. It was also hypothesized that no differences would exist between the uninvolved shoulder in the pain group and the matched shoulder.

Specific Aim 7: Determine if differences in torso rotation range of motion exist between 32 whitewater kayakers with and without shoulder pain. Comparisons were made between 16 whitewater kayakers with shoulder pain and 16 kayakers without shoulder pain, using an electromagnetic tracking device. Comparisons were also made between the involved and uninvolved side in the pain group, between the involved shoulder and control match, and the uninvolved shoulder and control match.

Hypothesis 7: It was hypothesized that the kayakers with shoulder pain would exhibit decreased torso rotation range of motion on the involved side compared bilaterally and to control participants. It was also hypothesized that no differences would exist between the uninvolved shoulder in the pain group and the matched shoulder.

Specific Aim 8: Determine if differences in shoulder range of motion and posterior shoulder tightness exist between 32 whitewater kayakers with and without shoulder pain. Comparisons were made between 16 whitewater kayakers with shoulder pain and 16 kayakers without shoulder pain, using a digital inclinometer. Comparisons were also made between the involved and uninvolved side in the pain group, between the involved shoulder and control match, and the uninvolved shoulder and control match.

Hypothesis 8: It was hypothesized that the kayakers with shoulder pain would exhibit decreased shoulder range of motion and increased posterior shoulder tightness on the involved side compared bilaterally and to control participants. It was also hypothesized that no differences would exist between the uninvolved shoulder in the pain group and the matched shoulder.

2.0 REVIEW OF THE LITERATURE

Shoulder girdle injuries constitute a large proportion of injuries seen in whitewater kayakers, due to the high repetition and demands placed upon the shoulder.[3, 6-9] Like many dynamic sport activities, the forward kayak stroke requires precise, rapid movement of the shoulder to propel the kayak in the intended direction. The shoulder has been shown to be the most commonly injured area in surveys of competitive and recreational kayakers.[6, 7, 9] While there is some understanding of the injuries sustained by whitewater kayakers, there is a large void in the investigation of the mechanisms of these injuries. An understanding of the shoulder and torso motions associated with the kayak forward stroke, along with the physical characteristics of the shoulder and torso, is needed in order to reduce the risk of injuries in this population.

2.1 INJURIES IN WHITEWATER KAYAKERS

Several authors have used questionnaires as a means to assess the injury types and their severity that occur in whitewater paddlers, which includes kayakers and canoeists.[6-9] Krupnick et al[6] submitted questionnaires to all athletes attempting to qualify for the 1996 Olympic team for whitewater slalom kayaking, with 54 of the participants responding. The average injury occurrence for competitive slalom athletes was 0.46 injuries per year.[6] The most frequent type of injury was classified as “sprain” or “tendonitis”, which accounted for 54% of the orthopedic type injuries.[6] The most common location of injury was the shoulder, which accounted for greater than 20% of the injuries.[6] These competitive athletes likely have a greater number of exposures to whitewater than recreational participants, therefore these findings are applicable to this population specifically.

Schoen and Stano[7] created a questionnaire which divided injuries into two categories, acute or chronic. Self-reported injury profiles were created for 319 whitewater paddlers (primarily non-competitive). The injury occurrence for the recreational whitewater paddling group was 0.29 injuries per year.[7] The average number of acute injuries was 1.2 injuries per participant and 0.9 injuries of chronic nature per participant since the inception of their whitewater participation.[7] This study also subdivided injuries per 1000 river days (exposures). This equated to 4.5 injuries per 1000 river days for paddlers, which is higher than downhill skiers whose injury rates have been reported to be 3.2 injuries per 1000 days skiing.[7] For both acute and chronic injuries, the shoulder and upper arm were the most common location of injury (30% and 26% respectively).[7] Fiore and Houston[8] also collected information regarding injuries in 392 recreational whitewater kayakers. Their results were similar to the results of Schoen and Stano[7], with 0.20 injuries per person per year on average.[8] These authors report the most common type of injury to be split between abrasion and tendonitis.[8] As with the other reports, the most common injury location was the upper extremity (61%) with nearly half of these occurring at the shoulder.[8]

While self reported injuries in kayakers are helpful in determining trends of injury type and location, they do not provide true diagnosis of the type of injury. In a study by Hagemann et al,[3] kayaking shoulder injuries were evaluated by range of motion assessment, clinical tests of shoulder integrity, and MRI in 52 marathon kayakers with and without self reported shoulder injury.[3] Marathon kayaking differs from whitewater in that these are endurance events which take place on flatwater, whereas whitewater rivers have large waves and fast currents.

Comparison to the current study will be made however, as the motions required for boat propulsion are similar. Participants were included in the study if they had been participating in kayaking for seven or more years and had recently completed at least one marathon kayak race (>120 km).[3] Approximately half of the kayakers had some clinical signs of shoulder pathology (subjective pain, decreased range of motion, or positive clinical signs) and 52% were noted to have pathological shoulders as detected on MRI.[3] Interestingly, 41% of the participants who had anatomical signs of pathology on MRI reported no symptoms of shoulder injury.[3] Additionally, the authors demonstrated that kayaker's age, years kayaking, and number of endurance races completed did not significantly correlate to symptoms or pathology as noted on MRI or by clinical exam.[3] MRI findings showed the most common pathological findings to be acromioclavicular joint hypertrophy and acromial/clavicular spurs associated with subacromial bursitis, supraspinatus and biceps degeneration.[3]

2.2 SHOULDER INJURY MECHANISMS

As reported above, epidemiological research shows the majority of injuries sustained in whitewater kayakers are concentrated at the shoulder.[3, 7, 8] Conditions such as rotator cuff tendonitis, biceps tendonitis, subacromial bursitis, and dislocation are common among kayakers.[3] Of these injuries rotator cuff tendonitis, biceps tendonitis, and subacromial bursitis have all been associated with decreased subacromial space.[32, 36, 41] The supraspinatus tendon, subacromial bursa, and the long head of the biceps tendon are the three major structures that occupy this region and are at risk for injury if there are decreases in subacromial space.[32] Maintenance of the subacromial space allows for these structures to function normally.

Subacromial impingement is a mechanical narrowing of the subacromial space, which results in pinching of the subacromial structures between the humeral head and the inferior portion of the coracoacromial ligament, acromion, or coracoid process.[49] Subacromial impingement has been associated with suboptimal scapulohumeral kinematics which do not maintain subacromial space.[32, 36, 50] Patients with subacromial impingement often present with pain during humeral elevation, which tends to magnify between 60° and 120° of humeral elevation.[32] This is commonly known as the "painful arc".[32] Assessment of scapulohumeral kinematics using an electromagnetic tracking device in participants diagnosed with subacromial impingement has shown several scapular motions that differ from participants without signs of impingement (during humeral elevation).[32, 36, 41] Decreases in scapular upward rotation, anterior tilting, and elevation are common findings in participants with subacromial impingement, particularly at angles greater than 90°.[32, 36, 41] All of these kinematic alterations are associated with a decrease in subacromial space. During normal scapulohumeral motions, movement of the humerus coincides with movement of the scapula in attempt to maintain subacromial space and optimize the length tension relationship of the muscles attached to both segments.[50, 51] If aberrant scapulohumeral kinematics exist in kayakers, the potential for injury could be great. Humeral elevation during the kayak stroke tends to be less than 90°.[52] However, the potential for injury in kayakers related to suboptimal scapulohumeral kinematics will likely be greater than non-overhead athletes due to the large numbers of strokes taken while kayaking.

Rotator cuff injury also may occur from repetitive tensile loading while kaykaing.[3, 7, 8] As the main function of the rotator cuff is to compress the humeral head in the glenoid, injury may occur to these tendons from repeated stretching under contractile load, causing micro trauma.[53, 54] The micro trauma leads to inflammation and pain, which imparts reflexive inhibition to these muscles.[53, 54] If the rotator cuff muscles are painful and have decreased activation, this facilitates decreased compression of the humeral head in the glenoid. Subsequent translation of the humeral head superiorly may facilitate mechanical pinching of the subacromial structures, thus multiplying the existing inflammation with mechanically induced inflammation. Assessment of MRI's of kayakers with shoulder pain reveal infrequent spatial restrictions of the subacromial space and minimal physical damage to the rotator cuff musculature, suggesting overuse as the main culprit causing shoulder pain.[3] Epidemiological studies support this notion, with significant correlations between overuse injuries and increased number of exposures.[7, 8] These results may be specific to kayakers, as the motions associated with the kayak stroke are unique.[3] It has also been suggested that improving paddling technique can decrease shoulder injuries.[8] Facilitating torso rotation, in addition to shoulder motion, for boat propulsion is one way to improve technique.[12] Using the torso, along with the shoulder, for propulsion decreases stress on the shoulder and allows for effective transfer of energy along the kinetic chain.[4, 12]

Alterations in muscle strength or muscle strength imbalance have also been implicated in shoulder injury in kayakers.[10, 55] Comparison of paddle force generation symmetry was performed on a kayak ergometer, measuring peak force bilaterally in kayakers with shoulder pain.[10] This was done indirectly, through the use of kayak ergometer output, which represents the force applied by the shoulder and torso for each side independently. The authors found that decreased force was applied through the injured side.[10] This may be due to asymmetric paddling mechanics which lead to injury, or indicative of a side-to-side strength imbalance leading to shoulder injury.[10] Isolated isokinetic strength imbalances have not been evaluated in kayakers.

2.3 KINEMATICS DURING THE KAYAK STROKE

To date, few studies have assessed the motion of the forward kayak stroke.[11, 48] Mann and Kearney[11] used cinematography while kayaking on the water to assess the biomechanics of the kayak stroke in Olympic flatwater kayakers. They describe the kayak stroke as having six time points, three occurring while the paddle blade is in the water and three with the blade in the air.[11] This study defined several biomechanical components of the kayak stroke, including stroke phase and its velocity and acceleration components. Paddle-water association is the time point where the paddle enters the water. Paddle shaft vertical is the point in time where the paddle is on the side of the kayaker, perpendicular to the plane of the water. Paddle-water dissociation is the time point when the paddle blade exits the water. The three time points during the air phase correspond to the three time points on the contralateral limb. As the blade exits the water on one side, the paddle on the other side is prepared to enter the water. Thus for one stroke, starting on the right side, the sequence of time points during the paddle stroke is as follows: right paddle-water association, right paddle shaft vertical, right paddle-water dissociation, left paddle water association, left paddle shaft vertical, and finally left paddle water dissociation.

Begon et al[48] used a five camera system to compare kayaking on the water to kayaking on an ergometer in a case study. These authors used the time points described by Mann and Kearney[11] and assessed only the in-water phases of the kayak stroke. The authors assessed phase duration of the stroke, upper torso rotation, and pelvic rotation in-water on the ergometer. They reported no difference in phase duration between the two conditions, nor any difference in upper torso rotation. They note, however, large discrepancies with pelvic rotation between the conditions. This is attributed to the motion of the boat underneath the participant which is not replicated on a kayak ergometer. The authors state that a kayak ergometer closely replicates kayaking kinematics on the water, except for factors which cannot be created with this type of ergometer, such as boat instability in the water and visual displacement perception while moving in the kayak.[48]

2.4 BILATERAL COMPARISON OF THE FORWARD KAYAK STROKE

Another important aspect described by Mann and Kearney[11] is the bilateral asymmetry in stroke phases between the "control" arm and the "off" arm. The control arm is defined as the arm which the hand does not release grip of the paddle during any phase of the stroke.[11] Conversely, the "off" arm will allow paddle shaft rotation for blade entry on the opposite side.[11] The authors theorized the asymmetry to be related to the "feather" of the paddle shaft, which is the amount of offset of the blades on either end of the paddle. Feathers are measured and referenced to as degree offsets and range from 0º to 90º. If the blades are in the same plane as each other this is referred to as a 0º feather. The most common whitewater offsets are between 30º and 60º. The paddles used in kayak racing are usually 90º to give the least wind resistance during the air phase. While the authors describe many parameters which differ when comparing one side to the other (percent total stroke, percent time in water, percent time entry to vertical, and percent time vertical to exit) none of these reached significance, likely due to the small sample size in the study (n=9).[11]

Lovell and Lauder[10] have also reported bilateral asymmetry in the kayak stroke between upper extremity injured, torso injured, and uninjured flatwater kayakers. Comparisons were made using a K1 kayak ergometer. Peak force and force-impulse were analyzed. The upper extremity injured group showed significantly greater asymmetry for peak force compared to the uninjured group.

A pilot project was undertaken by the investigator of the current study to quantify kayaking shoulder kinematics on an ergometer, using an electromagnetic tracking device. This project included twelve expert (class V) whitewater kayakers without shoulder pain or self reported injury in the previous six months. Participants were asked to paddle on the ergometer at a self-selected pace for ten minutes. The first ten strokes during the 3rd minute were used for analysis. In an attempt to evaluate their normal stroke mechanics, participants were not aware when data collection was occurring. Comparisons were made bilaterally at modified time points based on the description of the kayak stroke by Mann and Kearney.[11] The modified time points were based on kinematics of the humerus, versus paddle position in the water, as testing was performed using an ergometer. The kinematic time points were determined by the position of the receivers of the electromagnetic tracking device on the humerus in relation to the global coordinate system (GCS). The x-axis of the GCS is directed medial/lateral (positive to the right), the y-axis is directed vertically (positive pointing superior), and the z-axis is directed anterior/posterior (positive pointing backward). Therefore, paddle water association was defined as the point where the ipsilateral humeral receiver was positioned most anterior (minimal z-axis position). Humerus position is most anterior at this point in attempt to reach forward to place the paddle in the water to initiate stroke.[12] Paddle shaft vertical was defined as the point with greatest vertical difference (along the y-axis) for the humeral receivers. Having the humeral receivers at the greatest distance vertically from one another ensures that the paddle is vertical because the paddle-arm component acted as one segment. As the paddle is vertical, this position ensures the difference in humeral separation vertically is maximal. Paddle water dissociation was defined as the point with minimal difference along the y-axis for the humeral receivers. At this time the paddle was horizontal as it is taken out of the water to initiate the stroke on the opposite limb.

Scapular and humeral kinematics were compared bilaterally during the time points described above. Specifically, scapular upward/downward rotation, internal/external rotation, anterior/posterior tilting, protraction/retraction, elevation/depression, humeral elevation and horizontal adduction/abduction were analyzed. No significant differences were found when comparing right versus left side at any corresponding time points for any of the kinematic variables.

This information demonstrates that while differences in bilateral comparison between limbs in flatwater kayakers have been shown, no difference was found in this set of expert whitewater kayakers while paddling on a kayak ergometer.

2.5 ELECTROMYOGRAPHY OF THE KAYAK STROKE

Measurement of muscle activity during athletic tasks is commonly studied in attempt to understand the contribution of specific muscles to sport specific actions.[56-61] Knowledge of muscle activity during sporting tasks allows rehabilitation and training programs to be specifically designed to target the muscles used. Comparison of muscle activity between injured and healthy participants allows identification of deficits in muscle activity related to specific pathologies.[56, 60]

Trevithick and colleagues[62] performed a study on skilled recreational kayakers without pathology in order to analyze the consistency of muscle activity of eight shoulder muscles during the kayak stroke. Consistency of muscle activity was chosen for analysis as it was felt this variable would best represent the repeatability of muscle activation patterns across participants.[62] The muscles analyzed included subscapularis, supraspinatus, infraspinatus, serratus anterior, rhomboid major, latisimus dorsi, middle deltoid, and upper trapezius, on the dominant arm only.[62] The kayak stroke was broken down into three phases (two phases occurred when the paddle was in the water and one in the air). Consistent muscle activity (correlations greater than 0.50) was found for upper trapezius, supraspinatus, serratus anterior, rhomboid major, and latisimus dorsi, while the paddle was in the water.[62] While the paddle was in the air, activities of the upper trapezius and supraspinatus were found to be consistent.[62] These authors report that the latisimus dorsi is the primary mover of the kayak as this muscle was the only consistently active muscle during both phases of the stroke while the paddle was in the water.[62] This is logical, considering one of the main actions of the latisimus dorsi is humeral extension.

In the pilot study, completed by the investigator and described previously, muscle activity (mean activation) of the anterior deltoid, posterior deltoid, serratus anterior, latisimus dorsi, lower trapezius, and triceps were measured bilaterally during a kayak ergometer performance. These muscles were chosen as they are prime movers of the scapula and humerus, which were speculated to be involved with the kayak stroke. As described previously, four phases of the kayak stroke were analyzed. The first phase was from paddle water association to paddle shaft vertical. The second phase was from paddle shaft vertical to paddle water dissociation. The third and fourth phases correspond to the same phases on the contralateral side. Muscle activation was expected to be greatest during the phases chosen for analysis as resistance would be applied through the paddle during these times, and these phases constitute greater than 90% of the time for one stroke. As described previously, proper kayaking technique first requires pushing by the thrust segments, followed by pull from the draw segments.[11] Therefore, during the first and third phase the thrust segments should be pushing the blade; conversely during the second and fourth phases, the draw segments should be pulling the blade, when assessing bilaterally.[11] Muscle activity was compared to determine if differences exist when comparing bilaterally. During all phases of the kayak stroke, no difference in activity was noted. This information, along with the kinematic data from the same investigation, has shown that for healthy expert whitewater kayakers no difference in side-to-side kinematics or muscle activity exists while paddling on a kayak ergometer. Comparison of shoulder muscle activity in healthy and pathological kayakers helped to determine if differences exist in a shoulder injured group while kayaking.

2.6 PHYSICAL CHARACTERISTICS

2.6.1 Shoulder Rotation Strength

Kayakers take up to 200 strokes during a slalom race which are contested over only 2-3 minutes.[63] During kayak marathon races, it has been reported that greater than 8,000 strokes can occur over a two hour period.[4] Due to the high repetitions of strokes, shoulder strength may be an important component of maintaining joint stability during this task. It has been reported that maximal muscle strength plays a major role in providing functional stability at the shoulder.[64] This was reported through shoulder modeling in which the rotator cuff muscles limited translation of the humeral head during throwing.[64] Shoulder internal and external rotation strength is a highly studied area in upper extremity athletes.[18-21, 65, 66] Baseball players have received great attention in shoulder strength, as the demands of the shoulder during throwing are great. It is reported that pitchers can reach velocities greater than 7000º/second at the shoulder while throwing. However, the use of upper extremity motion in baseball players is not as frequent as in kayakers.[67] In comparison, data from the pilot study shows that kayaking kinematics at the shoulder occur near 45º/sec. Many authors have reported strength ratios of humeral external:internal rotation at the shoulder.[17-21] Comparison among these studies is difficult due to the variety of speeds and protocols used for comparison. The range of values reported for external:internal rotation strength in these studies was 0.55-0.70.[18, 21] All authors noted internal rotation strength to be greater than external rotation strength.

Codiene at al[18] compared four groups of athletes for humeral external:internal rotation strength ratios (peak torque) at three speeds (60º/sec, 180º/sec, and 300º/sec) at the dominant shoulder. The four groups of participants studied were baseball players, tennis players, runners, and non-athletes.[18] These authors report that runners had values similar to non-athletes, with external:internal rotation varying from 0.67-0.77.[18] Shoulder rotation strength does not play a large role in running, which is likely why these groups had similar values. Tennis players had lower strength ratios than both runners and non-athletes. The external:internal strength values were all near 0.67.[18] Baseball players' values were less than all other groups, with values ranging from 0.56-0.59.[18] Baseball players exhibited greater internal rotation strength than tennis players, as baseball requires great internal rotation strength to propel the ball at high velocities.[21] As shown by the discrepancy in the values reported for the rotational strength between the various sports, strength is likely to be sport and demand specific. Both tennis and baseball players use their upper extremity with greater repetition and force compared to runners and non-athletes. Therefore, strength values seen for upper extremity athletes do not compare to the general population or to non-upper extremity athlete values. No studies to date have evaluated shoulder rotation strength in healthy kayakers. As kayaking is an upper extremity sport, it was expected that the external:internal rotation strength values would be greater than non-upper extremity athletes and the general population.

Quantification of shoulder rotation strength in pathologic populations can also provide information regarding the association between specific injuries on strength characteristics. Comparison of studies assessing injured participants is difficult given the definitions of injury types and methods differences between studies. Few authors have compared shoulder strength in rotator cuff injured populations while attempting to assess the effect of injury. This is possible by removing pain through local anesthetic.[68, 69] Itoi el al[69] used shoulder external:internal isokinetic rotation strength ratios to show the decrement in strength on shoulders with isolated supraspinatus tears.[69] They used rotator cuff surgical patients preoperatively to assess the relationship between injury and strength. Additionally, a local anesthetic was used to determine the effect of pain on strength.[69] Internal and external rotation strength were tested at 60º/sec and 180º/sec bilaterally.[69] Both internal and external rotation strength were significantly decreased on the injured shoulder compared with the non-injured shoulder.[69] They also found that internal rotation strength in participants with a supraspinatus tear improved to the same level as controls following injection. However, external rotation strength remained significantly decreased even following pain reduction.[69] This suggests that participants with shoulder injury may present with alterations in shoulder rotation strength testing.

Bjerkefors et al[70] compared shoulder flexion/extension, internal/external rotation, and abduction/adduction strength, in a group of spinal cord injured participants before and after a ten week kayak ergometer training program.[70] The authors used a ten week kayak training program, utilizing mostly technique and interval training, on a kayak ergometer. Following the ergometer training program, there was a significant increase in all isokinetic strength measures. This shows that for a group of spinal cord injured participants, kayak ergometer training was able to provide sufficient stimulus in all three planes of shoulder motion to create improvement in strength. The authors also tested a control group of healthy individuals without spinal cord injury who did not partake in kayak training, but completed isokinetic testing ten weeks apart. They found no significant change in strength over the ten weeks in control participants. The improvements in strength for the spinal cord injured group during the training program were sufficient to match up to control participants.[70] The specific adaptations on shoulder strength are currently unknown in healthy kayakers.

2.6.2 Shoulder Protraction/Retraction Strength

Studies utilizing shoulder protraction and retraction strength are rare.[15, 16, 71] Cools et al.[71] initially assessed and reported the reliability for using the closed chain attachment device on the isokinetic dynamometer for shoulder protraction and retraction strength when assessed at 12.2 and 36.6 cm/sec. The linear velocities of 12.2 cm/sec and 36.6cm/sec were equivalent to 60°/sec and 180°/sec angular velocities. They found, that in a group of healthy participants, the test-retest reliability of the protraction and retraction strength was high (ICC 0.88-0.96).[71] These authors in a subsequent study used this method of strength testing to compare two groups of overhead athletes, one group with signs of shoulder impingement and a healthy group.[16] The group with impingement signs was included in the study based on shoulder pain in the dominant shoulder and positive findings on two clinical tests for shoulder subacromial impingement. The results of this study brought up several important points. The injured group of participants had decreased protraction/retraction strength ratios compared when compared to the control group.[16] Additionally, protraction strength in the healthy group was significantly greater than retraction strength, with a protraction:retraction strength ratio at 12.2 cm/sec of 1.18.[16] In the impingement group, athletes had strength ratios of just less than one (retraction stronger than protraction). This may imply an association between impingement and decreased protraction strength. It is not known whether this is the cause of the impingement, or an effect of this pathology. The protraction:retraction strength characteristics are unknown in healthy and pathological kayakers.

2.6.3 Shoulder Range of Motion

Specific alterations in shoulder range of motion are reported in various types of upper extremity athletes.[17, 24, 29, 72, 73] Baseball players are commonly studied as examples of upper extremity athletes. These studies report that throwers have alterations in shoulder internal and external rotation range of motion, when assessed at 90º abduction, compared to non-throwers and compared to their non-throwing shoulder.[24, 26, 29] The specific changes seen in healthy throwing athletes are believed to be based on the specific physiological demands of repetitive throwing.[24] In a study by Myers and colleagues,[24] throwers with pathologic internal impingement were compared to a group of healthy throwers. This study found that while the healthy throwers exhibited the specific changes reported by others[26, 29] (decreased internal rotation and increased external rotation), the pathologic group had significantly greater external rotation and significantly decreased internal rotation range of motion compared to the healthy group.[24] These finding suggest that while there are compensatory range of motion changes associated with repetitive throwing, there is also a limit on the healthy adaptations that occur, and once this has been reached shoulder pathology may result.[24] Tennis players have also been studied as athletes who primarily use their upper extremity. Decreases in internal rotation, leading to decreases in total rotation motion, was found in the tennis players.[66, 73, 74] Ellenbecker et al[73] used a group of elite junior tennis players and made bilateral comparisons of shoulder rotation range of motion. They found tennis players to have significant differences in total range of rotation motion between the serving shoulder and the non-serving shoulder, where the serving shoulder had decreased total rotation range of motion by nearly 10º.[73] This loss of total range of motion was primarily due to decreases in internal rotation, without coinciding increases in external rotation as seen in baseball players.[73] The authors did not describe the possible reasons for the specific alteration in rotation range of motion but concluded that the sports specific demands of tennis are related to the differences in their results.[73] The range of motion characteristics of whitewater kayakers is currently unknown.

2.6.4 Torso Rotation Range of Motion

The kinetic link model is a biomechanical model which represents the body as a linked system of interdependent segments, often working in a proximal to distal sequence to produce extremity joint motion.[23] This model is often used to describe the motions and movement patterns associated with high force actions, such as kicking a soccer ball or swinging a tennis racket. This model states that movement sequences initiated proximally for distal action are predictable and most efficient.[23] The kinetic link model is important to consider during the rehabilitation of athletes, and exercises which incorporate multiple segments of the kinetic link model should be included.[75] No information associating alteration in torso rotation range of motion with extremity injuries can be found. Therefore the kinetic link model will be used to substantiate this analysis. The kayak stroke requires coordinated effort to transfer force from hips, torso, and the upper extremity, to move the paddle in the water for kayak propulsion.[10, 12] Because torso rotation range of motion is needed for proper kayaking technique, limitations in torso motion may cause other joints to adapt by going beyond their normal contribution in order to achieve the desired range of motion during each stroke. This compensation may result in injury distal to the torso along the kinetic chain, resulting in shoulder pain. While this concept is only theoretical, it shows the potential detrimental effects of decreased torso rotation range of motion on shoulder injuries in kayakers.

2.6.5 Scapular Kinematics during a Standardized Elevation Task

The function of the scapula is to provide a stable base of support for the humerus, to allow coordinated movement of the upper extremity.[13] Assessment of 3D scapular kinematics has received much attention in the literature due to the association of altered scapular kinematics with shoulder pathology. Many authors have studied scapular kinematics with electromagnetic tracking devices in healthy and pathological participants during a humeral elevation task.[33, 35-38, 76] This has allowed a greater understanding of scapular kinematics in individuals with shoulder pathologies such as adhesive capsulitis, subacromial impingement, and internal impingement.[32, 36, 38, 77] Assessment of scapular kinematics has also been performed on participants with isolated shoulder fatigue.[40] The effect of seated posture on scapular kinematics has also been studied.[35, 40]

Ludewig and Cook[32] compared a group of overhead workers with clinical signs of impingement, to a healthy control group for scapular kinematics and EMG of several scapular muscles during a standardized humeral elevation task. They also compared weighted and un-weighted conditions to simulate the effort required during normal working tasks to determine if load would induce changes in EMG or scapular kinematics.[32] This study showed that specific alterations existed in scapular kinematics for the group of impingement participants. Specifically, the impingement group exhibited decreased scapular upward rotation below 60º of humeral elevation, increased posterior tilting and increased medial rotation when elevating, while lifting a weight vs. no weight.[32] The weighted condition also increased activity of the serratus anterior.[32]

Laudner and colleagues[77] used a matched group of overhead athletes, both with and without pathologic internal impingement, to assess scapular kinematics during an elevation task in the scapular plane. The results of this study showed that throwing athletes diagnosed with pathologic internal impingement were found to have increased scapular elevation and scapular posterior tilting during the elevation task.[77] While there is little other published work done on this pathology, they theorized the increased elevation and posterior tilting was an adaptation to avoid contact between the humeral head and the posterior-superior glenoid.[77] As previously shown, the effects of various types of injury and sports performance manifest in alterations in scapular kinematics during an elevation task. It is unknown what, if any, alteration in scapular kinematics are present in whitewater kayakers with and without shoulder injury.

2.7 ERGOMETRY

Ergometers serve to help in the scientific assessment of athletic endeavors that are difficult or impossible to test during true performance. Ergometers are advantageous for use in clinical research as the participant will be relatively stationary, which facilitates biomechanical analysis. While ergometers often closely replicate sport actions, they may not wholly represent the demands required for each sport. Environmentally prohibitive water sports (rowing, swimming, and kayaking) and cold weather sports (cross-country skiing) have been assessed through ergometry. Ergometers are also use to study running and cycling.

Rowing research has received great attention through the use of rowing ergometers, as these devices are readily available and often used by clubs and teams to train during inhospitable weather. The kinematics of rowing have been studied through the use of an electromagnetic tracking device.[78] Holt el al[78] compared rowing kinematics and force curves in elite rowers as they assessed differences in rowing kinematics over a one-hour fatiguing rowing session. There was considerable kinematic difference in technique among this group of highly trained oarsmen. Kinematic variations were seen at the initial phases after the catch and at the finish of the stroke.[78] Changes were noted for the initial force production at the beginning of the pull on the handle.[78] Increased angle of trunk flexion was also seen, at the end of a one hour session.[78] These changes are theorized to be stemming from fatigue or weakness of the trunk muscles. The authors believe that altered kinematics may impart increased load to the spinal column and leave the athlete susceptible to injury.[78]

Elliott et al[79] enrolled eight nationally ranked rowers in their study to compare rowing kinematics and blade and oar force during a 500 meter simulated session on the ergometer, and during a 500 meter rowing distance on the water at three different stroke rates. These authors found that kinematics during the catch and finish were similar between on-water rowing and rowing on the ergometer during all stroke rates tested.[79] Similarly, the authors compared force curves for the right and left side while rowing under the two conditions and found high correlations (0.97-0.99), indicating high correspondence between the conditions.[79] This study is similar in scope to the comparison of kayaking vs. kayak ergometry performed by Begon et al.[48] While kayaking on an ergometer, similar movements were noted for shoulder motion and upper torso rotation when compared to kayaking on the water.[48] Yet different kinematics are shown to exist at the pelvis, as the ergometer was unable to adequately replicate the unsteadiness of the water.[48]

2.8 METHODOLOGICAL CONSIDERATIONS

2.8.1 Kinematic Analysis using a 3D Electromagnetic Tracking Device

Electromagnetic tracking systems have been used to study analysis of movement in many functional and sport specific activities.[32, 33, 35-39, 41, 42, 44, 76, 78, 80-82] The validity of 3D motion analysis of the scapula during several functional humeral tasks was established by Karduna et al.[76] This study compared scapular kinematics through the use of a skin based system, to data collected via bone pins embedded within the scapula.[76] The authors reported good agreement in scapular kinematics between the two conditions.[76] This study consisted of a group of non-pathological shoulder participants (n=8), and one participant diagnosed with subacromial impingement. The authors reported high agreement between bone pin data and the electromagnetic tracking device for horizontal adduction, humeral rotations at 90º abduction, and elevation, in several planes at angles less than 120º of humeral elevation.[76] When the shoulder was elevated to greater than 120º, the recording from the skin sensor became incorrect due to soft tissue and muscle approximation underneath the receiver.[76] The reliability of seated posture, as in kayaking, for measuring scapular kinematics has been investigated by Finley and colleagues.[35] These authors used two seated conditions, one of upright "correct" posture, and one while "slouched" to represent increased thoracic kyphosis. Reliability was assessed using the coefficient of multiple correlation (CMC) and the root mean square error was calculated to assess intraparticipant repeatability of trials. This study found that repeatability of scapular movement for both conditions was good (CMC=0.75-0.95) and precision to be between 0.8-1.0º.[35]

The use of 3D motion analysis in sport is valuable in understanding the exact kinematic demands occurring during the activity, and also for use in inverse dynamics to determine joint forces/moments. 3D motion analysis has been applied to study sports with the use of electromagnetic tracking devices.[44, 78] Both of these studies assessed rowing mechanics, specifically spinal motion, in an attempt to determine what techniques or level of fatigue may be contributing to thoraco-lumbar pathology.[44, 78]

The International Shoulder Group (ISG), a subset of the International Society of Biomechanics, has created a standardized protocol for shoulder joint kinematics using various motion analysis methods.[81] For measurement with an electromagnetic tracking device, the described protocol places a global coordinate system essentially in alignment with the body.[81] The orientation of the GCS of axes are as follows; x-axis directed horizontal from left to right, y-axis vertically up, and z-axis horizontal from anterior to posterior. The protocol also calls for local coordinate systems defined utilizing a set of bony landmarks.[81] The electromagnetic receivers are placed on bony locations to reduce soft tissue movement and to limit impediment of motion of the LCS determination of joint motion. Additionally, an Euler angle sequence was provided to accurately represent the motions which occur around that coordinate system. For the scapula the Euler sequence is external rotation, upward rotation, and posterior tilting.[81] This

Euler sequence has been validated.[76, 82] For humeral motion, a sequence of plane of elevation, followed by elevation, and finally rotation, was utilized.[83]

2.8.2 Electromyography

The application of electromyography (EMG) in clinical research is abundant. [51, 56-59, 62, 84-96] EMG can be used to quantify activation of muscles,[51, 92] determine muscle onset times,[56, 61, 93] and quantify fatigue.[95, 96] Meskers and colleagues[97] assessed the reliability of EMG at the shoulder using surface and indwelling electrodes during a repeated resistance task. Resistance was measured by a force transducer and shown to the participant as a target force (biofeedback) in an effort to standardize contraction exertion.[97] The muscles tested included pectoralis major, anterior deltoid, posterior deltoid, teres major, serratus anterior, lower trapezius, upper trapezius, latisimus dorsi, supraspinatus, infraspinatus, and subscapularis. Intrasession reliability of integrated EMG was found to be moderate to high (less teres major) for all muscles tested (ICC= 0.69-0.84, SEM= 4.02-15.3).[97]

2.8.3 Isokinetic Strength Assessment

For clinical research, isokinetic testing is the standard for strength assessment. Isokinetic strength testing devices are capable of assessing isometric, concentric, and eccentric measures. For concentric and eccentric measures, the speed can be varied between 10º/sec - 500º/sec. For isokinetic rotational strength exercises Drouin et al[98] analyzed intersession reliability of the Biodex System 3 dynamometer and found reliability to be very high (ICC=0.99 and SEM=0.39Nm). Assessment of protraction:retraction strength requires the use of the Biodex closed-chain attachment which varies from other measures on the Biodex, in that the motion is linear. Because protraction and retraction are not angular movements, these measures were reported in cm/sec. Protraction:retraction strength testing reliability has been shown to be high (ICC=0.88-0.96, SEM=20.8-42.9N) for values of 12.2cm/sec.[71] This value correlates with a rotational torque value of 60º/sec.

2.8.4 Range of Motion Assessment

Wassinger et al[99] examined goniometric shoulder rotation range of motion in contrast to an electromagnetic tracking device in 13 healthy participants.[99] The results show an error of approximately 3º for internal and external rotation when measured in supine, with scapular stabilization. Additionally, reliability among these measures was moderate to good for internal and external rotation (ICC= 0.73-0.85, SEM=1.51-1.75º, respectively). Precision between the electromagnetic tracking device and goniometry was very high (ICC=0.94-0.98, SEM=0.90-1.02º) for external and internal rotation.[99]

Measurement of posterior shoulder tightness has been measured in the supine and sidelying positions. In a study by Myers et al[28] the reliability and precision of the sidelying and supine methods were compared using an electromagnetic tracking device.[28] This study assessed intersession and intrasession accuracy, reliability, and precision of the supine and sidelying positions for measuring posterior shoulder tightness. The amount of horizontal adduction range of motion, while manually maintaining scapular retraction, was quantified for both methods, and was compared over two sessions. Test sessions were separated by at least two days. The results of this study reveal that measurement of horizontal adduction in supine demonstrated higher reliability and validity for horizontal adduction with scapular stabilization. Similar accuracy was found for both methods.[28]

2.9 SUMMARY

Kayak propulsion requires coordinated movements of the hips, torso, and shoulders for the normal paddle stroke.[11, 12, 48] Due to the high repetitions that occur during kayaking, there is high potential for shoulder injury to occur.[4] As participation in whitewater kayaking is becoming more popular, so too are the potential injuries that may occur in the individuals participating in this sport.

Identification of the mechanisms behind shoulder injury in kayakers is difficult, as many factors may contribute to shoulder pathology. Overuse injuries are prevalent in whitewater kayakers and have been shown to exist in recreational and competitive kayakers.[6, 7] Additionally, acute shoulder injuries are common, which may be due to the dynamic nature of whitewater kayaking.[7] Kayak stroke shoulder kinematics, shoulder range of motion, and shoulder strength may all contribute to the injuries seen in kayakers. Additionally, suboptimal physical characteristics of the trunk including torso rotation range of motion may be contributors to shoulder pain in whitewater kayakers.

Understanding of the physical characteristics associated with shoulder pain in kayakers will be beneficial to identifying potential injury risk factors in whitewater kayakers. This information will also be useful to rehabilitation specialists, who treat these individuals and can be utilized for injury prevention programs. This information may also be extrapolated to aid in designing kayak specific training programs for competitive kayakers.

3.0 METHODOLOGY

3.1 DEPENDENT VARIABLES

This comparative study assessed kayakers with and without shoulder pain. The independent variables were group (shoulder pain or no shoulder pain) and limb (involved or uninvolved). See Table 1 for dependent variables.

Table 1 Dependant Variables

Measure	Dependent Variables	
Scapular Kinematics	Scapular internal/external rotation (º) Scapular upward/downward rotation (º) Scapular anterior/posterior tilt (º) Scapular protraction/retraction (º) Scapular elevation/depression (º)	@ the six time points during the kayak stroke & @ 0º, 30º, 60º, 90º, and 120º of humeral elevation during the elevation task
Humeral Kinematics	Humeral elevation (º) Humeral horizontal abduction/adduction (º)	@ the six time points during the kayak stroke
Torso Kinematics	Torso rotation (º)	@ the six time points during the kayak stroke
Muscle Activity	Anterior Deltoid (%MVIC) Posterior Deltoid (%MVIC) Serratus Anterior (%MVIC) Lower Trapezius (%MVIC) Latisimus Dorsi (%MVIC) Triceps (%MVIC)	during the four phases of the kayak stroke
ROM	Internal rotation ROM (º) External rotation ROM (º) Forward flexion ROM (º) Extension ROM (º) Abduction ROM (º) Torso rotation (º)	
Strength	ER peak torque normalized to body weight @ 60º/sec (Nm/kg) IR peak torque normalized to body weight @ 60º/sec (Nm/kg) ER: IR strength ratio @ 60º/sec Protraction peak force normalized to body weight @12.2cm/sec (N/kg) Retraction peak force normalized to body weight @ 12.2cm/sec (N/kg) Protraction: retraction strength ratio @ 12.2cm/sec	
PST	PST non-dominant - PST dominant (º)	

3.2 PARTICIPANTS

Prior to the current study the investigators performed a pilot study on 12 healthy whitewater kayakers to aid in the determination of an appropriate sample size for the current project. Assessment of bilateral scapulohumeral kinematics (upward/downward rotation, anterior/posterior tilting, internal/external rotation, protraction/retraction, elevation/depression) with a calculated effect size of 1.0 and an alpha of 0.05 (one-tail hypothesis) required 16 participants per group to show a power of 0.80. The effect size calculation for the current study is assuming a simliar difference as demonstrated in the pilot study (right vs. left) for comparison between shoulders of dominance in the healthy and the involved shoulder in pathological participants. Participants were recruited from whitewater kayaking clubs in Western Pennsylvania, West Virginia, and Ohio. Participants with shoulder pain during kayaking were asked to complete the QuickDASH and QuickDASH Sport Module (See Appendix A). Shoulder pain participants underwent a clinical exam by two trained clinicians in attempt to arrive at a clinical diagnosis. (See Appendix B). All participants were required to meet the following criteria:

Inclusion Criteria Both Groups:

1. Male or female

2. Between the ages of 18-45

3. Currently able to navigate class III or higher whitewater as per the International Scale of River Difficulty (Appendix C)

Inclusion Criteria Shoulder Pain Group:

1. Individuals who currently participate in kayaking and who have had mechanical shoulder pain in the previous year which limited their performance or ability to kayak

2. Shoulder pain was from kayaking or aggravated by kayaking

3. Shoulder pain was centered around the shoulder or shoulder girdle

4. QuickDASH score greater than 10/100[100] (Appendix A)

Inclusion Criteria Healthy Group:

1. Participants who report no history of shoulder pain in the past 1 year

2. Gender, age (±5 years), and ability matched to shoulder pain participants

Exclusion Criteria Both Groups:

1. Participants with a history of shoulder, back, or neck surgery in the past 1 year

2. Participants with history of neurological disorders

3. Knowingly pregnant females

3.3 INSTRUMENTATION

3.3.1 3D Electromagnetic Tracking Device

The MotionMonitor (Innovative Sports Training, Chicago, IL) electromagnetic tracking device consists of an extended range electromagnetic field transmitter and six receivers which are capable of measuring motion with six degrees of freedom. The extended range transmitter creates an electromagnetic field with a 12 foot radius. This electromagnetic system has a sampling rate range of 30 to 144 Hz. Kinematic data is presented in real time 3D animation and graphical data display.

The six receivers were attached to various body segments which convey the position and orientation of each receiver to a computer via hard wiring. The position and orientation error of the system has been previously established by this laboratory, with 0.003m and 0.57° respectively. Optimal accuracy of the system has been established between 0.91m and 1.20m directly in front of the electromagnetic transmitter. Therefore all data collection occurred with participants seated or standing in this region.

Distortion of the receiver position and orientation can be adversely affected by metal within the field.[101] Assessment of the distortion caused by the metal kayak ergometer was tested by analyzing a known distance between two receivers with and without the kayak ergometer in the field. The discrepancy between these conditions yielded less than 0.001m difference between these two conditions, which is less than the previously described positional error.

For shoulder research using an electromagnetic tracking device, the International Shoulder Group, a subgroup of the International Society of Biomechanics, has devised a method to standardize shoulder joint motion analysis.[82] This method utilizes an arbitrary Global Coordinate System (GCS) and a Local Coordinate System (LCS) defined by bony landmarks of the thorax, scapula, and humerus. Joint motion is described as the movement of a distal LCS with respect to a proximal LCS.[83] The GCS is based on having the x-axis horizontal (pointing laterally to the right), the y-axis pointing superior, and the z-axis horizontal (pointing backward).[82]

The MotionMonitor software uses matrix algebra to describe the rotations from one orientation to another in the form of rotation matrices.[83] These matrices are then mathematically converted into Euler angles, which describe 3D joint motion that is occurring in the electromagnetic field and are defined as three successive angles of rotation about preset (anatomic) axes.[83] The order of rotation is first about the global axis, then about the local axis and finally the second local axis.[102] Based on previous research, the order of rotational analysis is vital as different sequences may produce different angle calculations;[103] therefore the Euler sequence of scapular external rotation, followed by upward rotation, and finally posterior tilting were used.[83] For humeral motion a sequence of plane of elevation, followed by elevation, and finally rotation were utilized. [83] Karduna and associates[76] have verified the accuracy of measuring scapulohumeral motion in this manner through the use of bone pin fixed receivers. These scapular and humeral movements will be described in greater detail later in this section.

Torso rotation was defined in relation to a neutral position. Neutral was defined with the participant seated motionless on the kayak ergometer facing away (negative z-axis) from the transmitter. Torso (axial) rotation was defined as rotation of the thoracic LCS about the y-axis of the sacral coordinate system.[104]

3.3.2 Electromyography

Surface EMG signals was collected utilizing the Noraxon Telemyo Telemetry EMG System (Noraxon USA Inc., Scottsdale, AZ). This wireless EMG system utilizes eight Federal Communications Commission (FCC) approved radio bands that transmit analog signals from a transmitter worn by the participant to a remotely located receiver. Signals were passed from the Ag-AgCl pre-gelled bipolar surface electrodes (Medicotest, Inc. Rolling Meadows, IL) through leads to the frequency modulated (FM) transmitter. After amplification, the telemetry signals were then passed from the transmitter to the receiver for further amplification (for an overall gain of 1000) and filtered with a bandwidth filter (10 Hz low pass 500 Hz high pass Butterworth filter, common mode rejection ratio of 130db). Signals from the receiver were then converted from analog to digital data via Measurement Computing PCI A/D board (Measurement Computing Corporation, Norton, MA) at 1200 Hz and stored within the MotionMonitor software.

3.3.3 Biodex System 3 Isokinetic Strength Testing Device

The Biodex System 3 Multi-Joint Testing and Rehabilitation System (Biodex Medical Inc., Shirley, NY; Model #835-000) uses a special software program combining dynamometer strain gauges, potentiometers, and remote range of motion set switches, along with specific limb attachments, for clinical research, rehabilitation, and diagnostic purposes for a variety of joints and muscle groups.

At the shoulder, the Biodex System 3 is capable of measuring shoulder strength for elevation in all planes, internal and external rotation in the frontal and scapular plane, horizontal abduction and adduction, diagonal shoulder patterns and scapular protraction and retraction.

The Biodex software allows the user to set resistance and speed options to customize the motions and speeds of the testing performed. Speeds range from 0-500º/sec and the Biodex can impart up to 569Nm of resistance. Many strength variables are calculated within the software including, peak torque, peak torque per body weight, average peak torque, power, and work.

Prior to strength testing a calibration was performed as per manufacturer protocols. This requires the use of a specific calibration attachment provided by the company with a known mass of 67.8 Nm. The calibration attachment was attached to the machine and set at an angle of 0º (parallel to the ground). The calculated value was then be compared to the known mass, they were equal.

3.3.4 Digital Inclinometer

Shoulder flexion, abduction, extension, and internal and external rotation (at 90º abduction) range of motion were measured using the Saunders Digital Inclinometer (The Saunders Group Inc, Chaska, MN). The inclinometer is capable of measuring joint motion in any gravity dependant position and has an accuracy of ± 1.0º. To determine the intrasession reliability for measurement of shoulder range of motion using a digital inclinometer, the principal investigator examined shoulder motions in 15 healthy participants. The results for all motions tested were ICC= 0.892-0.978 with SEM=1.77-2.71º.[105]

3.3.5 Kayak Ergometer

The Vasa Ergometer (Vasa Inc., Essex Junction, Vermont) is a variable wind resistance ergometer with two independent flywheels for resistance. The Vasa Ergometer was designed for swimming and has been modified by the manufacturer with a seat adaptation to simulate kayaking (Figure 2). The ergometer has been further modified by the investigators with a paddle for replication of kayaking on the water. The flywheels have seven levels of resistance. The ergometer is attached to a computer which is capable of reporting time, stroke rate, power, calories used, distance, pace per 100 meters, average power, and average force per side (left or right).

Figure 2. Kayak Ergometer Setup

3.4 TESTING PROCEDURES

All participant testing occurred at the Neuromuscular Research Laboratory located at the UPMC Center for Sports Medicine. Each participant completed a University of Pittsburgh IRB approved consent form as well as had all questions answered concerning their participation in this study prior to testing. At this time participants were questioned to ensure they were eligible to participate based on the inclusion and exclusion criteria as stated above.

3.4.1 Kinematic Assessment

There were two setups for the kinematic analyses. One assessed scapulohumeral kinematics, while paddling and during an elevation task, and the other assessed torso kinematics while paddling. The setup for the electromagnetic tracking device, for measuring scapulohumeral kinematics, began with the participant standing in front of the electromagnetic transmitter. The participant started relaxed and motionless with his/her arms relaxed at their side during the digitization process. Participants were dressed to allow accessibility to bony anatomy while maintaining privacy, for men this entailed removing their shirt and for women an appropriate tank top or sports bra were worn. Participants had five receivers attached to their skin for monitoring scapular and humeral kinematics (Figure 3). The receivers were attached to the skin with double-sided tape and further secured with medical tape to minimize motion between the receiver and the skin. The receiver setup was as follows: one receiver was attached over the 7^{th} cervical vertebrae, two receivers were attached to the broad flat portion of the acromion on the scapula (approximately one-third the distance from the angulus acromialis to the acromioclavicular joint) bilaterally, and bilateral receivers were secured to the humerus (approximately midway between the angulus acromialis and the lateral humeral epicondyle) through the use of a neoprene cuff.[106]

Figure 3. Scapulohumeral Kinematic Analysis Setup

The participants then had several bony landmarks digitized by a stylus. The bony landmarks were first be marked by surgical pen for replacement accuracy. The anatomical points digitized included the medial (ME) and lateral (LE) humeral epicondyles, 7th cervical vertebrae (C7), 8th thoracic vertebrae (T8), 12th thoracic vertebrae (T12), sternoclavicular joint, acromioclavicular joint, suprasternal notch (IJ), xiphoid process (PX), anterior coracoid, most lateral dorsal point on scapula (AA), medial most portion of the scapular spine (TS), and inferior angle of the scapula (AI). Since the glenohumeral joint center (GH) is not palpable, a least squares algorithm was calculated within the MotionMonitor software to determine the point of the humerus which moved least during several short arc movements.[107] The short arc movements were passively performed by one of the investigators while stabilizing the scapula in attempt to isolate humeral motion.[107] The point determined to move least with respect to the scapula was defined as the glenohumeral joint center. The 3D representation of anatomical position and orientation had at least three non-collinear points to define vectors that were mutually exclusive within each LCS.[108] The three perpendicular vectors of each bony segment (humerus, scapula, and thorax) defined provided the location of that segment within the GCS.[108]

The setup for the electromagnetic tracking device, for measuring torso kinematics, began with the participant standing in front of the electromagnetic transmitter. The participant started relaxed and motionless with his/her arms relaxed at their side during the digitization process. Participants had four receivers attached to their skin for monitoring torso and humeral kinematics (Figure 4). The humeral receivers were collected as the kayaking time points are based off of humeral positions as described previously. The receivers were attached to the skin with double-sided tape and further secured with medical tape to minimize motion between the receiver and the skin. The receiver setup was as follows: one receiver was attached over the 7th cervical vertebrae, one receiver was attached over the first sacral vertebrae, and bilateral receivers were secured to the humerus (approximately midway between the angulus acromialis and the lateral humeral epicondyle) through the use of a neoprene cuff.[106]

Figure 4. Torso Kinematic Analysis Setup

The participants then had several bony landmarks digitized by a stylus. The bony landmarks were first marked by surgical pen for replacement accuracy. The anatomical points digitized included the medial (ME) and lateral (LE) humeral epicondyles, 7th cervical vertebrae (C7), 8th thoracic vertebrae (T8), 12th thoracic vertebrae (T12), sternoclavicular joint, , suprasternal notch (IJ), xiphoid process (PX), ASIS bilaterally, PSIS bilaterally, lateral malleolus bilaterally, and 1st sacral vertebrae (S1). Glenohumeral joint center (GH) was determined as previously described. The 3D representation of anatomical position and orientation had at least three non-collinear points to define vectors that were mutually exclusive within each LCS (figure 5 and Table 2).[108] The three perpendicular vectors of each bony segment (humerus, scapula, and thorax) defined provides the location of that segment within the GCS.[108]

Reliability of kinematic measurement in the Neuromuscular Research Laboratory utilizing this method has been previously established (ICC=0.88-0.99, SEM=0.46-2.25º).[106]

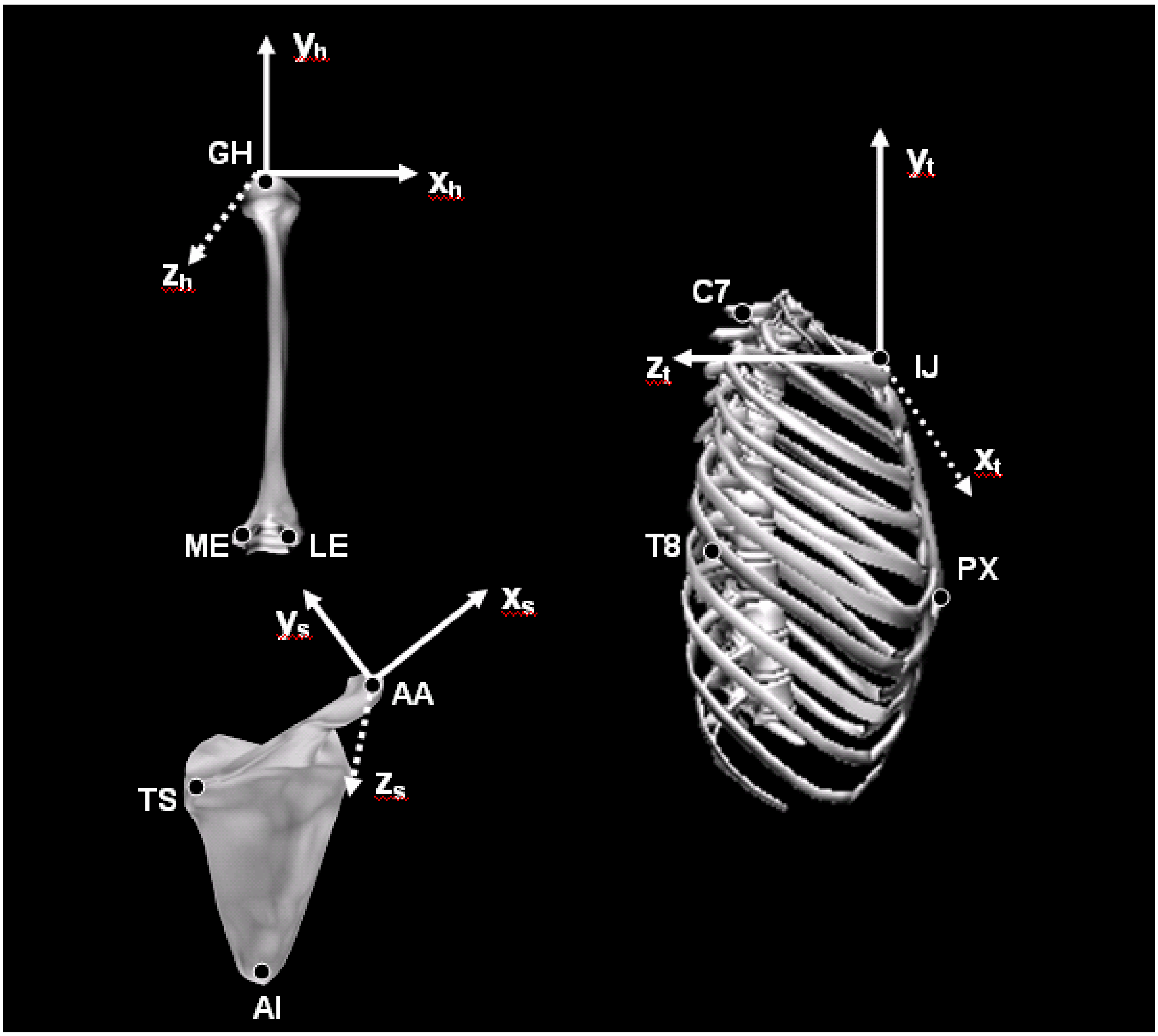


Figure 5. LCS and Anatomical Landmarks for Digitization

Table 2 Description of Local Coordinate Systems

LCS	Axis	Definition
Thorax	y_t	Vector from the midpoint of PX and T8 to the midpoint between IJ and C7
	x_t	Vector perpendicular to the plane fitted by midpoint of PX and T8, the midpoint of IJ and C7, and IJ
	z_t	Vector perpendicular to x_t and y_t
	Origin	IJ
Scapula	x_s	Vector from TS to AA
	y_s	Vector perpendicular to the plane fitted by TS, AA, and AI (scapular plane)
	z_s	Vector perpendicular to x_s and y_s
	Origin	AA
Humerus	y_h	Vector from midpoint of ME and LE to GH
	x_h	Vector perpendicular to the plane fitted by GH, ME, and LE
	z_h	Perpendicular to y_h and x_h
	Origin	GH

3.4.2 Kinematic Tasks

3.4.2.1 Kayak Task

Assessment of motion of the humerus and scapula occurred during a five minute kayaking task. Participants had a warm-up consisting of at least ten minutes on the kayak ergometer. Data collection occurred following the warm-up. Participants were seated within the zone determined to have optimal accuracy. The paddle stroke rate was regulated via a metronome, participants were asked to paddle at a stroke rate equal to 30 strokes per minute. Participants were able to acclimate to the stroke rate during the warm up period. Data was collected for 30 seconds during the 3rd minute. The participants were not aware when data collection was occurring in attempt to record their normal kayaking stroke.

A second kayak task was performed to assess torso kinematics. Participants had a warm-up following the second setup if desired, if not data collection began immediately after setup. Participants were seated within the zone determined to have optimal accuracy. The paddle stroke rate was regulated via a metronome, participants were again asked to paddle at a stroke rate equal to 30 strokes per minute. Data was collected for 30 seconds during the 3rd minute. The participants were not aware when data collection was occurring in attempt to record their normal kayaking stroke.

3.4.2.2 Elevation Task

Angular position of the scapula relative to the thorax was also collected during a standardized elevation task. Participants stood within the zone determined to have the highest accuracy. The starting position of the task had the participant with his/her hands in resting position (0º of elevation) facing forward. From this position the participant elevated both arms ten times along a guide representing the scapular plane (Figure 6). One cycle of elevation, from resting to arms overhead and back to resting position, took approximately four seconds (two seconds to reach full elevation, and two seconds to return to resting position). Time was standardized through the use of a metronome.

Figure 6. Elevation Task

All of the following kinematic variables were calculated at the six time points of the kayak stroke and at five humeral elevation angles (0º, 30º, 60º, 90º, and 120º) using the position and orientation data from the receivers. Torso rotation was not analyzed during the elevation task. Scapular orientations, (Figure 7) of internal/external rotation, upward/downward rotation, and anterior/posterior tilt, were defined as rotation about an axis perpendicular to the scapular plane (y-axis), rotation relative to the coronal plane (z-axis), and tilting about a medial-lateral axis (x-axis), respectively. The two degree of freedom motion of acromioclavicular joint (AC) with respect to the thorax LCS origin (IJ) was used to represent scapular elevation/depression and protraction/retraction. Protraction is defined by the angle of the projection of the vector from the IJ to the AC in the horizontal plane of the thorax LCS with respect to the medial/lateral thoracic axis and elevation was described as the angle of the projection of this vector onto the frontal plane of the thorax with respect to the superior/inferior axis of the thorax LCS. (Figure 8).

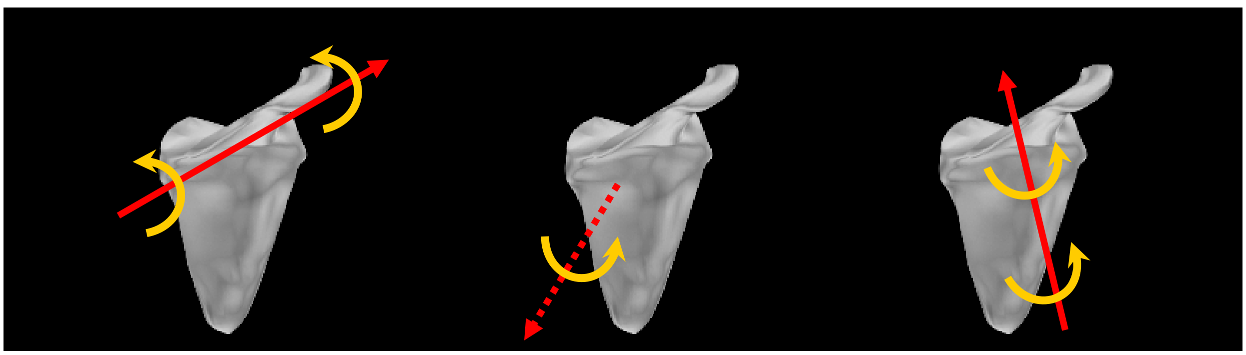
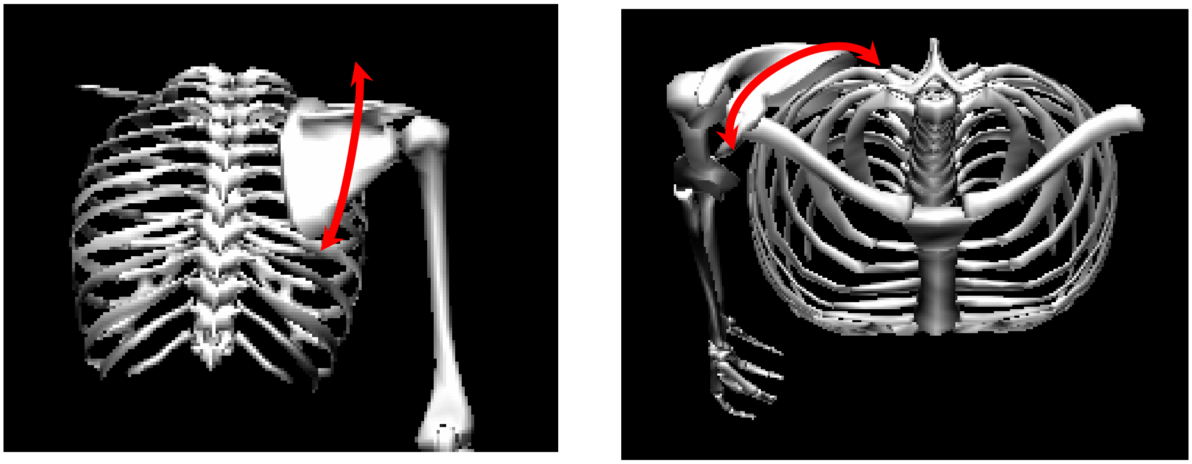


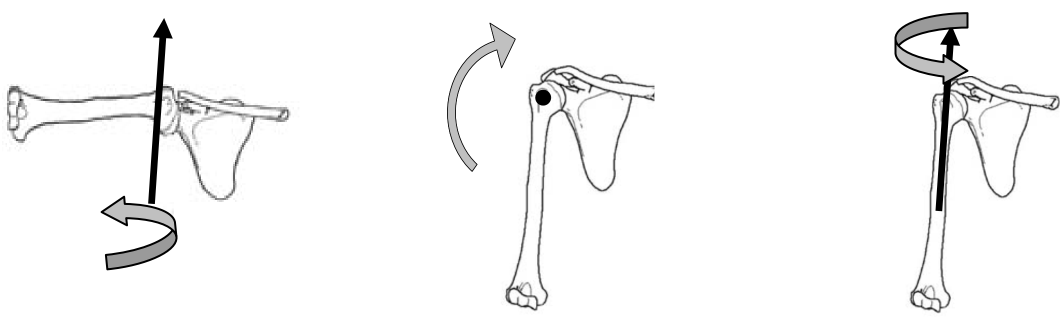
Figure 7. Scapular Orientations



Elevation/Depression Protraction/Retraction

Figure 8. Scapular Positions

Scapulohumeral rotations were defined as such: axial rotation was described as rotation of the humeral LCS about the y-axis of the scapular coordinate system with the arm elevated to 90° of humeral elevation, elevation was described as the rotation of the humeral LCS about the z-axis of the LCS of the scapular coordinate system, and finally plane of elevation was described as the rotation of the humeral LCS about the y-axis of the scapular coordinate system (Figure 9).



Axial Rotation Elevation Plane of Elevation

Figure 9. Scapulohumeral Rotations

Torso rotation (Figure 10) was defined in relation to a neutral position. Neutral was defined with the participant seated motionless on the kayak ergometer facing away from the transmitter. Torso (axial) rotation was defined as rotation of the thoracic LCS about the y-axis of the sacral coordinate system.[104] Torso kinematics were defined by a sequence of flexion, followed by lateral bending, and lastly axial rotation.[109]

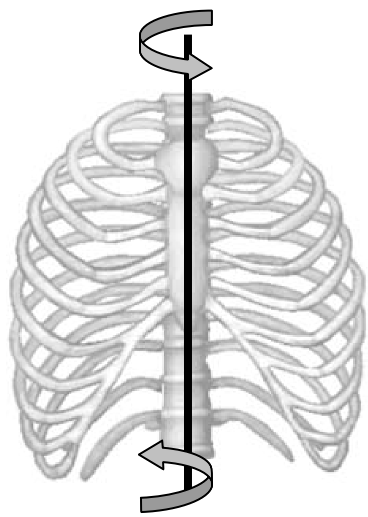


Figure 10. Torso Rotation

3.4.3 Assessment of Muscle Activity

Assessment of muscle activity occurred simultaneously with the kinematic assessment during the five minute kayaking task. The twelve muscles tested were anterior deltoid, posterior deltoid, serratus anterior, latisimus dorsi, triceps, and lower trapezius. All muscles were assessed bilaterally.

Setup for the EMG (Figure 11) included identification of all muscles through palpation and specific isolated manual muscle testing.[110] Once the location of the muscle has been identified, it was marked with surgical marker. To minimize skin electrode impedance, the area was then be prepared for surface EMG by first shaving any hair if present, rubbing the area with an emory board, and cleaning the area with a 70% isopropyl alcohol pad. Ag-AgCl surface electrodes were used for measurement of all muscles. Two surface electrodes were placed side by side with 1.0cm separating the centers of the electrode perpendicular to the orientation of the muscle fibers for all muscles tested.[111] Two ground electrodes were placed bilaterally on the olecranon process.

EMG activity during maximal voluntary isometric contractions (MVIC) for all muscles tested were recorded over a five second trial.[110, 111] Measurements of MVIC were used as the standard manual muscle testing positions for all muscles tested.[110] Muscle activity of the anterior deltoid, posterior deltoid, serratus anterior, latisimus dorsi, triceps, and lower trapezius were measured bilaterally.

Lateral View

Posterior View

Figure 11. EMG Setup

3.4.4 Strength Assessment

Shoulder protraction and retraction strength was measured using the closed chain attachment on the isokinetic dynamometer.[15] The participant was seated in the chair, with shoulder and waist straps secured to minimize extraneous movements. The closed chain attachment was positioned horizontally in the scapular plane (30º anterior to the frontal plane) at the height of the participants shoulder. The participant's elbow was maintained in extension throughout the test and motion occurred from protraction and retraction of the scapula through the arm against the handle (Figure 12). The participant was instructed to hold the handle and move their scapula toward protraction and retraction while maintaining full elbow extension. Several familiarization trials were given until the participant was comfortable with correct testing procedures. Participants performed ten repetitions at 12.2 cm/sec (linear equivalent to 60º/sec).[15] Strength measures were collected bilaterally. Peak force normalized to participant body weight for protraction and retraction were compared along with the protraction:retraction strength ratio. Shoulder protraction and retraction strength reliability has been previously established in the Neuromuscular Research Laboratory (ICC=0.89-0.96, SEM= 2.1-7.7N/kg).

Figure 12. Shoulder Protraction/Retraction Strength Assessment

Internal and external shoulder rotation strength were measured in the seated position. The participant was seated in the chair, with shoulder and waist straps secured to minimize extraneous movements. The participant's shoulder was placed in approximately 10º of elevation in the scapular plane (Figure 13). Each participant was given several familiarization trials get comfortable with the protocol. Five repetitions of concentric internal and external rotation were preformed at 60º/sec. Peak torque normalized to participant body weight for internal and external rotation were compared along with the external:internal rotation strength ratio. Shoulder rotation strength reliability has been previously established in the Neuromuscular Research Laboratory (ICC=0.94-0.95, SEM= 0.3-0.7Nm/kg).

Figure 13. Shoulder Internal/External Rotation Strength Assessment

3.4.5 Range of Motion Assessment

Passive range of motion of the shoulder was assessed as described by Norkin and White.[112] To assess internal rotation, external rotation, and flexion range of motion the participant was in supine on a plinth. A towel was used to place the humerus in a neutral position relative to horizontal adduction and abduction for rotation measures. Participants started with the forearm perpendicular to the floor and in neutral humeral rotation. This was the zero position. From here the examiner passively rotated the shoulder, while providing stabilization to the scapula. At the end range of motion a digital inclinometer measured the angle of the forearm with respect to the vertical which was recorded (Figure 14). The reliability of measuring shoulder rotation range of motion using a digital inclinometer has been previously established in the Neuromuscular Research Laboratory (ICC=0.93-0.97, SEM=2.4-2.5º).

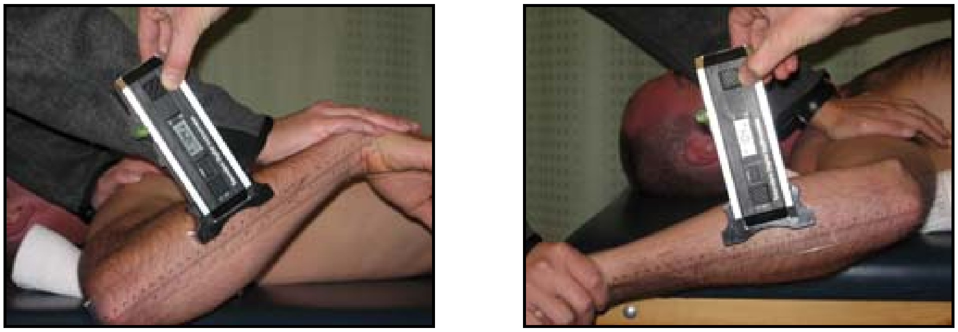


Figure 14. Humeral Rotation Range of Motion Assessment

Passive shoulder flexion range of motion was assessed in supine by passively moving the humerus from a neutral position next to the body to full elevation in the sagittal plane. At the end range of motion a digital inclinometer measured the angle of the humerus with respect to the horizontal which was recorded (Figure 15). The reliability of measuring shoulder flexion using a digital inclinometer has been previously established in the Neuromuscular Research Laboratory (ICC=0.98, SEM=1.8º).

Figure 15. Humeral Flexion Range of Motion Assessment

Passive shoulder abduction was assessed in sidelying by passively moving the humerus from a neutral position next to the body to full abduction in the frontal plane. At the end range of motion a digital inclinometer measured the angle of the humerus with respect to the horizontal which was recorded (Figure 16). The reliability of measuring shoulder abduction using a digital inclinometer has been previously established in the Neuromuscular Research Laboratory (ICC=0.98, SEM=2.2º).

Figure 16. Shoulder Abduction Range of Motion Assessment

Shoulder extension was measured in prone by passively extending the humerus in the sagittal plane. At the end range of motion a digital inclinometer measured the angle of the humerus with respect to the horizontal which was recorded (Figure 17). The reliability of measuring shoulder extension using a digital inclinometer has been previously established in the Neuromuscular Research Laboratory (ICC=0.96, SEM=2.0º).

Figure 17. Humeral Extension Range of Motion Assessment

Torso rotation range of motion was measured in the seated position using an electromagnetic tracking device (Figure 18). Torso rotation was defined in relation to a neutral position. Neutral was defined with the participant seated motionless on the kayak ergometer facing away from the transmitter. Torso (axial) rotation was defined as rotation of the thoracic LCS about the y-axis of the sacral coordinate system.[104] The reliability of measuring torso rotation range of motion with an electromagnetic tracking device has been previously established in the Neuromuscular Research Laboratory (ICC= 0.88, SEM= 4.02º).

Figure 18. Torso Rotation Range of Motion Assessment

3.4.6 Posterior Shoulder Tightness Assessment

Assessment of the supine PST test was assessed as described by Myers et al.[28] Measurement of PST required the participant to lie supine on a plinth. The measure began with the participant in 90º abduction at the glenohumeral joint with neutral position for internal/external rotation. The examiner then stabilized the lateral border of the scapula to maintain a fully retracted position throughout the measure. The humerus was passively moved in to horizontal adduction until the motion ceased without scapular protraction. Care was taken to ensure humeral internal or external rotation did not occur. At the end range of motion a digital inclinometer measured the angle of the humerus with respect to the horizontal which was recorded (Figure 19). The reliability of measuring PST using this method has been previously established in the Neuromuscular Research Laboratory (ICC =0.93, SEM = 1.1º).[28]

Figure 19. Posterior Shoulder Tightness Assessment

3.5 DATA REDUCTION

3.5.1 Kinematic Assessment

All kinematic analyses was analyzed using the protocol set forth by the International Society of Biomechanics. The sequence of Euler angles that was used for scapular motion is scapular external rotation, followed by upward rotation, and finally posterior tilting.[83] For humeral motion a sequence of plane of elevation, followed by elevation, and finally rotation was utilized. [83] For the thorax a sequence of flexion, followed by lateral bending, and lastly axial rotation was used.[109]

3.5.1.1 Kayak Task

Modified time points based on kinematics of the humerus were used to define the time points originally described using the paddle position on the water.[11] The kinematic time points were referenced by the position of the receivers of the electromagnetic tracking device on the humerus in relation to the global coordinate system (GCS). The GCS was made up of three axes. The x-axis was directed medial/lateral (positive to the right), the y-axis was directed vertically (positive pointing superior), and the z-axis was directed anterior/posterior (positive pointing backward). Paddle water association was defined as the point where the humeral receiver had the greatest excursion along the negative z-axis (anterior). The humerus would be most anterior at this point in attempt to reach forward to place the paddle in the water to initiate stroke.[12] Paddle shaft vertical was defined as the point with greatest difference on the y-axis (vertically) for the humeral receivers. Having the humeral receivers at greatest distance vertically separated ensured that the paddle was vertical because the paddle-arms component acts as one segment. Thus, when the paddle was vertical the difference in humeral separation vertically was maximal. Paddle water dissociation was defined as the point with minimal difference on the y-axis for the humeral receivers. At this time the paddle was horizontal as it was taken out of the water to initiate the stroke on the opposite limb.

The kinematic variables discussed above at each time point of ten strokes during the 30 second trial were averaged and used for the data set for each participant. A dual pass fourth-order Butterworth filter with a cut-off frequency of 10 Hz was used to filter the kinematic data within the MotionMonitor software. The dependent variables were scapulothoracic rotations (upward/downward rotation, anterior/posterior tilting, and internal/external rotation) and translations (elevation/depression and protraction/retraction), humeral rotations (elevation and horizontal abduction/adduction), and torso rotation in degrees at the six time points during the kayak stroke.

3.5.1.2 Elevation Task

The scapulothoracic kinematic variables previously discussed at 0º, 30º, 60º, 90º, 120º of humeral elevation during the middle five of ten trials were averaged and used for the data set of each participant. A dual pass fourth-order Butterworth filter with a cut-off frequency of 10 Hz was used to filter the kinematic data within the MotionMonitor software. The dependent variables were scapulothoracic rotations (upward/downward rotation, anterior/posterior tilting, and internal/external rotation) and translations (elevation/depression and protraction/retraction), at all humeral elevation angles described.

3.5.2 Assessment of Muscle Activity

Muscle activity was determined as mean amplitude of EMG during the four phases of the kayak stroke (described previously) for anterior deltoid, posterior deltoid, serratus anterior, latisimus dorsi, triceps, and lower trapezius bilaterally. A customized program, using Matlab Version 7.0.4 (The Mathworks, Inc., Natick, MA) was used to process all EMG signals. All EMG data was sampled at 1000Hz. Data initially had a high pass filter set at 10Hz and a low pass filter at 350Hz.[91] As kinematic and EMG data were collected simultaneously, all EMG data were band-stop filtered at notches of 99-101Hz, 199-201Hz, and 299-301Hz.using a Butterworth filter. The band-stop filters were used to reduce harmonics associated with sampling frequencies of electromagnetics (100Hz in the current study) and EMG concurrently. Root mean square processed (50 milliseconds time constant) EMG was normalized to MVIC for each muscle tested. The dependent variables were mean activation expressed as percentage of MVIC during each phase of the kayak stroke for anterior deltoid, posterior deltoid, serratus anterior, latisimus dorsi, triceps, and lower trapezius bilaterally.

3.5.3 Strength Assessment

Peak torque normalized to body weight (Nm/kg) was compared for shoulder internal and external rotation. Peak force normalized to body weight (N/kg) was used for shoulder protraction and retraction.

3.5.4 Range of Motion Assessment

All range of motion measures were assessed three times. The average of three values for each variable was used for analysis. The dependent variables were bilateral measures of shoulder flexion, extension, abduction, internal rotation, external rotation, and torso rotation in degrees.

3.5.5 Posterior Shoulder Tightness Assessment

Posterior shoulder tightness was assessed three times. The difference between shoulders was used (injured-healthy and the matched limbs for control participants). The average of the three values was used for analysis. The dependent variable was the average difference in posterior shoulder tightness in degrees.

3.6 STATISTICAL ANALYSIS

Statistical analysis of all variables was performed using SPSS version 14.0 (SPSS Inc., Chicago, IL). Multiple analyses of variance (ANOVA) were run for each dependent variable. To account for a type 1 error rate due to multiple analyses, a Bonferonni correction was applied. The alpha level for all analyses was set at 0.025.

There were two between-participant factors in the design, namely, group (pain vs. control) and arm (involved vs. uninvolved). For the variable groupings of scapular kinematics, humeral kinematics, and muscle activity, the within-participants factor of time point during the kayak stroke or humeral elevation angle is also included in the design. Therefore a three-way ANOVA (group x arm x time) was a possible way to analyze variables within these groupings. However, results of the pilot study showed no limb differences between the scapular kinematics, humeral kinematics, and EMG for participants in a healthy group of kayakers. Furthermore, if significant three-way interactions were found, interpretation of results could become complex. For both these reasons, we replaced the full three-factor design with planned comparisons: involved vs. uninvolved are in the pain group, the involved arm of pain group vs. the "matching" arm in the control group, and the uninvolved arm of the pain group with the "matching" arm in the control group. This allowed comparison within the pain group and to both arms of the control group. Analysis of the uninvolved arm of the pain group allowed an understanding of both arms in the pain group to determine if differences are unilateral or bilateral. All comparisons are described below.

Scapular Kinematics during the Kayak Stroke

Three separate two-way analyses of variance (α=0.025) were used to analyze variables related to scapular kinematics. The dependant variables were scapular internal/external rotation, upward/downward rotation, anterior/posterior tilting, protraction/retraction, and elevation/depression at the six time points of the kayak stroke (paddle water association, paddle shaft vertical, paddle water dissociation during the water and the air phase of the stroke). The first (arm x time) included only participants in the pain group. The second (group x time) included only the involved arm of the pain group and the "matching" arm in the control group.

The third (group x time) included only the uninvolved arm of the pain group and the "matching" arm in the control group (Specific Aim 1).

Torso Kinematics during the Kayak Stroke

Three separate two-way analysis of variance (α=0.025) was used to detect differences in torso rotation kinematics. The first (side(arm) x time) included only participants in the pain group. The second (group x time) included only the involved arm of the pain group and the "matching" side in the control group. The third (group x time) included only the uninvolved arm of the pain group and the "matching" side in the control group (Specific Aim 2).

Electromyographic Analysis during the Kayak Stroke

Three separate two-way analyses of variance (α=0.025) were used to analyze muscle activity. The dependant variables were mean activation of the twelve muscles (anterior deltoid, posterior deltoid, serratus anterior, triceps, latisimus dorsi, and lower trapezius) at the six time points of the kayak stroke (paddle water association, paddle shaft vertical, paddle water dissociation during the water and the air phase of the stroke). The first (arm x time) included only participants in the pain group. The second (group x time) included only the involved arm of the pain group and the "matching" arm in the control group. The third (group x time) included only the uninvolved arm of the pain group and the "matching" arm in the control group (Specific Aim 3).

Scapulothoracic Kinematics during an Elevation Task

Three separate two-way analyses of variance (α=0.025) were used to analyze variables related to scapular kinematics. The dependant variables were scapular internal/external rotation, upward/downward rotation, anterior/posterior tilting, protraction/retraction, and elevation/depression at 0º, 30º, 60º, 90º, 120º of humeral elevation. The first (arm x humeral angle) included only participants in the pain group. The second (group x humeral angle) included only the involved arm of the pain group and the "matching" arm in the control group. . The third (group x humeral angle) included only the uninvolved arm of the pain group and the "matching" arm in the control group (Specific Aim 4).

Internal and External Shoulder Rotation Strength

Three separate one-way analyses of variance (α=0.025) were used to determine significant differences for internal and external shoulder rotation strength (Nm/kg). The first included only participants in the pain group (pain vs. control). The second included only the involved arm of the pain group and the "matching" arm in the control group. The third included only the uninvolved arm of the pain group and the "matching" arm in the control group (Specific Aim 5).

Shoulder Protraction and Retraction Strength

Three separate one-way analyses of variance (α=0.025) were used to determine significant differences for shoulder protraction and retraction strength (N/kg). The first included only participants in the pain group (pain vs. control). The second included only the involved arm of the pain group and the "matching" arm in the control group. The third included only the uninvolved arm of the pain group and the "matching" arm in the control group (Specific Aim 6).

Torso Range of Motion

Three separate one-way analyses of variance (α=0.025) were used to determine significant differences in range of motion for torso rotation The first included only participants in the pain group (pain vs. control). The second included only the involved arm of the pain group and the “matching” arm in the control group. The third included only the uninvolved arm of the pain group and the “matching” arm in the control group (Specific Aim 7).

Shoulder Range of Motion

Three separate one-way analyses of variance (α=0.025) were used to determine significant differences in shoulder range of motion for flexion, extension, abduction, internal and external rotation and posterior shoulder tightness The first included only participants in the pain group (pain vs. control). The second included only the involved arm of the pain group and the “matching” arm in the control group. The third included only the uninvolved arm of the pain group and the “matching” arm in the control group (Specific Aim 8).

4.0 RESULTS

Thirty-two (32) whitewater kayakers participated in the study (16 kayakers with shoulder pain and 16 kayakers without shoulder pain). The demographics for the participants in the study are presented in Table 3. Participant groups were matched on age (± 5 years), skill level, and gender. The level of abilities of the kayakers that participated were as follows: four subjects per group were of class III ability, six subjects per group were of class IV ability, and six subjects per group were of class V ability. Pain scores were quantified using the QuickDASH injury questionnaire and QuickDASH Sport Module (See Table 4). The QuickDASH score quantifies the level of disability (0 as no disability and 100 as complete disability). Additionally, all participants underwent clinical examination by two clinicians, a physical therapist and a certified athletic trainer, who have experience examining and treating orthopedic shoulder injuries. Each clinician was blind to the other clinician's examination results. The results of those examinations appear in Table 5. All participants were currently able to navigate class III whitewater and were free of back or neck pain within the previous six months.

Table 3. Participant Demographics

	Pain Group		**Control Group**	
	Mean	**± SD**	**Mean**	**± SD**
Age (years)	33.06	7.34	31.94	6.34
Height (cm)	178.63	10.05	177.69	8.75
Weight (kg)	83.44	13.76	81.25	14.51

Table 4. Pain Characteristics

	Pain Group		Control Group	
	Mean	**± SD**	**Mean**	**± SD**
QuickDASH Score	23.65	9.02	0.14	0.58
QuickDASH Sport Module Score	46.09	20.65	0.00	0.00
	Right	**Left**	**Right**	**Left**
Dominant Shoulder	16	0	16	0
Involved Shoulder	12	4	N/A	N/A

Table 5. Findings from Clinical Examination

	Examiner	Subacromial Impingement	Biceps Tendonitis	Instability	Internal Impingement
Primary Diagnosis	1	6	1	2	7
Secondary Diagnosis		1	1	1	0
Primary Diagnosis	2	6	0	3	7
Secondary Diagnosis		1	3	2	0

4.1 SHOULDER RANGE OF MOTION

All shoulder range of motion data are presented in Table 6. Significant differences were found between the involved and uninvolved limb in the pain group for internal rotation ($p = 0.003$) and abduction ($p = 0.011$) (Figures 20 and 21). Kayakers with shoulder pain had decreased internal rotation and abduction on their involved side in comparison with their uninvolved side. A significant group difference was found for internal rotation ($p = 0.012$) and abduction ($p = 0.006$) (Figures 20 and 21). Kayakers with shoulder pain displayed decreased range of motion in internal rotation and abduction when compared to the matched limbs of the kayakers in the control group. No significant group differences were found between the uninvolved limb of the pain group and the matched limb of the control group (p = 0.05-0.846).

Table 6. Shoulder Range of Motion

	Pain Group Involved		Pain Group Uninvolved		Control Group Involved Match		Control Group Uninvolved Match	
	Mean	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**
Internal rotation (°)	38.79* [t]	7.67	44.92	8.27	47.52	9.49	50.13	9.31
External rotation (°)	95.17	15.51	95.48	12.82	103.44	5.12	101.36	7.51
Flexion (°)	171.94	12.54	174.52	11.07	181.69	10.40	181.79	10.79
Extension (°)	54.96	7.31	55.54	7.37	59.04	10.05	57.10	8.16
Abduction (°)	173.92* [t]	22.24	183.06	14.04	191.90	8.25	190.90	7.76

*** Indicates significant difference between limbs**

[t] **Indicates significant difference between groups for matched limb**

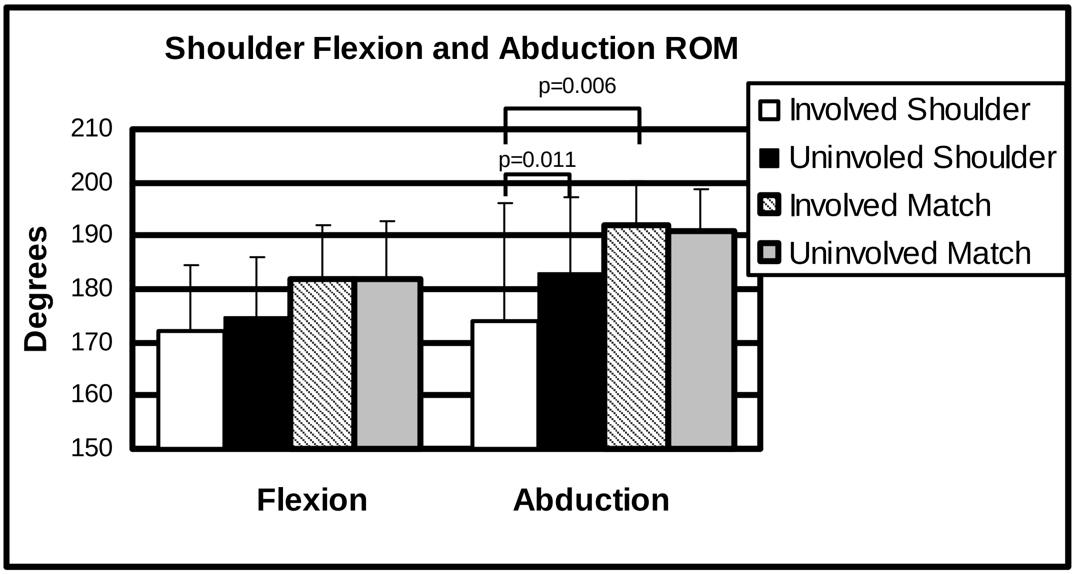


Figure 20. Shoulder Flexion and Abduction Range of Motion

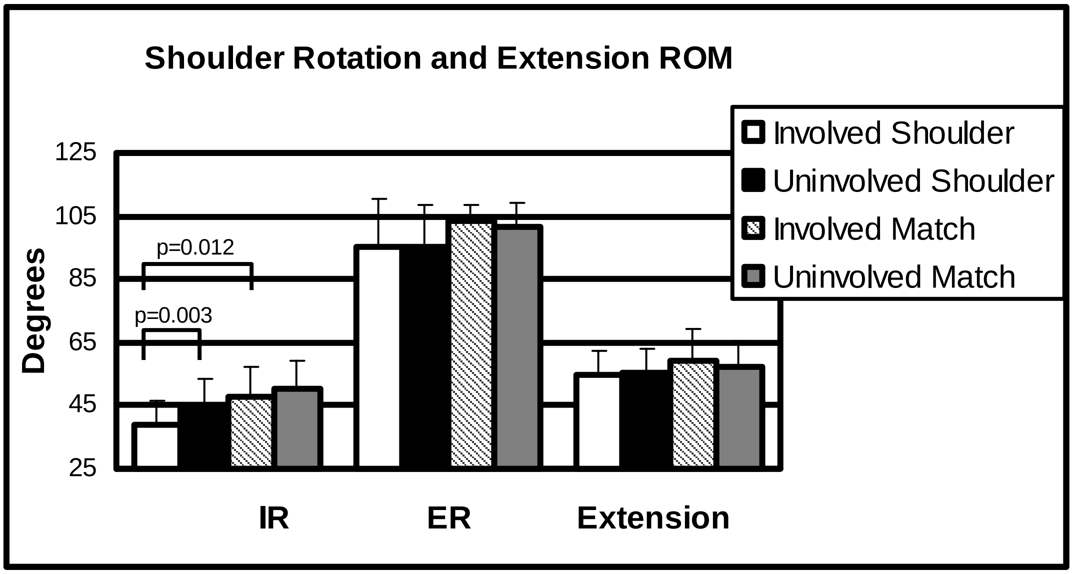


Figure 21. Shoulder Rotation and Extension Range of Motion

4.2 POSTERIOR SHOULDER TIGHTNESS

There was no significant difference in posterior shoulder tightness between involved and uninvolved limbs in the shoulder pain group ($p = 0.486$), between the involved shoulder in the pain group and matched shoulder in the control group ($p = 0.119$), or between the uninvolved shoulder in the pain group and matched shoulder in the control group ($p = 0.095$). Additionally, there was no significant difference between the shoulder pain group and control group when taking the difference of uninvolved and involved limb ($p = 0.819$) (see Table 7).

Table 7. Posterior Shoulder Tightness

	Pain Group Involved		Pain Group Uninvolved		Control Group Involved Match		Control Group Uninvolved Match	
	Mean	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**
Posterior Shoulder Tightness (°)	94.44	8.42	95.63	9.54	101.12	9.67	101.79	8.51
Uninvolved – Involved (°)	1.19	1.12			0.67	1.52		

4.3 TORSO ROTATION RANGE OF MOTION

There was no significant difference in torso rotation range of motion between sides in the shoulder pain group (p = 0.533), between the involved and matched side (p = 0.332), or uninvolved and matched shoulder (p = 0.846) in the control group (see Table 8).

Table 8. Torso Rotation Range of Motion

	Pain Group Involved		Pain Group Uninvolved		Control Group Involved Match		Control Group Uninvolved Match	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Torso Rotation (°)	44.81	8.62	43.25	5.00	47.71	6.71	43.73	7.56

4.4 SHOULDER STRENGTH

4.4.1 Internal and External Rotation Strength

No significant differences were found for shoulder internal rotation strength (p = 0.902), external rotation strength (p = 0.221), or the external:internal rotation strength ratio (p = 0.391) between limbs in the shoulder pain group. No significant differences were found for internal rotation strength (p = 0.581), external rotation strength (p = 0.242), or the external:internal rotation strength ratio (p = 0.678) between groups for the involved shoulder and matched limb. Additionally, no significant differences were noted for internal rotation strength (p = 0.973), external rotation strength (p = 0.376), or the external:internal rotation strength ratio (p = 0.459) between the uninvolved and matched limb (see Table 9).

Table 9. Internal and External Rotation Strength at 60°/second

	Pain Group Involved		Pain Group Uninvolved		Control Group Involved Match		Control Group Uninvolved Match	
	Mean	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**
Internal rotation (Nm/kg)	49.71	12.18	49.44	8.66	51.59	13.05	49.34	12.62
External rotation (Nm/kg)	37.84	5.89	39.89	8.66	40.03	8.74	37.99	7.41
ER/IR ratio	0.78	0.10	0.82	0.12	0.79	0.11	0.78	0.11

4.4.2 Protraction/Retraction Strength

No significant differences were found for shoulder protraction strength (p = 0.169), retraction strength (p = 0.049), or the protraction:retraction strength ratio (p = 0.996) between limbs in the shoulder pain group. Additionally, no significant differences were noted between groups for the involved and matched limb (protraction strength (p = 0.080), retraction strength (p = 0.036), or the protraction:retraction strength ratio (p = 0.525)). No significant differences were noted between the uninvolved and matched limb (protraction strength (p = 0.595), retraction strength (p = 0.234), or the protraction:retraction strength ratio (p = 0.235)) (see Table 10).

Table 10. Protraction and Retraction Strength at 12.2cm/second

	Pain Group Involved		Pain Group Uninvolved		Control Group Involved Match		Control Group Uninvolved Match	
	Mean	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**
Protraction (N/kg)	3.71	1.13	4.04	1.10	4.30	1.74	4.24	1.19
Retraction (N/kg)	3.23	1.12	3.66	1.35	3.83	1.37	4.12	1.55
Pro/Ret ratio	1.17	0.21	1.17	0.32	1.13	0.30	1.07	0.19

4.5 SCAPULAR KINEMATICS

4.5.1 Kinematics during the Elevation Task

The kinematic data for the elevation task are presented in Table 11. Two-way ANOVA's were used to test two effects of interest, 1) the main effect of limb (involved or uninvolved within the pain group) or group (involved vs. matched control and uninvolved vs. matched control between the groups); and 2) the interaction between the limb or group and angle. Although a test of the effect of angle is automatically generated through this analysis, this test will not be further discussed since it is not relevant to the aims of the study. No significant interactions were discovered ($p = 0.189 - 0.969$). Therefore, no differences were noted between groups [$F(4,60) = 0.047 – 1.280$] or between the involved and uninvolved limb [$F(4,60) = 0.359 -1.460$] at corresponding humeral elevation angles. The main effect of limb or group was not significant for any scapular variable at any humeral elevation angle ($p = 0.205 – 0.856$). Thus, no significant differences were found between the involved and uninvolved limb in the pain group [$F(1,15) = 0.329 – 1.757$]. No significant differences were found between the involved shoulder in the pain group and the matched shoulder in the control group ($p = 0.271 - 0.981$). No significant differences were noted between the uninvolved shoulder in the pain group and the matched shoulder in the control group [$F(1,15) = 0.000- 1.758$] ($p = 0.205 - 0.987$).

Table 11. Scapular Kinematics during the Elevation Task

	Pain Group Involved		Pain Group Uninvolved		Control Group Involved Match		Control Group Uninvolved Match	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Upward/downward rotation (°)								
0° humeral elevation	-6.58	6.27	-5.73	4.82	-6.62	7.51	-5.10	4.92
30° humeral elevation	-4.52	7.39	-4.11	5.51	-2.95	7.45	-2.89	5.92
60° humeral elevation	4.49	7.48	4.54	6.52	6.47	7.12	5.42	6.75
90° humeral elevation	14.40	8.36	15.11	7.99	15.84	6.57	14.82	6.86
120° humeral elevation	23.32	9.64	25.29	11.97	23.41	7.54	23.02	7.43
External /internal rotation (°)								
0° humeral elevation	18.42	9.08	20.98	6.16	20.66	5.95	21.52	11.42
30° humeral elevation	17.20	8.98	19.71	6.03	19.10	5.87	20.12	10.80
60° humeral elevation	16.35	9.39	18.69	6.92	18.93	6.32	19.72	11.22
90° humeral elevation	16.79	9.91	18.56	8.94	19.62	7.19	20.42	11.52
120° humeral elevation	22.21	13.35	21.01	12.71	25.99	10.97	25.57	11.83
Posterior/anterior tilt (°)								
0° humeral elevation	-19.31	5.47	-18.03	6.85	-18.22	6.79	-19.06	5.48
30° humeral elevation	-16.51	6.50	-16.32	6.47	-15.56	5.56	-17.00	5.12
60° humeral elevation	-13.28	7.03	-13.63	6.24	-11.66	4.65	-13.72	4.95
90° humeral elevation	-9.20	8.60	-9.78	6.75	-7.50	5.38	-9.73	6.54
120° humeral elevation	-2.55	9.23	-3.88	8.13	-3.41	7.69	-3.47	7.88
Protraction/retraction (°)								
0° humeral elevation	-22.42	5.13	-20.93	5.58	-22.48	3.88	-19.18	5.25
30° humeral elevation	-24.76	4.96	-23.07	5.25	-24.95	3.73	-21.64	5.24
60° humeral elevation	-27.39	5.35	-25.84	5.66	-27.25	4.60	-23.77	5.89
90° humeral elevation	-30.31	5.90	-28.95	6.17	-30.21	5.36	-26.28	6.95
120° humeral elevation	-34.55	6.60	-33.34	6.88	-34.71	6.26	-29.90	7.72
Elevation (°)								
0° humeral elevation	11.00	4.90	10.23	4.86	9.34	7.14	11.17	5.42
30° humeral elevation	11.83	4.92	10.85	4.95	10.99	6.63	12.28	5.40
60° humeral elevation	16.60	4.42	15.25	5.21	16.57	6.47	17.10	5.38
90° humeral elevation	22.78	4.31	21.51	5.61	23.00	7.01	23.22	5.66
120° humeral elevation	30.72	4.36	28.99	5.31	30.63	8.38	30.80	5.93

4.6 KINEMATICS DURING THE KAYAKING TASK

4.6.1 Scapular Kinematics

The scapular kinematic data for the kayaking task are presented in Table 12. Two-way ANOVA's were used to test two effects of interest, 1) the main effect of limb (involved or uninvolved within the pain group) or group (involved vs. matched control and uninvolved vs. matched control between the groups); and 2) the interaction between the limb or group and kayak stroke time point. Although a test of the effect of kayak stroke time point is automatically generated through this analysis, this test will not be further discussed since it is not relevant to the aims of the study. No significant interactions were found ($p = 0.140 - 0.795$). Therefore, no differences were noted between groups [$F(5,75) = 0.296 – 1.910$] or between the involved and uninvolved limb [$F(5,75) = 0.341 – 2.208$] at corresponding time points of the kayak stroke. The main effect of limb or group was not significant for any scapular variable at any time point during the kayak stroke ($p = 0.584 – 0.917$). Thus, no significant differences were found between the involved limb and uninvolved limb in the pain group [$F(5,75) = 0.011 – 0.313$]. No significant differences were found between the involved shoulder in the pain group and the matched shoulder in the control group [$F(5,75) = 0.003 – 0.496$] ($p = 0.492 – 0.958$). No significant differences were noted between the uninvolved shoulder in the pain group and the matched shoulder in the control group [$F(5,75) = 0.007 – 0.333$] ($p = 0.572 - 0.935$).

Table 12. Scapular Kinematics during the Kayaking Task

	Pain Group Involved		Pain Group Uninvolved		Control Group Involved Match		Control Group Uninvolved Match	
	Mean	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**
Upward/downward rotation (°)								
Draw PWA	1.55	10.03	4.97	7.76	0.80	8.03	3.43	6.05
Draw PSV	-6.87	8.34	-3.10	6.94	-7.38	7.37	-3.63	5.14
Draw PWD	-8.15	8.28	-3.72	7.30	-8.09	8.31	-2.61	9.85
Thrust PWA	-0.40	9.50	-4.00	8.58	0.50	6.15	-3.49	9.06
Thrust PSV	14.40	11.40	10.84	9.17	13.06	5.65	11.76	9.55
Thrust PWD	10.97	10.00	7.73	10.35	8.75	5.20	6.13	7.54
External /internal rotation (°)								
Draw PWA	37.94	6.73	38.93	8.40	38.99	7.25	37.55	7.60
Draw PSV	28.49	6.51	31.52	6.83	30.37	7.97	32.05	6.94
Draw PWD	25.22	7.39	29.07	7.42	26.14	8.23	31.35	8.57
Thrust PWA	26.93	8.17	23.75	7.46	28.32	7.67	24.91	9.80
Thrust PSV	40.94	9.09	38.10	7.46	42.35	6.37	42.42	8.95
Thrust PWD	41.67	8.11	40.07	7.05	40.91	7.18	41.75	6.70
Posterior/anterior tilt (°)								
Draw PWA	-12.54	6.27	-15.73	6.59	-14.87	6.42	-14.37	7.62
Draw PSV	-15.26	6.75	-17.33	5.60	-16.20	6.84	-15.77	5.15
Draw PWD	-17.19	5.97	-18.76	6.70	-18.38	8.28	-16.15	5.46
Thrust PWA	-19.62	8.58	-17.12	6.97	-16.11	6.71	-17.52	6.65
Thrust PSV	-11.78	7.95	-10.65	5.74	-10.64	6.47	-11.93	5.82
Thrust PWD	-12.96	7.21	-10.86	6.27	-12.55	7.71	-12.48	6.16
Protraction/retraction (°)								
Draw PWA	-19.42	5.95	-19.09	5.83	-17.04	5.22	-19.25	5.69
Draw PSV	-21.12	5.95	-22.49	6.00	-20.30	3.66	-22.91	5.45
Draw PWD	-22.25	5.85	-23.31	5.75	-21.85	4.26	-23.46	5.33
Thrust PWA	-24.57	5.73	-22.94	6.48	-24.31	5.10	-21.86	5.02
Thrust PSV	-20.30	5.60	-20.81	6.43	-18.98	6.47	-19.16	5.69
Thrust PWD	-18.92	4.76	-18.92	4.76	-18.15	5.67	-17.11	5.59
Elevation (°)								
Draw PWA	17.98	7.24	18.97	8.51	17.19	8.16	17.80	7.90
Draw PSV	12.28	5.88	13.77	7.16	13.62	6.90	13.89	6.21
Draw PWD	12.25	6.00	14.00	7.13	13.22	6.24	15.54	8.33
Thrust PWA	15.12	7.91	13.84	5.52	15.94	6.03	14.64	6.02
Thrust PSV	23.58	9.56	22.64	7.31	23.66	6.51	24.02	7.71
Thrust PWD	22.52	9.93	22.52	9.93	21.22	7.43	21.23	7.07

[PWA- paddle water association, PSV- paddle shaft vertical, PWD- paddle water dissociation]

4.6.2 Humeral Kinematics

The humeral kinematic data for the kayaking task are presented in Table 13. Two-way ANOVA's were used to test two effects of interest, 1) the main effect of limb (involved or uninvolved within the pain group) or group (involved vs. matched control and uninvolved vs. matched control between the groups); and 2) the interaction between the limb or group and kayak stroke time point. Although a test of the effect of kayak stroke time point is automatically generated through this analysis, this test will not be further discussed since it is not relevant to the aims of the study. No significant interactions were discovered ($p = 0.142 - 0.724$). Therefore, no differences were noted between groups [$F(5,75) = 0.623 – 1.903$] or between the involved and uninvolved limb [$F(5,75) = 0.838 – 1.623$] at corresponding time points of the kayak stroke. The main effect of limb or group was not significant for any humeral variable at any time point during the kayak stroke ($p = 0.201 - 0.340$). Thus, no significant differences were found between the involved limb and uninvolved limb in the pain group. No significant differences were found between the involved shoulder in the pain group and the matched shoulder in the control group [$F(1,15) = 0.007- 0.309$] ($p = 0.587 - 0.932$). No significant differences were noted between the uninvolved shoulder in the pain group and the matched shoulder in the control group [$F(1,15) = 0.069 – 1.058$] ($p = 0.320 - 0.796$).

Table 13. Humeral Kinematics during the Kayaking Task

	Pain Group Involved		Pain Group Uninvolved		Control Group Involved Match		Control Group Uninvolved Match	
	Mean	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**	**Mean**	**± SD**
Humeral Elevation (°)								
Draw PWA	68.03	9.78	68.95	11.22	68.53	7.05	67.27	10.44
Draw PSV	34.30	9.70	34.27	9.79	31.37	7.41	32.40	7.76
Draw PWD	31.38	13.99	31.22	9.53	33.66	8.33	37.16	17.34
Thrust PWA	42.96	14.93	40.56	12.27	46.04	9.36	46.79	11.77
Thrust PSV	84.61	14.81	77.52	14.08	82.96	7.67	84.44	8.22
Thrust PWD	79.44	13.22	76.24	11.25	76.38	10.37	76.91	10.19
Plane of Elevation (°)								
Draw PWA	63.25	7.35	66.61	9.65	63.61	12.53	67.87	11.43
Draw PSV	28.65	13.34	38.63	15.00	23.83	13.42	32.87	18.65
Draw PWD	3.07	20.52	12.31	20.22	-10.04	27.16	7.69	27.63
Thrust PWA	-5.97	27.24	1.02	27.22	4.64	17.60	-11.00	29.82
Thrust PSV	74.25	12.96	60.85	14.27	77.90	9.52	71.32	16.06
Thrust PWD	74.74	8.28	65.50	16.82	75.04	13.82	70.60	15.19

[PWA- paddle water association, PSV- paddle shaft vertical, PWD- paddle water dissociation]

4.6.3 Torso Kinematics

The torso rotation kinematic data for the kayaking task is presented in Table 14. Two-way ANOVA's were used to test two effects of interest, 1) the main effect of limb (involved or uninvolved within the pain group) or group (involved vs. matched control and uninvolved vs. matched control between the groups); and 2) the interaction between the limb or group and kayak stroke time point. Although a test of the effect of kayak stroke time point is automatically generated through this analysis, this test will not be further discussed since it is not relevant to the aims of the study. As torso rotation is not a bilateral measure, only three time points were used for analysis. No significant interactions were found ($p = 0.273 - 0.951$). Therefore, no differences were noted between groups [$F(2,30) = 0.414 – 1.356$] or between the involved and uninvolved limb [$F(2,30) = 0.050$] at corresponding time points of the kayak stroke. The main effects of limb or group were not significant for torso rotation at any time point during the kayak stroke [$F(1,15) = 0.167$] ($p = 0.688$). Thus, no significant differences were found between the involved limb and uninvolved limb in the pain group. No significant differences were found between the involved side in the pain group and the matched side in the control group [$F(1,15) = 3.546$] ($p = 0.079$). No significant differences were noted between the uninvolved side in the pain group and the matched side in the control group [$F(1,15) = 0.017$ ($p = 0.899$).

For the torso rotation data (Table 14), positive values indicate rotation toward the front of the kayak on the draw side (paddle water association). A value of zero indicates neutral torso rotation, and a negative value indicates rotation toward the rear of the kayak on the draw side (paddle water dissociation).

Table 14. Torso Rotation during the Kayaking Task

	Pain Group Involved		Pain Group Uninvolved		Control Group Involved Match		Control Group Uninvolved Match	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Rotation (°)								
Draw PWA	13.70	8.07	12.99	7.85	20.63	8.65	13.35	9.63
Draw PSV	3.30	8.25	1.98	7.00	4.91	7.97	2.95	8.92
Draw PWD	-5.81	8.00	-6.46	4.90	-3.70	5.71	-8.41	9.45

[PWA- paddle water association, PSV- paddle shaft vertical, PWD- paddle water dissociation]

4.7 MUSCLE ACTIVITY DURING THE KAYAKING TASK

The electromyographic data for the kayaking task is presented in Table 15. Two-way ANOVA's were used to test two effects of interest, 1) the main effect of limb (involved or uninvolved within the pain group) or group (involved vs. matched control and uninvolved vs. matched control between the groups); and 2) the interaction between the limb or group and phase. Although a test of the effect of phase is automatically generated through this analysis, this test will not be further discussed since it is not relevant to the aims of the study. No significant interactions were found ($p = 0.026 - 0.917$). Therefore, no differences were noted for any muscle between groups [$F(3,45) = 0.077 – 0.921$] or between the involved and uninvolved limb [$F(3,45) = 0.048 – 2.720$] at corresponding phases of the kayak stroke. The main effect of limb was not significant for any muscle. Thus, no significant differences were found between the involved limb and uninvolved limb in the pain group [$F(1,15) = 0.005 – 3.558$] ($p = 0.082 – 0.944$). The main effect of group was not significant for any muscle. Thus, no significant differences were found between the involved shoulder in the pain group and the matched shoulder in the control group [$F(1,15) = 0.081 – 5.242$] ($p = 0.039 - 0.824$). No significant differences were noted between the uninvolved shoulder in the pain group and the matched shoulder in the control group [$F(1,15) = 0.055 – 1.285$] ($p = 0.277 - 0.818$).

Table 15. Muscle Activity during the Kayaking Task

	Pain Group Involved		Pain Group Uninvolved		Control Group Involved Match		Control Group Uninvolved Match	
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Anterior Deltoid (% MVIC)								
Draw PWA to PSV	18.83	28.52	21.45	42.15	14.84	36.26	19.98	31.35
Draw PSV to PWD	24.60	35.81	21.16	29.20	18.75	24.54	24.59	25.41
Thrust PWA to PSV	21.23	9.38	26.91	17.66	19.56	8.97	24.60	18.72
Thrust PSV to PWD	24.08	10.72	29.85	35.03	25.49	20.25	28.96	21.46
Posterior Deltoid (% MVIC)								
Draw PWA to PSV	35.99	26.57	26.71	13.60	33.57	38.25	43.94	44.59
Draw PSV to PWD	39.17	32.17	21.44	13.65	17.43	13.47	29.60	28.21
Thrust PWA to PSV	20.95	34.93	19.16	35.68	24.10	27.21	11.36	11.92
Thrust PSV to PWD	19.09	17.87	17.44	38.24	8.64	2.79	18.45	28.78
Triceps (% MVIC)								
Draw PWA to PSV	28.38	26.00	27.90	29.87	26.31	20.23	45.25	37.55
Draw PSV to PWD	24.09	26.70	16.02	24.18	15.57	22.09	21.01	26.06
Thrust PWA to PSV	27.00	25.69	30.26	33.08	9.48	5.71	32.65	36.71
Thrust PSV to PWD	16.08	11.80	15.37	21.01	21.41	29.90	22.09	30.44
Serratus Anterior (% MVIC)								
Draw PWA to PSV	51.58	30.48	68.51	30.98	37.86	27.69	82.17	43.98
Draw PSV to PWD	45.04	33.43	79.67	60.57	39.10	38.59	59.16	31.54
Thrust PWA to PSV	38.91	23.40	53.55	46.50	27.66	25.71	40.95	36.14
Thrust PSV to PWD	37.18	19.34	45.36	38.56	31.05	27.96	34.43	14.84
Latisimus Dorsi (% MVIC)								
Draw PWA to PSV	47.17	25.78	53.73	31.68	48.92	38.26	58.90	41.31
Draw PSV to PWD	35.45	33.47	36.62	20.43	24.36	20.17	47.09	46.47
Thrust PWA to PSV	31.32	27.24	32.48	30.61	34.83	35.99	35.72	45.74
Thrust PSV to PWD	27.93	18.35	28.72	30.15	21.03	23.81	38.41	49.71
Lower Trapezius (% MVIC)								
Draw PWA to PSV	78.27	52.99	74.20	20.72	73.65	53.85	66.91	65.85
Draw PSV to PWD	57.67	38.90	48.97	34.22	49.49	41.84	36.74	26.88
Thrust PWA to PSV	24.69	15.83	28.24	44.00	18.94	10.92	23.18	25.83
Thrust PSV to PWD	34.93	22.58	29.03	20.78	22.76	10.58	23.64	15.84

[PWA- paddle water association, PSV- paddle shaft vertical, PWD- paddle water dissociation]

5.0 DISCUSSION

The purpose of this study was to investigate 3D torso and scapulohumeral kinematics and muscle activation patterns of the kayak forward stroke while kayaking on an ergometer. In addition scapulohumeral kinematics during a standardized elevation task, shoulder and scapular strength, shoulder flexibility, posterior shoulder tightness, and torso flexibility were assessed Two groups of kayakers were evaluated, those with and without shoulder pain.

5.1 PAIN CHARACTERISTICS

Kayakers in the shoulder pain group had an average of 23.65% disability in shoulder function, as recorded by the QuickDASH shoulder function questionnaire. The QuickDASH questionnaire describes the amount of self-reported disability for shoulder function, scores range from 0, no disability, to 100 complete disability. The QuickDASH Sport Module showed an even greater disability when referring to their self-reported sport performance. Kayakers with shoulder pain report an average of 46.09% disability specifically affecting their capacity to kayak. The averages for the control group were 0.14% disability for shoulder function and 0% disability related to their capacity to kayak (Table 4).

Participants in the shoulder pain group underwent a clinical examination by two clinicians who were blinded to the others examination findings. The most common finding from the clinical exam were shoulder injuries associated with overuse, including subacromial impingement, biceps tendonitis, and internal impingement (Table 5). These findings are consistent with the self-reported injuries on several epidemiological studies that comprise a majority of the literature available on whitewater kayakers.[6-8, 10, 113] These surveys all report the majority of injuries as overuse, with the shoulder being one of the most commonly injured areas.[6, 7, 113] One unanticipated finding from the clinical exam was the presence of isolated pathologic internal impingement in over 40% of the injured kayakers. Pathologic internal impingement has previously been described in overhead athletes (throwers).[24, 77] In throwers, internal impingement has been speculated to be caused by hyper-horizontal abduction of the humerus beyond the plane of the scapula.[29] While the humerus is posterior to the scapula, the posterior/superior rotator cuff tendons become mechanically pinched between the humerus and the posterior glenoid causing pain and inflammation.[29] A similar mechanism of hyper-horizontal abduction is possible while kayaking. One common turning stroke in kayaking uses the torso and humerus to place the paddle just behind the kayakers' hip (see Figure 22). If insufficient torso rotation occurs during this stroke, the humerus may go beyond the scapular plane and create pathologic internal impingement. The pathologic internal impingement found in the subjects in this study could potentially be due to this poor turning technique. Given the void in knowledge of injuries in whitewater kayakers, this finding may warrant further investigation.

Figure 22. Kayak Turning Stroke

5.2 RANGE OF MOTION

5.2.1 Shoulder Range of Motion

As hypothesized, the involved shoulder displayed decreases in range of motion compared to the uninvolved shoulder in the pain group. Correspondingly, decreases were noted between the involved shoulder in the pain group and the control group. Specifically, decreases were noted for internal rotation and abduction in the involved shoulder compared the uninvolved shoulder and compared to the matched shoulder (Table 6 and Figures 20 and 21). No significant differences were noted between the uninvolved shoulder in the pain group and matched control.

Decreased shoulder abduction range of motion is a common finding in participants with non-specific shoulder pain.[114-117] This may be due to pain associated with decreases in subacromial space, which has been shown to occur at higher humeral elevation angles.[32, 36, 37, 41, 118] While not all kayakers in the pain group had injuries associated with decreases in subacromial space, the majority of participants had clinical diagnoses involving the rotator cuff or biceps tendon (Table 5). The most commonly injured structures associated with decreased subacromial space include the rotator cuff, biceps tendon, and subacromial bursa.[32, 36, 37, 41] As the humerus nears end range of motion in abduction, pain could be elicited and thus limit the amount of motion available. Therefore, as expected, the involved shoulder showed deficits compared to the uninvolved shoulder and the matched shoulder.

Unilateral decreases in internal rotation have been associated with several pathologies including SLAP lesion, internal impingement, and subacromial impingement.[14, 24, 119] Often this decreased internal rotation is reported as glenohumeral internal rotation deficit (GIRD).[24, 25, 119, 120] GIRD is measured as the deficit in internal rotation when comparing the involved (or dominant) shoulder to the uninvolved (non-dominant) shoulder and is often found in overhead throwing athletes.[14] The amount of GIRD demonstrated in the current study (6.13°) is less than amount of GIRD associated with injury in throwers, which has been reported as high as 19.7° in injured throwers and as high as 11.1° in uninjured throwers.[24, 119] This discrepancy between sports is likely due to differing shoulder kinematics and kinetics. GIRD found in throwers has been attributed to posterior-inferior capsular scarring and thickening, as the shoulder attempts to decelerate the arm during the throwing motion.[14] No similar deceleration is present at any time during the kayak stroke. Therefore, it is unlikely a deceleration mechanism underlies the GIRD found in this group of injured kayakers.

GIRD has also been reported in individuals with subacromial impingement.[25, 121] GIRD has been theorized to occur in impingement patients through a low-energy traumatic event, which is often initially misdiagnosed as a muscle strain.[121] Whitewater kayaking places large demands on the shoulder in a dynamic environment.[113] It is feasible that such a traumatic event could occur while kayaking creating the deficit seen.

There were no significant differences found between the involved and uninvolved shoulder in the pain group for shoulder flexion, extension, or external rotation. In addition, there were no significant differences between the involved shoulder in the pain group and matched shoulder, nor were there differences between the uninvolved shoulder in the pain group and matched shoulder for flexion, extension, or external rotation. Thus our hypothesis was rejected for these motions. All shoulder range of motion values in the control group and uninvolved shoulders in the pain group are similar to expected values of healthy shoulders in overhead athletes.[122]

5.2.2 Posterior Shoulder Tightness

Although several studies have associated posterior shoulder tightness with shoulder pathology, no difference was found in posterior shoulder tightness between the pain and control groups in this study (Table 7). Therefore our hypothesis was rejected. The bilateral difference for both the pain and control group was quite small (1.19°). In the pain group, an average of both shoulders' posterior shoulder tightness measures was near 95°. In the control group, the individual measures were just above 101°. Thus, it may be suggested that participants in the pain group had increased posterior shoulder tightness bilaterally. The measurement of posterior shoulder tightness in the current study utilizes a difference score between involved and uninvolved shoulders. As such, bilateral tightness may be masked. Previous work has assessed posterior shoulder tightness in swimmers (a bilateral upper extremity sport) and non-overhead athletes (runners and soccer players).[123] Posterior shoulder tightness was not noted in these groups of athletes either.[123] However, the unilateral measures are similar to the control group in the current study. Although no significant difference was found for the bilateral measure or the unilateral measure, the amount of shoulder posterior tightness exhibited by the shoulder pain group may be indicative of bilateral posterior shoulder tightness.

Tyler et al.[25] reported an association between posterior shoulder tightness and decreased glenohumeral internal rotation. The methods used to measure posterior shoulder tightness differed between the two studies, making direct comparison difficult. However, in the group of kayakers with shoulder pain in the current study, decreases were noted bilaterally for internal rotation compared to the control group. The shoulder pain group also had increased posterior shoulder tightness bilaterally, compared to the control group. This could be used as an indicator that kayakers with shoulder pain do exhibit posterior shoulder tightness. As no information regarding the characteristics of healthy or injured whitewater kayakers' shoulders currently exists, this is an area in which further investigation should be considered.

While not statistically significant, it should be noted that for all range of motion measures and posterior shoulder tightness, the control group tended to have greater range of motion than the pain group. This was true when comparing the involved shoulder to matched shoulder and when comparing the uninvolved shoulder to matched shoulder (Tables 6, 7, and 8, Figures 20 and 21).

While not statistically significant, it should be noted that for all range of motion measures and posterior shoulder tightness, the shoulder pain group displayed decreased values compared to the control group. This was true when comparing the involved shoulder to matched shoulder and when comparing the uninvolved shoulder to matched shoulder (Tables 6, 7, and 8, Figures 20 and 21). This finding on the uninvolved shoulder was unexpected as individuals with unilateral injury were only expected to show deficits on the involved shoulder. To date no study has described a bilateral deficit in shoulder range of motion in individuals with unilateral injury. As this is a cross-sectional study the results cannot be interpreted as cause or result of the deficits seen, however the discrepancy found between the uninvolved and matched shoulder may be indicative of an adaptive alteration in range of motion in kayakers with shoulder pain. Potentially, decreases in shoulder range of motion may be predictive of shoulder pathology in kayakers, as the involved shoulder displayed decreased range of motion for all values compared to the uninvolved shoulder and compared to the control group. While the uninvolved shoulder did not exhibit statistically significant decreases compared to the matched shoulder, the deficits found may be clinically significant, specifically for the motions of internal rotation and abduction.

5.2.3 Torso Rotation Range of Motion

Contrary to our hypothesis, there were no significant differences found in any comparison for torso rotation range of motion, which contradicts our hypothesis that kayakers with shoulder pain would have decreased torso rotation range of motion compared to the control group. To date, no study has described the impact of decreased torso range of motion on extremity pathology. As torso rotation was similar bilaterally and between groups, this seems unlikely to be associated with shoulder injuries in kayakers. While torso rotation is a large contributor to propulsion of the kayak[4, 10, 63], an association between altered torso rotation range of motion and shoulder pain has not been established in this study. The torso rotation range of motion obtained by participants in the current study are similar to other studies using similar methodology to assess athletes.[124]

5.3 SHOULDER STRENGTH

5.3.1 Internal and External Rotation Strength

It was hypothesized that kayakers with shoulder pain would exhibit a decreased external:internal rotation strength ratio because of decreased external rotation strength, when compared to the uninvolved limb and to control participants. Contrary to our hypothesis, no differences existed in peak torque normalized to body weight between the external, internal, or the external:internal rotation strength ratio in bilateral comparison or between groups (Table 9). Previous studies compared bilateral internal and external rotation strength in unilateral overhead athletes (baseball and tennis players), and reported increased internal rotation strength on the dominant/throwing shoulder.[17, 19, 66] Comparison of these results was difficult as kayaking is bilateral in nature. No difference would be expected between limbs in healthy individuals. Swimming, a bilateral upper extremity sport, would provide good comparison for kayaking for upper extremity strength. It has been shown that healthy swimmers have no significant bilateral differences in internal and external rotation strength and exhibit similar values to non-overhead athletes.[123] Also, swimmers showed external:internal rotation strength ratios bilaterally.[123] The kayakers in this study, both in the shoulder pain group and the control group, had similar values bilaterally. No between group differences were noted for the kayakers either. The ratios between the healthy swimmers, non-overhead athletes (in the previous study), and both groups of kayakers (in the current study) were similar. As such, it appears that a strength imbalance around the shoulder is not a contributor to the shoulder pain seen in this group of kayakers.

For the involved shoulder, it would be expected that decreases in strength would occur. It was hypothesized that kayakers with shoulder pain would show decreased external rotation strength and thus decreased external:internal rotation strength ratio. It has been shown that strength decreases occur in both internal and external rotation in individuals with partial thickness and full thickness rotator cuff tears.[69] The decrease in strength was shown to be mainly attributed to pain, as following pain injection, strength significantly increased in both groups.[69] In this group of kayakers with unilateral shoulder pain, no alteration was seen in internal or external rotation strength. As no pain injection was used as part of the current study, it is unknown what effect pain had on the involved shoulder.

5.3.2 Protraction and Retraction Strength

Contrary to our hypothesis, no differences existed in peak force normalized to body weight for protraction, retraction, or the protraction:retraction strength ratio in bilateral comparison or between groups (Table 10). Protraction and retraction strength has been assessed in healthy overhead athletes and in athletes with signs of shoulder impingement.[16, 71] Protraction and retraction strength variables previously reported were slightly higher than protraction and retraction strength found in the current study in both the healthy group and the injured group.[16] This may be due to the younger age of the participants in the previous study, or the lower body masses of the participants.[16]

It should be noted that the healthy group tended to have greater normalized peak force in all measures and a lower protraction:retraction strength ratio, although no significant differences were found between limbs or groups (Table 10). This is in agreement with Cools et al[16], who demonstrated non-significantly increased protraction and retraction strength in the uninvolved shoulder compared to the involved shoulder in a sample of athletes with overuse injuries of the shoulder.[16] These authors did not compare the uninvolved strength to a control group. The differences found in the current study may not have reached statistical significance due to the large variability associated with the measures. Despite the lack of statistical significance, the bias of increased strength bilaterally in the control group was unexpected, especially considering the description of proper kayaking technique as having a “push-pull” sequence of motion.[11] Protraction and retraction strength testing may be more sport specific in kayakers than in overhead athletes such as tennis and volleyball players.[16] This information may be valuable in showing an association between strength and injury risk. Given the study design it is difficult to state with certainty, however it seems as though increased protraction and retraction strength may be protective against injury. It is unlikely that pain was the limiting factor for protraction or retraction strength, as no strength difference was noted between limbs in the pain group. Additionally, both limbs in the shoulder pain group were diminished compared to their respective controls. Further investigation of protraction and retraction strength on shoulder injuries in kayakers is warranted.

Further comparison of these two studies should consider the kinematics of the sports investigated. Considering the description of proper kayaking technique as having a “push-pull” sequence of motion[11], protraction and retraction strength testing may be more sport specific in kayakers than in overhead athletes such as tennis and volleyball players.[16] This information may be valuable in showing an association between strength and injury risk. Further investigation of protraction and retraction strength on shoulder injuries in kayakers is warranted.

5.4 SCAPULAR KINEMATICS DURING AN ELEVATION TASK

The relationship between specific shoulder pathologies and scapular kinematics during a standardized elevation task had been well estabilished.[32, 36, 39, 41, 77] This was the first study to assess scapular kinematics during an elevation task in a group of participants with non-specific shoulder pain. Our hypothesis was that the involved shoulder would exhibit alterations in scapular kinematics compared to the uninvolved shoulder, and compared to the matched shoulder in the control group. Additionally, it was hypothesized that no significant differences existed between the uninvolved shoulder in the pain group and the matched shoulder. No significant differences were observed in this study for any of the variables measured (Table 11). The involved shoulder in the pain group was not one specific type of injury, but a group of different injuries. This may have lead to the lack of differences found. In previous work, differences in scapular kinematics occurred in specific shoulder impairments such as subacromial impingement, internal impingement, and adhesive capsulitis.[32, 36, 39, 41, 77]

Where available, comparisons between the current study and prior studies show similar results, except for scapular upward rotation.[37, 77, 123] In the current study, there was decreased upward rotation trend in the kayakers, whether involved or uninvolved, at all angles of elevation. This may potentially be due to the repetitive downward rotation that occurs during the "pull" associated with the kayak stroke. This downward rotation initiates at paddle water association and increases through paddle water dissociation. Furthermore, during the kayak stroke, humeral elevation angles rarely exceed 90°. Most of the kinematics of the kayak stroke occur at lower humeral elevation angles. Therefore, upward rotation (as a means to increase subacromial space) may not be as important as in other sports such as swimming, which occur throughout a much greater range of motion. Increasing subacromial space may not be as important as in tasks such as the kayak stroke, which required low and mid range humeral elevation. Hagemann et al.[3] conducted magnetic resonance imaging on 52 marathon kayakers with and without shoulder pain to determine the integrity of the shoulder and potential pathoanatomical changes that underlie shoulder injury in this group of kayakers. The large majority of positive findings on the images were related to overuse of the rotator cuff.[3] It was concluded that these types of injuries were not due to spatial restrictions of the subacromial space.[3] These authors went on to conclude that the overuse of the rotator cuff was due to repetitive use and was specific to kayakers.[3] Given the clinical presentation of overuse injuries of the participants in the current study, along with the findings of Hagemann et al.,[3] the decreases noted in upward rotation of kayakers may be a specific adaptation to the kayak stroke and thus would only be found in this group of athletes.

Previous work has demonstrated that sports specific adaptations to scapular kinematics during an elevation task occur in healthy overhead athletes. Myers and colleagues[37] reported an increase in upward rotation and internal rotation at all angles of humeral elevation in the throwing shoulder of baseball players. Additionally, they found increased scapular retraction at higher angles of humeral elevation (90° and 120°).[37] The authors hypothesize these alterations to stem from attempting to increase subacromial space and allow greater retraction during the late cocking phase of throwing for upward rotation and retraction respectively.[37] As kayaking is a bilateral sport, and there was no control group comprised of non-kayakers, it is difficult to assess how the values seen in the current study compare to other bilateral overhead athletes (swimmers) and non-overhead athletes.

5.5 KINEMATICS DURING THE KAYAKING TASK

5.5.1 Scapular Kinematics

It was hypothesized that scapular kinematics would differ during the kayaking task between the involved and uninvolved shoulder, and between the involved shoulder and matched control. It was also hypothesized that no difference would occur between the uninvolved shoulder and matched control. It was shown that no differences in scapular kinematics occurred for any of the comparisons (Table 12). No differences were shown in the pilot study as well, when assessing bilateral kinematics during the forward stroke in expert whitewater kayakers. In this study, kayakers with shoulder pain did not show any significant bilateral differences either. The values between the pilot study and the current study are similar. No prior studies which compare scapular kinematics during kayaking are available. Further interpretation of these results is difficult. Lovell et al.[10] compared bilateral forces from a computerized kayak ergometer and found a significant asymmetry in participants with shoulder pain for peak force. The authors used force output from an ergometer to describe the asymmetry, not kinematic data. Additionally, it is difficult to ascertain where the asymmetry stems from, as the force of a kayak stroke is a resultant force from the elbow, shoulder, torso, and hips on each side of the body.[11] Based on the results of this study, it appears that no differences exist between involved and uninvolved shoulder for scapular kinematics in whitewater kayakers.

5.5.2 Humeral Kinematics

Contrary to our hypothesis, no significant differences in humeral kinematics were found for kayakers with shoulder pain upon bilateral comparison or to a control group. Likewise, no differences were found between the uninvolved shoulder and the matched control. The humeral kinematics are similar between the two studies. To date, one study has compared upper extremity biomechanics while kayaking.[11] While specific joint angles were not reported on, they did report a non-significant bilateral asymmetry in Olympic level kayakers for stroke phase, and its velocity and acceleration components.[11] The general kinematics of the humerus in the current study are similar to descriptions given of correct paddling technique described previously.[11]

One potential reason for the lack of significant differences seen during the kayak stroke in the current study was the variability in stroke kinematics. This was especially true for the humerus where much greater ranges of motion are available compared to the scapula. In whitewater kayaking, there is no gold standard for teaching the correct kayak stroke, nor is there consensus among kayak coaches on what is correct technique. The amount of variability seen in the current study may be a reflection of this trend. Similarly, variability has been shown in spinal kinematics while rowing in a study of intercollegiate level rowers.[44] Rowing and kayaking have vastly different kinematic patterns. However, both of the groups studied participate at a high level and still show large kinematic variability. Therefore, stroke kinematics variations may not be a contributor to injury. Examination of the association between kinematics and performance or metabolic efficiency was not an aim of this study, however these aspects should be examined further in future studies. It may, however, be implicated with performance and metabolic efficiency.[45]

Another potential contributor to the variability seen was the difference in skill levels between class III and class V kayakers. The potential exists that kayakers with lower skill level use different kayaking kinematics compared to their more skilled counterparts. This may contribute to the variability seen between skill levels. It has been previously reported that rowers of varying skill level can be stratified based on biomechanical performance variables, including stroke-to-stroke consistency.[125]

5.5.3 Torso Kinematics

Despite the emphasis, both in the scientific literature and anecdotally[4, 10-12, 63], on the importance of torso rotation for proper kayak stroke kinematics, no differences were found for any comparisons of torso kinematics. It was hypothesized that torso kinematics would differ between sides in the pain group and between the involved side and matched side in the control group. It was also hypothesized that no difference would occur between the uninvolved side in the pain group and the matched side in the control group. Torso rotation kinematics has not been previously assessed in whitewater kayakers while kayaking. One case study assessing torso rotation kinematics in a flatwater kayaker has been performed.[48] The purpose was to compare kayaking kinematics on an ergometer to kayaking on the water. The torso rotation range of motion found in the case study was much larger than the reported range of motion in the current study.[48] There are several potential explanations for this. The subject in the case study was a world champion flatwater kayak racer. The objective of flatwater kayak racing is to propel the kayak as fast as possible from one place to the next (in a straight line). Therefore no turning strokes are required. Whitewater kayaking requires a variety of strokes for turning as well as strokes in reaction to different currents, waves, and obstacles in the river (rocks, etc.). As such, the flatwater kayak technique will be remarkably proficient at the forward stroke, while whitewater kayaking requires proficiency in many strokes. Additionally, given the level of ability of the racer, as well as his access to coaching, and specialization in the forward stroke only, his forward stroke technique was likely far superior than the group of kayakers in the current study. Finally, the calculations used to represent torso rotation did not account for pelvic rotation or kayak rotation in the water and were a summation of all of these rotations.[48]

5.5.4 Description of Kayaking Kinematics

No prior study has described the torso and scapulohumeral kinematics of the kayak stroke. The following description will explain the component motions of the kayak stroke. The values used for the description are the averaged values for the dominant shoulder of the control group (Table 12). Because no significant differences were found between limbs in healthy kayakers or between groups, this description may be applicable to both groups studied.

The sequence of motion of the kayak stroke started with paddle water association to paddle shaft vertical on the draw side. During this time, the torso rotated toward the draw side, while the humerus extended and adducted as the paddle was pulled posteriorly. Also during this time, the scapula downwardly rotated, externally rotated, and posteriorly tilted, while simultaneously becoming more retracted and depressed. The kinematics that occurred at the torso and humerus are similar to what has been described previously.[11, 12, 63] The kinematics of the scapula have not been previously described. Trying to extend and adduct the humerus with resistance requires the sequence of motion at the scapula which was seen, i.e. downward rotation, external rotation, posterior tilting, retraction, and depression.

From paddle shaft vertical to paddle water dissociation on the draw side, the torso continued to rotate toward the draw side while the humerus continued to extend, as reported previously.[11, 12, 63] At the same time, the scapula continued the same kinematic sequence that occurred from paddle water association to paddle shaft vertical. That was downward rotation, external rotation, posterior tilting, retraction, and depression. This kinematic sequence would again be expected as the humerus pulled the paddle against the force of the water (ergometer).

As the draw side changed, the contralateral arm was positioned for paddle water association. During this time, the torso continued to rotate toward the draw side, while the humerus elevated slightly. The scapula upwardly rotated, externally rotated, and posteriorly tilted, while being slightly elevated. This sequence of scapular motions was consistent with the humerus position being changed to initiate paddle entry on the contralateral side.

As the thrust side moved from paddle water association to paddle shaft vertical, the torso rotated toward the thrust side, and the humerus elevated and horizontally adducted. All the while, the scapula upwardly rotated, internally rotated, and posteriorly tilted. Simultaneously, it protracted and elevated. The torso and humerus characteristics are consistent with previous reports.[11, 12, 63] The scapular motion seen would be expected given the altered position of the humerus.

Between the last two points of the kayak stroke, the torso continued to rotate toward the thrust side, while the humerus showed decreased elevation. This would be predicted as the paddle exited the water on the contralateral side.[11, 12, 63] The scapula downwardly rotated, externally rotated, and posteriorly tilted slightly. Also, the scapula protracted and depressed simultaneously. Again, given the movement that occurred at the humerus, these scapular motions would be anticipated.

5.6 MUSCLE ACTIVITY DURING THE KAYAKING TASK

It was hypothesized that differences in muscle activity would occur during several phases of the kayak stroke between the involved and uninvolved shoulder in the pain group and between the involved shoulder and the matched shoulder in the control group. Contrary to our hypothesis, no significant differences were found for any comparisons made. As described previously, there is large variability among kayakers kinematics, thus disparity in muscle activation would also be expected. The large variability associated with this measure likely contributed to the lack of differences found. One possible explanation for the variability seen in muscle activity is related the methodology used in the study. In the current study, the stroke rate was normalized at 30 strokes per minute. The air-braked component of the ergometer changes resistance based on the load imparted, therefore higher stroke rates (load) create greater resistance from the ergometer. The effect of normalizing stroke rate was to normalize the resistance from the ergometer. While it can be reasonably assumed all participants had similar resistance from the ergometer, strength and endurance of the kayakers was not accounted for. It is possible that the resistance from the ergometer required a greater percentage of maximal isometric contraction for the smaller or less physically conditioned participants, compared to the stronger more conditioned kayakers tested.

In contrast to the ergometer, resistance during the kayak stroke on the water is given by the kayaker's body weight in the water and water currents. Another possible contributor to the inconsistency seen in muscle activity is the variability seen in kayaking kinematics. Given the variability in humeral kinematics, it would be expected that no significant differences would be found for muscle activity, potentially due to the large variability in both measures.

One study has assessed muscle activity during a kayaking task. Trevithick and colleagues[62] measured consistency of muscle activity during the kayak stroke for several shoulder muscles. Through this analysis, they conclude the latisimus dorsi to be the prime mover of the paddle during the kayak stroke, as it was consistently active while the paddle was in the water. While analysis of the current study chose to assess mean activation instead of consistency of activation, the latisimus dorsi had relatively high mean activation at corresponding time points to the previous assessment.[62] The activity levels found during the draw phases were higher than the thrust phases for all subjects. This is in agreement with the previous study which reports the latisimus dorsi as primary mover of the kayak paddle during the forward stroke.

5.7 LIMITATIONS OF THE STUDY

There are several limitations of this study which merit mention. First, the shoulder pain participants in this study did not all have the same clinical diagnosis. If the entire shoulder pain group had the same injury (clinical diagnosis), additional significant differences could become apparent. In addition, no advanced imaging technology was used to offer a specific diagnosis of the injuries seen. Therefore, the clinical diagnoses may not accurately characterize the pain causing tissues or structures. Second, kinematic analysis of the kayak stroke was only analyzed during the forward stroke. This is the primary stroke used by kayakers, however many turning strokes exist which have the potential to place greater force across the shoulder joint and may play a greater role in shoulder injuries in whitewater kayakers. Similarly, this study used a kayak ergometer to assess kayaking kinematics. Kayak ergometers have been shown to replicate kinematics of kayaking[48], the kinematics of the participants of this study may vary between kayaking on the water and on the ergometer. Finally, kayaking on whitewater requires alteration in mechanics based on changes in the external environment (currents, waves, rocks, etc), while kayak on the ergometer does not involved a dynamic external environment.

5.8 CLINICAL SIGNIFICANCE

Heeding the results of this study, differences that appear to be related to shoulder injury exist between kayakers with and without shoulder pain. Specifically, kayakers with unilateral shoulder pain have significantly decreased shoulder internal rotation and abduction range of motion compared to their uninvolved shoulder and compared to a group of kayakers without shoulder pain. Surprisingly, kayakers with unilateral shoulder injury exhibit bilateral deficits in all shoulder range of motion variables assessed, including posterior shoulder tightness. The bilateral deficiency has been shown for shoulder flexibility significantly in abduction and internal rotation, and non-significantly for flexion, extension, external rotation, and posterior shoulder tightness.

The protraction and retraction strength of whitewater kayakers with shoulder pain is another area which warrants discussion. While differences were not significant, it was shown that kayakers without shoulder pain tended to be stronger in both protraction and retraction strength, bilaterally. That is, upon comparison of the involved and uninvolved shoulder, kayakers in the control group had greater peak torque for protraction and retraction strength. The greater strength in the control group bilaterally, may be seen as preventative against injury.

Treatment of kayakers with shoulder pain should address the specific deficits discovered in this study. With an understanding of the bilateral nature of the deficiencies for shoulder strength and range of motion in kayakers, strict attention should be paid to these variables. Often in rehabilitation, the contralateral (uninjured) side is used as a benchmark and treatment goals are set to rehabilitate the injured side to a level equivalent to the uninjured side. As shown in this study, rehabilitation of kayakers with unilateral shoulder pain should address deficits which appear bilaterally, specifically for shoulder range of motion, posterior shoulder tightness, and protraction and retraction strength. Treatment should aim at increasing shoulder protraction and retraction strength bilaterally while incorporating flexibility interventions into all planes of motion at the shoulder as well.

Given the lack of information regarding physical characteristics of healthy and injured whitewater kayakers, the results from this study can be used as a normative data set for the healthy group. Findings from clinical examination give some insight into the nature of injuries common to whitewater kayakers with shoulder pain.

5.9 FUTURE DIRECTIONS

Future research is needed to help understand and explain the injuries associated with whitewater kayaking. Future studies should assess the types of injuries found in whitewater kayakers, particularly internal impingement, given the prevalence seen in this sample. Additionally, future work should continue to address the deficits found in this study for shoulder range of motion and posterior shoulder tightness. Observing the scapular kinematics seen during the standardized elevation task, comparisons to other bilateral overhead athletes (swimmers) and non-overhead athletes may show unique characteristics found exclusively in kayakers. Finally, continued research on the protraction and retraction strength in kayakers with and without shoulder pain is warranted given the potential protective effect of increased strength for this kayaking specific motion.

5.10 CONCLUSIONS

The findings of this study demonstrate differences in physical characteristics among whitewater kayakers with shoulder pain, when compared to their uninvolved side and to a matched control group. Specifically, kayakers with shoulder pain exhibited significant decreases in abduction and internal rotation range of motion of the involved shoulder upon bilateral comparison and to a matched control group. No significant differences were noted between these groups of kayakers for strength, scapular kinematics during an elevation task, kayaking kinematics of the torso, humerus, or scapula, or muscle activity while kayaking.

APPENDIX A. QUICKDASK FORM

*Quick*DASH

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Do heavy household chores (e.g., wash walls, floors).	1	2	3	4	5
3. Carry a shopping bag or briefcase.	1	2	3	4	5
4. Wash your back.	1	2	3	4	5
5. Use a knife to cut food.	1	2	3	4	5
6. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
7. During the past week, *to what extent* has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups?	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
8. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem?	1	2	3	4	5

Please rate the severity of the following symptoms in the last week. *(circle number)*	NONE	MILD	MODERATE	SEVERE	EXTREME
9. Arm, shoulder or hand pain.	1	2	3	4	5
10. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
11. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? *(circle number)*	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions relate to the impact of your arm, shoulder or hand problem on playing *your musical instrument or sport or both*. If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you:____

❑ I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week.

Did you have any difficulty:	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

APPENDIX B. ASES SHOULDER FORM

SHOULDER ASSESSMENT FORM AMERICAN SHOULDER AND ELBOW SURGEONS				
Name:		Date:		
Age:	Hand dominance: R L Ambi	Sex: M F		
Diagnosis:		Initial Assess? Y N		
Procedure/Date:		Follow-up: M; Y		

PHYSICIAN ASSESSMENT				
RANGE OF MOTION Total shoulder motion Goniometer preferred	RIGHT		LEFT	
	Active	Passive	Active	Passive
Forward elevation (Maximum arm trunk angle)				
External rotation (Arm comfortable at side)				
External rotation (Arm at 90° abduction)				
Internal rotation (Highest posterior anatomy reached with thumb)				
Cross-body adduction (Antecubital fossa to opposite acromion)				

SIGNS 0= none; 1= mild; 2= moderate; 3=severe			
SIGN		Right	Left
Supraspinatus/greater tuberosity tenderness		0 1 2 3	0 1 2 3
AC joint tenderness		0 1 2 3	0 1 2 3
Biceps tendon tenderness (or rupture)		0 1 2 3	0 1 2 3
Other tenderness - List:		0 1 2 3	0 1 2 3
Impingement I (Passive forward elevation in slight internal rot)		Y N	Y N
Impingement II (Passive internal rot with 90°)		Y N	Y N
Impingement III (90° active abduction-classic painful arc)		Y N	Y N
Subacromial crepitus		Y N	Y N
Scars - location		Y N	Y N
Atrophy - location		Y N	Y N
Deformity: describe		Y N	Y N

(record MRC grade)

0= no contraction; 1= flicke; 2= movement with gravity eliminated
3= movement against gravity; 4= movement against some resistance; 5= normal power

	Right	Left
Testing affected by pain?	Y N	Y N
Forward elevation	0 1 2 3 4 5	0 1 2 3 4 5
Abduction	0 1 2 3 4 5	0 1 2 3 4 5
External rotation (Arm comfortably at side)	0 1 2 3 4 5	0 1 2 3 4 5
Internal rotation (Arm comfortably at side)	0 1 2 3 4 5	0 1 2 3 4 5

INSTABILITY

0= none; 1= mild (O-1 cm translation)
2= moderate (1-2 cm translation or translates to glenoid rim)
3= severe (>2 cm translation or over rim of glenoid)

	Right	Left
Anterior translation	0 1 2 3	0 1 2 3
Posterior translation	0 1 2 3	0 1 2 3
Inferior translation (sulcus sign)	0 1 2 3	0 1 2 3
Anterior apprehension	0 1 2 3	0 1 2 3
Reproduces symptoms?	Y N	Y N
Voluntary instability?	Y N	Y N
Relocation test positive?	Y N	Y N
Generalized ligamentous laxity	Y N	

Other physical findings:

Examiner's name:

____ ____________________Date

APPENDIX C. INTERNATIONAL SCALE OF RIVER DIFFICULTY

There has been a universal system set up for defining the difficulty of specific rivers and rapids. This system uses “classes” which range from I to VI. Where I is the easiest and VI is considered unkayakable. The actual definitions of each class are presented below (taken from the International Scale of River Difficulty):

Class I: Easy. Fast moving water with riffles and small waves. Few obstructions, all obvious and easily missed with little training. Risk to swimmers is slight; self-rescue is easy.

Class II: Novice. Straightforward rapids with wide, clear channels which are evident without scouting. Occasional maneuvering may be required, but rocks and medium sized waves are easily missed by trained paddlers. Swimmers are seldom injured and group assistance, while helpful, is seldom needed. Rapids that are at the upper end of this difficulty range are designated "class II+".

Class III: Intermediate. Rapids with moderate, irregular waves which may be difficult to avoid and which can swamp an open canoe. Complex maneuvers in fast current and good boat control in tight passages or around ledges are often required; large waves or strainers may be present but are easily avoided. Strong eddies and powerful current effects can be found, particularly on large-volume rivers. Scouting is advisable for inexperienced parties. Injuries while swimming are rare; self-rescue is usually easy but group assistance may be required to avoid long swims. Rapids that are at the lower or upper end of this difficulty range are designated "class III-" or "class III+" respectively.

Class IV: Advanced. Intense, powerful but predictable rapids requiring precise boat handling in turbulent water. Depending on the character of the river, it may feature large, unavoidable waves and holes or constricted passages demanding fast maneuvers under pressure. a fast, reliable eddy turn may be needed to initiate maneuvers, scout rapids, or rest. rapids may require “must" moves above dangerous hazards. Scouting may be necessary the first time down. Risk of injury to swimmers is moderate to high, and water conditions may make self-rescue difficult. Group assistance for rescue is often essential but requires practiced skills. A strong eskimo roll is highly recommended. rapids that are at the upper end of this difficulty range are designated "class IV-" or "class IV+" respectively.

Class 5.0: Expert. Extremely long, obstructed, or very violent rapids which expose a paddler to added risk. Drops may contain large, unavoidable waves and holes or steep, congested chutes with complex, demanding routes. Rapids may continue for long distances between pools, demanding a high level of fitness. What eddies exist may be small, turbulent, or difficult to reach. at the high end of the scale, several of these factors may be combined. Scouting is recommended but may be difficult. Swims are dangerous, and rescue is often difficult even for experts. A very reliable eskimo roll, proper equipment, extensive experience, and practiced rescue skills are essential. Because of the large range of difficulty that exists beyond class iv, class 5 is an open ended, multiple level scale designated by class 5.0, 5.1, 5.2, etc... Each of these levels is an order of magnitude more difficult than the last. Example: increasing difficulty from class 5.0 to class 5.1 is a similar order of magnitude as increasing from class IV to class 5.0.

Class VI: Extreme and exploratory. These runs have almost never been attempted and often exemplify the extremes of difficulty, unpredictability and danger. The consequences of errors are very severe and rescue may be impossible. For teams of experts only, at favorable water levels, after close personal inspection and taking all precautions. After a class VI rapids has been run many times, it's rating may be changed to an appropriate class 5.x rating.

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