BIOMECHANICAL ADAPTATIONS
OF THE SHOULDER
IN COLLEGIATE SWIMMERS

by

Kelsey E. Shonk

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fulfillment of the requirements for the degree of Master of Science in Exercise Science

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LIST OF ABBREVIATIONS

HR – Humeral Retrotorsion

PST – Posterior Shoulder Tightness

PCT – Posterior Capsule Thickness

ROM – Range of Motion

ER – External Rotation

IR – Internal Rotation

UR – Upward Rotation (Scapular)

SD – Scapular Dyskinesis

OH – Overhead

GIRD – Glenohumeral Internal Rotation Deficit

MVC – Maximum Voluntary Contraction

GH – Glenohumeral

ABSTRACT

Context: Several studies have found alterations in range of motion, posterior shoulder tightness, posterior capsular thickness, and humeral retrotorsion among overhead throwing athletes. However, despite its popularity and high incidence of shoulder pain, few studies have been conducted on swimmers to determine whether similar adaptations occur. **Objective:** The purpose of this study was to determine if biomechanical adaptations develop in swimmers' shoulders and how those changes are related to injury history and distance specialty. **Methods:** 26 swimmers volunteered (8 males, 18 females; 5 distance, 21 sprint swimmers; 6 injured, 20 uninjured swimmers) to take part in this study. A post-test only study design was used to analyze glenohumeral internal and external rotation, scapular upward rotation, and posterior shoulder tightness (humeral horizontal adduction) by an inclinometer. Posterior capsular thickness and humeral retrotorsion (HR) were examined through diagnostic ultrasound. All measurements were performed on both the dominant and non-dominant arms. Prior to testing all subjects completed a questionnaire to asses injury and swimming history. **Results:** A 3 way ANOVA was run for each dependent variable. The dominant arm was found to have greater external rotation (p=0.002), but less internal rotation (p=0.001), upward rotation at 90° (p=0.039), and upward rotation at 120° (p=0.046) than the non-dominant arm. Uninjured swimmers and sprinters had significantly greater HR than their injured (p=0.008) and distance (p=0.017) counterparts. There was a significant correlation between HR and IR both the dominant (r=-.461, p=0.014) and non-dominant (r=-.428, p=0.023) sides. All other variables were not significant. **Conclusions:** The dominant arms of swimmers display some anatomical and biomechanical adaptations, but less than other overhead athletes. The development of humeral retrotorsion in swimmers is reflected in both distance specialty and injury history. Soft tissue characteristics, such as posterior capsule thickness, offer less insight of shoulder injury and specialty in a swimming population.

Chapter 1

INTRODUCTION

Swimming is a very popular sport worldwide, with more than one hundred million individuals participating in the United States each year.[24] However, complaints of shoulder pain and the prevalence of injury is very high.[1] Up to 91% of swimmers will experience some shoulder pain during the course of their careers with 70% complaining of shoulder pain during the pull through phase, prompting the sports medicine vernacular term "swimmer's shoulder."[5,26,46,49,54,57,59,64,67]

"Swimmer's shoulder" does not have an exact definition or etiology due to lack of conclusive evidence, but despite a great deal of research there has been limited success in distinguishing a cause, prevention strategy, and optimal post-injury intervention plan.[3,16,22,50,68] These results may be inconsistent due to a lack of understanding for the anatomical adaptations in a swimmer's shoulder as a result of the stroke, thereby confounding results of previous studies. Consequently, clinicians struggle to develop effective, individualized rehabilitation plans without a full understanding of the potential scapulothoracic and glenohumeral maladaptations that precipitate pain as a result of swimming.

Several potential deleterious adaptations have been identified through research on overhead athletes such as humeral retrotorsion (HR), posterior shoulder tightness (PST), posterior capsule thickness (PCT), and range of motion (ROM). These variables can be instructive when attempting to determine biomechanical adaptations of the shoulder in swimmers, but data are limited or absent. It is common to observe excessive external rotation (ER) and less internal rotation (IR) in the dominant arm as compared to the non-dominant arm in overhead throwing populations. [4,5,10,52,62,63] This loss of IR has been found to be related to shoulder pathologies such as internal impingement syndrome. [40,65] Clinical ROM measurements of both IR and ER have also been associated with increased PCT, HR, and PST. [13,15,40,53,56,60,61]

Thomas et.al. investigated HR in baseball players and found a 16° difference between sides, which is consistent with previous literature. [27,42,61,69] A lesser, 6.4°, difference has been observed in adolescent swimmers. [69] Significantly thicker posterior capsules have been reported in the dominant arms of overhead athletes and PCT has also been related to HR. [60,61] Greater HR and PCT have been postulated to be causes of scapular dyskinesis (SD), which may lead to injury. [10,11,27] Both PCT and HR are theorized to contribute to greater PST, which presents clinically with less IR. [65] Greater amounts of PST are also associated with shoulder injury such as anterior rotator cuff pathology, SLAP lesions, pathological internal impingement, and subacromial impingement. [40,55,65]

These potentially harmful soft tissue and osseous adaptations are thought to occur over a long period of time due to repetitive stresses placed on the shoulder during overhead throwing. [10,11] During swimming, the front crawl stroke puts the joint in similar motion patterns as overhead throwing. [49,69] Pink and Tibone (2000) equate the point of maximal ER in the recovery phase of swimming, to the late cocking stage of the throwing motion. [49] During the pull-through phase of the swimming stroke cycle, the subscapularis activates and works continuously at submaximal levels, analogous to throwing where the muscle achieves maximum contraction levels. While the subscapularis is more active in the pitch, the pectoralis major and latissimus dorsi muscles are more active in the pull-through phase of swimming strokes. [18,48]

Swimmers do not require the excess ROM or eccentric force generation compared to baseball players, but they perform significantly more repetitions during every training session. [49] Thus, swimmers may undergo similar morphological adaptations, but to a lesser extent than in throwing athletes. This hypothesis is supported by the findings that adolescent swimmers have slightly greater HR and ER with less IR in their dominant shoulders compared to their non-dominant side. [5,52,69] Varied adaptations may occur in distance specialists and sprint specialists, but limited data is available. Sprint specialists apply a faster pull-through phase, indicating increased muscle force, while distance specialists have a higher stroke velocity (stroke frequency*stroke length) and repetitions. [36,37] Theoretically, these subtle differences between stroke mechanics could impact the biomechanical adaptations that occur, but this is the first study to examine possible relationships.

Utilizing muskuloskeletal ultrasound, this study examined, for the first time, the biomechanical adaptations swimmer's shoulders undergo as a result of training. The prevalence of injury in the swimming population is very high, and this study compared which, if any, soft tissue and osseous adaptations occur at the glenohumeral joint. This knowledge may benefit clinicians in their development of more efficient and effective prevention and treatment protocols.

Specific Aim 1: To determine whether side to side differences are present in PCT, HR, PST, and ROM in swimmers.

Hypothesis 1.1: There will be side-to-side differences in humeral retrotorsion.

Hypothesis 1.2: PST will show side to side differences.

Hypothesis 1.3: There will be side-to-side differences in the posterior capsule thickness.

Hypothesis 1.4: ROM will show side-to-side differences.

Specific Aim 2: To determine whether the PCT, HR, PST, and ROM are altered in swimmers who have a history of shoulder pathology as compared to those who do not.

Hypothesis 2.1: Those swimmers without a history of pain will present with greater HR.

Hypothesis 2.2: PST will be greater in those swimmers with a history of injury.

Hypothesis 2.3: The posterior capsule will be thicker on average in swimmers with a history of shoulder pain than those without.

Hypothesis 2.4: Those swimmers without a history of shoulder pain will present with greater IR and scapular upward rotation, with no difference in ER.

Specific Aim 3: To determine whether the PCT, HR, PST, and glenohumeral and scapular ROM are altered in swimmers who specialize in different distance specialties (in terms of freestyle stroke).

Hypothesis 3.1: Sprint specialists will present with greater HR than distance specialists.

Hypothesis 3.2: Distance specialists will present with greater PST and PCT than sprint specialists.

Hypothesis 3.3: There will be no difference in ROM measurements between sprint and distance specialists.

Chapter 2

METHODOLOGY

Research Design

A post-test only study design was used to examine the relationship between 6 dependent variables and 3 independent variables. The independent variables include arm dominance, history of shoulder injury, and distance specialty. Dependent variables include humeral retrotorsion, posterior shoulder tightness, posterior capsular thickness, glenohumeral internal rotation, glenohumeral external rotation, and scapular upward rotation.

Participants

26 subjects volunteered to participate in this study (8 males, 18 females). Their demographic information is presented in Table 5.1. Each participant signed an informed consent and completed a questionnaire to assess injury and swimming history prior to testing. Participants were drawn from intercollegiate swim teams and met the criteria for a competitive swimmer. A competitive swimmer was defined as a) competing in regular competitions for at least 5 years and b) swimming an average of at least 10,000 yards per week. Inclusion criteria included competing on a varsity intercollegiate swim team, age 18-24, and meeting the criteria for a competitive swimmer. Exclusion criteria included any previous shoulder surgery within one year and any neurological disorders.

Subjects were divided into two groups based on injury history and distance specialty. Injury history was divided into two groups, those with and without a previous soft tissue injury to the shoulder (examples: rotator cuff tendonitis, supraspinatus impingement, labral pathology). A history of injury was defined as any self-reported shoulder injury. Distance specialty was also divided into two groups: sprinters, defined as swimmers who predominantly train for events less than 400 yards, and distance swimmers, defined as swimmers who predominantly train for events greater than 400 yards.

Procedures

Ultrasound Scanning

Posterior capsular thickness and humeral retrotorsion were assessed through use of a commercially available compact ultrasound system (Sonosite Titan, Sonosite Inc., Bothell, WA) and a 13 MHz transducer. The measurement accuracy of this tool was 0.1 mm for posterior capsular thickness and 0.15 mm for humeral retrotorsion. [43,45,60,61,69]

Inclinometer Assessment

Glenohumeral internal rotation (Figure 1), glenohumeral external rotation (Figure 2), and horizontal adduction (Figure 3) were assessed using a Saunders Digital Inclinometer (The Saunders Group Inc., Chaska MN). Scapular upward rotation (Figure 4) was assessed using a digital inclinometer that rests on the scapular spine.

Posterior Capsule Thickness

To assess posterior capsular thickness, the subject sat in an upright position in a chair. The arm rested at the side with the forearm on the thigh in order to standardize the amount of glenohumeral rotation. Standard acoustic coupling gel was applied, and the ultrasound transducer was applied to the posterior aspect of the shoulder allowing for visualization of the humeral head, glenoid labrum, and rotator cuff. The posterior capsule was identified as the tissue immediately lateral to the lateral tip of the labrum between the humeral head and the rotator cuff. [61] Once the structures were identified, the image was paused and the posterior capsule was measured. The image and the measurement were saved to the hard drive, and removed for analysis after completion of testing. Three separate measurements were taken and averaged for data analysis.

Humeral Retrotorsion Assessment

To assess humeral retrotorsion, subjects lay supine on a treatment table with the arm actively placed at 90 degrees of abduction and 90 degrees elbow flexion. Standard acoustic coupling gel was applied. The first examiner placed the ultrasound transducer vertically on the anterior aspect of the subject's shoulder and actively internally or externally rotated the subjects arm until the bicipital groove pointed vertically on the ultrasound screen. Verticality of the transducer was confirmed using a bubble level. A second examiner placed a digital inclinometer on the shaft of the subjects' ulna and record the degree of (humeral) rotation. [13,41,45,61] Three separate measurements were taken and averaged for data analysis.

Glenohumeral Internal and External Rotation Measurement

To assess glenohumeral internal and external rotation, subjects lay supine on a treatment table with the shoulder passively abducted to 90 degrees and the elbow flexed to 90 degrees. The scapula was stabilized by the tester's hand and the arm was rotated until scapular motion was detected. The inclinometer was then placed on the dorsal surface of the forearm for internal rotation and the ventral surface for external rotation. Once the end range of motion was reached, the hold button on the inclinometer was pressed to record the measurement. [17,63] Three separate measurements were taken and averaged for data analysis.

Glenohumeral Horizontal Adduction Assessment

To assess glenohumeral horizontal adduction, subjects lay supine on a treatment table with the shoulder passively abducted to 90 degrees and the elbow flexed to 90 degrees. The scapula was stabilized by the tester's hand. The tester then moved the arm into passive horizontal adduction. A second tester recorded the measurement with the inclinometer placed on the ventral midline of the humerus.[43] Three separate measurements were taken and averaged for data analysis.

Scapular Upward Rotation Assessment

To assess scapular upward rotation, subjects stood in a natural position. A guide pole was used to ensure the 60°, 90°, and 120° angles at the glenohumeral joint were maintained throughout the measurement process. The lateral arm of the inclinometer was then placed on the posterior lateral acromion and the medial arm over the root of the scapular spine. [25,63] Three separate measurements were taken and averaged for data analysis.

Reliability

The reliability of the primary investigators' measurements were established through ICC's. All measurements displayed good to excellent reliability across trials as evidenced by $ICC_{(3,1)}$ values ranging from .75 to .99. Swimming and injury history will be established through a general health history questionnaire.

Data Analysis

All data was analyzed using SPSS version 20.0 (SPSS Inc., Chicago, IL.). A 3-way ANOVA was run for each dependent variable. Pearson product moment correlation coefficients were used to establish potential relationships between the dependent variables. An *a priori* alpha level was set at 0.05.

Chapter 3

RESULTS

Dominant vs. Non-Dominant Comparison

Side to side results are presented in Table 2. Significant differences were found in all range of motion measures. The dominant arm presented with greater ER (125.28 ± 10.06°, 120.43 ± 8.87°, p = 0.002) and less IR (48.28 ± 11.23°, 52.48 ± 11.25°, p = 0.001) than the non-dominant arm. UR at 90 and 120 was also significant, with the non-dominant arm presenting with greater UR at 90°(20.41 ± 5.3°, 18.19 ± 5.74°, p=0.039) and 120° (37.41 ± 6.82°, 34.25 ± 7.07°, p=0.046). UR at 60° was trending towards significance, with the non-dominant arm (5.58 ± 3.45°) showing greater UR than the dominant arm (4.15 ± 3.66°, p=0.054). There were no side to side differences in HR (-16.6 ± 11.2°, -19.51 ± 9.5°, p=0.718), PST (5.64 ± 4.19°, 6.7 ± 4.61°, p=0.965) or PCT (1.609 ± 0.182 mm, 1.611 ± 0.175 mm, p=0.336). There was a significant correlation between HR and IR on both the dominant (r=-.461, p=0.014) and non-dominant (r=-.428, p=0.023) sides, while a correlation between the HR and ER on the dominant (r=.351, p=0.067) and non-dominant (r=.360, p=0.060) was trending. These results are displayed in Tables 5 and 6 respectively.

Injured vs. Non-Injured Comparison

Results between the injured and non-injured groups are presented in Table 3. A significant difference in HR (p = 0.008) was found between groups with injured subjects (-25.13 ± 11.34°) being less retrotorted than uninjured subjects (-15.71 ± 9.02°). The two groups did not differ in their amount of PST (5.83 ± 2.92°, 6.17 ± 4.41°, p=0.422) or PCT

(1.608 ± 0.208 mm, 1.611 ± 0.168 mm, p=0.336). IR, ER, and all UR were not significantly different between groups.

Distance vs. Sprint Comparison

Results between the sprint and distance groups are presented in Table 4. A significant difference was present with sprinters (-16.35 ± 9.22°) having greater HR than distance swimmers (-25.23 ± 12.4°, p= 0.017). There was no difference between PCT (1.607 ± 0.187 mm, 1.623 ± 0.13 mm, p=0.301) or PST (6.41 ± 4.59°, 5.16 ± 3.48°, p=0.864). IR, ER, and all UR measurements were not significant.

Chapter 4

DISCUSSION

The most important findings of this study indicate that previously injured swimmers present with less HR than uninjured swimmers, distance swimmers have less HR than sprint swimmers, and all swimmers display small differences in dominant and non-dominant range of motion. Although no other comparisons reached statistical significance, some results may be clinically relevant, including both the lack of difference between all groups for PCT and PST, and the 10° increase in IR in the injured swimmers.

Humeral Retrotorsion

The most significant finding related to HR in swimmers was the tendency for injured swimmers to have less HR than swimmers with no previous history of pain. This mean difference of 10.14° is most likely both clinically and statistically significant. Lower HR values have previously been related to higher risk of injury in handball players and baseball players. [7,45,47] It is postulated that a beneficial adaptations occurs as HR increases. As a result, greater shoulder ER and less IR can be achieved. This shift toward ER results in less stress on the anterior-inferior GH capsular ligaments when the arm is placed in the cocking phase of a baseball throws.[45] Since a similar mechanism exists during the pull-through phase of the freestyle stroke, greater humeral retrotorsion in swimmers may also reduce micro-trauma on the anterior-inferior capsule during each stroke cycle. Based on our results, increased HR in a swimming population appears to be an adaptive benefit, and those who did not develop it may have been likely to experience injury.

Contrary to our hypotheses, we found a small difference in HR of 2.91° between the dominant and non-dominant shoulders of the swimmers tested. The only other study to examine HR in a swimming population was Whiteley et al, who found a 6.4° difference side to side. They proposed that even a symmetrical sport like swimming was not enough to overcome the natural progression of higher retrotorsion values in the dominant arm. [69] Both of these findings of lower side-to-side HR differences in swimmers contrasts from other overhead sports such as baseball, handball, and volleyball in which differences between 9 and 17° have been observed.[15,42,47,56,61] The lack of difference in HR observed in our study may be due to the bilateral nature of swimming and the similar forces that are placed on the shoulder with each stroke cycle. Another potential reason for the lack of difference between dominant and non-dominant arms may be that the forces present during the swimming motion are not as great as those seen in other overhead sports. For instance, during a baseball throw, the pectoralis major and latissimus dorsi are recruited at 100% of MVC while in swimming, these muscles are recruited at a lesser degree (70%).[18,48,69] The net torque placed on the shoulder is therefore less in swimming, resulting in less adaptive HR that other overhead sport.

Based on the conflicting results between our study and the other previous study examining HR in swimmers, we decided to run a secondary analysis examining the effect of preferred breathing side on HR values because of the altered forces on the breathing side arm compared to the contralateral limb. Our secondary analysis also found no significant differences when using breathing side compared to arm dominance ($p=0.37$). The reason for the differences in HR between our study and the previous literature may be twofold. First, our participants had a higher mean age and range, meaning they were closer to skeletal maturity. These different age ranges may have allowed us to see the changes that occur between adolescence and adulthood in elite swimmers. Our second theory focuses on the role of previous sport history. Based on information from our health history questionnaire, few of our athletes tested played other overhead sports at a young age whereas previous studies did not collect this information. [69] Therefore, the HR progression that can be more closely identified with swimming rather than other sports that may cause additional anatomical changes.

We also found sprinters to have significantly greater HR (8.9°), than distance swimmers. The difference between these two groups may be indicative of distinct forces applied to the shoulder by swimming specialties. Sprinters have a much higher stroke frequency than distance swimmers, resulting in a shorter overall stroke.[36,37] This difference would cause an increase in the force required of the prime movers during all phases of the stroke cycle. This greater required net torque in sprinting would therefore increase HR development.[48,69]

Posterior Shoulder Tightness

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Posterior Capsule Thickness

Even though HR differences existed in our population, there was a lack of soft tissue differences as measured by PST. Since PST is an indirect measure of soft-tissue adaptation, examining posterior capsular thickness may highlight the importance of both bony and soft tissue adaptations. However, we found there to be no difference on average in PCT between the dominant and non-dominant sides. To our knowledge, no other studies have examined PCT in a swimming population. Thomas et al [60] found an average PCT of 2.03mm on the dominant arm and 1.65 mm on the non-dominant arm in baseball players, while Bey et al [6] found the average PCT in a normal adult population to be 1.3 mm. This would place the PCT of swimmers in the middle of these two extremes.

This indicates the eccentric forces present in other overhead sports may be more than in swimming, resulting in less PCT.

PCT is thought to develop in overhead athletes when the posterior musculature fails to adequately control deceleration, and initially provide increased stiffness of the GH joint. Over time the PCT would undergo connective tissue proliferation and adaptive thickening to accommodate the repetitive and heightened loads. However, as the capsule continues to thicken, it may shift the humeral head anteriorly and superiorly, potentially altering scapular mechanics. [10,60] Despite the freestyle stroke requiring significantly less eccentric deceleration than other overhead sports, we hypothesized that the range of motion and muscle force required during a complete stroke cycle, combined with the number of stroke cycles during practice and competitions, could result in PCT differences between all groups. Despite these factors, there were no differences found between sprint and distance swimmers. There were also no differences found between the injured and uninjured groups. This data suggests that PCT development in swimmers was not linked to previous shoulder pathology or conditioning history (sprint vs distance). Since it is currently unknown when PCT begins to associate shoulder pathology, this study may indicate that its development in swimmers aids in stiffness and is actually beneficial.

Considerable speculation exists over the role of scapular dyskinesis in the development of shoulder injury, specifically swimmers shoulder. If the PCT development that occurs in swimming is not linked to injury development, scapular dyskinesis may play less of a role in swimming than previously suspected or there is a different mechanism than those proposed in baseball.

Range of Motion

One of the few reliable means of quantifying scapular movement is measuring scapular upward rotation. [25,63] We found no difference in any of the UR measurements between the injured and uninjured group or the sprint and distance groups. We did find the non-dominant arm to have significantly greater UR than the dominant arm UR at 120° and 90° with UR at 60° trending towards significance. However, the mean differences between the dominant and non-dominant sides of between 1.43-3.15° were very small, and are therefore may not be clinically relevant. We found swimmers to have significantly less UR at all testing intervals than previously reported, [58,63] but the methodologies and reporting strategies varied slightly. Based on our findings in PCT and UR, there seems to be no difference between the injured and non-injured groups. This would suggest a decreased influence of scapular dyskinesis, or another mechanism through it develops in swimming.

We also found IR and ER to be different between the dominant and non-dominant arms, although the mean difference was small (4.19° and 4.84° respectively). This result was unsurprising, as other studies have found small differences between the dominant and non-dominant side. [5,52] Secondary analysis showed that IR was significantly correlated to HR on both the dominant ($p = 0.01$, $r = -0.494$) and non-dominant sides ($p = 0.011$, $r = -0.498$) while a correlation was trending between ER and HR in both the dominant ($p = 0.055$, $r = 0.381$) and the non-dominant ($p = 0.077$, $r = 0.353$) arms. This correlation between HR and shoulder range of motion may help explain the differences in IR values between our injured and non-injured subjects. While we did not find statistical significance between our injured and uninjured group, we found a mean difference of 9.9°, which may be clinically significant. Our findings would be contrary to the observation that individuals with shoulder pathologies present with less IR. [11,40,65]

However, the IR deficits match our findings of injured swimmers presenting with 10.14° less HR than uninjured swimmers, suggesting that the injured swimmers loss of internal rotation are the result of bony rather than soft tissue adaptations.

Conclusions and Limitations

There were several limitations in this study. We utilized a small sample size that resulted in uneven groups that may not have been representative of the entire swimming population. We did not control for warm up, and many of the subjects were tested immediately post-workout. This could have resulted in greater ranges of motion than pre-workout. Finally, all previous injury history was self-reported. Therefore, subjects may have excluded items from their injury history or given incomplete data that could have affected the analyses.

Future research should focus on when the humeral torsion changes we observed occur, and if there are any strategies that aid in the beneficial adaptation into humeral retrotorsion. Few soft tissue adaptations were seen to have a significant influence, indicating that humeral torsion is the dominant factor affecting previous injury and distance specialty in swimmers.

Chapter 5

LITERATURE REVIEW

Background

Swimming is a very popular sport in the United States, with over 100 million Americans participating for recreation, fitness, and/or competition each year. [24] According to their most recent demographic study released in 2012, USA Swimming© had over 300,000 athletes swimming registered to compete year-round. [66] Participation in competitive swimming is growing, as USA Swimming reports a 4-11% total growth after each Olympic year with additional growth during non-Olympic years. Similarly, the NCAA participation study reveals men and women competing in swimming and diving has increased in all divisions from 17,586 on 866 teams in the 2001-02 season to 21,435 on 940 teams in the 2011-12 season. [9] These higher participation numbers will likely correspond with an increase in the number of injuries if historical rates remain the same.

Epidemiology

The Fédération Internationale de Natation, an international aquatic sports governing body, reports that shoulder injuries are the most common ailment in all aquatic disciplines. [1] Several studies over the years have attempted to quantify the prevalence and scope of these shoulder injuries. One of the first studies on this topic found that 3% of Canadian swimmers were experiencing shoulder pain. [26] Later studies have found significantly higher complaints of pain, between 38-91%, over the course of a swimmer's career, with many of the subjects (23 -69%) experiencing pain at the time of the study. [5,46,49,54,57,59] The extreme discrepancies observed in these studies may result from the fact that a variety of factors including gender, age, questionnaire method and skill level potentially confounded the results. Also, since swimmers were asked about their symptoms over several different periods of time, the results of these studies are hard to compare.

Although collecting statistics on how many swimmers experience pain over their competitive lifetimes, or at one moment in time, is an important research tool, data collected over a one year period may be more applicable to athletic trainers. One such study used weekly pain diaries and biweekly check-ins to determine that 38% of swimmers between ages 11-27 experience pain severe enough to alter their training over the course of a 12 month period. [67] If we extrapolate this data from the total number of swimmers that compete in the NCAA, we find that 8,145 swimmers will experience a severe shoulder injury in the course of one training year. [9] Furthermore, with 940 NCAA teams (men's and women's) currently participating in the sport, an average of 9 injures (40% of the team) will occur per team each training year.

Biomechanics of "Swimmer's Shoulder"

Shoulder pain in swimmers is not easily defined, which may contribute to the lack of congruity in current research. Kennedy et al. (1978) coined the term "swimmer's shoulder," and it remains common in the vernacular today without reference to a specific pathology. Recent research has shown that rotator cuff and biceps pathologies, especially impingement, are probable causes of "swimmer's shoulder." [57] When the arm is moved into an abducted position adequate blood flow to the supraspinatus and (long head) biceps tendon exists. However, when the arm is adducted, the most distal end of the supraspinatus (closest to the insertion) is avascular. Similar findings were observed in the biceps tendon as well. [34] The inadequate blood flow is then compounded by mechanical impingement, whereby the supraspinatus tendon is compressed beneath the coracoacromial arch by structures such as the subacromial bursa and intraarticular capsule. [44] Additionally, the biceps can also be impinged by the coracoacromial arch, and the greater tuberosity's contact with the acromion process can lead to the symptoms observed in a swimming population (unpublished work). [49] The chronic "pinching" combined with the avascular episodes of the supraspinatus tendon can irritate the tendons, causing cell death and an inflammatory response, which can eventually cascade into tendonitis, subacromial bursitis, and possibly microtearing of the rotator cuff. [26] A biomechanical analysis of the swimming stroke may help explain why the shoulder is such a commonly injured structure in swimming.

The front crawl, or freestyle, is the most commonly performed stroke. Competitive swimmers train using freestyle up to 80% of total training time. [19] This stroke generates the most speed, and its mechanics may provide insight into why swimmers experience shoulder pain and impingement. Freestyle is characterized by the smooth transition and timing as the body uses the shoulder as a fulcrum to pull itself over top of the arms. [14] Throughout the stroke, the body maintains a streamline position that reduces drag resistance and prolongs the momentum developed by each stroke cycle. The freestyle stroke can be broken into three main phases: glide, pull-through, and recovery in which many muscles are active at different times. The glide phase occurs when the swimmer extends forward to "catch" the water, begins to pull the body over the arm, and roll the body to the side of the extended arm. [14] During this phase, the scapula rotates upwardly to allow humeral head clearance (clearance).[48] Even though this upward rotation of the scapula should decrease impingement, the forced elevation of the humerus greatly increases the moment arm; consequently, 10.1% of total mechanical shoulder impingement takes place during this portion of the stroke.[72]

After the glide phase, the arm enters the pull-through phase in which the power of the stroke is generated. The pull-through phase can be broken into three sub-phases (early, mid-pull, and late) that last from the moment of full forward extension to the hand's exit from the water. From a shoulder injury perspective, the mid-pull sub-phase is the most important part of the pull-through because 4.3% of total mechanical shoulder impingement occurs, and this sub-phase is associated with the increased internal rotation and powerful adduction, which can stress the shoulder structures.[72] Also of note, 70% of swimmers with shoulder pain, experience it at the mid-pull phase of the stroke cycle.[49]

After the pull-through is complete, hand-exit begins, thereby starting the recovery phase. The recovery phase of the stroke cycle is shorter than the pull-through, since there is no water resistance. During recovery, the prime movers of the shoulder flex and abduct the humeral head, creating superior translation and potential for impingement. At mid recovery the arm is in its maximum external rotation.[23,49] This combination of movements allows the greatest amount of mechanical impingement to occur at this point (10.4%), and 18% of the pain located here in swimmers who experience shoulder pain report discomfort at this time point.[49,72] As the arm moves into late recovery and prepares for hand re-entry, the scapula upwardly rotates once more to alleviate the impingement position and allow for clearance.[48]

Competitive swimming utilizes freestyle in two capacities: sprint (> 400 yards) and distance (<400 yards).Until recently, evidence suggested that sprinters utilized a deeper pulling action of the hand, greater extension of the elbow during the pull through phase, and different degrees of body roll. [12,70] However, these studies did not control for swim pace and specialty. When sprinters and distance swimmers work at the same pace (either sprint or distance), their stroke technique shows little variation. [36,37] During sprinting, sprinters have a decreased pull-through phase, while distance swimmers obtain max shoulder roll earlier in the stroke cycle. [36] When both specialties swim distance, the only difference is that distance swimmers have a higher stroke velocity (stroke length*stroke frequency). [2]

The biomechanics of swimming and external signs and symptoms of "swimmer's shoulder" have been studied extensively, but currently there is no clear adaptation or pathology associated with its development. Because of the mechanics of the swimming motion and the fact that 24.7% of the total stroke cycle spent by the shoulder in a mechanically impinged position, shoulder impingement may be a specific cause of "swimmer's shoulder." [72] Since "swimmer's shoulder is a chronic, there may be other events that occur prior to its clinical presentation that may lead to the development of this pathology.

Traditional Ideas on "Swimmer's Shoulder"

Further research into "swimmer's shoulder" has found specific abnormalities in a high percentage of the population. [54] These abnormalities include excessive external rotation at 90 degrees of abduction, strong shoulder internal rotators that significantly lower the external rotation/internal rotation strength ratio, and alterations in scapular movement including winging and excessive protraction. [54]

The changes in scapular positioning are the most important of these adaptions and may be another potential cause of “swimmer’s shoulder.” Scapular dyskinesis, defined as a malpositioning of the scapula, produces altered shoulder kinematics and muscle forces that can eventually lead to pain. [11] This concept has recently generated a great deal of research, including links for various shoulder pathologies. Scapular dyskinesis has been linked with impingement, rotator cuff injury, multi-directional instability, and labral pathology by altering muscle activation and scapular biomechanics. [10,28,29,33] However, research remains inconclusive in regards to whether swimmers suffer from scapular dyskinesis, and if it is related to “swimmer’s shoulder.” One study examined swimmers pre and post training session, but failed to find any significant differences in scapular positioning. [16] Contrary to those results, Madsen et.al. found that after a single training session, 82% of asymptomatic swimmers presented with scapular dyskinesis. [35]

Even though scapular dyskinesis may be one cause of shoulder pain in swimmers, other factors still exist that may help explain the development and underlying causes of “swimmers shoulder.” One such theory is that the instability swimmers present with is an indication of glenohumeral laxity. This proposed laxity would lead to more humeral translation and subsequent pain. [49] It is suggested that any supraspinatus tendonitis or impingement, which develops from compression of the hypermobile humeral head, is secondary to the development of laxity in a swimmer’s shoulder. This secondary impingement stresses the rotator cuff, leading to scapular dyskinesis and disrupts the normal scapulothoracic rhythm. [49]

However, this theory on shoulder laxity has only been purported by anecdotal evidence. The instability differences in swimmers are subtle and not classified as unstable in symptomatic and asymptomatic swimmers' shoulders.[49] A more recent study found that elite swimmers showed no significant difference in glenohumeral laxity than the non-swimming controls.[8] They also did not find a significant difference in laxity between swimmers with and without a history of pain.[8] Therefore, the authors postulated that glenohumeral laxity is only a minor factor in the development of shoulder pain in swimmers.

Based on the inconclusiveness of previous research, it is clear that "swimmer's shoulder" is a multifaceted pathology to which we have few definite answers, and most probably, not one clear condition that begins the cascade. It is a combination of impingement, and possibly laxity, instability, and muscle imbalance. Thus, to further explore the potential causes of the high incidence of shoulder pain, it is imperative to look past these gross clinical measurements and examine the soft tissue and osseous adaptations that may occur simultaneously and play a significant role in injury development.

Recently, baseball and other overhead sports have been searched for physiological adaptations that may contribute to shoulder injury. Very little in this body of knowledge has examined swimming, and observations cannot be carried over from other overhead sports because of swimming's unique biomechanical aspects. For instance, while a pitcher may throw 150-200 times per practice including warm-up, a swimmer performs 2,500 or more number of strokes per day.[49] The range of motion and force may not be as extreme as other overhead sports, but adaptive changes to the soft tissue and bony structures of the shoulder, that have been shown in other sports, may occur in swimmers because of the repetitive stresses.

Posterior Capsule Thickness

Instead of examining traditional theories of "swimmer's shoulder," more researchers have begun to focus on other factors that may produce shoulder pain such as tissue hypertrophy and anatomical adaptations. One of these morphological changes is a thickening of the supraspinatus tendon. [57] MR images of 80 elite youth swimmers found that 69% showed signs of supraspinatus tendinopathy. [57] The repetitive movement of swimming (ie. stroke cycles) may lead this increased tendon thickness. The thicker tendon is pushed against the coracoacromial arch, resulting mechanical impingement symptoms felt by patients with "swimmer's shoulder" (Neer). The study also noted that swimmers who train more than 15 hours per week are twice as likely to develop supraspinatus tendinopathy, and those who swim more than 35 km (21.5 miles) per week are four times as likely to develop the condition. [57]

Another anatomical structure where swimmers may experience morphological thickening is the posterior capsule, which is defined as a portion of the glenohumeral complex consisting of the posterior band of inferior glenohumeral ligament complex just proximal to the edge of the glenoid labrum. [6] During the overhand (OH) throw, and the pull-through phase in swimming, a forceful eccentric lengthening of the posterior structures is needed to decelerate the arm. Ideally, the posterior musculature absorbs this energy and very little is required of the posterior capsule. In reality, the posterior musculature may not be able to withstand the energy absorption demands, and the posterior capsule must help dissipate the energy from this contraction. If this insufficiency occurs acutely, the shoulder is at risk for a muscle strain, but if stresses occur chronically, these forces on the posterior capsule may cause adaptive connective tissue proliferation. If this proliferation continues, it can lead to a cycle of tissue inflammation and healing that may will cause a hypertrophied posterior capsule. [10,11,60]

Posterior capsule thickness (PCT), as an adaptive mechanism, is thought to be beneficial in aiding glenohumeral stability, but may also be associated with altered scapular mechanics, thus explaining a potential reason for swimmers to develop scapular dyskinesis. [11] Since other overhead athletes, with similar joint excursions, experience both PCT and scapular dyskinesis, swimmers may exhibit these alterations chronically as well, although the results on acute changes are still ambiguous. [16,21,28,30,31,35,48,58,63] Our lab found a positive correlation between PCT and scapular upward rotation. [60] Scapular upward rotation measurements offer a means of objectively measuring scapular function and has been found to be decreased in overhead athletes with shoulder pathologies. [32,33] This finding holds true for swimmers with subacromial impingement as well. [58]

Sein et al (2008) reported that an increase in supraspinatus tendon thickness led to the assumption that the posterior musculature was absorbing some of the energy during the recovery phase of the stroke. If the posterior musculature fails, the posterior capsule would then have to absorb that energy, resulting in adaptations such as increased capsular thickness and potentially scapular dyskinesis, both of which are thought to produce pain in overhead athletes. However, other physiological changes in the shoulders of swimmers may also lead to the high incidence of pain in swimmers.

Posterior Shoulder Tightness / Range of Motion

It has been well documented that swimmers and other overhead athletes present with side-to-side differences in glenohumeral rotation. Specifically, lower internal rotation and higher external rotation values are present in the dominant arm compared to the non-dominant arm, and shoulders of non-overhead athletes. [5,15,40,46,51-53,56,60] This common alteration can become symptomatic when the amount of glenohumeral internal rotation loss exceeds external rotation gains and is referred to as GIRD (glenohumeral internal rotation deficit). [11] GIRD is related to several shoulder pathologies, including pathological impingement. [40,65]

Decreased internal rotation in overhead athletes has been associated with greater posterior shoulder tightness (PST). [40,55,65] An arthroscopic diagnosis of PST is threefold and includes: 1) narrowing of the posterior-inferior joint space, 2) loss of elasticity in posterior capsule and PIGHL (posterior-inferior glenohumeral ligament), and 3) absence of PIGHL laxity in early abduction. [55] PST is a common clinical measurement used to examine the role of tight posterior structures. However, the relationship between the posterior musculature and the posterior capsule cannot be ignored, as both may contribute to the degree of PST. [39] The posterior musculature (ie.: rotator cuff, deltoid) must fail to adequately absorb force in order for the posterior capsule to become involved in energy absorption. Clinically, PST has been found in relation to several shoulder pathologies, including anterior rotator cuff pathology, SLAP lesions, pathological internal impingement, and subacromial impingement. [40,55,65] There appears to be an osseous adaptation that plays a role in the development of PST known as humeral retrotorsion HR).

Humeral Retrotorsion

Even though overhead athletes present with higher external rotation and lower internal rotation values on the dominant side, range of motion, PST, and PCT significantly correlate with greater humeral retrotorsion. [15,40,51,56,60,62,63,70] Furthermore, when range of motion values are adjusted for humeral retrotorsion, there are no differences in internal rotation side to side. [42,56]

Humeral torsion is the angular difference between the orientation of the proximal humeral head and the axis of the elbow at the distal humerus. The angle is measured at the point where the line that bisects the proximal humeral head, and the transepicondylar bisection cross. [53] At birth, the proximal humerus is significantly retrotorted and by the age of 8 it is close to the neutral torsion expected in adulthood. [20] However, the epiphysis at the proximal humerus doesn't fully fuse in the majority of people until after the age of 18. Overhead activities, such as swimming, may alter the humeral physis' natural progression into anteversion, [20] and early participation in competitive youth sports may keep the humerus in relative retrotorsion. [38]

A great deal of research pertaining to humeral retrotorsion in overhead athletes has been conducted in baseball players. [15,45,51,53,56,69,71] Our lab has been involved in this research and has revealed a significantly higher retrotorsion in the dominant arm than the non-dominant arm, with a mean difference of 16 degrees. [61] This finding is consistent with current literature that reports a 15-17 degree mean difference between sides. [15,42]

To our knowledge, only one study has examined humeral retrotorsion in a swimming population. Whiteley et al (2009) found that while swimming is thought to be a symmetrical bilateral sport, a mean difference exists between the dominant and non-dominant sides. However, in comparison to other overhead sports' mean difference being as high as 17 degrees, swimmers mean difference is 6.4 +- 9.9 degrees. The authors attributed the side to side differences to handedness, asymmetric stroke patterns based on handedness, or breathing patterns. However, swimmers did present with greater amounts of humeral retrotorsion than adult controls. [69]

Another explanation for both the overall and side-to-side differences found between overhead throwers and swimmers is the different contraction patterns. Both activities require numerous, forceful internal rotation repetitions. During the acceleration phase of a baseball pitch, the subscapularis is contracting at 100% maximum voluntary contraction (MVC), with the pectoralis major and latissimus dorsi contracting at around 50% MVC. In relation to the pectoralis major and latissimus dorsi, the subscapularis attaches more anteriorly on the humeral head, therefore the net torque during this contraction pattern would tend to promote retrotorsion. [18,69] In comparison, during the freestyle stroke, the subscapularis contracts at only 60% MVC, while the pectoralis major and latissimus dorsi contract at around 75%. This contraction pattern would also promote retrotorsion, but at a lesser degree than the extremes of other overhead sports. [48,69]

Osseous adaptations are thought to play a role in shoulder injuries in baseball, but there is limited data on the extent swimmers undergo these osseous adaptations and what role they may play in "swimmer's shoulder." Just as "swimmer's shoulder" appears to be a multifaceted condition, the physiological changes that lead to it are varied, so looking at a measurement that takes multiple factors in to account may lead to a better understanding of why swimmers develop shoulder pain.

Conclusions

Clearly, a high rate of injury exists among the swimming population. However, the cause of this shoulder pain is unclear. Examining physiological soft tissue and osseous adaptations may answer several questions and enable healthcare professionals to better define "swimmer's shoulder."

The uniqueness of this study lies in observing several different adaptations through portable, valid and reliable, and easily accessible means that can be applied to a clinical atmosphere. By determining the soft tissue and osseous adaptations present in swimmers shoulders, more efficient and effective prevention and treatment protocols can be established for “swimmer’s shoulder.”

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Appendix A

TABLES AND FIGURES

Table 1 Subject Demographics

	Males	Females	Total	Range
Number	8	18	26	
Height (cm)	182.4 ± 4.3	170.7 ± 5.3	174.8 ± 7.4	157.2-190.5
Weight (kg)	79.7 ± 5.7	65 ± 5.9	69.7 ± 8.7	58.9-90.71
Age	19.3 ± 1.6	19.6 ± 0.97	19.7 ± 1.2	18-22
Years Swim	10.9 ± 4.4	11.5 ± 4	11.2 ± 3.8	4-16

Table 2 Dominant vs. Non-Dominant Comparison

Dominant vs. Non-Dominant Comparison				
	Dominant	Non-Dominant	Mean Difference	Significance (p value)
HR	-16.6 ± 11.2°	-19.5 ± 9.5°	2.9°	0.718
PCT	1.6 ± 0.18 mm	1.6 ± 0.17 mm	0.0021 mm	0.336
PST	5.6 ± 4.1°	6.7 ± 4.6°	1°	0.965
IR	48.2 ± 11.2°	52.4 ± 11.2°	4.1°	0.001*
ER	125.2 ± 10°	120.4 ± 8.8°	4.8°	0.002*
UR60	4.1 ± 3.6°	5.5 ± 3.4°	1.4°	0.054ł
UR90	18.1 ± 5.7°	20.4 ± 5.3°	2.2°	0.039*
UR120	34.2 ± 7.07°	37.4 ± 6.8°	3.1°	0.046*
* Indicated statistical significance; ł Indicates trend towards significance				

Table 3 Dominant Side Correlation – HR and GH ROM

Dominant Arm Correlation Humeral Retrotorsion		
	IR	ER
Pearson Correlation	-.461	.351
Significance	.014*	.067 ł
* Indicated statistical significance; ł Indicates trend towards significance		

Table 4 Non-Dominant Side Correlation – HR and GH ROM

Non-Dominant Arm Correlation Humeral Retrotorsion		
	IR	ER
Pearson Correlation	-.428	.360
Significance	.023*	.060 ł
* Indicated statistical significance; ł Indicates trend towards significance		

Table 5 Injured vs. Non-Injured Comparison

Injured vs Non-Injured Comparison				
	Injured	Non-Injured	Mean Difference	Significance (p value)
HR	-25.1 ± 11.3°	-15.7 ± 9°	10.1°	0.008*
PCT	1.6 ± 0.2 mm	1.6 ± 0.1 mm	0.0031 mm	0.336
PST	5.8 ± 2.9°	6.2 ± 4.4°	0.3°	0.422
IR	58 ± 7.2°	48 ± 11.3°	9.9°	0.126
ER	117.5 ± 9°	124.4 ± 9.4°	6.9°	0.224
UR60	4.2 ± 3°	5 ± 3.7°	0.8°	0.674
UR90	19.9 ± 5.1°	19.1 ± 5.7°	0.8°	0.589
UR120	37.9 ± 5.2°	35.19 ± 7.5°	2.7°	0.266
* Indicated statistical significance; ł Indicates trend towards significance				

Table 6 Sprint vs. Distance Comparison

Sprint vs. Distance Comparison				
	Sprint	Distance	Mean Difference	Significance (p value)
HR	-16.3 ± 9.2°	- 25.2 ± 12.4°	8.8°	0.017*
PCT	1.6 ± 0.18 mm	1.6 ± 0.1 mm	0.0159 mm	0.301
PST	6.4 ± 4.5°	5.1 ± 3.4°	1.2°	0.864
IR	48.9 ± 10.8°	56.5 ± 11.9°	7.6°	0.224
ER	123.2 ± 9.2°	121.3 ± 11.7°	1.8°	0.701
UR60	4.5 ± 3.6°	6.2 ± 3.8°	1.7°	0.346
UR90	19.5 ± 5.3°	18.4 ± 6.7°	1.1°	0.925
UR120	36.8 ± 6.8°	31.3 ± 6.1°	5.4°	0.607
* Indicated statistical significance; ł Indicates trend towards significance				

Figure 1 GH IR Testing Set Up

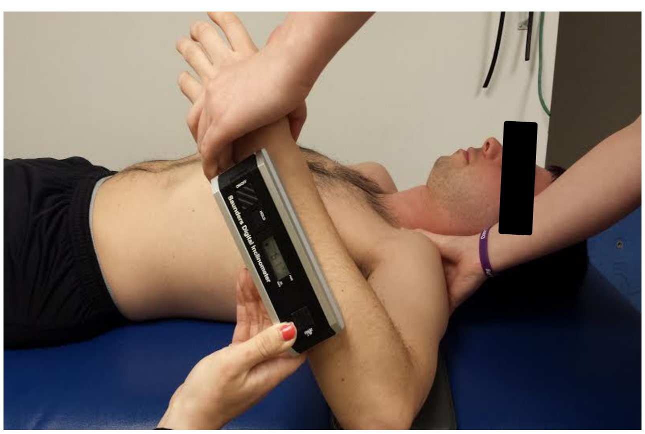
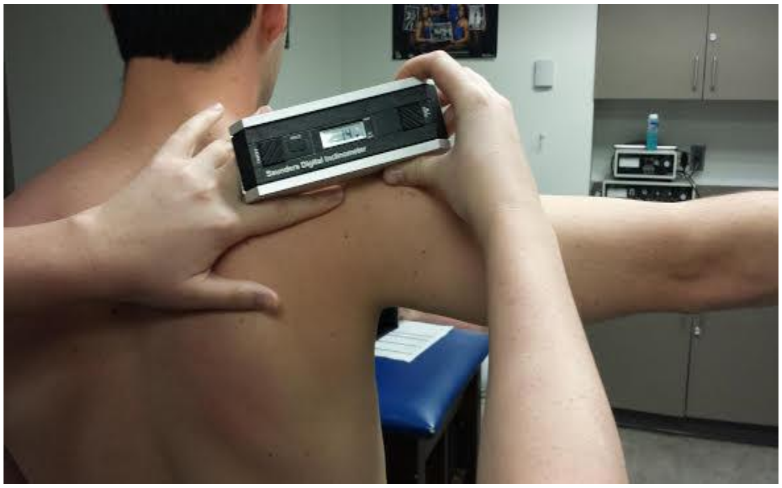


Figure 2 GH ER Testing Set Up

Figure 3 PST Testing Set Up

Figure 4   Scapular UR Testing Set Up



Appendix B

HEALTH HISTORY QUESTIONNAIRE

Inclusion Criteria Survey

Subject_____________ Gender____________ Height_______________

Weight_____________ Age_______________

1. Are you currently in good general health?

YES NO

2. Are you currently a member of a competitive sports team?

YES NO

3. If the answer to question 2 is yes, what sport(s) are you currently participating in?

____
___

4. If the answer to question 2 is yes, how long (years/months) have you been a member of a competitive team in that sport(s)?

____
___

5. Have you ever been a member of a competitive sports team in a sport(s) that you are no longer playing competitively?

YES NO

6. If the answer to question 5 is yes, what sport(s) did you participate in?

____
____

7. If you are a swimmer, do you swim an average of 10,000 yards per week?

YES NO

8. Have you ever been diagnosed with any neurological disorder?

YES NO

9. Have you undergone a shoulder surgery within the last year?

YES NO

Health History Survey

Subject______________ Gender_____________ Height________________

Weight______________ Age________________

1. Have you ever broken your forearm, upper arm, collarbone, or shoulder blade?
No
Yes
If yes, explain.

2. Have you ever had surgery on your elbow or shoulder?
No
Yes

If yes, explain. Please included date and specific procedure. __________________

____

____

____

____

____

____

____

3. Have you ever had a subluxation/dislocation of your elbow or shoulder?
No
Yes
If yes, explain.

4. Have you ever visited a physician for an injury to your shoulder or elbow?
No
Yes
If yes, explain. What was the diagnosis?__________________________________

____

____

____

____

Subject_____________

5. Have you ever experienced pain in your shoulder or elbow that has caused you to miss practice/competition or alter your activity for an extended period of time?
No
Yes

If yes, explain all injuries. How many have you experienced? How long did you stop practicing or competing? What were the restrictions on your activity? How long did the activity restriction last? ____

____

____

____

____

____

____

6. Which hand do you throw with?
Right _______Left ___________

**SWIMMERS ONLY

7. Which side do you feel most comfortable breathing to?

LEFT RIGHT

**COLLEGE SWIMMERS ONLY

8. What category best defines your swimming events?

DISTANCE (400 yards and up)

SPRINT (below 400 yards)

Penn Shoulder Score, Pain and Satisfaction

Subject ___________________

Please indicate the number closest to your current level of pain or satisfaction:

Pain at rest with arm by your side

0	1	2	3	4	5	6	7	8	9	10
No pain possible									Worst pain	

Pain during normal activities (eating, dressing, bathing)

0	1	2	3	4	5	6	7	8	9	10
No pain possible									Worst pain	

Pain during strenuous activities (reaching, lifting, pushing, pulling, throwing):

0	1	2	3	4	5	6	7	8	9	10
No pain possible									Worst pain	

Please indicate the number closest to your level of pain or satisfaction in the past month:

Pain at rest with arm by your side

0	1	2	3	4	5	6	7	8	9	10
No pain possible									Worst pain	

Pain during normal activities (eating, dressing, bathing)

0	1	2	3	4	5	6	7	8	9	10
No pain possible									Worst pain	

Pain during strenuous activities (reaching, lifting, pushing, pulling, throwing):

0	1	2	3	4	5	6	7	8	9	10
No pain possible									Worst pain	

***SWIMMERS ONLY

When do you currently experience pain?

0	1	2	3	4	5	6	7	8	9	10
No pain		Only After Heavy Workouts		During AND After Workouts			Interferes with Performance			Prevents Competitive Swimming

In the past month, when have you experienced pain?

0	1	2	3	4	5	6	7	8	9	10

No pain	Only After Heavy Workouts	During AND After Workouts	Interferes with Performance	Prevents Competitive Swimming

Over your swimming career, what is the worst level of pain you have experienced?

0	1	2	3	4	5	6	7	8	9	10

No pain	Only After Heavy Workouts	During AND After Workouts	Interferes with Performance	Prevents Competitive Swimming

Appendix C

IRB APPROVAL DOCUMENT

UNIVERSITY OF DELAWARE
RESEARCH OFFICE
210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE:	April 11, 2013
TO:	Aaron Struminger, MA
FROM:	University of Delaware IRB
STUDY TITLE:	[449758-1] Biomechanical adaptations to the shoulder in collegiate and youth swimmers
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	April 11, 2013
EXPIRATION DATE:	April 10, 2014
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # *4*

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Expedited Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the study and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the study via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All sponsor reporting requirements should also be followed.

Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.

Please note that all research records must be retained for a minimum of three years.

Based on the risks, this project requires Continuing Review by this office on an annual basis. Please use the appropriate renewal forms for this procedure.

If you have any questions, please contact Jody-Lynn Berg at (302) 831-1119 or jlberg@udel.edu. Please include your study title and reference number in all correspondence with this office.