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# Relationship Between Pectoralis Minor Length, Subacromial Space, and Pain in Swimmers and Overhead Athletes

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Relationship Between Pectoralis Minor Length, Subacromial Space,  
and Pain in Swimmers and Overhead Athletes

Erika Jaci Richards

A thesis submitted to the faculty of  
Brigham Young University  
in partial fulfillment of the requirements for the degree of  
Master of Science

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## ABSTRACT

### Relationship Between Pectoralis Minor Length, Subacromial Space, and Pain in Swimmers and Overhead Athletes

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Master of Science

**Introduction (Context):** The purpose of this study was to measure and correlate pectoralis minor length (PML) and acromiohumeral distance (AHD) in male and female collegiate swimmers, overhead athletes, and a control group. **Methods:** Participants underwent assessment of pain related to impingement syndrome with special tests (painful arc, external rotation resistance, empty can, and Neer's impingement test), as well as range of motion, measurement of PML, and measurement of subacromial space via ultrasound. **Design:** Cross-sectional, correlational study. **Setting:** University modalities laboratory. **Participants:** 60 healthy subjects (20 swimmers, 20 overhead athletes, 20 controls, age =  $21.5 \pm 2.4$  years; height =  $178.7 \pm 10.2$  cm; weight =  $76.9 \pm 13.4$  kg; BMI =  $24 \pm 3.4$ ) with 20 subjects in each of the 3 experimental groups: swimmers, overhead athletes, and control. **Results:** Height-normalized PML for both the dominant and nondominant arms was positively and weakly correlated with AHD at  $0^\circ$  ( $r = .361$ ;  $p = .002$ ; ( $r = .277$ ;  $p = .016$ ) respectively. Differences were shown between groups in AHD at  $0^\circ$  but no differences were shown in PML. **Conclusions:** There was a weak positive relationship between height-normalized PML and AHD at  $0^\circ$  both in dominant and nondominant shoulders. Swimmers and overhead athletes were observed to have more AHD than controls.

Keywords: pectoralis minor length, acromiohumeral distance, swimmers, overhead athletes

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## INTRODUCTION

Shoulder injuries are common to overhead athletes who participate in swimming, baseball, volleyball and tennis, as well as athletes that participate in activities that require significant and repetitive shoulder movements.<sup>1</sup> In NCAA Division I swimmers shoulder injuries account for 31% of the total reported injuries in men and 36% in women.<sup>2</sup> Similar numbers are seen in other overhead sport athletes.<sup>3</sup> Swimmers perform approximately 16,000 rotations of the shoulder joint every practice and 44.4% of injuries are related to overuse.<sup>4,5</sup> Throwing requires 80%–100% of the maximum voluntary contraction of the shoulder musculature.<sup>1,3,6</sup> Similar levels of maximum voluntary contraction of the rotator cuff muscles are seen in football passing, tennis serving and volleying, as well as volleyball serving and spiking.<sup>6</sup> The most common shoulder injuries in overhead athletes are muscular strains, impingement syndrome, and tendonitis.<sup>3,4</sup> Due to the large number of overuse injuries and the pain associated with it involving the shoulder joint, it is important to examine, determine and understand the etiology of these pathologies.

Impingement syndrome, or the impingement of the shoulder, occurs in the subacromial space which is formed by the acromion, acromioclavicular joint, and coracoacromial ligament superiorly and the humeral head inferiorly.<sup>7</sup> Contained within the subacromial space are the subacromial bursa and rotator cuff tendons all structures that could potentially produce pain.<sup>8,9</sup> Narrowing of the subacromial space can lead to subacromial or external impingement syndrome.<sup>7-9</sup> Bailey et al defined subacromial space narrowing as an acromiohumeral distance (AHD) of less than 7 mm.<sup>10</sup> Subacromial impingement syndrome can lead to inflammation and degeneration of the bursa and tendons and is said to potentially be caused by mechanical compression.<sup>8,9</sup> A distance of less than 7 mm at rest might also be indicative of shoulder

pathologies such as a rotator cuff tear, glenohumeral internal rotation deficit, or subacromial impingement syndrome.<sup>11-13</sup> Subacromial impingement syndrome is one of the observed pathologies associated with “swimmers’ shoulder,” a term used for the presence of shoulder pain in these athletes.<sup>5,7,14,15</sup> Likewise, impingement syndrome has also been known to affect other overhead athletes.<sup>1,16</sup>

There are many hypothesized causes of impingement syndrome. The one most pertinent to swimmers and overhead athletes is the altered mechanics and its deleterious effect on the movement of the shoulder joint and shoulder girdle.<sup>9,17,18</sup> Shortened or tight pectoralis minor predisposes swimmers to demonstrate a posture with forward head, rounded shoulders, and increased thoracic kyphosis.<sup>5,17</sup> This posture decreases shoulder abduction, which forces the shoulder to alter its mechanics during overhead activities. In addition, a shortened pectoralis minor protracts the scapula by tilting it anteriorly, potentially decreasing the subacromial space.<sup>9</sup> The repetitive motion related to swimming, throwing, and hitting often results in degenerative changes to the shoulder joint. This repetition might result in the shortening, or contracture, of the pectoralis minor muscle.<sup>14</sup> Thus, pectoralis minor shortening may be either a cause or effect of impingement syndrome.

The purpose of this study was to measure and correlate pectoralis minor length (PML) and acromiohumeral distance (AHD) (the two-dimensional representation of subacromial space from the most inferior aspect of the acromion of the scapula to the nearest point of the echo of the humeral head) in swimmers, overhead athletes, and a control group (controls).<sup>10</sup> To our knowledge, measurements of PML have only been performed on a female population of NCAA Division I swimmers.<sup>14,15</sup> In these studies, the relationship between PML and subacromial space had only been speculated.<sup>14,15</sup> We believe that if a correlation between PML and narrowing of the

subacromial space exists, this knowledge could lead to improved prophylactic and rehabilitation techniques with regard to impingement syndrome and/or rotator cuff tendonitis. We expected that there would be a strong positive correlation ( $r \geq 0.80$ ) between PML and AHD. We also expected that swimmers would have bilateral subacromial space narrowing and pectoralis minor shortening while overhead athletes would exhibit the same unilaterally in their dominant or throwing/hitting arms. Additionally, we expected a strong correlation ( $r \geq 0.80$ ) between AHD and pain.

## **METHODS**

### **Participants**

We performed a power analysis using data by Desmeules et al ( $\alpha = 0.05$ ; mean = 9.9 mm; standard deviation =  $\pm 1.5$  mm) which yielded a required subject number of 20 in each group.<sup>19</sup> Sixty healthy subjects (30 female, 30 male, age =  $21.5 \pm 2.4$  years; height =  $178.7 \pm 10.2$  cm; weight =  $76.9 \pm 13.4$  kg; BMI =  $24 \pm 3.4$ ) participated in this study. There were 20 subjects in each of the three experimental groups: swimmers, overhead athletes, and controls. Subjects were recruited through the use of fliers, personal contact, and word of mouth. The swimmers and overhead athletes were members of various NCAA Division I sports teams including swim and dive, baseball, men's and women's volleyball, women's track and field, men's and women's tennis, and football. The subjects all signed a written Institutional Review Board (IRB)-approved consent form before participating in the study.

## Procedures

Subjects completed questionnaires. Assessment of shoulder pain, performance of special tests (painful arc, external rotation resistance, empty can, and Neer's impingement test), measurements of range of motion and PML as well as subacromial space were completed.

**Questionnaires.** The Sports and Symptom Survey (ICC = 0.94, MCID = 11.4) was administered to the swimmers and a modified Sports and Symptom Survey was given to overhead athletes and to the controls.<sup>14,15</sup> Included within this survey was a subscale of the Penn Shoulder Score.<sup>14,15</sup> The Penn Shoulder Score questions contained a pain rating for rest, normal activities of daily living, and strenuous activities on a scale from 0 (no pain) to 10 (worst possible pain) (MCID = 11.4).<sup>14,15,20</sup> The scores from each of the categories were subtracted from 10 and added together with a maximum score of 30 denoting no pain.<sup>14,15</sup> Additionally, hand-dominance was reported on the Sport and Symptom Survey. Next, the shoulder function with regard to sport involvement was measured utilizing the Sports/Performing Arts Module of the Disabilities of the Arm, Shoulder, and Hand Outcome Measure or DASH (ICC = 0.90, MCID = 10.2).<sup>14,15</sup> These data were collected to correlate reported shoulder function with AHD. Since our population consisted primarily of athletes, the sports module was a valid outcome measure as there was not a sport-specific DASH for athletes.<sup>14,15</sup>

**Physical Examination.** Shoulder impingement tests were performed by the primary researcher, after being instructed by a physical therapist, to determine if any of the subjects tested positive for impingement syndrome. The special tests consisted of the Neer's test (sensitivity [SN] = 0.72, specificity [SP] = 0.60), the painful arc test (SN = 0.33, SP = 0.81), the empty can test (SN = 0.50, SP = 0.87), and the external rotation resistance test (SN = 0.56, SP = 0.87).<sup>21,22</sup> The anterior apprehension test (SN = 0.62, SP = 0.42) was administered to rule out

shoulder instability.<sup>21,22</sup> Based on the diagnostic power of a cluster of positive tests (positive painful arc, positive empty can, and positive external rotation resistance test), subjects could be said to have clinical impingement syndrome.<sup>21,22</sup> After the special tests were performed, the subject's active and passive shoulder ROM (flexion, abduction, internal rotation and external rotation) were measured using a goniometer (ICC = 0.88–0.93). The subject was supine for all measurements.

**Pectoralis Minor Measurement.** PML was measured with the use of the PALM palpation meter (Performance Attainment Associates, St. Paul, MN) (ICC = 0.98–0.99).<sup>14,15</sup> It uses the muscle's origin on the coracoid process to its insertion on the fourth rib as landmarks which has been shown to be valid.<sup>14,15</sup> In order to ensure additional, and possibly improved, accuracy of our measurements, ultrasound imaging was used to corroborate the origin and insertion sites of pectoralis minor for the first 10 subjects. PML was measured by palpation for all subsequent subjects. The length of pectoralis minor was normalized by height (length in centimeters/participant height in cm; multiplied by 100), a method suggested by both Harrington et al and Tate et al.<sup>14,15</sup>

**Ultrasound Imaging.** We visualized the subacromial space by measuring AHD using diagnostic ultrasound (the GE LOGIQ e portable ultrasound machine General Electric Co.) ( $r = 0.77–0.86$ , ICC = 0.91–0.95) with a 12 L ultrasound linear array transducer set at a frequency of 8 MHz to 10 MHz.<sup>10,19,23</sup> The ultrasound head was positioned on the lateral aspect of the shoulder joint approximately 1.5 cm away from the most anterior portion of the acromion, parallel to the longitudinal axis of the humerus.<sup>12</sup> The participant was instructed to sit as upright as possible in the lumbar spine but was allowed to assume his or her normal resting posture in the thoracic spine. Images were taken at 0° as well as at 45°, 60° and 90° of shoulder abduction

in the frontal plane, both passively and actively.<sup>12</sup> Random samples from the data set were used to obtain ultrasound reliability data. The ICC measure at 0° was 0.880, which denotes an appropriate amount of reliability. All other ICC measures were above .75, meaning appropriate reliability.

### **Study Design and Data Analysis**

This study had a cross-sectional, correlational design. Ultrasound images were used to measure AHD, using an internal software program. The relationship between PML and AHD and the relationship between pain and AHD were obtained using a correlation analysis (Pearson's product correlation). The differences between groups and nondominant and dominant arms for the variables AHD, PML, pain, and abduction range of motion were compared using univariate analysis of variance (ANOVA). Group effects and interactions within the variables were observed. For all subjects, the right side was their dominant side for their activity. Post-hoc analysis was performed with least significant difference (LSD) to note differences between experimental groups.

## **RESULTS**

### **Descriptive Statistics**

All swimmers swam freestyle during practice and in competition, 6 swam freestyle, 6 swam backstroke, 3 swam breaststroke, 1 swam the butterfly, and 4 competed in 2 or more strokes. The overhead athletes were composed of 6 baseball players (all male), 6 volleyball players (2 male, 4 female), 4 track and field throwers (all female), 3 tennis players (1 male, 2 female), and 1 football player (male). The positions of the baseball players included 3 pitchers, 2 infielders, and 1 outfielder. The volleyball players included 2 setters, 2 middle blockers, and 2 outside hitters. Of the track and field throwers 1 threw discus, 1 threw javelin, and 2 threw

hammer and shot put. The football player was a quarterback. Over half of the 60 subjects (17 men, 18 women) and subjects in each group (7 in control, 17 in collegiate swimmers, 11 in collegiate overhead athletes) were experiencing some kind of shoulder pain. See Table 1 for demographics.

### **Correlations Between PML and AHD**

The relationship between height-normalized PML at  $0^\circ$  was correlated with the averages of two measurements taken of AHD at the 4 different points of range of motion, both passive and active, through the use of a Pearson correlation. In all subjects normalized PML dominant and nondominant were positively but weakly correlated with AHD at  $0^\circ$ ,  $r = .361$ ;  $p = .002$  and  $r = .277$ ;  $p = .016$ , respectively. However, when analyzing within the groups, the swimmers group did not show this relationship on either side, while in overhead athletes, this relationship was shown on the dominant side ( $r = .469$ ;  $p = .019$ ) only. In the control group, these correlations were strong on the dominant side ( $r = .572$ ;  $p = .004$ ) and on the nondominant side ( $r = .627$ ;  $p = .002$ ). The relationship between height normalized PML and AHD at  $0^\circ$  is shown in Figure 1.

**AHD ANOVA.** Univariate analysis of variance (ANOVA) was performed to observe differences between our experimental groups in our dependent variables of AHD measured at different points of range of motion in both passive and active control. Group differences were shown in the variables AHD at  $0^\circ$  dominant ( $p = .02$ ), AHD at  $45^\circ$  nondominant active ( $p = .027$ ), AHD at  $60^\circ$  nondominant passive ( $p = .031$ ), AHD at  $90^\circ$  nondominant passive ( $p = .001$ ), and AHD at  $90^\circ$  nondominant active ( $p = .024$ ). Post-hoc analysis of least significant difference (LSD) showed that the differences at  $0^\circ$  dominant were between the control and swimmers ( $p = .012$ ) and between the control and the overhead athletes ( $p = .020$ ). Post-hoc analysis (LSD) showed a difference between the control and the swimmer groups ( $p = .010$ ) at  $45^\circ$  nondominant



active. Post-hoc analysis (LSD) noted differences between the control and the swimmer groups ( $p = .011$ ) at  $60^\circ$  nondominant passive. Differences were shown between the control and swimmers ( $p = .000$ ) and the control and the overhead athletes ( $p = .027$ ) at  $90^\circ$  nondominant passive. Differences were observed at  $90^\circ$  nondominant active between the control and the swimmers ( $p = .009$ ) and the control and the overhead athletes ( $p = .046$ ).

An additional univariate analysis of variance was done to evaluate differences between AHD at  $0^\circ$  on both sides. There were no differences were shown between the dominant and the nondominant arm ( $p = .501$ ).

**Average AHD.** The change in AHD over the different points in range of motion ( $0^\circ$ ,  $45^\circ$ ,  $60^\circ$ ,  $90^\circ$ ) is shown graphically in Table 2 and in Figures 2 and 3. Collegiate swimmers, overall, had greater AHD than both collegiate overhead athletes and controls. Collegiate overhead athletes had greater AHD than the control. The control had the narrowest AHD of the three groups.

Very few subjects were found to have a narrowed subacromial space. No pattern was noticed in the instances of narrowed space as those subjects with AHD of less than 7 mm were from varying experimental groups and experienced narrowing at differing ranges of motion (see Appendix I).

**Pectoralis Minor Length ANOVA.** Univariate analysis of variance (ANOVA) was completed to analyze for differences between our experimental groups in the dependent variable of PML. No group differences were observed in height-normalized PML ( $p = .504$ ). Mean PMLs are shown in Table 3.

An additional univariate analysis of variance was done to evaluate differences between pectoralis minor on the dominant and nondominant sides. No differences were shown between sides ( $p = .510$ ).

### **Correlations Between Abduction Range of Motion and AHD**

The correlation between abduction range of motion and AHD at  $0^\circ$  was not significant either actively or passively,  $p = 0.062$  and  $p = .454$ , respectively.

**Abduction Range of Motion ANOVA.** Abduction range of motion was measured both actively and passively. Univariate analysis of variance was completed for both active and passive abduction ranges of motion to note any differences between the three groups and between dominant and nondominant arms. ANOVA for active abduction range of motion showed significant group differences ( $p = .008$ ;  $F = 5.104$ ). Differences were shown between the controls and the swimmers ( $p = .002$ ) and between the controls and the overhead athletes ( $p = .043$ ). There was no difference between the swimmers and the overhead athletes. Passive range of motion also showed that group differences were significant ( $p = .010$ ;  $F = 4.826$ ). Differences between the controls and swimmers were significant ( $p = .003$ ). No other differences were observed. Mean abduction range of motion both active and passive are shown in Table 4.

## Correlations Between the DASH Score and AHD

The correlation between the DASH score and AHD at 0° was not statistically significant ( $p = .215$ ).

**DASH ANOVA.** Univariate analysis of variance was completed on the DASH score to note differences between our experimental groups. There were no differences between the experimental groups in DASH score ( $p = .187$ ). Mean DASH scores are shown on Table 5.

## DISCUSSION

It was hypothesized that swimmers would have bilateral subacromial space narrowing and pectoralis minor shortening. Contrary to our expectation that swimmers would demonstrate subacromial space narrowing, swimmers were observed to have a larger AHD at 0° compared to overhead athletes and the control group. The average AHD in the swimmers group was 10.76 mm on the dominant side and 11.1 mm on the nondominant side. There were no swimmers whose subacromial space measured less than 7 mm. This is interesting, considering that several authors have surmised that a decreased AHD is one of the reasons for the swimmers developing subacromial impingement syndrome or “swimmer’s shoulder.”<sup>5,7,14,15,17</sup> Decreased AHD suggesting subacromial impingement syndrome might not be as prevalent a cause of “swimmer’s shoulder” as previously thought.

Additionally, it was hypothesized that overhead athletes exhibit subacromial space narrowing and pectoralis minor shortening unilaterally in their dominant or throwing/hitting arms. No differences were shown between the dominant and nondominant side AHD within any of the groups assessed. At 0° of shoulder abduction, both overhead athletes and swimmers demonstrated significantly greater AHD bilaterally than the control, but there was no difference between overhead athletes and swimmers. Both overhead athletes and swimmers routinely move

their hands over their heads in the performance of their sports. Additionally, these athletes are generally stronger and more flexible than the individuals in the control group. These differences may help account for the difference in AHD noted in this study. Average AHD for overhead athletes was 10.68 mm on the dominant side and 10.31 mm on the nondominant side, both of which are considered within the normally observed AHD range reported to be between 10 to 15 m.<sup>10,11,24</sup> There were instances where different overhead athletes (2 volleyball players; 2 baseball players; 3 males; 1 female) experienced narrowing. However, these same subjects experienced narrowing at various ranges of motion, not at rest. Furthermore, these four subjects were not experiencing impingement syndrome symptoms.

The most surprising finding was that the control group had the narrowest AHD and the most occurrences of narrowed space (ie, < 7 mm). Six male subjects exhibited AHD lower than 7 mm, with three of those subjects having multiple instances of narrowed spaces. Group differences existed between the control and each of the two athletic groups in AHD at 0° for the dominant side. None of the control subjects had positive results to the impingement cluster tests. Control subjects were selected based on their not having participated in overhead athletics during high school or college. Furthermore, the students were not athletes in nonoverhead sports recreationally or competitively. It has been surmised that a sedentary lifestyle, like the one experienced by a lot of college students and attributable to more intense coursework requiring more time leaves less time to exercise.<sup>25,26</sup> Lack of exercise could lead the control group to exhibit more shoulder girdle and joint weakness as compared to the athlete groups thus potentially leading to a narrowed subacromial space. College students are also prone to developing postural changes based on increased computer and backpack use, with approximately 53% of senior undergraduate students experiencing upper extremity pain.<sup>27,28</sup> The postural

changes could result in a narrowed subacromial space. Intercollegiate sports were also described as a potential protective factor against the development of shoulder pain in college students.<sup>28</sup> It is possible that by recruiting college students who do not participate in overhead sport activities, the control group lacked the sufficient muscular strength needed to overcome postural changes and superior migration of the humeral head and thus had less subacromial space.<sup>27-30</sup>

A potential reason for the increased space in the athlete groups is that they could have stronger shoulder joint musculature, specifically the adductor muscles. Shoulder adductors cause an increase in humeral head depression, increasing the subacromial space throughout abduction range of motion.<sup>30,31</sup> The humeral head can migrate superiorly into the subacromial space if it is not compressed onto the glenoid fossa.<sup>1,30,32</sup> The adductor muscles work as a potential compensating compression mechanism when the rotator cuff muscles are weak.<sup>30</sup> Strengthening the pectoralis major, latissimus dorsi, and teres major specifically, was noted to increase the subacromial space width and aid in the depression of the humeral head.<sup>31</sup> It is likely that muscular adaptations, specifically in the shoulder adductors in athletes, prevent this from occurring.<sup>1,30,31,33</sup> The athletes in this study routinely perform supervised and balanced shoulder strengthening exercises including specific adductor, abductor and rotator cuff exercises. Thus, our group of highly trained athletes may have strength and flexibility development that allowed them to have the greater AHD than the control group.

Adductor strength has been found to be two times greater than abductor strength in competitive swimmers.<sup>33</sup> In swimmers, pectoralis minor and teres major are active during the early to mid-pull-through phase of the freestyle stroke. Latissimus dorsi is active during late pull-through in the freestyle stroke.<sup>34,35</sup> It is during this pull-through phase that the shoulder acts as a fulcrum to propel the swimmer through the water.<sup>34,35</sup> Similarly, in the butterfly stroke, the

backstroke, and the breaststroke, a majority of the pulling force is performed by the pectoralis major and latissimus dorsi.<sup>34</sup> In other overhead athletes, pectoralis major, latissimus dorsi, and other shoulder adductors are active during motions that require a lot of force. In the baseball pitch, during the cocking phase, muscle activity is high in the pectoralis major and latissimus dorsi creating necessary horizontal adduction and preventing anterior humeral head movement.<sup>3,6,36-38</sup> Similarly, with a football pass, the pectoralis major and latissimus dorsi are active in the acceleration phase of the throw, or when the most force is required to complete the necessary movement.<sup>6</sup> In either a serve or a spike in volleyball, the latissimus dorsi, pectoralis major, and teres major are most active in the acceleration phase of the hit.<sup>6</sup> The acceleration phase in a tennis serve or volley results when peak muscle contraction of latissimus dorsi, pectoralis major, and teres major occurs as well.<sup>6</sup> The greater AHD noticed in the athlete groups could be due to increased shoulder adductor strength.

Due to the paucity in the literature, specifically detailing minimal clinically significant difference and the significant amount of literature regarding the pathology-related changes in AHD we can assume that any AHD less than 7 mm is a critical decrease in AHD.<sup>11,13,16,19,24,39,40</sup> However, any increase in AHD, could make a significant difference in maintaining shoulder function especially for overhead athletes.<sup>12,16,40</sup> There was no significant difference between the experimental groups in their DASH score. Swimmers had the highest mean DASH score at  $6.5 \pm 4.7$ , followed by the control  $4.3 \pm 6.6$ , with the overhead athletes scoring lowest  $3.3 \pm 5.25$ . None of the average DASH scores were clinically significant (MCID = 10.2).<sup>14,15</sup> Additionally, there was no difference shown between our experimental groups suggesting that there were no functional discrepancies between the experimental groups. Swimmers and overhead athletes have increased abduction range of motion compared to the control group, however, there was no

relationship between abduction range of motion and AHD at 0°. This suggests that increased range of motion in swimmers and overhead athletes does not affect the amount of subacromial space at rest.

Swimmers had slightly shorter normalized PML than the control but this was not statistically significant. Swimmers and overhead athletes had roughly the same PML, there was no difference between groups. There was also no difference in PML between sides. Average PML of the swimmers in our study was  $9.68 \pm 0.77$  on the dominant and  $9.55 \pm 0.71$  on the nondominant, which would be classified as a long pectoralis minor.<sup>41</sup> Borstad and Ludwig utilized a height-normalized PML and considered less than 7.65 units “short.”<sup>41,42</sup> Tate et al found that pectoralis minor tightness, or shortening, was associated with swimmers aged 12 years and older.<sup>15</sup> The pectoralis muscle group (pectoralis major, pectoralis minor) is also responsible for the necessary force required to complete the different swim strokes causing them to be overdeveloped.<sup>34</sup> Pectoralis minor also assists in forced inspiration, such as needed during swimming.<sup>43</sup> Shortened or tight pectoralis minor predisposes swimmers to demonstrate a posture with forward head, rounded shoulders, and increased thoracic kyphosis.<sup>5,17</sup> Overhead athletes have also been observed to have forward-head, rounded shoulder posture suggesting a shortened pectoralis minor.<sup>44</sup> A shortened resting PML has been associated with shoulder pain.<sup>14</sup> However, since the athletes in our group did not demonstrate a shortened pectoralis minor, we cannot support that supposition.

Research suggests that there are discrepancies in range of motion, strength, and movement between the dominant and nondominant arm of overhead athletes.<sup>45-47</sup> A strength training protocol for overhead athletes at the university requires the athletes to do exercises bilaterally. Additionally, it has been shown that total body workouts increase strength more than

focusing on just one joint, side, or muscle group.<sup>48</sup> This training protocol could be the reason no differences were shown between the dominant and nondominant pectoralis minor or AHD.

The experimental groups were experiencing some amount of pain, though not at clinically significant levels.<sup>20</sup> Our findings might suggest that the ‘swimmer’s shoulder pain’ is likely not primarily caused by subacromial impingement.<sup>5,7,14,15,17,49</sup> Asymptomatic shoulders have been shown to have 0.5 mm increased subacromial space compared to a shoulder experiencing rotator cuff tendinopathy.<sup>39</sup> The cause of this pain could be related to other factors—for example postworkout muscle soreness, shoulder instability, biceps tendonitis or strain, a labral tear, or SLAP lesions.<sup>5,15,34,50-52</sup> Since function based on DASH scores was not seen at clinically significant levels, the pain does not appear to be debilitating. Pain could also be explained by the increased load going through the rotator cuff tendon as the athletes perform their overhead movements.<sup>53</sup> When increased strain occurs, the rotator cuff tendon tissue responds with temporary increases in collagen production to protect itself during repetitive motions.<sup>53</sup> Rotator cuff tendinopathy indicates degeneration without knowing the specific cause or mechanism of injury.<sup>54</sup> The supraspinatus tendon is frequently at risk for inflammation and degeneration in overhead sports.<sup>39</sup> The rotator cuff tendon could be irritated by repetitive motions but not experience inflammation that would preclude the subacromial space. Based on the results of this study, we cannot correlate narrowed subacromial space with clinical impingement caused by an irritated rotator cuff tendon.



## **Limitations**

This study had some limitations. First, we did not measure PML at different shoulder ranges of motion. We also did not perform any strength testing. At the time this study was derived we did not think that strength could play a role in AHD. We also did not measure rotator cuff tendon characteristics such as thickness or lesions that could affect the size of the subacromial space.

## **CONCLUSION**

This study provided information on the relationship between PML and subacromial space represented by AHD. There was a weak positive relationship between height-normalized PML and AHD at 0° on both sides. More studies should be conducted adding further length measurements of the pectoralis minor at different ranges of motion in order to firmly establish this relationship. Additionally, increased AHD was observed in healthy athletic populations compared to a control group. This could be due to increased strength in shoulder adductor muscles which has been shown previously to increase AHD. Future research should examine the strength of shoulder adductors and rotator cuff muscles in athletes and how overall muscle strength influences AHD. The narrowed space experienced by college students could be due to postural adaptations caused by increased computer usage and backpack wearing and their sedentary lifestyle. Postural changes as well as adductor strength in college students and the relationship to AHD should be explored in future research.

In conclusion, the results of this study indicate that the pain experienced by swimmers was not correlated with a decreased AHD, in fact, swimmers had the greatest AHD among the groups. It should, however, be noted that our swimmers did not exhibit clinical impingement syndrome, as indicated by our screening tests.

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Table 1: Demographics ( $\pm$  standard deviations)

	Total Groups	Men	Women	Control	Swimmers	Overhead Athletes
Age (years)	21.5 $\pm$ 2.4	22.4 $\pm$ 2.8	20.7 $\pm$ 1.6	23.2 $\pm$ 2.6	20.7 $\pm$ 2.1	20.8 $\pm$ 1.5
Height (cm)	178.7 $\pm$ 10.2	184.0 $\pm$ 9.6	173.4 $\pm$ 7.9	172.7 $\pm$ 9.6	180.2 $\pm$ 9.2	183.12 $\pm$ 9.3
Weight (kg)	76.9 $\pm$ 13.4	83.0 $\pm$ 9.3	70.7 $\pm$ 14.2	69.5 $\pm$ 12.4	75.5 $\pm$ 9.06	85.6 $\pm$ 13.5
BMI	24.0 $\pm$ 3.4	24.6 $\pm$ 3.1	23.4 $\pm$ 3.4	23.2 $\pm$ 3.8	23.2 $\pm$ 2.3	25.5 $\pm$ 3.4
Pain	27.1 $\pm$ 3.9	27.9 $\pm$ 3.2	26.3 $\pm$ 4.4	28.4 $\pm$ 3.3	25.3 $\pm$ 4.4	27.7 $\pm$ 3.5

Table 2: Average AHD (mm) at Various Points of Range of Motion

	0°	45°		60°		90°	
		Passive	Active	Passive	Active	Passive	Active
<b>Dominant Passive</b>							
Control	9.66 ± 1.3*	10.78 ± 2.0	9.89 ± 2.0	10.58 ± 2.5	9.87 ± 2.6	10.74 ± 2.6	10.34 ± 3.0
Swimmers	10.76 ± 1.5*	11.35 ± 1.5	11.18 ± 1.5	11.9 ± 1.7	11.1 ± 2.1	11.59 ± 2.4	11.16 ± 2.4
Overhead Athletes	10.68 ± 1.5*	10.43 ± 1.5	10.25 ± 1.7	10.65 ± 1.9	10.13 ± 1.7	11.25 ± 1.6	10.71 ± 2.6
<b>Nondominant Passive</b>							
Control	10.07 ± 1.6	10.12 ± 1.8	9.47 ± 1.7*	10.14 ± 2.4*	9.86 ± 2.7	9.72 ± 1.9*	9.36 ± 1.9
Swimmers	11.1 ± 1.3	11.64 ± 1.8	11.12 ± 2.0*	11.97 ± 2.3*	11.01 ± 2.6	11.95 ± 1.8*	11.06 ± 1.9
Overhead Athletes	10.31 ± 1.5	10.97 ± 2.0	10.68 ± 2.1*	10.62 ± 2.0*	10.07 ± 2.0	11.01 ± 2.0*	10.67 ± 2.2

\*indicates significance at the  $p \leq 05$  level

Table 3: Height Normalized Pectoralis Minor Length ( $\pm$  standard deviations) at 0° of Shoulder Abduction

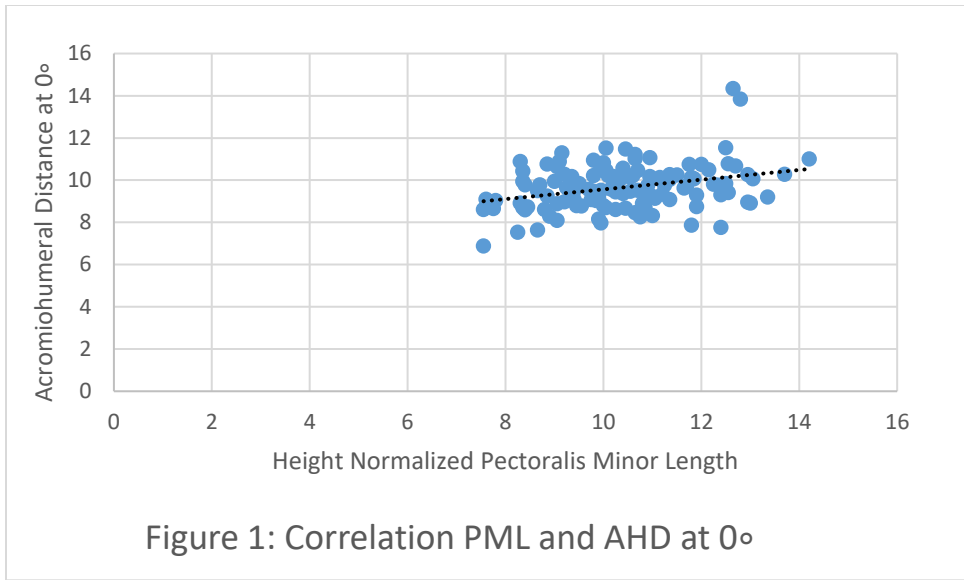
	Control	Swimmers	Overhead Athletes
Dominant	9.85 $\pm$ 1.38	9.68 $\pm$ 0.77	9.66 $\pm$ 1.06
Nondominant	9.74 $\pm$ 1.34	9.55 $\pm$ 0.71	9.51 $\pm$ 1.18

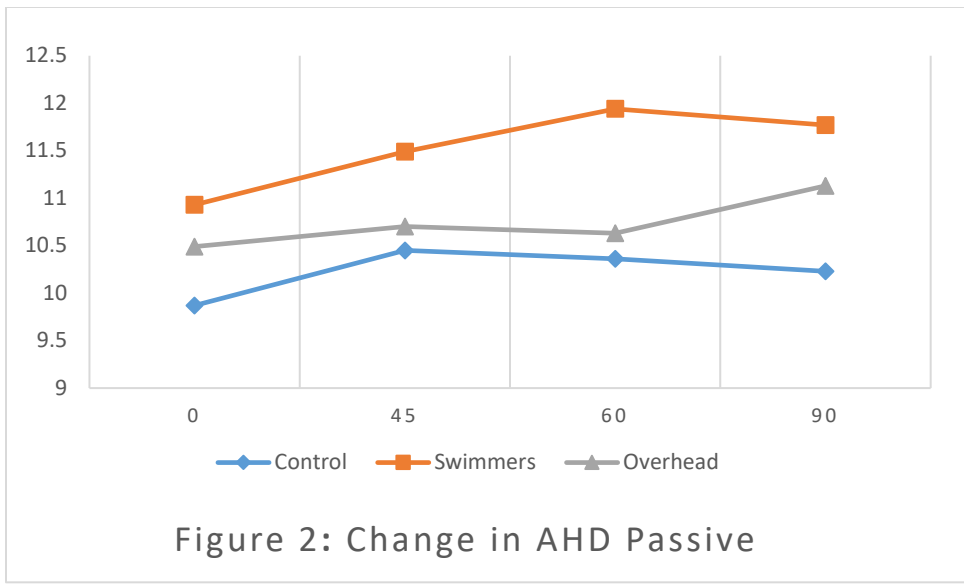
Table 4: Mean Abduction Range of Motion

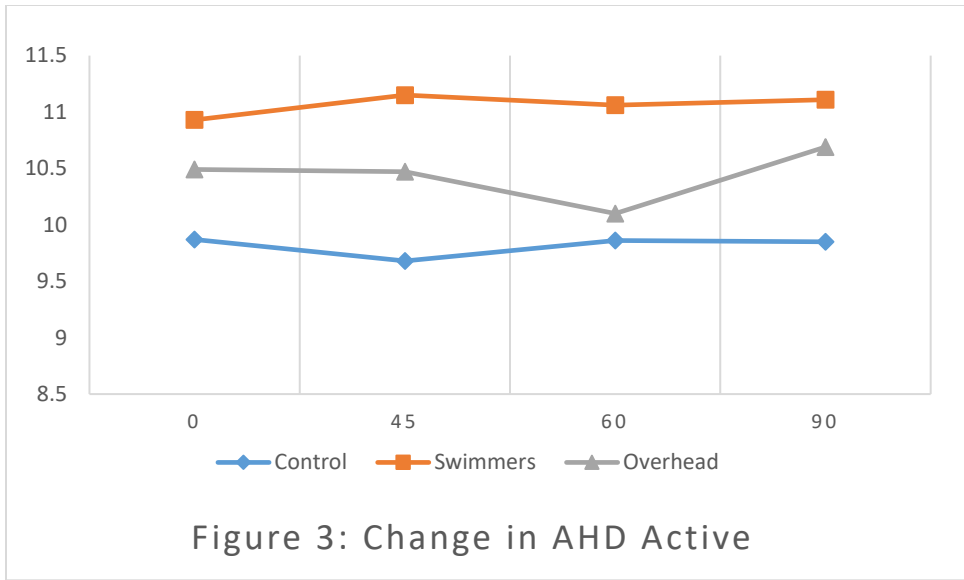
	Total		Control		Swimmers		Overhead Athletes	
	Passive	Active	Passive	Active	Passive	Active	Passive	Active
Dominant	196 ± 11.5	187 ± 9.6	193 ± 10.5	185 ± 8.5	201 ± 8.8	190 ± 7.0	194 ± 13.2	186 ± 12
Nondominant	198 ± 9.0	188 ± 9.2	195 ± 11	183 ± 10.8	200 ± 6.4	190 ± 6.6	199 ± 8.6	190 ± 8.1

Table 5: Mean DASH Scores

	Total	Control	Swimmers	Overhead Athletes
DASH Score	4.8 ± 5.5	4.3 ± 6.6	6.5 ± 4.7	3.3 ± 5.3









## Appendix I: Instances of Narrowed Space

Point of Range of Motion $\leq 7\text{mm}$	Subject	Sport (if applicable)
45° nondominant active	Overhead Athlete 12	Volleyball
60° dominant active	Control 5	
	Control 9	
	Control 10	
60° nondominant passive	Control 7	
	Overhead Athlete 13	Volleyball
60° nondominant active	Control 7	
	Control 9	
	Control 13	
	Overhead Athlete 1	Volleyball
90° dominant passive	Control 6	
90° dominant active	Control 6	
	Overhead Athlete 6	Baseball
	Overhead Athlete 7	Baseball
90° nondominant passive	Control 7	
90° nondominant active	Control 5	
	Control 7	
	Control 9	

Appendix II. Measurement Images.



Acromiohumeral Distance Ultrasound Image.



Pectoralis Minor Length Measuring.



Acromiohumeral Distance Measuring Set-Up.