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An Ultrasonographic Analysis of the Structures of the Subacromial Space, as They Relate to the Postures of Upper String Musicians

Elliot V. Smithson
smithson7@marshall.edu

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AN ULTRASONOGRAPHIC ANALYSIS OF THE STRUCTURES OF THE SUBACROMIAL SPACE, AS THEY RELATE TO THE POSTURES OF UPPER STRING MUSICIANS

A thesis submitted to
the Graduate College of
Marshall University
In partial fulfillment of
the requirements for the degree of
Master of Science
in
Athletic Training
by
Elliot V. Smithson
Approved by
Dr. Mark K. Timmons, Committee Chairperson
Dr. Gary McIlvain
Dr. Elizabeth Reed Smith

Marshall University
May 2016
We, the faculty supervising the work of Elliot V. Smithson, affirm that the thesis, An Ultrasonographic Analysis of the Structures of the Subacromial Space, As They Relate to the Postures of Upper string Musicians, meets the high academic standards for original scholarship and creative work established by the Master’s of Athletic Training Program and the Marshall University School of Kinesiology. This work also conforms to the editorial standards of our discipline and the Graduate College of Marshall University. With our signatures, we approve the manuscript for publication.

Dr. Mark K. Timmons, PhD, ATC, School of Kinesiology, Committee Chairperson

Dr. Gary McIlvain, EdD, ATC, LAT, School of Kinesiology

Dr. Elizabeth Reed Smith, DMA, School of Music
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ABSTRACT

Background: The leading source of general population shoulder pain is subacromial impingement syndrome (SAIS) which can contribute to rotator cuff disease (RCD).\textsuperscript{1} It has been reported that up to 12\% of musicians end their musical career due to musculoskeletal injury.\textsuperscript{2} SAIS is a common source of shoulder pain in the bowing arm of upper string musicians.\textsuperscript{3} However, the mechanisms leading to shoulder pain in upper string musicians are not well known.

Purpose: The purpose of this study was to characterize aspects of the subacromial space anatomy while in standard playing positions of upper string musicians, specifically measurements taken of the acromiohumeral distance (AHD) and supraspinatus tendon thickness.

Methods: Experienced musicians (n = 23) were recruited from the university and local communities. Ultrasound images of the participants’ shoulders were collected using standard imaging techniques.

Results: On the right side, the arm position main effect was significant (p < 0.001), the AHD in the 4\textsuperscript{th} string position (8.459 ± 0.449mm) was less than the 1\textsuperscript{st} string (10.978 ± 0.319mm) and resting (11.713 ± 0.327mm) positions. There was a significant difference in the AHD between the resting (13.428 ± 0.606mm) and the 1\textsuperscript{st} finger, 1\textsuperscript{st} string (10.765 ± 0.488mm) positions in the left side. The resting AHD was smaller (p < 0.001) on the right side (11.713 ± 0.327mm) compared to the left (12.273 ± 0.404mm). Tendon thickness of the left shoulder (5.687 ± 0.211mm) was not significantly different when compared to the right side (5.889 ± 0.262mm).

There was a statistically significant difference (p < 0.001) in the occupation ratio (tendon thickness / AHD) between the left (0.472 ± 0.021mm) and right shoulder (0.507 ± 0.022mm).
Conclusions and Practical Relevance: The reduced resting AHD measurements of the right shoulder and the reduction of AHD measurements as the arm is brought into elevation suggest upper string musicians are at greater risk for RCD than the general population, especially on the right side. Treatment interventions that help musicians maximize the width of the subacromial space may reduce the prevalence of shoulder pain in this population.
CHAPTER 1

INTRODUCTION

Purpose

The purpose of this study was to observe how various positions associated with playing upper string musical instruments affect the acromiohumeral distance (AHD) and supraspinatus tendon thickness in both the bow-arm and the arm supporting the instrument. This study specifically made comparisons of supraspinatus tendon thickness bilaterally, bilateral comparisons of AHD, unilateral comparisons of AHD while in playing positions, and unilateral comparisons of AHD in the arm holding the instrument. These measurements are noteworthy due to the association between AHD, supraspinatus tendon thickness and painful shoulder pathologies, which can stem from SAIS. 4-6 Several studies have been published examining the effects of posture, arm position, and scapular kinematics on the subacromial space in general populations. 7-12

There is, however, a void of literature exploring the relations between positions associated with playing an upper string instrument and the AHD measurement. This study will provide a baseline for biomechanical observations of the musical population, specifically upper string musicians. These biomechanical standards will be used to explore the relationship between upper body postures and positions, and shoulder pain associated with playing an upper string instrument.

Significance

Musicians experience a wide range of musculoskeletal problems that stem from a variety of mechanisms such as the postures and positions associated with playing the instrument. 2,3,13-37 These problems often lead to missed time from work/practice/school/performances, create
substantial healthcare cost for the musicians or the institutions they play for, and can even lead to career ending injuries.\textsuperscript{38} Musicians are often hesitant about reporting these injuries due to fear of missing time from work or school and the associated stigma in the competitive world of performing arts.\textsuperscript{21,27,38,39} The results of this study will help to provide a better understanding of shoulder mechanics and anatomical changes seen in upper string musicians. This better understanding will provide clinicians with the ability to make recommendations for the best interventions available in order to reduce the risk of these problems.

Studies performed among musicians at large show that upper string musicians are more susceptible to shoulder injuries, especially in the arm that holds the bow, compared to other types of musicians.\textsuperscript{3,15,26,27,39,40} One of the main reasons these musicians develop shoulder pain can be due to the repetitive motions that stress the shoulder joint.\textsuperscript{41} When playing an upper string instrument, a musician positions the bow-arm between 35° - 2° of shoulder abduction, 87° - 15° of shoulder flexion and 80° -50° of internal rotation.\textsuperscript{41} Combining shoulder abduction with internal rotation and flexion creates a narrowing of the subacromial space associated with supraspinatus tendon impingement.\textsuperscript{42} Putting these shoulder structures under repeated stress, as high level upper string musicians do, may cause SAIS.

SAIS is a common mechanism for limiting sensation and mobility in the arms of upper string musicians.\textsuperscript{38} SAIS is defined as an injury mechanism that can lead to a shoulder pain / dysfunction and refers to the compression of any of the structures that lie beneath the acromion.\textsuperscript{43,44} The space beneath the acromion can be measured ultrasonographically by observing the distance between the head of the humerus and the anterior third of the acromion. In the same fashion, the thickness of the supraspinatus tendon can be measured.\textsuperscript{45,46} SAIS in general populations has been linked to risk factors such as postural abnormalities, scapular dyskinesia,
repetitive internal rotation with horizontal flexion, and overuse of the rotator cuff, which can lead to a thickening of the supraspinatus tendon.\textsuperscript{7-12,47} Upper string musicians are associated with many if not all of these risk factors when playing in a professional or academic environment, which can account for the reportedly high SAIS prevalence specifically in the bow-arm of upper string musicians.\textsuperscript{3,32,48}

**Null Hypothesis**

The null hypothesis of this study stated that there will be no bilateral or unilateral differences in AHD, supraspinatus tendon thickness, or occupation ratio in the bow-arm or support-arm.

**Alternative Hypothesis**

1. It was hypothesized that ultrasonographic measurements, of the resting AHD measurements, will be smaller in the bow-arm compared to the arm supporting the violin, due to the increased elevation of the shoulder on that side.

2. It was hypothesized that the supraspinatus tendon, in the bow-arm, will be thicker than the tendon in the arm supporting the instrument, due to the repeated arm motions associated with moving the bow.

3. It was hypothesized that occupation ratio for the bow-arm will be a larger quantity than the opposite side, due to the increased elevation of the shoulder on that side and the repeated arm motions associated with moving the bow.

4. It was hypothesized that the AHD in the unilateral comparison of the bow-arm will be smaller, as the bow is placed on the 4th string, when compared to the 1st string.
5. It was hypothesized that the AHD, in the unilateral comparison of the support-arm, will be smaller as the arm is brought up to support the instrument, compared to the resting position.

Limitations

1. AHD measurements were only taken in static positions. The data collected may not represent the characteristics of the subacromial space during arm motion.
2. This study did not take fatigue into account when making measurements of the subacromial space. The data that was collected may not represent the characteristics of the subacromial space, as the musicians play a piece over a period of time.
3. Participants were not excluded based on body mass index (BMI); morphometric characteristics can affect the quality of the ultrasound images.
4. Extrinsic daily activity factors that could affect shoulder characteristics were not accounted for when describing the population.
5. No distinctions were made in analysis between violinists and violists. It is likely slightly different measurements would have been collected if the study had isolated just violinists or violists.

Delimitations

1. Recruited population was 23 upper string musicians between 18-70 years of age.
2. Recruited participants will be upper string musicians currently enrolled in Marshall University’s College of Arts and Media, musicians currently playing in the Huntington/West Virginia Symphony, and musicians currently playing live shows regularly in the greater Huntington area.
3. The Penn Shoulder Score Questionnaire, the DASH (Disabilities of the Arm, Shoulder and Hand) and FABQ (Fear Avoidance Belief Questionnaire) will be used to assess participant self-reported levels of pain, satisfaction, and function.

4. A Mindray M5 Ultrasound scanner with variable frequency 5cm sound head (Shenzhen Mindray Bio-Medical Electronics Co. LTD: Shenzhen, China) will be used to assess tendon thickness as well as AHD.

Assumptions

1. The participants are a satisfactory representation of the advanced upper string musician population.

2. The participants will answer all survey questions honestly and to the best of their abilities.

3. The mid-bow positions utilized in the ultrasonographical testing represent an accurate mean of all possible positions an upper string musician may find themselves in any given performance situation.

Major Operational Definitions

*Subacromial Impingement Syndrome (SAIS)* - Injury mechanism that can lead to a number of different pathologies and refers to the compression of any of the structures that lie between the anterior and inferior portion of the acromial head and the superior aspect of the humeral head.\(^{43,44}\)

*Acromiohumeral Distance (AHD)* - Delineated by the humeral head, the acromion, and the coraco-acromial ligament. In between these structures are the subacromial bursa, the tendons of the rotator cuff, and the long head of the biceps, which are common sites of inflammation and degeneration in SAIS.\(^{43}\)
Occupation Ratio (OR) – Supraspinatus tendon thickness measurement divided by resting AHD measurement.\(^9\)

Rotator Cuff Disease (RCD) – Pathology pertaining to the rotator cuff.

Diagnostic Ultrasonography - The practice of using a diagnostic ultrasound unit to image and measure tissue.

Upper String Musicians – Musicians that play a stringed instrument supported above the shoulders such as the violin or viola.

Bow-Arm – The arm responsible for holding the instrument’s bow, typically the musician’s right arm.

Support-Arm – The arm responsible for holding the instrument up on the shoulder, typically the musician’s left arm.

First String (1\(^{st}\)) – E String / Rightmost string from musician’s point of view.

Fourth String (4\(^{th}\)) – G String / Leftmost string from musician’s point of view.
CHAPTER 2

REVIEW OF LITERATURE

Introduction

Professional as well as student musicians often suffer from musculoskeletal disorders due to long hours of repetitive motions, sometimes in uncomfortable positions. These injuries can affect a wide range of body parts including, but not limited to: fingers, neck, lower back, jaw, shoulder, elbows, etc. Upper extremity injuries seem to be the most prevalent, due to the extensive upper body mechanics required to play an instrument. These body mechanics can be considered to be occupational hazards. Some of these workplace hazards that are specific to musicians include: static loading of muscles, repetition, precision grip, and psychosocial work pressures. These conditions are often exacerbated by misinformation from instructors and the musician’s reluctance to come forward with symptoms, fearing a loss of income or receiving poor grades. Among professional organizations and institutions these musicians end up requiring treatment for ailments that may have been avoided, if preventative measures had been taken before injuries advanced to complicated stages. As many as 12% of musicians end up abandoning the profession, due to injuries sustained throughout their career. Among this population, orchestral violinists are particularly susceptible to shoulder injuries, specifically SAIS. Determining the etiology of this condition is complicated, but examining the various postures these musicians utilize is a valuable first step in understanding how these injuries can be prevented. This review will be comprised of an exhaustive report of the available literature on the epidemiology of musculoskeletal pain in upper string musicians, the kinesiology involved in playing an upper string instrument, SAIS, scapular kinematics, and diagnostic ultrasound techniques.
The intention of this review is to make clear the biomechanical structures and factors involved in creating shoulder pain in upper string musicians, and to illuminate the most effective ways to measure variation in those elements.

**Epidemiology**

In order to understand the significance of examining incidence and prevalence of shoulder pain in musicians, it is important to explore the occurrence in general populations first. A survey performed between the years of 1971-1975, in the USA, reported that approximately 7% of adults between the ages 25-75 years old reported having a shoulder disorder of some kind, lasting at least one month, in the past year.\(^5\) Surveys that collected data in multiple countries reported that the one-year period prevalence of shoulder disorders in adults ranged from 20%-51%.\(^5\)\(^5\)\(^4\) A study performed in Sweden, in 1974, on the prevalence of shoulder pathology in various age groups, reported results that showed a 7% prevalence rate for people between the ages of 30-35, a 25% prevalence rate among people 56-70 years of age.\(^5\) A more recent systematic review (2004) performed in the Netherlands, looking at incidence and prevalence rates of shoulder pain in general populations, revealed similar trends for shoulder pain. Within the studies examined for the systematic review, average incidence rates for adults of different age groups were 0.9%–2.5%.\(^5\)\(^6\) These rates are in agreement with data presented by Feleus et al., who examined incidence rates of non-traumatic injuries of the shoulder over the course of a year in Dutch general practices that placed incidence rates at 2.95%.\(^5\)\(^7\) Average prevalence statistics for adults of various ages ranged from 6.9% to 26% for point prevalence (proportion of population who have a disease or condition at the particular time of testing), 18.6%–31% for one-month prevalence (adults that experienced shoulder pain at some point within a one month period), 4.7%–46.7% for one-year prevalence (adults that experienced shoulder pain at some
point within a one year period), and 6.7%–66.7% for lifetime prevalence (adults that experienced shoulder pain at some point within their lifetime up to the point of the study).  

Violinists are musicians that can potentially experience a great deal of pain and disability from musculoskeletal disorders. Among violinists, the most prevalent sites for injury are the neck, shoulder, and wrist.  

Visentin et al. states that 46%–66% of professional musicians must stop performing for an extended period of time at some point in their career, due to occupational injuries identified as overuse syndrome in the shoulder.  

In early questionnaires presented to “premiere violinists” in 1983 who attended the Second Quadrennial International Violin Competition, 51.7% responded that they had sustained a performance limiting injury at some point in their career. The most frequent reported sites for pain were the right shoulder and wrist. Of the five respondents who reported shoulder specific pain, two were right side only, one was left shoulder pain, and two experienced pain bilaterally. There was no data collected on side dominance in this study.  

In 1989, Middelstadt and Fishbein administered one of the foundational comprehensive questionnaires given to musicians. This questionnaire consisted of 4,000 professional musicians, employed across the United States by 48 different symphony orchestras, who were questioned about musculoskeletal disorders that they may have experienced. Out of the 55% of these musicians who responded to the questionnaire, 31% were identified as violinists. Sixteen percent (16%) of these violinists reported right shoulder pain, as the predominant site of injury. Of the total population polled, 9.3% were violists. Among these musicians, similar results were found, with 16% reporting right shoulder pain. Females also reported higher prevalence of shoulder pain than male string players. Between the years 1986-1996 a series of student health services, at various universities, were surveyed to determine the population of music students with the highest
incidence of injury. It was determined that violins and violas classified as medium injury rate instruments (6.0% -11.9%) with an incidence rate of 9.7% of the injuries seen by the medical centers polled. Other instruments taken into account in this study included all the brass instruments, oboe, bassoon, all the bowed string instruments, the saxophone, clarinet, organ, flute, percussion, piano, guitar, and harp. Similar studies performed with music schools in Australia showed results with 8% of the musician population receiving treatment for injuries, being violinists and violists. A retrospective questionnaire study was performed at the University of Western Ontario, Canada music department. When 300 students were polled, violin students accounted for 42.1% of musculoskeletal injuries per capita. The side of injury was not mentioned in the study. The mechanisms most responsible for these injuries included posture, technique, and playing habits. The information for this study was also gleaned from medical records of music students retained at the student health clinic of the university. More recent studies reported similar findings. Cross-sectional questionnaires performed in Germany received data from 408 musicians spanning ten professional classical orchestras. Overall 72% of the musicians reported that the most common sites of pain included the neck/cervical spine, followed by pain in the left shoulder (55.1%), and left wrist (52.2%). Among the musicians polled, violinist populations were determined to have the highest incurrence of neck, shoulder and wrist problems. It was noted that violinists may be reporting pain in these regions due to their early start in life as opposed to other musicians. This study accounted for gender, and suggested that women showed higher reported incidences of pain in these areas, than men. A similar study performed in Britain polled 243 orchestral musicians spanning six different professional orchestras. Data returned suggested that higher rates of
musculoskeletal injuries were found in the shoulder, elbow, wrist, and hand in violinists when compared to brass or woodwind sections.25

Utilizing several questionnaires, another study examined 59 musicians and cross-examined the results. Questionnaires utilized were the Standardized Nordic Questionnaire (SNQ), examining musculoskeletal pain felt over the prior 12 months; the Disabilities of the Arm, Shoulder and Hand questionnaire (DASH), a 30-item questionnaire that measures biomechanical function and symptoms in populations with preexisting upper extremity musculoskeletal disorders; the National Institute for Occupational Safety and Health (NIOSH) Generic Job Stress Questionnaire assessing four stressor factors including “Perceived Physical Environment” (PPE), “Job Control Assessment” (JC), “Quantitative Job Requirements” (JR), and “Perceived Workload” (PW); and the Rapid Upper Limb Assessment (RULA) was used to determine the biomechanical and postural loading of the upper limbs, assessing positioning of the fingers on the instrument, angulation of the joints, degree of movement, and weight bearing over the whole body. Through cross-examination of the responses received, it was determined that 61% of strings players reported shoulder pain compared to 32% of wind musicians.2

Although these aforementioned studies give us some insight into the problems these musicians face, they do not all take into account other factors that may contribute to pain amongst violinists e.g.: outside activities, postural differences (seated/standing) past medical history, occupations, size of chin rest, etc. Given the current research, it is reasonable to deduce, from looking at the presented data, that violinists in general experience a greater number of injuries in the shoulder over any other body part.32,48 When comparing prevalence rates of shoulder pain in violinists vs. the general population, violinists have higher percentages, especially in younger populations. Non-descript shoulder pain prevalence, from survey data
collected from general practice physicians in America of adults ages 25-75, was 7%. Similar numbers (8%-9.7%) of prevalence rates are seen in multiple sets of survey data collected from music school health services, which inherently deal with a much younger population. This comparison lends credence to the notion that upper string musicians develop shoulder pain in higher numbers than the general population.

**Kinesiology of Upper String Musicians**

To understand why these musicians are having musculoskeletal problems, it is necessary to understand the mechanics of the body holistically and track how changes in the upper extremity motions affect the subacromial space. The first step is to understand the motions necessary to create sound with a violin. The violin is considered an asymmetric instrument, due to the fact that there is an unequal distribution of weight bilaterally. It is normally held in the left hand and played with a bow in the right. Dr. Earl Owen, a leading Australian authority on musicians’ injuries, stated that upper string musicians are the most damaged group of musicians, due to the unadvantageous playing positions they must assume in their day to day playing routines. He also elaborated on the complex series of muscular contractions that must occur in order to make music with a violin, stating, “For every muscle in obvious activity there is another muscle also working to balance it.”

The arm mechanics involved in moving a bow across the strings to produce a sound are a complex series of events that must happen simultaneously to execute notes properly. As described by Schoonderwaldt et al, there are two movement phases of bow movement: the “to” phase and the “fro” phase with a shift in dominant hand elevation between the phases. The angle of the bow movement requires abduction/adduction and extension/flexion of the shoulder as well as internal and external rotation of the glenohumeral joint. Demonstrable by a Hawkins-
Kennedy impingement test, as the greater tuberosity of the humerus is internally rotated towards the anterior inferior aspect of the acromion, subacromial space is reduced. The radial component is primarily caused by flexion/extension of the elbow and ulnar/radial deviation of the wrist. These motions can be performed in long strokes, but during intense playing can be performed in short repeated oscillations. There is a scapular motion component to the bowing action as well. During the “to” phase of increased upper extremity horizontal flexion there is an increase in scapular upward rotation. Contrariwise the “fro” phase increases upper extremity horizontal extension and there is a decrease in scapular plane elevation.

One study quantitatively described the biomechanical motion associated with playing an upper string instrument from observations made using motion-capture data. The three-dimensional motion analysis showed the left arm is held in a near static position. The range of motion of the shoulder and elbow joints remained within 5° as did wrist abduction and adduction. Wrist flexion, extension, and rotation varied about 10°. Generally playing on different strings had no significant influence on the range of motion of the left arm joints (p > 0.05). The left shoulder flexion and extension range was constant at 31° (SD = 11°), abduction of 13° (SD = 6°), and internal rotation of 22° (SD = 10°); elbow flexion was 101° (SD = 6°). In contrast, the right arm showed dynamic properties and the positions characterized by the maximum and minimum angles of the shoulder were notably affected by playing on different strings. The instrument’s G string (leftmost string) showed the greatest variability in this motion. The right shoulder flexion and extension range for the G string was 87° max - 64° min. Shoulder adduction and abduction range was 35° max - 10° min. Internal and external rotation range was 80° max - 63° min. The E string (rightmost string) showed smaller variability in range of motion. The right shoulder flexion and extension range for E string was 60° max - 15° min. Shoulder adduction and
abduction range was 26° max - 2° min. Internal and external rotation range was 68° max - 50° min.\textsuperscript{41}

There is also a lateral flexion and rotational component of the cervical spine away from the bow-arm as the violinist rests his/her chin on the chin rest of the violin. This cervical motion is characterized by a lateral flexion and lateral rotation of the cervical spine. The degree to which the cervical spine is angled depends greatly on the size of the violin or viola and whether or not the musician is using a shoulder rest below the violin. The musician must also maintain muscular contracture in the left upper trapezius and sternocleidomastoid muscles to support the violin.\textsuperscript{30}

Musicians’ posture is one of the most important factors that affect the quality of play and stress put on the body over an extended period of time.\textsuperscript{14,21,27,31} Postural deviations, in a population of violin students from the Academy of Music in Wroclaw, were studied. It was found that, when compared to a non-musician student population, the violin students had more pronounced (deeper and longer) characteristics of thoracic kyphosis (p < 0.01) and less pronounced, shallower lumbar lordosis (p < 0.05). It was also reported that there was a smaller inclination angle of the thoracolumbar and lumbosacral section of the spine (p < 0.01).\textsuperscript{14}

In order to understand how shoulder pain and, more specifically, SAIS occur in the upper string musician population, it is important to pay close attention to the motions that the shoulders must undergo in order to create sound with a violin. Internal/external rotation motion combined with the horizontal flexion/extension motion causes a narrowing of the subacromial space.\textsuperscript{42} Repeating these motions for hours a day for years, wear is inevitable on the structures in the subacromial space. These factors combined with any postural deviations that may inhibit scapular motion can potentially cause impingement in the shoulder joint of violinists.
Shoulder Impingement Syndrome

SAIS is one of the most common shoulder problems associated with the population at large accounting for 44%-65% of all shoulder complaints during a physician’s office visit. It is also one of the most common complaints among violin musicians experiencing shoulder pain in the bow-arm. SAIS is an injury mechanism that can lead to a number of different pathologies and refers to the compression of any of the structures that lie between the anterior and inferior portion of the acromial head and the superior aspect of the humeral head. Neer originally described impingement in 1972. He stated that impingement is most likely to occur at the anterior edge and undersurface of the anterior third of the acromion, the coroacromial ligament, and also the acromioclavicular joint. Structures most often compressed include the supraspinatus tendon, the long head of the biceps brachii, and the subacromial bursa. The subacromial space is defined by the distance between the head of the humerus and the acromion. Shoulder impingement has been classified into two main categories: structural and functional. Neer also stated that 95% of all rotator cuff strains/tears could be credited to mechanical compression. This claim has been contested in recent years. Budoff et al. estimated that 90% to 95% of rotator cuff defects could possibly be attributed to the intrinsic breakdown of the rotator cuff tendons because of tension overload, overuse, and traumatic injury rather than direct mechanical compression. Though there is a “Chicken Vs Egg” debate regarding the mechanism of rotator cuff injury it is clear that SAIS plays a role in the degradation of the rotator cuff and it is beneficial to recognize the factors that can cause these complications.

Subacromial impingement is caused by structural factors such as development and structure of the acromion, repetitive eccentric loading or continued use of the arm over 90
degrees of elevation which leads to an increased thickness of the supraspinatus tendon,\textsuperscript{9,62,64-66} or functional factors such as superior migration of the humeral head (caused by weakness and/or muscle imbalance), abnormal scapular motion associated with rotator cuff or scapular muscle pathologies,\textsuperscript{6,67-69} poor posture,\textsuperscript{70-72} as well as capsular abnormalities such as laxity or tightness.\textsuperscript{73-75}

Five (5) special tests can be used to rule in or out SAIS: Neer, Hawkins-Kennedy, painful arc, empty can (Jobe), and external rotation resistance tests. The cut point of three or more positive of these five tests can confirm the diagnosis of SAIS, while less than three positive of these five rules out SAIS. Singular special tests such as painful arc, external rotation resistance, and Neer are helpful screening tests to rule out SAIS, while painful arc, external rotation resistance, and empty can are useful to confirm SAIS.\textsuperscript{76}

A systematic review performed in 2011 examined the use of ultrasonographic readings of the subacromial space as a reliable diagnostic method in SAIS. The review covered studies that involved patients with rotator cuff pathologies including cases pertaining to full thickness tears. It was determined that AHD was a reliable marker for determining the extent of subacromial impingement, as well as the reliability of diagnostic ultrasound to give accurate readings of the subacromial space.\textsuperscript{12}

**Systematic Reviews**

Several systematic reviews of the literature have been performed on the subject of musculoskeletal injuries in upper string musician populations. These reviews have analyzed a multitude of articles and have provided quality insights into the nature of these kinds of injuries in these special populations.
One systematic review, performed in 2015, examined the occurrence of musculoskeletal complaints among professional musicians. This review searched nine literature databases without time limits as well as the complete index of the journal *Medical Problems of Performing Artists (MPAA)* up to June 2015. Citation tracking and reference checking of the selected articles were performed. The search consisted of the combination of three groups of keywords: musician (e.g., musician, violin, music student, instrument player) and musculoskeletal (e.g., musculoskeletal, tendon, shoulder, arthritis) and epidemiology (e.g., prevalence, incidence, occurrence). Twenty-one (21) articles describing 5424 musicians were included in this review. It was found that point prevalences of musculoskeletal complaints in professional musicians range between 9-68%; 12-month prevalences range between 41-93%; lifetime prevalences range between 62-93%. Ten (10) out of 12 studies show a higher prevalence of musculoskeletal complaints among women. The neck and shoulders are the anatomic areas most affected and elbows are least affected. It was found that there was no clear consensus among the literature which group of instrumentalists experienced the most musculoskeletal complaints. Contrariwise it was found that the literature supports evidence that brass instrumentalists seem to be the least likely group of musicians to be affected by musculoskeletal complaints. The study concluded that further research elucidating the specific epidemiology of various musculoskeletal complaints is necessary to fill the gaps in the research.23

Another systematic review, performed in 2012, looked specifically at the research surrounding musculoskeletal disorders in professional violinists and violists. Of the 58 that were selected and read, 30 fulfilled the initial inclusion criteria and were used in this study. Articles, theses, and dissertations, searched for through Medline, Lilacs, Cochrane and Scielo databases were used in this study. The key words utilized were “musculoskeletal disorder,” “lesions,” and
“musicians” in Portuguese, English and Spanish. Only articles in Portuguese, English and Spanish were selected, without any deadline. It was noted in the findings that the musculoskeletal problems observed most often in musicians are overuse (50%), nerve compression or thoracic outlet syndrome (20%), and focal dystonia (10%). It was also concluded that the neck, shoulder, and temporomandibular joint were the most common sites for musculoskeletal complaints in upper string musicians, due to prolonged flexion of the head and shoulder involved with playing these instruments.²⁹

**Scapular Kinematics**

Kibler et al.⁷⁷-⁷⁹ describe scapular dyskinesis as an abnormal scapular motion or position during active arm elevation. It is theorized to contribute to SAIS by reducing the subacromial space.⁷⁷-⁷⁹ During humeral elevation, a healthy scapula will rotate three-dimensionally into a position of upward rotation, external rotation, and posterior tilt.¹¹

A systematic review performed in 2014 concluded that the links between scapular kinematics and subacromial space were not consistent enough to determine whether the two conditions are directly linked.⁸⁰ The ten studies included in the review, utilizing various methods for determining the scapular position and subacromial space, included two-dimensional radiological measurements, 360° inclinometers, and three-dimensional motion tracking devices. The studies stated that, due to SAIS’s multifactorial nature, it is difficult to isolate one common cause.⁸⁰ Although there has not been sufficient evidence to form an established link, scapular dyskinesis is often seen in patients with SAIS. Studies have suggested that there is a link between scapular dyskinesis and reduction of subacromial space with passive motion.⁴⁶ Seitz et al. found that patients with scapular dyskinesis saw an increase in subacromial space when the
scapula was manually stabilized, suggesting that maintaining healthy scapular kinematics is important to maximizing the distance between the glenohumeral head and the acromion.\textsuperscript{11,12}

Scapular motion is also determined by postural factors. Increasing the kyphotic curve, by slouching over, will decrease the ability of the scapula to rotate upwards, tilt posteriorly, internally rotate, and elevate.\textsuperscript{72} Increased kyphosis is also associated with anterior tilting of the scapula as well as internal rotation.\textsuperscript{81} Due to the link between slouched posture and negatively affected scapular motion and the link between SAIS and scapular dyskinesia, it stands to reason that hyper kyphotic posture can contribute to reducing the subacromial space and subsequently increase the likelihood of SAIS.\textsuperscript{11,12,72} One study investigated how various postures effect subacromial space throughout different ranges of arm motion. The research did not find any significant differences in AHD when using a slouched posture, as opposed to a relaxed or upright posture, when the arm was at rest beside the participants. There was, however, a considerable increase in the AHD measurements when participants assumed an upright posture and abducted their arm to 45°.\textsuperscript{8}

**Diagnostic Ultrasound**

Diagnostic ultrasound has been used to image and measure various aspects of the subacromial space. Shoulder structures able to be imaged include AHD and supraspinatus tendon thickness. Diagnostic ultrasound has been shown to be reliable in measuring tendon thickness as well as AHD. Desmeules et al. reported findings related to diagnostic readings of subacromial space in various shoulder positions.\textsuperscript{82} It was shown in the study that intraclass correlation coefficient, for interobserver reliability, ranged from 0.86 to 0.92, for the three shoulder positions. It was also shown that there was a significant reduction of the AHD within groups between rest and active abduction (p < 0.05). Comparison of AHD between groups was not
statistically different (P = 0.06; beta < 0.80). Anozzi et al. performed tests comparing radiographic examination to sonographic examination. It was demonstrated that values obtained from ultrasonography were not distinguishable from values obtained from radiography (p>0.8). One-way ANOVA showed that sonographic measurements were statistically different, among the four groups that were tested (p < 0.05). The authors suggested that these tests demonstrated that ultrasonography can be precise and accurate when taking measurements of the subacromial space.

Patient Reported Outcome Measures

When performing research, it is beneficial to have background information about the participants in order to derive summary statistics about the population. Surveys that have been found valid and reliable include the Penn Shoulder Score Questionnaire (PSS), Fear-Avoidance Beliefs Questionnaire (FABQ) and the Disabilities of the Arm, Shoulder and Hand (DASH). These are used to assess participant self-reported levels of pain, satisfaction, function, and to monitor change over time.

Leggin et al. described the scoring mechanism behind the PSS. The PSS is a 100-point shoulder-specific self-report questionnaire consisting of three subscales including pain, satisfaction, and function. The three subscales of the pain section include items that address pain at rest, with normal activities and with strenuous activities. Participants are asked to circle a number from one to ten that represents their pain.

Leggin et al. reported a reliability analysis that demonstrates the survey is a reliable and valid measure for reporting the outcome of patients with various shoulder disorders (Test-retest ICC of 0.94)(95% CI, 0.89-0.97). Internal consistency analysis revealed a Cronbach alpha of 0.93. Standard error of measurement was ± 8.5 scale points (based on a 90% CI) and the minimal
detectable change (MDC) was ± 12.1 scale points (based on a 90% CI). The minimal clinically important difference (MCID) for improvement was 11.4 points. Pearson product moment correlation coefficients between the PSS and the CSS and ASES were 0.85 and 0.87, respectively. Responsiveness analysis revealed an effect size of 1.01 and a standardized response mean of 1.27.85

The Disabilities of the Arm, Shoulder and Hand (DASH) Outcome Measure is a 30-item questionnaire, with a five-item response option for each item designed to measure physical function and symptoms in participants with any or several musculoskeletal disorders of the upper limb. The test has a maximum score of 100, where higher scores reflect greater disability. It can be used as either a one-time measure or to determine change over time.86

The DASH was found valid and reliable for testing both proximal and distal disorders of the upper extremity for multiple joints. Test-retest reliability (ICC = 0.96) was found to be satisfactory. Internal Consistency (Cronbach’s alpha) was found to be 0.90. Responsiveness SRM (ES) was found to be 1.2 (0.7). Standard Error of Measurement (points) were found to be 4.6, 7.1. Minimal Detectible Change (points) were found to be 12.75, 12.8.86

The Fear-Avoidance Beliefs Questionnaire (FABQ) focuses specifically on how a participant’s fear-avoidance beliefs about how physical activity and work may affect and contribute to his/her low back pain (i.e. the cognitive/affective components of pain that are differentiated from specific tissue damage, injury, and nociception) and resulting disability.

This Self-reported questionnaire consists of 16 questions scaled from zero to six (maximum score of 96; higher score indicates fear avoidance behaviors). The first five questions pertain to physical activity while the remaining 11 pertain to work. The Physical Activity
subscale (FABQ-PA, range: 0 to 24) is the sum of items 2-5; the Work subscale (FABQ-W, range: 0 to 42) is the sum of items 6, 7, 9-12, and 15.

The FABQ (when “back” is replaced with “shoulder” in the measure) is an excellent predictor of how fear avoidance behaviors contribute to shoulder pain and disability (ICC = 0.88, 95% CI of 0.75-0.93).87,88

Significance

The purpose of this study was to determine the relationship between various arm positions associated with playing upper string instruments and the AHD and supraspinatus tendon thickness in both the bow-arm and the support-arm. It is expected that this information will be useful in understanding the etiology of SAIS as it specifically relates to upper string musicians. This research will improve treatments of shoulder pain and develop shoulder pain preventive interventions for upper string musicians with subacromial syndrome.

Further research

Further research regarding SAIS in the general population is needed, to identify and isolate the individual functional factors that contribute to the pathology. Studies utilizing 3D kinematic analysis should be paired with ultrasonographical measures to thoroughly explore the subacromial space in various postures and positions.
CHAPTER 3

METHODS

Purpose

The primary purpose of this study was to determine how various arm positions, associated with playing upper string instruments, affect AHD and supraspinatus tendon thickness in both the bow-arm and the support-arm, specifically bilateral comparison of supraspinatus tendon thickness, bilateral comparison of AHD, unilateral comparison of AHD throughout various bow positions, and unilateral comparison of AHD in the arm holding the instrument. A description of the research design, participant selection, research instrumentation, survey procedure, and methods of analysis are discussed in this chapter.

Participants

Participant Recruitment

Participants were recruited from the Marshall University Department of Music, the Huntington Symphony Orchestra, the West Virginia Symphony Orchestra, as well as the greater Huntington, WV area. The target participants play an instrument that classifies as an upper string instrument, such as the violin or viola. Participants were between the ages of 18-70 years old. Due to the difficulty and time it takes to master the instrument, it is commonplace for serious upper string musicians to begin their training in the formative years, as young as three or four years old, qualifying 18 year old musicians that have been accepted to an accredited music program as valid representations of the advanced musician population.
Participants

Twenty-three (23) upper string musicians participated in the study, 20 of which were violinists (86.95%) and three were violists (13.04%). No participants were excluded from the study. Of the participants, 14 females (60.86%) and nine males (39.13%) were evaluated. Ten upper string musicians reported current shoulder pain (43.4%) and 13 did not (56.52%). No participants had a clinical presentation of SAIS. Of the ten that reported shoulder pain, only three presented with two or more positive special tests in one or both shoulders (13.04%), and only one presented with 3 positive SAIS tests (4.34%). Of the 13 that reported no shoulder pain, one presented with two or more positive special tests in one or both shoulders (4.35%). (Table 3.1) Participants’ ages ranged between 19 to 66 years (33.87 ± 15.18 years). The average age of participants that complained of current shoulder pain was (33.00 ± 14.69 years). The average age of participants that did not complain of current shoulder pain was (32.31 ± 15.93 years). Mean reported practicing time daily for primary instrument was (2.21 ± 1.21 hours) with a weekly mean of (5.01 ± 1.48 days). Mean years played for primary instrument was (23.87 ± 13.84 years). Survey response data revealed high participant rated functionality among participants who reported shoulder pain as well as those that did not. Expanded demographic information regarding the two groups is presented in Table 3.2.

IRB Consideration

All musicians were required to fully comprehend and sign an informed consent form before being admitted for participation (Appendix A). A medical/biological IRB application was submitted and approved by the Marshall University Office of Research Integrity (Appendix B).
Exclusion Criteria:

- Musicians greater than 70 years old and younger than 18 years old were not considered for participation.
- Musicians with restricted arm motion greater than 50% in any plane of motion, were not considered for participation.
- Musicians with any medical condition that would prevent them from sitting for a period of an hour, were not considered for participation.
- Musicians with any medical hardware in their shoulder that would prevent accurate ultrasound readings were not considered for participation.

Inclusion Criteria:

- Male and female upper string musicians
- Musicians between the ages 18-70

Study Design

This study was a descriptive within participant study. The study was broken up into five separate comparisons in order to test the hypotheses stated earlier.

1. Bilateral comparison of AHD
2. Bilateral comparison of tendon thickness
4. Unilateral comparison of the AHD in the bow-arm (rest, 1st string).
5. Unilateral comparison of the AHD in the support-arm (rest, support position).
Independent Variables

Bilateral Comparisons of AHD, Tendon Thickness, and Occupation Ratio

- Position of arm
  - Resting on thigh
  - Hand on small of the back

Unilateral Comparison of the AHD in the Bow-Arm

- Position of bow-arm
  - Resting
    - Mid-bow 1st string (Figure 3.3)
    - Mid-bow 4th string (Figure 3.4)

Unilateral Comparison of the AHD in the Support-Arm

- Position of support-arm
  - Resting
  - Supporting Violin (Figure 3.5)

Dependent Variables

Bilateral Comparisons of AHD, Tendon Thickness, and Occupation Ratio

- Supraspinatus tendon thickness
- AHD
- Occupation Ratio (Tendon thickness / Resting AHD)

Unilateral Comparison of the AHD in the Bow-Arm

- AHD

Unilateral Comparison of the AHD in the Support-Arm

- AHD
Instrumentation

This study utilizes a variety of instruments to assess AHD, supraspinatus tendon thickness, postural deviations, and length of the bow.

- A Mindray M5 Ultrasound scanner with variable frequency 5cm sound head (Shenzhen Mindray Bio-Medical Electronics Co. LTD: Shenzhen, China) was used to assess tendon thickness as well as AHD. Diagnostic ultrasound has been shown to be reliable in measuring tendon thickness as well as AHD.\textsuperscript{82-84}
- Wall mounted height chart in centimeters
- A medical scale that measures weight in kilograms
- A standard metric tape measure to determine bow length and midpoint
- A twist tie to mark the midpoint of the bow
- A chair
- The Penn Shoulder Score Questionnaire to assess participant self-reported levels of pain, satisfaction, and function. The PSS is a 100-point (100 = perfect shoulder function) shoulder-specific self-report questionnaire consisting of three subscales of pain, satisfaction, and function. This scale has been shown to be a reliable method for assessing participant subjective shoulder pain.\textsuperscript{85}
- The Disabilities of the Arm, Shoulder and Hand (DASH) is a 30-item questionnaire, with a five-item response option for each item designed to measure physical function and symptoms in participants with any or several musculoskeletal disorders of the upper limb. The test has a maximum score of 100, where higher scores reflect greater disability. It can be used as either a one-time measure or to determine change over time. The DASH
has been found valid and reliable for testing both proximal and distal disorders of the upper extremity for multiple joints.\textsuperscript{86}

- Fear-Avoidance Beliefs Questionnaire (FABQ) is a self-reported questionnaire consisting of 16 questions scaled from zero to six. The first five questions pertain to physical activity while the remaining 11 pertain to work. This questionnaire has shown excellent reliability for assessing participant’s fear-avoidance beliefs about how physical activity and work may affect and contribute to pain.\textsuperscript{87,88}

**Procedure**

Participants were tested one at a time by a certified athletic trainer.

**Demographics**

Sex and age were identified by the participant and recorded by the investigator.

**Measurements**

The participant was asked to stand up straight, feet together, with back pressed up against a wall mounted height chart. Height was recorded in centimeters by the examiner.

The participant was then asked to step on a medical floor scale. Weight was recorded in kilograms by the examiner.

The bow was then measured using a standard metric tape measure and a mid-point was established and marked with a twist tie as to not leave a mark on the bow.

**Special Tests**

The participant was then tested for possible shoulder pathologies using various special tests namely the Neer’s test\textsuperscript{43}, the Hawkins-Kennedy test\textsuperscript{42}, Jobe’s Test\textsuperscript{45}, Painful Arc Test\textsuperscript{90}, \textit{et al.}
Drop Arm Test$^{91}$, Sulcus Sign$^{91}$, Apprehension/Relocation Tests$^{91}$, External Rotation Lag Sign$^{92}$, Liftoff Test$^{93}$, and Scapular Assistance Test$^{94}$.

**Surveys**

Participants were first given the Penn shoulder (ICC of 0.94 (95% CI, 0.89-0.97), (Cronbach alpha = 0.93), (SEM = ± 8.5), (MDC = ±12.1), (MCID = 11.4 points) (Appendix C) and given ample time to fill it out. Shoulder pain grading was performed later by a single examiner. Pain was scored on a scale of one to ten with one being “no pain” and ten being “worst imaginable pain.” The test was scored for each section by subtracting the number circled from the maximum of ten. Thirty points are awarded when a participant reports no pain. If a participant was not able to use the arm for normal or strenuous activities, zero points were scored for that item. Participant satisfaction with shoulder function is also assessed with a ten-point numeric rating scale. Scale was rated from ‘‘not satisfied’’ to ‘‘very satisfied.’’ A maximum of ten points for this section indicates that the participant was ‘‘very satisfied’’ with the current level of their shoulder function. The function subsection was based on a sum of 20 items, each with a four-point Likert scale. The response options include zero (can’t do at all), one (much difficulty), two (with some difficulty), and three (no difficulty). Most participants complete the test in less than ten minutes, and the clinician typically calculated the final scores in less than two minutes.$^{85}$

Participants were then given the DASH (ICC = 0.96), (Cronbach’s alpha = 0.90). (SEM = 4.6, 7.1), (MDC = 12.75, 12.8) (Appendix C)$^{86}$ and ample time to fill it out. The DASH was scored in two components. The first component is the disability/symptom questions (30 items, scored one - five). The second component was the optional high-performance sport/music or work section (four items, scored one - five). At least 27 of the 30 items must be completed for a
score to be calculated. The assigned values for all completed responses are simply summed and averaged, producing a score out of five. This value was then transformed to a score out of 100, by subtracting one and multiplying by 25. This transformation was done to make the score easier to compare to other measures scaled on a 0-100 scale. A higher score indicates greater disability.95

Participants were then given the FABQ (ICC = 0.88, 95% CI of 0.75-0.93) and ample time to fill it out (Appendix C). The FABQ consists of two subscales, which are reflected in the division of the outcome form into two separate sections. The first subscale (items one - five) is the Physical Activity subscale (FABQPA), and the second subscale (items six - 16) is the Work subscale (FABQW). Not all items contribute to the score for each subscale; however the participant should still have completed all items as these items were included when the reliability and validity of the scale was initially established. Each subscale was graded separately by summing the responses to respective scale items (zero - six for each item); for scoring purposes, only four of the physical activity scale items are scored (24 possible points) and only seven of the work items (42 possible points). It was extremely important to ensure all items were completed, as there is no procedure to adjust for incomplete items.88

**Diagnostic Ultrasound Methods**

Four (4) separate sets of ultrasound imaging trials were conducted. These trials measured bilateral supraspinatus tendon thickness, bilateral comparison of AHD, unilateral comparison of AHD throughout various bow positions, and unilateral comparison of AHD in the arm holding the instrument. Evaluation of the shoulder was performed as described by Jacobson.96 A targeted examination of the structures of the rotator cuff was imaged. This procedure was used to image the structures that are most commonly sites of shoulder pain and will allow for the assessment of
the structures involved in the individual participant. Anatomical structures imaged, in order of evaluation as recommended by Jacobson are:

1. The supraspinatus tendon
2. AHD

Ultrasound measures of supraspinatus tendon thickness, and AHD were measured as previously described; these procedures have been described in the literature to be reliable.

**Tendon Thickness**

Tendon thickness was measured in millimeters (mm) and was calculated as the mean value of two images measuring supraspinatus tendon thickness in longitudinal and cross-sectional section. (Figure 3.6) Measurements were taken from the humeral head to the hyperechoic superior margin of the supraspinatus tendon using onscreen calipers as previously described.\(^{47,97}\) All measurements were made by the same single examiner.

**Acromiohumeral Distance**

A Mindray M5 Ultrasound scanner with variable frequency 5cm sound head (Shenzhen Mindray Bio-Medical Electronics Co. LTD: Shenzhen, China) with an adjustable 5.0-12.5 MHz frequency linear array transducer was used to capture images AHD measurement. The AHD, the shortest distance between the humeral head and the lateral inferior tip of the acromion in millimeters\(^{83,84}\), (Figure 3.7) was measured with software embedded in the scanner by a single examiner. The average of the two AHD measurements from two separate images was used for statistical analysis. AHD measures using this technique have demonstrated good reliability\(^{82,84}\) and concurrent validity with radiographs.\(^{83}\) Measurement of accuracy at a 40mm depth within ±3% was reported to be ≤ 1.5mm of error.\(^{98}\) Ultrasonographic measures of the posterior
Acromiohumeral distance measurements, used in the support-arm were also found to be within similar reliability ranges. Ultrasonographic measurements of the AHD and the supraspinatus tendon thickness were assessed for inter-rater reliability using test retest protocol with seven participants. AHD measurements showed high reliability with high interclass correlation coefficient, lower standard error of measurement as well as minimal detectible change (ICC = 0.962, SEM 95% = 0.379mm, MDC 95% = 0.536mm). Supraspinatus tendon measurements were found to be less reliable with lower interclass correlation coefficient and higher standard error of measurement as well as minimal detectible change (ICC = 0.760, SEM 95% = 0.619mm, MDC 95% = 0.876mm). All measures were made later by a single examiner from images saved on the ultrasound unit.

**Bilateral Supraspinatus Tendon Thickness**

For measurements of tendon thickness, ultrasonographic images were taken bilaterally in the standard I and II views (cross section and longitudinal views), as described by Teefey for best visualization of the supraspinatus tendons. The participants were placed in a seated position with the hand of the arm to be tested positioned on their iliac crest-hip. The elbow is directed posteriorly. The probe was placed perpendicular to the plane of the scapula on top of the supraspinatus muscle on the top of the shoulder. Two (2) images in each shoulder were captured for later measurement of the cross sectional width of the supraspinatus tendon.

**Bilateral Resting AHD**

The participant was placed in a seated position with their arms at their side in a relaxed position and their feet on the floor. The examiner palpated the clavicle and acromion process of the right shoulder. While the examiner palpated the acromion process, the ultrasound transducer
was aligned in the plane of the scapula and the anterior acromion process was located. The transducer was then placed above the anterior acromion and the image was recorded. Both shoulders were imaged. All images were measured at a later time by a single examiner.

Unilateral Comparison of AHD in Bow-Arm

AHD for two bow positions was analyzed for this trial (mid-bow 1st string and mid-bow 4th string). The participant was placed in a seated position, supporting the neck of the violin, with the violin positioned under the chin. The bow-arm was elevated and positioned on the 1st string at the marked midpoint of the bow. The examiner palpated the clavicle and acromion process of the bow-arm shoulder. While the examiner palpated the acromion process, the ultrasound transducer was aligned in the plane of the scapula and the anterior acromion process was located. The transducer was then placed above the anterior acromion and the image was recorded. The trial was then repeated with the bow positioned on the 4th string at the marked midpoint of the bow. All images were measured at a later time by a single examiner.

Unilateral Comparison of AHD in the Support-Arm

AHD for the support-arm shoulder was analyzed for this trial. The participant was placed in a seated position, supporting the neck of the violin, with the violin positioned under the chin. The bow-arm was elevated and positioned on the 1st string at the marked midpoint of the bow. The examiner palpated the clavicle and acromion process of the bow-arm shoulder. While the examiner palpated the acromion process, the ultrasound transducer was aligned in the plane of the scapula and the posterior acromion process was located. Because of the proximity of the transducer to the violin when using the anterior aspect of the acromiohumeral space the transducer was placed above the posterior acromion and the image was recorded. Two (2) Images were taken in each plane for accuracy. All images were measured at a later time by a
single examiner. Testing of posterior acromion as opposed to anterior acromion was found to be the most effective and reliable way to measure the subacromial space.99 This change in protocol was made after three participants had been tested resulting in (N = 20).

**Statistical Analysis**

Summary statistics were generated on basic demographic data and responses to Penn Shoulder, FABQ, and DASH Questionnaires. Means and standard deviations are reported in order to better describe the study. All statistical calculations were made using SPSS® 22.0 statistical software (SPSS Inc., Chicago, Il, USA). All statistical significant differences determined at p ≤ 0.05.

**Bilateral Supraspinatus Tendon Thickness**

A paired T-test was performed on the data collected regarding bilateral supraspinatus tendon thickness. Mean calculations for the bow-arm were attained. Mean calculations for the support-arm were attained. Standard deviation calculations for both measurements were acquired. A paired T-test was performed to determine if there were any significant differences in the data between sides.

**Bilateral Resting AHD**

A paired T-test was performed on the data collected regarding resting bilateral AHD figures. Mean and standard deviations calculated for the bow-arm were attained. Mean calculations for the support-arm were attained. Standard deviation calculations for both measurements were acquired. The paired T-test was performed to determine if there were any significant differences in the data between sides.
**Occupation Ratio**

An occupation ratio was calculated unilaterally by \( \frac{Tendon \text{ Thickness}}{Acromiohumeral \text{ Distance}} \). Mean calculations for the bow-arm were attained. Mean calculations for the support-arm were attained. Standard deviation calculations for both measurements were acquired, then a paired T-test was performed to determine if there were any significant differences in the data between sides.

**Unilateral Comparison of AHD in Bow-Arm**

A one way repeated measures ANOVA was used to compare AHD figures in the bow-arm. The independent variables are the positions of the bow-arm in relation to the strings of the violin: resting, 1\textsuperscript{st} string, 4\textsuperscript{th} string. The mean and standard deviation were calculated for the AHD measurements in each position. A *post hoc* analysis was then completed to identify where the differences occurred between arm positions, with all statistical differences determined at \( p \leq 0.05 \).

**Unilateral Comparison of AHD in the Support-Arm**

The mean and standard deviation of the AHD measurements were calculated for each arm position. A one-way ANOVA was performed in order to test the difference of arm positioning on AHD. The independent variable levels being the bow-arm positions in: resting, 1\textsuperscript{st} string, and 4\textsuperscript{th} string. Significant main effects were explored post-hoc using the paired T-test to statistically show significant differences in the AHD between arm position levels. A *post hoc* analysis was then completed with all statistical significance determined at \( p \leq 0.05 \).
**Table 3.1:** Participants with and without shoulder pain, special test results.

<table>
<thead>
<tr>
<th>Participants with Reported Pain</th>
<th>Painful Arc Test</th>
<th>Drop Arm Test</th>
<th>Sulcus Sign</th>
<th>Hawkins-Kennedy Test</th>
<th>Neer’s Impingement Test</th>
<th>Apprehension Test</th>
<th>Relocation Test</th>
<th>External Rotation Lag Sign</th>
<th>Liftoff Scapular Assistance Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 3</td>
<td>Right Shoulder Positive</td>
<td>Right Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Right Shoulder Positive</td>
<td>Right Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
</tr>
<tr>
<td>Participant 15</td>
<td>Right/Left Shoulder Positive</td>
<td>Right/Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Right Shoulder Positive</td>
<td>Right Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
</tr>
<tr>
<td>Participant 23</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Right Shoulder Positive</td>
<td>Right Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
</tr>
<tr>
<td>Participants with No Reported Pain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant 2</td>
<td>Right/Left Shoulder Positive</td>
<td>Right Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Right Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Right Shoulder Positive</td>
<td>Right Shoulder Positive</td>
<td>Left Shoulder Positive</td>
<td>Left Shoulder Positive</td>
</tr>
</tbody>
</table>
Table 3.2: Demographic information pertaining to upper string musicians included for participation that reported current shoulder pain and those that did not report current shoulder pain. Standard deviations or percentage of prevalence were reported as well for the individual groups.

<table>
<thead>
<tr>
<th></th>
<th>Means of Participants Reporting Current Shoulder Pain (n = 10)</th>
<th>Standard Deviation / Prevalence Percentage</th>
<th>Means of Participants Not Reporting Current Shoulder Pain (n = 13)</th>
<th>Standard Deviation / Prevalence Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>33.00 SD = ± 14.69</td>
<td>32.31 SD = ± 15.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>4 PP = 17.39%</td>
<td>5 PP = 21.73%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females</td>
<td>6 PP = 26.08%</td>
<td>8 PP = 34.78%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.88 SD = ± 9.51</td>
<td>168.89 SD = ± 8.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83.68 SD = ± 28.11</td>
<td>71.65 SD = ± 16.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily Practice (Hours)</td>
<td>2.2 SD = ± 1.11</td>
<td>2.2 SD = ± 1.33</td>
<td></td>
<td></td>
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<tr>
<td>Weekly Practice (Days)</td>
<td>4.85 SD = ± 1.47</td>
<td>5.14 SD = ± 1.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekly Practice (Hours)</td>
<td>11.2 SD = ± 8.15</td>
<td>10.85 SD = ± 5.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years Played</td>
<td>24.5 SD = ± 13.61</td>
<td>23.28 SD = ± 14.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participants Reporting Regular Exercise</td>
<td>8 PP = 34.78%</td>
<td>7 PP = 30.43%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean BMI</td>
<td>27.68 SD = ± 9.40</td>
<td>25.12 SD = ± 4.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FABQ (Physical Activity)</td>
<td>9.3 SD = ± 5.25</td>
<td>8.30 S D = ± 6.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>SEM</td>
<td>SD</td>
</tr>
<tr>
<td>----------------------</td>
<td>------</td>
<td>-------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>FABQ (Work)</td>
<td>10.5</td>
<td>± 8.20</td>
<td>5.153</td>
<td>± 6.87</td>
</tr>
<tr>
<td>DASH</td>
<td>11.59</td>
<td>± 7.75</td>
<td>5.59</td>
<td>± 6.91</td>
</tr>
<tr>
<td>DASH (Performance)</td>
<td>13.12</td>
<td>±14.26</td>
<td>4.32</td>
<td>± 7.38</td>
</tr>
<tr>
<td>PENN</td>
<td>86.1</td>
<td>± 8.19</td>
<td>95.53</td>
<td>± 4.91</td>
</tr>
</tbody>
</table>

Figure 3.3: 1st string mid-bow position for right side AHD measurements
Figure 3.4: 4th string mid-bow position for right side AHD measurements

Figure 3.5: Arm supporting the instrument with 1st finger on the 1st string
**Figure 3.6:** Ultrasonographic images of the supraspinatus tendon, longitudinal view (left), transverse view (right)

**Figure 3.7:** Ultrasonographic image of the AHD (arrow)
CHAPTER 4

RESULTS

Bilateral Resting AHD

A paired T-test was performed to determine if there were any significant differences in the data between sides (n = 23). It was found that there was a statistically significant difference in the right shoulder, when compared to the left shoulder (Mean difference = -0.561 ± 1.089mm; t = -2.471; p ≤ 0.001). It was found that the AHD in the right shoulder, (11.713 ± 0.327mm) was smaller than that of the left (12.273 ± 0.404mm) (Figure 4.1).

Bilateral Supraspinatus Tendon Thickness

Bilateral supraspinatus tendon thickness differences were analyzed using a paired T-test to determine if there were any significant differences in the data between sides (n = 23). It was found that there were no statistically significant side differences among the population samples for the transverse (t = 0.717; p < 0.481) and longitudinal (t = 1.445; p < 0.163) planes. The mean thickness for the left supraspinatus tendon (5.687 ± 0.211mm) was not significantly different when compared to the right side. (5.889 ± 0.262mm). Mean cross sectional difference = 0.143 ± 0.200mm; mean longitudinal difference = 0.261 ± 0.181mm (Figures 4.2, 4.3, 4.4).

Occupation Ratio

The occupation ratio was analyzed by \( \frac{Tendon\ Thickness}{Acromiohumeral\ Distance} \), and a paired T-test was performed to determine if there were any significant differences in the data between sides (n = 23). There was a statistically significant difference in the occupation ratio between the left (0.472 ± 0.021mm) (t = 1.527; p < 0.141) and right shoulder (0.507 ± 0.022mm) (t = 2.431; p < 0.024).
Mean cross sectional difference = 0.029 ± 0.019mm; mean longitudinal difference = 0.041 ± 0.017mm (Figure 4.5).

**Unilateral Comparison of AHD in Bow-Arm**

A unilateral comparison of AHD in the bow-arm was analyzed using a one-way ANOVA (n = 23). *Post hoc* analysis was then completed to confirm where the differences occurred between groups, with all statistical differences determined at p≤0.001. On the right side, analysis revealed, the arm position’s main effect was significant (F(1,22) = 74.317; p < 0.001), the mean AHD in the 4th string position (8.459 ± 0.449mm) was less than the 1st string (10.978 ± 0.319mm) and resting (11.713 ± 0.327mm) positions (Figure 4.6).

*Post hoc* analysis identified that the differences between all groups were significant: Resting position vs. 1st string position (Mean Difference = 0.735) (SEM = 0.220) (p ≤ .009) (95%CI = 0.164, 1.305), Resting position vs. 4th string position (Mean Difference = 3.254 mm) (SEM = 0.378mm) (p ≤ .001) (95%CI = 2.276, 4.233), 1st string position vs. resting position (Mean Difference = -0.735mm) (SEM = 0.220mm) (p ≤ .009) (95%CI = -1.305, -0.164), 1st string position vs. 4th string position (Mean Difference = 2.520mm) (SEM = 0.245 mm) (p ≤ .001), 4th string position vs. Resting position (Mean Difference = -3.254mm) (SEM = 0.378mm) (p ≤ .001), 4th string position vs. 1st position (Mean Difference = -2.520mm) (SEM = 0.245mm) (p ≤ .001).

**Unilateral Comparison of AHD in the Support-Arm**

Repeated measures ANOVA (n = 20) was performed in order to test the difference the effect of arm position had on AHD in the support-arm. *Post hoc* analysis was then completed with all statistical significance determined at p ≤ 0.05. Analysis revealed that the arm position’s
main effect was significant \(\left( F_{1,19} = 47.460; \ p < 0.001 \right)\). There was a significant difference in the AHD measurement between the resting mean and \(\left( 13.428 \pm 0.606\text{mm} \right)\) the 1st finger, 1st string mean \(\left( 10.765 \pm 0.488\text{mm} \right)\) positions on the left side. (Figure 4.7)

*Post hoc* analysis identified the differences between groups were significant: Resting vs. Support (Mean Difference = 2.663mm) (SEM = 0.386mm) \(\left( p \leq 0.001 \right)\) \(\left( 95\%\text{CI} = 1.854, 3.471 \right)\), Support vs. Resting (Mean Difference = -2.663mm) (SEM = 0.386mm) \(\left( p \leq .001 \right)\) \(\left( 95\%\text{CI} = -3.471, 1.854 \right)\).

**Summary of Hypothesis Testing**

**Hypothesis 1: Supported**

It was hypothesized that ultrasonographic measurements of the resting AHD measurements would be smaller in the bow-arm compared to the arm supporting the violin. This hypothesis was supported by the data collected. (Figure 4.1)

**Hypothesis 2: Not Supported**

It was hypothesized that the supraspinatus tendon in the bow-arm would be thicker than the tendon in the arm supporting the instrument. This hypothesis was not supported by the data. It was shown that there were no statistically significant differences in supraspinatus tendon thickness bilaterally. (Figures 4.2, 4.3,4.4)

**Hypothesis 3: Supported**

It was hypothesized that occupation ratio for the bow-arm would be a larger quantity than the support-arm. This hypothesis was supported by the data, as the occupation ratio on the right side was significantly larger than the left side. (Figure 4.5)
**Hypothesis 4: Supported**

It was hypothesized that the AHD in the unilateral comparison of the bow-arm would be smaller as the bow is placed on the 4th string, when compared to the 1st string. This hypothesis was supported by the data that was collected. On the right side, analysis revealed, the arm position’s main effect was significant, the AHD in the 4th string position was less than the 1st string and resting positions sequentially. (Figure 4.6)

**Hypothesis 5: Supported**

It was hypothesized that the AHD in the unilateral comparison of the support-arm would be smaller as the arm is brought up to support the instrument, compared to the resting position. This hypothesis was supported. It was shown that there was a significant difference in the AHD between the resting and the 1st finger, 1st string positions on the left side. (Figure 4.7)
Figures and Tables

**Figure 4.1:** Bilateral comparison of resting AHD (in millimeters). Standard error of measure bars included to indicate statistical significance of findings. Asterisk (*) indicates significant difference between right and left means (p < 0.001). (ICC = 0.962, SEM 95% = 0.37mm, MDC 95% = 0.53mm).

![Resting Position AHD](image1)

**Figure 4.2:** Bilateral comparison of supraspinatus tendon thickness (in millimeters) in the cross section view. Standard error of measure bars included to indicate lack of statistical significance of findings (p < 0.481). (ICC = 0.760, SEM 95% = 0.61mm, MDC 95% = 0.87mm).

![Supraspinatus Tendon Cross Section](image2)
**Figure 4.3:** Bilateral comparison of supraspinatus tendon thickness (in millimeters) in the longitudinal view. Standard error of measure bars included to indicate lack of statistical significance of findings ($p < 0.163$). (ICC = 0.760, SEM 95% = 0.61mm, MDC 95% = 0.87mm).

**Figure 4.4:** Bilateral comparison of supraspinatus tendon thickness (in millimeters) mean values. Standard error of measure bars included to indicate lack of statistical significance of findings. (ICC = 0.760, SEM 95% = 0.61mm, MDC 95% = 0.87mm).
**Figure 4.5**: Bilateral comparison of occupation ratio (in millimeters). Standard error of measure bars included to indicate statistical significance of findings. Asterisk (*) indicates significant difference between right and left means transverse (p < 0.141) and longitudinal (p < 0.024).

![Figure 4.5: Occupation Ratio Graph](image)

**Figure 4.6**: Unilateral comparison of right AHD in the resting 1st and 4th string positions. Standard error of measure bars included to indicate statistical significance of findings. Asterisk (*) indicates significant difference between positions (p < 0.001). (ICC = 0.962, SEM 95% = 0.37mm, MDC 95% = 0.53mm)

![Figure 4.6: Right Shoulder Graph](image)
**Figure 4.7:** Unilateral comparison of left AHD in the resting and support positions (in millimeters).

Standard error of measure bars included to indicate statistical significance of findings. Asterisk (*) indicates significant difference between positions (p < 0.001). (ICC = 0.962, SEM 95% = 0.37mm, MDC 95% = 0.53mm)
CHAPTER 5

DISCUSSION

Summary of Current Study

The AHD in the 4th string position was smaller than the AHD in the 1st string position and the AHD in the 1st string position was smaller than the resting position. There was also a difference observed in the AHD between the resting and the support positions in the left side. The resting AHD was smaller on the right side when compared to the left side AHD. Supraspinatus tendon thickness in the left shoulder was not observed to be different when compared to the right side. The occupation ratio was also larger in the right shoulder than in the left.

Current Study in the Context of Previous Relevant Studies

Although several studies have identified musculoskeletal conditions as common among musician populations and more specifically in upper string populations, there have been very few studies that have attempted to systematically identify the specific mechanisms that contribute to these musculoskeletal conditions.\textsuperscript{2,3,13-37,50,51} Researchers that have explored contributing factors of shoulder pain in upper string musician populations have utilized either EMG\textsuperscript{101-103}, external kinematic analysis\textsuperscript{37,38,41,104} or a combination of the two techniques.\textsuperscript{32,48} None of these studies took into account the internal characteristics of the subacromial space when attempting to determine the etiology of shoulder pain in violinists, which marks the distinction between this study and previous ones.
Observations and Conclusions

Unilateral Comparison of AHD in Bow-Arm

As hypothesized, the AHD in the right shoulder decreased as the violin bow was moved from the resting position through the 4th string position. The greater arm elevation that allows the musician to move the bow into the 4th string position, and the decrease in AHD associated with arm elevation in the current investigation, was similar to the decreases reported by Desmeules in patients with and without SAIS at 0°, 45°, 60° of active shoulder abduction and Seitz in patients with and without scapular dyskinesis at 0°, 45°, 90° of static scapular plane arm elevation. Reported min/max range of motion values for shoulder kinematics when playing on the 1st string are 60° max - 15° min of flexion and 26° max - 2° min of shoulder abduction. Reported mean AHD measurements for asymptomatic shoulders in 45° position ranges from (8.3 ± 1.9mm) for abduction to (8.3 ± 0.4mm) for flexion. The mean measurement for AHD in the right shoulder when the mid-bow is on the 1st string for this study was (10.978 ± 0.319mm). This value is 2.678mm larger than the reported values at 45° of flexion and abduction in healthy shoulders. This value is 1.4mm larger than shoulders with SAIS (9.5 ± 2.7mm at 45° abduction) and 3.1mm larger than shoulders with scapular dyskinesis (7.9 ± 0.4mm at 45° flexion). The range of motion for abduction in the bow-arm ends at 26°; this can account for the differences seen in healthy AHD measurements. Even though flexion can range up to 60°, the AHD values found in this study are still larger than the reported values in healthy shoulders. These reported values suggest that the complex bowing-arm angulation associated with playing an upper string instrument, on the 1st string, may not cause as much AHD narrowing, as the individual components of flexion and abduction.
Reported min/max range of motion values for shoulder kinematics when playing on the 4th string are 87° max - 64° min and shoulder abduction range is reported to be 35° max - 10° min.\textsuperscript{41} Reported mean AHD measurements for asymptomatic shoulders in 90° position of flexion is (9.2 ± 0.4mm).\textsuperscript{11} Since the maximum range of shoulder abduction in bow-arm is 35°, reporting results of analysis performed at 60° of shoulder abduction is unnecessary and the comparisons will be made based on the 45° measures. Reported mean AHD measurements for asymptomatic shoulders in 45° position is (8.3 ± 1.9mm) for abduction\textsuperscript{105}. The mean measurement for AHD in the right shoulder when the mid-bow is on the 4th string for this study was (8.459 ± 0.449mm). This value is 0.15mm larger than the reported value at 45° abduction and 0.75mm smaller than the reported value at 90° flexion in healthy shoulders. This value is 1.05mm smaller than shoulders with SAIS (9.5 ± 2.7mm at 45° abduction) and .35mm smaller than shoulders with scapular dyskinesis (8.8 ± 0.4mm at 90° flexion). Although the range of motion for abduction in the bow-arm ends at 35°, the AHD measurements in healthy and symptomatic subjects at 45° of abduction were similar to the mean values found in this study for the 4th string position. The values found in this study for 4th string position were similar to the values reported for 90° of shoulder flexion in healthy shoulders and shoulders with scapular dyskinesis. These reported values suggest that the positions associated with bowing on the 4th string can present the same (if not slightly more) levels of AHD narrowing seen in the individual positions. It is important to note that the measurements in this study were taken at the mid-bow position, which indicates that these similar narrowing effects are being seen not at the extreme ranges of motion but somewhere in the center.

The differences in AHD reported in this study were notable not only at the extreme ranges of motion (resting – 4th string position) but also within resting and 1st string positions as
well as 1st string and 4th string groups. The difference in mean values fell outside the initially established SEM (0.379mm) and MDC (0.536mm) for these measures. This implies that differences were not likely due to measurement error but rather decreases in the AHD associated with the change in arm position. These results help to explain the reported high levels of SAIS in upper string musicians. These reportedly high levels of SAIS can be due to the dynamic, rhythmic, compressive forces on the subacromial structures, which accompanies a narrowing of the AHD in the positions used to play the instrument. According to Neer compressive forces on structures of the subacromial space account for 95% of all rotator cuff pathologies.  

**Unilateral Comparison of AHD in the Support-Arm**

The AHD in the left shoulder also demonstrated narrowing, as the arm was brought from a resting position into 1st finger, 1st string position to support the instrument. The mean reported values for shoulder movement in the support-arm were more constant with 31 ± 11° of flexion and 13 ± 6° of abduction. Reported mean AHD measurements for asymptomatic shoulders in 45° position ranges from 8.3 ± 1.9mm for abduction to 8.3 ± 0.4mm for flexion. The current study found mean AHD measurements of 10.7 ± 0.48mm in the support position. This value is 2.46mm larger than the reported value at 45° abduction and flexion in healthy shoulders. This value is 1.27mm larger than shoulders with SAIS (9.5 ± 2.7mm at 45° abduction) and 2.86mm larger than shoulders with scapular dyskinesis (7.9 ± 0.4mm at 45° flexion). The values observed in this study (SAIS free population) are similar to the reported mean AHD values in healthy shoulders, as opposed to the pathologic shoulders.

The difference in mean AHD values fell outside the initially established SEM (0.37mm) and MDC (0.53mm). These differences imply that differences were not likely due to measurement error but rather decreases in the AHD associated with the change in arm position.
This narrowing can be attributed to the magnitude of the arm elevation, in combination with the
glenohumeral internal rotation, which reduced the width of the subacromial space outlet. These
results suggest that supporting the violin does not place excessive stress on the subacromial
structures.

**Bilateral Resting AHD**

It was also shown that, in the resting arm position, the right AHD was smaller than the
left AHD, as hypothesized. Reported mean AHD measurements for asymptomatic shoulders in
resting position range from \((9.9 \pm 1.5\text{mm})^{105}\) to \((10.9 \pm 0.4\text{mm})^{11}\). These values are smaller than
the mean right \((11.7 \pm 0.3\text{mm})\) and left \((12.2 \pm 0.4\text{mm})\) values obtained during this study. The
resting measurements in upper string musicians are more congruent with values reported for
shoulders with SAIS \((12.0 \pm 1.9\text{mm})^{105}\) and scapular dyskinesis \((11.3 \pm 0.4\text{mm})^{11}\). In general
populations, reported means for nonathletic, asymptomatic, resting AHD measurements based on
side dominance showed that there were no differences between dominant and non-dominant
AHD measurements.\(^{106}\) These findings suggest that the differences measured in resting AHD in
this study are not due to differences seen based on arm dominance, and right side AHD measures
are more similar to pathologic shoulders than healthy shoulders.

The difference in mean values fell outside the initially established standard error of
measurement \((0.37\text{mm})\) and minimal detectable change \((0.53\text{mm})\). These differences imply that
differences were not likely due to measurement error but rather decreases in the AHD. This
inherent difference in AHD measurements can most likely be attributed to the dynamic nature of
the bow-arm movement, when compared to the static nature of the support-arm. This side
difference in AHD may account for the increase in right side shoulder pain found in upper string
musicians as reported in the literature and more specifically the higher prevalence of right sided SAIS. 3,27,39,40

**Bilateral Supraspinatus Tendon Thickness**

It was expected that the supraspinatus tendon would be thicker on the right side than the left, due to the more dynamic activity of the arm, while playing the violin.

Mean reported value for supraspinatus tendons in asymptomatic shoulders is reported to be (6.0 ± 0.8mm). This is not different from the mean values obtained in this study for left (5.6 ± 0.2mm) and right side (5.8 ± 0.2mm) tendon measurements. The left side however is statistically smaller than the reported value for shoulders with subacromial impingement (6.6 ± 0.8mm). The difference in tendon thickness, in both the cross section and long view, was not of statistical difference. The difference in mean values fell inside the initially established standard error of measurement (0.6mm) and minimal detectable change (0.8mm). This finding is particularly remarkable given the previous results that suggest compression of the subacromial structures is increased on the right side. Tendon thickening has been attributed to chronic overloading of the rotator cuff tendons.9 This effect has been studied in asymptomatic baseball pitchers that show 1.5–1.6 mm thickness increase in the throwing shoulder as compared to the non-throwing shoulder.107 These findings suggest that the dynamic movements associated with the motion of bowing, when compared to the static movement of supporting the instrument, do not overload the rotator cuff tendons in a way that causes an increase in thickness.

**Occupation Ratio**

The occupation ratios found in the current study: left mean (0.47 ± 0.02mm) and right mean (0.50 ± 0.02mm), are not statistically different when compared to the mean occupation
ratios reported in symptom free shoulders (0.54 ± 0.07mm), and smaller than the occupation ratios found in patients with SAIS (0.617 ± 0.103mm).\textsuperscript{9} In accordance with the hypothesis, the occupation ratio was greater on the right side, compared to the left, due to the homogenous supraspinatus tendon thickness measurements bilaterally and the reduced AHD measurements on the right side. A greater occupation ratio indicates a smaller amount of available space beneath the acromion which leads to a greater chance of compression of these structures. These findings suggest a functional etiology is more likely the cause of SAIS in upper string musicians than a structural etiology. It is unclear which (if one singular) functional factor may be responsible for contributing to SAIS in upper string musicians. Possible functional mechanisms include: superior translation of the humeral head due to increased deltoid activation and diminished rotator cuff activation, as well as decreased upward rotation and posterior tilt of the scapula due to over-recruiting the upper and the lower trapezium while failing to adequately recruit the serratus anterior.\textsuperscript{6,63}

**Observations and Conclusions Relating to Demographic Data**

The majority of the participants in this study were female (n = 23) (60%); this is atypical for an orchestral composition where males tend to be the majority (F = 46%; M = 54%).\textsuperscript{27,108} Female musicians have been reported to have higher prevalence rates of musculoskeletal complaints.\textsuperscript{15,22,39,109} The ages of the participants ranged between 19-66 years of age. The average age of participants that complained of current shoulder pain was 33. This figure lies just outside the reported age range (26-30 years) for incidence of injury in Australian orchestral musicians.\textsuperscript{17} There were no differences between the mean practice/playing hours weekly for the injured participants (11.2 h) when compared to the uninjured participants (10.85 h). There was not a difference between the injured (34.78%) and uninjured (30.43%) population relating to
engaging regularly in upper extremity exercise. Mean BMI measurements for participants that reported shoulder pain was not different than \((27.68 \pm 9.40)\) participants that did not report shoulder pain \((25.12 \pm 4.69)\). Both groups fall into “Overweight classification” \((25.0–29.9)\).\(^{110}\) The lack of differences among groups for the demographic variables indicates the changes seen in AHD could be attributed to the movement of the instrument.

**Observations and Conclusions Relating to Physical Examination**

Of the whole population, 43.4% upper string musicians reported current shoulder pain and 56.52% did not. This prevalence of shoulder pain cannot be contributed to SAIS with only 13.04% of the sample presented with two or more positive SAIS special tests in one or both shoulders and complaining of shoulder pain. Of the total population, 4.35% presented with two or more positive SAIS special tests in one or both shoulders but did not complain of general shoulder pain. Only one participant tested positive for four SAIS special tests (all in the left shoulder). The majority of the nondescript shoulder pain described by the participants was caused by factors other than SAIS.

**Limitations of the Study**

Although this study effectively characterized the dimensions of the subacromial space in the extreme ranges of movement associated with playing an upper string instrument, limitations in the study design still persist.

1. This study ultrasonographically measured the structures of the subacromial space in several static positions that represented the end ranges of motion. While this method is convenient and useful for making assessments of the general
characteristics of the space, it does not provide an accurate portrayal of the specific characteristics during the transitions between positions.

2. This study did not take fatigue into account when making measurements of the subacromial space. All participants were ultrasonographically tested after performing several manual muscle tests but not a full fatigue protocol. Fatigue plays a large factor in subacromial space measurements and will inevitably be a factor during any real performance or practice session. We would have likely gotten different results if the participants were tested completely fresh or thoroughly fatigued.

3. Some participants had a thicker layer of subcutaneous adipose tissue which produced images that were harder to accurately measure compared to participants with very little adipose tissue. These morphometric factors may have made minor contributions to error of measurement.

4. Extrinsic factors that may stress the upper extremities other than playing the violin (such as regularly carrying small children), may not have been fully accounted for when describing the population.

5. Since all of the violists that participated in the study listed violin as their secondary instrument, violinists and violists were grouped together for all relevant analysis. Violists made up a relatively small percentage of the total population (n = 3) (13%) of this study. It is likely slightly different measurements would have been collected if the study had isolated just violinists or violists.
**Recommendations for Further Study**

1. Future research in this area should include a more dynamic method of assessment. Musicians could play a piece that thoroughly represented the entire range of motion available to the upper string musician, while ultrasound images were taken consistently in real-time throughout the piece. This data could be paired with three-dimensional kinematic analysis of the scapula and arm provided by an electromagnetic tracking system.

2. EMG analysis paired with three-dimensional kinematic analysis has been performed on the upper trapezius as well as the subscapularis in upper string musicians with SAIS.\textsuperscript{32,48} This type of study should be expanded to also include the subscapularis and infraspinatus which serve to inferiorly translate the humerus relative to the glenoid, as well as the deltoid which acts in the opposite direction. This type of study could be paired with ultrasonographical measurements of the subacromial space. These kinds of studies would provide more insight into the mechanics of superior translation of the humerus on the glenoid fossa.

3. A pre and post fatigue study should also be performed to determine the effects of playing long vs short pieces on the static measurements of the subacromial space. This would help to elucidate the etiology of the functional factors that contribute to SAIS.
REFERENCES

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Desmeules F, Minville L, Riederer B, Cote CH, Fremont P. Acromio-Humeral Distance Variation Measured By Ultrasonography And Its Association With The Outcome Of


95. HEALTH IFW. Scoring the DASH. Disabilities of the Arm Shoulder and Hand. 2006.


APPENDIX A.
Informed Consent

Informed Consent to Participate in a Research Study

The Assessment of Shoulder and Upper Extremity, Pain and Function of Upper String Musicians

Mark K Timmons PhD ATC, Principal Investigator

Introduction

You are invited to be in a research study. Research studies are designed to gain scientific knowledge that may help other people in the future. You may or may not receive any benefit from being part of the study. There may also be risks associated with being part of research studies. If there are any risks involved in this study then they will be described in this consent. Your participation is voluntary. Please take your time to make your decision, and ask your research doctor or research staff to explain any words or information that you do not understand.

Why Is This Study Being Done?

The purpose of this study is to increase the understanding of the mechanisms that produce shoulder and upper extremity pain in musicians that play the upper string instruments. This information will help healthcare providers develop better treatment plans for these individuals.

How Many People Will Take Part In The Study?

About 50 people will take part in this study. A total of 50 subjects are the most that would be able to enter the study.

What Is Involved In This Research Study?

During the study you will first fill out questionnaires about your back, shoulder, and arm then the researcher will perform an examination and make several measurements of your shoulder strength and motion. The researchers will take pictures of your shoulder in order to help make some of the measurements. After the examination the researcher will use an ultrasound machine to make several images of both of your shoulders. During the ultrasound imaging you will need to wear a sleeveless or tank top shirt. You will need to hold your musical instrument while some of the ultrasound images are taken. During the ultrasound imaging you will be asked to sit down and your arm will be placed in several positions, you will also be asked to perform several contractions of your shoulder muscles. The questionnaires, shoulder examination, and ultrasound imaging will take about 90 minutes to complete. You will be asked to return one year later for follow up testing, the follow up testing will be similar to the initial testing.

How Long Will You Be In The Study?

You will be in the study for two testing sessions that will take about 90 minutes to complete. The 2 testing sessions will be approximately 1 year apart.

Subject’s Initials ________
You can decide to stop participating at any time. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff to discuss what follow up care and testing could be most helpful for you.

The study doctor may stop you from taking part in this study at any time if he/she believes it is in your best interest; if you do not follow the study rules; or if the study is stopped.

**What Are The Risks Of The Study?**

Being in this study involves some risk to you. You should discuss the risk of being in this study with the study staff.

You should talk to your study doctor about any side effects that you have while taking part in the study.

Risks and side effects related to the testing session include: increased shoulder pain, muscle soreness, muscle fatigue and reduced shoulder strength. These risks and side effects are temporary and are no greater than the risks associated with any physical exercise program. These side effects can be reduced by stretching exercises, and applying either moist heat or ice. **If you experience pain that you would describe as being more than 7 out of 10 you should stop the testing session and contact your doctor.**

There may also be other side effects that we cannot predict. You should tell the research staff about all the medications, vitamins and supplements you take and any medical conditions you have. This may help avoid side effects, interactions and other risks. There are no funds available for compensation for any injury that occurs as a result of your participation in this study.

**Are There Benefits To Taking Part In The Study?**

If you agree to take part in this study, there may or may not be direct benefit to you. We hope the information learned from this study will benefit other people in the future. The benefits of participating in this study may be: If you are experiencing shoulder pain you might gain information that could help your physician treat your shoulder pain.

**What Other Choices Are There?**

You do not have to be in this study to receive treatment. You should talk to your doctor about all the choices you have. If you chose not to be in this study you should start or continue with treatment plan prescribed by your doctor.

**What About Confidentiality?**

We will do our best to make sure that your personal information is kept confidential. However, we cannot guarantee absolute confidentiality. Federal law states that we must keep your study records private. Nevertheless, certain people other than your researchers may also need to see your study records. By law, anyone who looks at your records must keep them completely confidential.

Those who may need to see your records are:

Subject’s Initials _______
• Certain university and government people who need to know more about the study. For example, individuals who provide oversight on this study may need to look at your records. These include the Marshall University Institutional Review Board (IRB) and the Office of Research Integrity (ORI). Other individuals who may look at your records include: the federal Office of Human Research Protection. This is done to make sure that we are doing the study in the right way. They also need to make sure that we are protecting your rights and your safety.

If we publish the information we learn from this study, you will not be identified by name or in any other way.

**What Are The Costs Of Taking Part In This Study?**

There are no costs to you for taking part in this study. All the study costs, including any study medications and procedures related directly to the study, will be paid for by the study. Costs for your regular medical care, which are not related to this study, will be your own responsibility.

**Will You Be Paid For Participating?**

You will not be paid for your participation you decide to take part in this study.

**Who Is Funding This Study?**

This study is being sponsored by Marshall University School of Kinesiology

**What Are Your Rights As A Research Study Participant?**

Taking part in this study is voluntary. You may choose not to take part or you may leave the study at any time. Refusing to participate or leaving the study will not result in any penalty or loss of benefits to which you are entitled. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff first to learn about any potential health or safety consequences.

**Whom Do You Call If You Have Questions Or Problems?**

For questions about this study or in the event of a research-related injury, contact the study investigator, Mark K Timmons ATC, PhD at (304)696-2925. You should also call the investigator if you have a concern or complaint about the research.

For questions about your rights as a research participant, contact the Marshall University IRB#1 Chairman Dr. Henry Driscoll or ORI at (304) 696-7320. You may also call this number if:

- You have concerns or complaints about the research.
- The research staff cannot be reached.
- You want to talk to someone other than the research staff.

You will be given a signed and dated copy of this consent form.

---

Subject’s Initials ________
SIGNATURES

You agree to take part in this study and confirm that you are 18 years of age or older. You have had a chance to ask questions about being in this study and have had those questions answered. By signing this consent form you are not giving up any legal rights to which you are entitled.

________________________________________
Subject Name (Printed)

________________________________________  ______________
Subject Signature                        Date

________________________________________  ______________
Person Obtaining Consent                Date

________________________________________  ______________
Principal Investigator                  Date

Subject's Initials ____________
APPENDIX B.
IRB Approval

November 16, 2015
Mark Timmons, PhD
Marshall University, Dept. of Kinesiology
RE: IRBNet ID# 692777-2
At: Marshall University Institutional Review Board #1 (Medical)

Dear Dr. Timmons:

Protocol Title: [692777-2] The Assessment of Shoulder Pain, Anatomy, and Function of Upper String Musicians

Expiration Date: December 11, 2016
Site Location: MU
Submission Type: Continuing Review/Progress APPROVED
Review Type: Expedited Review

The above study was approved for an additional 12 months by the Marshall University Institutional Review Board #1 (Medical) Chair. The approval will expire December 11, 2016. Since this approval is within 30 days of the expiration date, the fixed anniversary date of 12/11 was maintained. Continuing review materials should be submitted no later than 30 days prior to the expiration date.

If you have any questions, please contact the Marshall University Institutional Review Board #1 (Medical) Coordinator Trula Stanley, MA, CIC at (304) 696-7320 or stanley@marshall.edu. Please include your study title and reference number in all correspondence with this office.
APPENDIX C.
Subject Information Initial Visit Forms

Thank you for agreeing to participate in this study. This questionnaire will help us to better understand you and your overall health. If you are not sure how to answer a question, just give the best answer you can.

Name ___________________________ Date _______________

Age ______ years Date of Birth ___________ / / ______ Height ______ Weight ______ lbs.

Gender  O Male  O Female

Race  O American Indian  O Asian  O Pacific Islander  O Black or African American  O White or Caucasian  O Hispanic  O Other ______________________

Which hand do you use to write?
  O Right
  O Left
  O Both (ambidextrous)

What is your primary musical instrument?
  At what age did you start playing this instrument? _______________
  How many hours per day do play/practice this instrument? _______________
  How many days per week do play/practice this instrument? _______________

What is your secondary musical instrument?
  At what age did you start playing this instrument? _______________
  How many hours per day do play/practice this instrument? _______________
  How many days per week do play/practice this instrument? _______________

1. Do you currently experience shoulder pain?
   O Yes,
   O No
   If yes, which shoulder is painful?
     O Right
     O Left
     O Both, but RIGHT more than Left
     O Both, but LEFT more than Right

2. Have you experienced shoulder pain within the past year?
   O Yes,
   O No
   If yes, which shoulder is painful?
     O Right
     O Left
     O Both, but RIGHT more than Left
Completed by: Patient
- Both, but Left more than Right

3. How often do you have a shoulder pain?
- Constantly (all the time)
- Sometimes
- I do not have shoulder pain

4. When did this episode of shoulder pain begin? (Month/Date/Year)
   - I do not have shoulder pain

5. How did this episode of shoulder pain begin? (Please pick one answer)?
   - A specific traumatic event, for example: fall, car accident, hit on the shoulder
   - Gradually over time, without specific trauma
   - I do not have shoulder pain

6. Do you have popping, clicking or catching in your shoulder?
   - Yes
   - No

7. Do you have shoulder pain at night, when you are in bed?
   - Yes
   - No

8. Have you had previous episodes of shoulder pain?
   - Yes
   - No

9. Are you taking prescription medication for this episode of shoulder pain?
   - No
   - Yes, if yes, please list the medications:
     - I do not have shoulder pain

<table>
<thead>
<tr>
<th>Name of the Medication</th>
<th>Dose(milligrams)</th>
<th>How many pills per day?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10. Do you take any of the following non-prescription medication for this episode of shoulder pain?
    Indicate all that you are taking:
    - I do not have shoulder pain
    - Advil/Aleve
    - Herbal Supplements
    - Vitamins
    - Tylenol
    - Motrin
    - Aspirin
11. During the past week how often have you taken any pain medication for your shoulder pain?
   ○ Not at all
   ○ Once a week
   ○ Once every couple of days
   ○ Once or twice a day
   ○ Three or more times a day
   ○ I do not have shoulder pain

12. Has this injury caused you to stop or reduce your activity (ex., practice, performance, work, sports or exercise as compared to before this episode of shoulder pain started?)
   ○ Yes
   ○ No
   ○ I do not have shoulder pain

13. Do you regularly exercise, more than 3 days per week?
   ○ Yes
   ○ No

14. Do you participate in any type of sports or exercise totaling at least 3 times per week?
   ○ No
   ○ Yes, if yes, which one(s) do you participate in? Indicate all that apply:
     ○ Racquet sports
     ○ Basketball, soccer
     ○ Gym / lift weights
     ○ Golf
     ○ Baseball/ softball
     ○ Football, Hockey
     ○ Running / walking
     ○ Swimming, Lacrosse, Volleyball
     ○ Exercise class (Yoga, Pilates, etc)
     ○ Other

15. Does your shoulder pain occur with your sports activities or exercise?
   ○ Yes
   ○ No
   ○ I do not have shoulder pain

16. Did your shoulder pain start with/ during your sports activities or exercise?
   ○ Yes
   ○ No
   ○ I do not have shoulder pain

17. Have you ever dislocated your shoulder or do you feel it slip out of joint?
   ○ Yes
   ○ No

18. Are you currently receiving treatment or have you ever had treatment for shoulder pain?
   ○ Yes
   ○ No
   ○ I do not have shoulder pain
19. What best described your current work status?
   ○ Full time, regular duty
   ○ Part time, regular duty
   ○ Full time, Light duty/Modified duty
   ○ Part time, Light duty/Modified duty
   ○ Temporary unable to work, due to shoulder pain/problem
   ○ Permanent unable to work or retired due to health status pain/problem
   ○ Homemaker (not working outside the home)
   ○ Student and not currently working
   ○ Not working because:
   ○ Disabled Retired
   ○ Cannot find a job/unemployed

20. What best describes the work you do?
   ○ Sedentary, majority of sitting; e.g., clerical, computer/office work
   ○ Light Manual, occasional lifting and carrying of 10lbs or less; e.g. retail sales
   ○ Manual, demanding physical activity, frequent or heavy lifting & carrying 20lbs or more; e.g. construction

21. Does your job require you to use your arm at or above shoulder height during the day?
   ○ No
   ○ Yes

22. If yes, what percentage of the day are you using your arm at or above shoulder height?
   ○ 0-25%
   ○ 26-50%
   ○ 51-75%
   ○ 76-100%

23. Do you work with heavy vibrating tools, other than your musical instrument?
   ○ Yes
   ○ No

24. Is this episode of shoulder pain a work related injury?
   ○ Yes
   ○ No
   ○ I do not have shoulder pain

25. How much work have you missed due to this episode of shoulder pain?
   ○ Have not missed any work
   ○ Less than one week
   ○ 1-4 weeks
   ○ More than 4 weeks
   ○ I do not have shoulder pain

26. What level of education have you completed?
   ○ Less than high school
   ○ Graduated from high school
   ○ Some college
   ○ Graduated from 2 year college
   ○ Graduated from 4 year college
   ○ Some post graduate course work
   ○ Completed post graduate degree

Page 4 of 6
Completed by: Patient

27. Do you currently smoke?
   ○ No
   ○ Yes, if yes, please answer the following questions:
   27a. How many cigarettes do you smoke per day?
   ○ 1-10
   ○ 11-20
   ○ 21-40
   ○ More than 40
   27b. How many years have you smoked? □□□□ years

28. Have you ever smoked cigarettes on a regular basis?
   ○ No
   ○ Yes, but I have quit. Please answer 27a, 27b, and 27c.
   28a. How many years did you smoke? □□□□ years
   28b. When did you quit? □□□□ years ago

29. Do you currently drink alcohol?
   ○ No
   ○ Yes
   29a. If yes, how much do you drink per day on average (1 drink = 12oz beer, glass of wine, mixed drink)
   ○ Less than 1 drink
   ○ 1 drink
   ○ 1-2 drinks
   ○ 3-4 drinks
   ○ More than 4 drinks

30. During the past month:
   30a. Have you been bothered by feeling down, depressed, or hopeless?
   ○ Yes
   ○ No
   30b. Have you been bothered by little interest or pleasure in doing things?
   ○ Yes
   ○ No
   30c. If you answered "yes" to either 36a or 36b, is this something with which you would like help?
   ○ No
   ○ Yes
   ○ Yes, but not today
Below is a list of common health problems. First, indicate if you have any of these problems and then please indicate if you are currently receiving treatment for the problem indicated.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Do you have this problem?</th>
<th>Do you currently receive treatment for this problem?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Osteoporosis</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Heart disease</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>High Blood pressure</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Low Blood pressure</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Lung/breathing problems</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Arthritis</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Cancer</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Epilepsy/Seizures</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Fibromyalgia</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>High Cholesterol</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Pacemaker</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Psoriasis</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Ulcer or stomach disease</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Dizziness or Vertigo</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Nerve Disease/Disorder</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Anxiety</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Depression</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Thyroid problems</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Rheumatoid Arthritis</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Liver Disease</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Recent Infection</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Recent, unexplained weight loss</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Fever, Chills, Night sweats</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
# Fear Avoidance Belief Questionnaire (FABQ)

**Subject number _______________________**  **Date ______________**

Here are some of the things which other patients have told us about their pain. For each statement please circle any number from 0 to 6 to say how much physical activities such as bending, lifting, walking or driving affect or would affect your pain.

<table>
<thead>
<tr>
<th></th>
<th>COMPLETELY DISAGREE</th>
<th>UNSURE</th>
<th>COMPLETELY AGREE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. My pain was caused by physical activity</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Physical activity makes my pain worse</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Physical activity might harm me</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. I should not do physical activities which (might) make my pain worse</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. I cannot do physical activities which (might) make my pain worse</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The following statements are about how your normal work affects or would affect your pain.

<table>
<thead>
<tr>
<th></th>
<th>COMPLETELY DISAGREE</th>
<th>UNSURE</th>
<th>COMPLETELY AGREE</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. My pain was caused by my work or by an accident at work</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. My work aggravated my pain</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. I have a claim for compensation for my pain</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. My work is too heavy for me</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. My work makes or would make my pain worse</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. My work might harm my back</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. I should not do my normal work with my present pain</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. I cannot do my normal work with my present pain</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. I cannot do my normal work until my pain is treated</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. I do not think that I will be back to my normal work within 3 months</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. I do not think that I will ever be able to go back to that work</td>
<td>0 1 2 3 4 5 6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
INSTRUCTIONS

This questionnaire asks about your symptoms as well as your ability to perform certain activities.

Please answer every question, based on your condition in the last week, by circling the appropriate number.

If you did not have the opportunity to perform an activity in the past week, please make your best estimate of which response would be the most accurate.

It doesn’t matter which hand or arm you use to perform the activity; please answer based on your ability regardless of how you perform the task.
QuickDASH

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

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

<table>
<thead>
<tr>
<th>Activity</th>
<th>NOT AT ALL</th>
<th>SLIGHTLY</th>
<th>MODERATELY</th>
<th>QUITE A BIT</th>
<th>EXTREMELY</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. During the past week, to what extent has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity</th>
<th>NOT LIMITED AT ALL</th>
<th>SLIGHTLY LIMITED</th>
<th>MODERATELY LIMITED</th>
<th>VERY LIMITED</th>
<th>UNABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please rate the severity of the following symptoms in the last week. (Circle number)

<table>
<thead>
<tr>
<th>Symptom</th>
<th>NONE</th>
<th>MILD</th>
<th>MODERATE</th>
<th>SEVERE</th>
<th>EXTREME</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Arm, shoulder or hand pain.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Tingling (pins and needles) in your arm, shoulder or hand.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity</th>
<th>NO DIFFICULTY</th>
<th>MILD DIFFICULTY</th>
<th>MODERATE DIFFICULTY</th>
<th>SEVERE DIFFICULTY</th>
<th>SO MUCH DIFFICULTY THAT I CAN'T SLEEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>11. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? (Circle number)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

QuickDASH DISABILITY/SYMPTOM SCORE = \left( \frac{\text{sum of n responses}}{n} - 1 \right) \times 25, where n is equal to the number of completed responses.

A QuickDASH score may **not** be calculated if there is greater than 1 missing item.
WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is:

☐ I do not work. (You may skip this section.)

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

<table>
<thead>
<tr>
<th>Did you have any difficulty:</th>
<th>NO DIFFICULTY</th>
<th>MILD DIFFICULTY</th>
<th>MODERATE DIFFICULTY</th>
<th>SEVERE DIFFICULTY</th>
<th>UNABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. using your usual technique for your work?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. doing your usual work because of arm, shoulder or hand pain?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. doing your work as well as you would like?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. spending your usual amount of time doing your work?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

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

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

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

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

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

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.

An optional module score may not be calculated if there are any missing items.
Initial Data Collection Forms

Subject ID number: ______________________ Date: ___/___/___

Initial Data Collection Forms
Procedure Checklist

1. Inclusion & exclusion criteria
   a. Eligibility Screening exam

2. Subject Informed Consent
   a. Read, discuss, ask questions, sign

3. General Questions- Eligibility and Screening
   a. Intake information
   b. Patient reported outcomes (Penn Shoulder Score, DASH)
   c. Physical activity assessment
   d. Height, Weight
   e. Arm length

4. Clinical Evaluation

5. Strength Procedure
   a. ER
   b. IR
   c. ABd

6. Posture assessment

7. Ultrasound Imaging- tendon thickness, AHD

Subject meets inclusion/exclusion criteria (circle one): 1= Yes  2= No

Inclusion criteria:
   __1. At least 18 years of age
   __2. No current shoulder pain (shoulder/arm)
   __3. An upper string musician

Exclusion criteria (any 1 excludes):
   __1. Active or passive cervical spine range produces shoulder symptoms
   __2. History of upper arm fracture
   __3. Systemic musculoskeletal disease
   __4. Shoulder surgery
   __5. Shoulder pain ≥7/10

Page 1 of 9
Subject ID number: ___________________________ Date: ___/___/___

Research Study Questionnaire
Participant completes:

DOB (mm/dd/yy): ___/___/___

Age: ____ (years)  Sex: 1 = Female  2 = Male

1. Do you have any systemic musculoskeletal disease (like Rheumatoid Arthritis)?
   (Circle One)  1 = Yes
                     If yes, please list______________________________
   2 = No

2. Do you have shoulder pain or have had shoulder pain in the last 6 months?
   (Circle One)  1 = Yes  2 = No

3. Which shoulder is your dominant shoulder?
   1 = Right
   2 = Left
   3 = Ambidextrous

4. How would you rate your shoulder today (as “a percentage of normal”)?
   (0% - 100% with 100% being normal) = ______

5. Do you have a known shoulder problem/pathology?
   1 = Yes  2 = No
   a. If yes, which shoulder?  1 = Right  2 = Left  3 = Both
   b. If yes, have you sought treatment for this problem
      1 = Yes  2 = No
   c. If yes, when did your shoulder pain start?
      1 ___ Less than 6 weeks ago
      2 ___ 6-12 weeks ago
      3 ___ More than 12+ weeks ago
      4 ___ I do not have shoulder pain
   d. If yes, please describe: ________________________________________________
      ________________________________________________
      ________________________________________________
      ________________________________________________
6. How would you rate your upper extremity today as “a percentage of normal”? (0% - 100% with 100% being normal) = _____ %

7. Do you have a known upper extremity problem/pathology?
   1 = Yes  2 = No
   a. If yes, which upper extremity?  1 = Right  2 = Left  3 = Both
   b. If yes, have you sought treatment for this problem?
      1 = Yes  2 = No
   c. If yes, when did your extremity pain start?
      1 ____ Less than 6 weeks ago
      2 ____ 6-12 weeks ago
      3 ____ More than 12+ weeks ago
      4 ____ I do not have shoulder pain
   d. If yes, please describe: ________________________________
      ________________________________
      ________________________________

8. How would you rate your neck/upper trunk today as “a percentage of normal”? (0% - 100% with 100% being normal) = _____ %

9. Do you have a known neck/upper trunk pathology?
   1 = Yes  2 = No
   a. If yes, which neck/upper trunk?  1 = Right  2 = Left  3 = Both
   b. If yes, have you sought treatment for this problem?
      1 = Yes  2 = No
   c. If yes, when did your extremity pain start?
      1 ____ Less than 6 weeks ago
      2 ____ 6-12 weeks ago
      3 ____ More than 12+ weeks ago
      4 ____ I do not have shoulder pain
   d. If yes, please describe: ________________________________
      ________________________________
      ________________________________

Page 3 of 9
The PENN Shoulder Score

Subject ID number: ____________________________ Date: _____/____/_____  

Penn Shoulder Score

<table>
<thead>
<tr>
<th>PENN SHOULDER SCORE</th>
<th>Part 1: Pain &amp; Satisfaction: Please circle the number closest to your level of pain or satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>office use only</td>
</tr>
<tr>
<td>Pain at rest with your arm by your side:</td>
<td></td>
</tr>
<tr>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
<td>No Pain Possible Worst Pain</td>
</tr>
<tr>
<td>Pain with normal activities (eating, dressing, bathing):</td>
<td></td>
</tr>
<tr>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
<td>No Pain Possible Worst Pain</td>
</tr>
<tr>
<td>Pain with strenuous activities (reaching, lifting, pushing, pulling, throwing):</td>
<td></td>
</tr>
<tr>
<td>0 1 2 3 4 5 6 7 8 9 10</td>
<td>No Pain Possible Worst Pain</td>
</tr>
</tbody>
</table>

PAIN SCORE: = _____/30

How satisfied are you with the current level of function of your shoulder?  

| 0 1 2 3 4 5 6 7 8 9 10 | Not Satisfied Very Satisfied |

= _____/10 (9 circled)
Subject ID number: _______________  Date: ___/___/____

<table>
<thead>
<tr>
<th>Part II: Function: Please circle the number that best describes the level of difficulty you might have performing each activity.</th>
<th>No difficulty</th>
<th>Some difficulty</th>
<th>Much difficulty</th>
<th>Can't do at all</th>
<th>Did not do before injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Reach the small of your back to tuck in your shirt with your hand.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>2. Wash the middle of your back/brush bra.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>3. Perform necessary toileting activities.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>4. Wash the back of opposite shoulder.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>5. Comb hair.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>6. Place hand behind head with elbow held straight out to the side.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>7. Dress self (including putting on coat and pulling shirt on overhead).</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>8. Sleep on affected side.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>9. Open a door with affected side.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>10. Carry a bag of groceries with affected arm.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>11. Carry a briefcase/small suitcase with affected arm.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>12. Place a soup can (1-2 lbs.) on a shelf at shoulder level without bending elbow.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>13. Place a one gallon container (8-10 lbs.) on a shelf at shoulder level without bending elbow.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>14. Reach a shelf above your head without bending your elbow.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>15. Place a soup can (1-2 lbs.) on a shelf overhead without bending your elbow.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>16. Place a one gallon container (8-10 lbs.) on a shelf overhead without bending your elbow.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>17. Perform usual sport/hobby.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>18. Perform household chores (cleaning, laundry, cooking).</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>19. Throw overhead, swim, overhead raquet sports. (circle all that apply to you)</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>20. Work full-time at your regular job.</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>X</td>
</tr>
</tbody>
</table>

**SCORING:**

Total of columns = (a)

Number of "X"s" x 3 = (b), 60 - (b) = (c)

If no "X"s" are circled, function score = total of columns

Function Score = ____ (a) / ____ (c) = ____ x 60 = ____/60

Stop Here. Remainder to be completed by study personnel. Thank you.
# Screening Exam

**Subject ID number:** ________________________________  **Date:** ____/____/____

## Screening Exam

Research Team completes

**Subject height:** _______ (cm)  **Subject weight:** _______ (Kg)

Cervical motion reproduces shoulder pain: Yes  **No**

- Right lateral flex
- Left lateral flex
- Flexion
- Extension
- Right rotation
- Left rotation

### Shoulder AROM:

<table>
<thead>
<tr>
<th></th>
<th>Right Shoulder</th>
<th>Left Shoulder</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ER</strong></td>
<td>___________</td>
<td>___________</td>
</tr>
<tr>
<td><strong>IR</strong></td>
<td>___________</td>
<td>___________</td>
</tr>
<tr>
<td><strong>Abduction</strong></td>
<td>___________</td>
<td>___________</td>
</tr>
<tr>
<td><strong>Flexion</strong></td>
<td>___________</td>
<td>___________</td>
</tr>
</tbody>
</table>

**Posture assessment**

- **T1-T3 angle**
- **T10-T12 angle**

### Special Tests:

<table>
<thead>
<tr>
<th></th>
<th>Right shoulder</th>
<th>Left Shoulder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Painful Arc</td>
<td>+ -</td>
<td>+ -</td>
</tr>
<tr>
<td>Drop Arm</td>
<td>+ -</td>
<td>+ -</td>
</tr>
<tr>
<td>Sulcus Sign</td>
<td>+ -</td>
<td>+ -</td>
</tr>
<tr>
<td>Hawkins:</td>
<td>+ -</td>
<td>+ -</td>
</tr>
<tr>
<td>Neer:</td>
<td>+ -</td>
<td>+ -</td>
</tr>
<tr>
<td>Apprehension test</td>
<td>+ -</td>
<td>+ -</td>
</tr>
<tr>
<td>Relocation</td>
<td>+ -</td>
<td>+ -</td>
</tr>
<tr>
<td>ER LAG sign:</td>
<td>+ -</td>
<td>+ -</td>
</tr>
<tr>
<td>Lift off test</td>
<td>+ -</td>
<td>+ -</td>
</tr>
<tr>
<td>SAT (flex)</td>
<td>+ -</td>
<td>+ -</td>
</tr>
</tbody>
</table>

Pain levels with the SAT: Flexion

- **Flexion = pain ____/10**
- **Flexion w/ SAT = pain ____/10**

### Scapular Dyskinesia Test, External load, 0 lbs, 3 lbs. (BW < 68.2kg, 150lbs), 5 lbs. (BW >68.2kg, 150)

<table>
<thead>
<tr>
<th>Left</th>
<th>Flexion Classification</th>
<th>Normal</th>
<th>Subtle</th>
<th>Obvious</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Winging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shrugging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dumping</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Right</th>
<th>Flexion Classification</th>
<th>Normal</th>
<th>Subtle</th>
<th>Obvious</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Winging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shrugging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dumping</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

Page 6 of 9
Subject ID number: ___________________________ Date: ___/___/___

Participant's Physical Measures

Height (cm): _____  Weight (kg): ______

<table>
<thead>
<tr>
<th>Arm Length (cm)</th>
<th>Trial 1</th>
<th>Trial 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Left arm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior Acromion → Olecranon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olecranon → Ulnar styloid</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Right arm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior Acromion → Olecranon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olecranon → Ulnar styloid</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Manual Muscle Tests

<table>
<thead>
<tr>
<th></th>
<th>Right 1</th>
<th>Right 2</th>
<th>Left 1</th>
<th>Left 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serratus anterior</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Trapezius</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle trapezius</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip Strength position 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip Strength position 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scapular position

<table>
<thead>
<tr>
<th></th>
<th>UR 1</th>
<th>UR 2</th>
<th>AP 1</th>
<th>AP 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right shoulder</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm @ side</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm @ 45°</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm @ 90°</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&quot; string</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4&quot; string</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Left shoulder</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm @ side</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm @ 45°</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm @ 90°</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FORCE AND PAIN

**Left Shoulder**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Condition</th>
<th>Pain (0-10)</th>
<th>Force (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ER</td>
<td>IR</td>
<td>ABD</td>
</tr>
<tr>
<td>2</td>
<td>ER</td>
<td>IR</td>
<td>ABD</td>
</tr>
<tr>
<td>3</td>
<td>ER</td>
<td>IR</td>
<td>ABD</td>
</tr>
<tr>
<td>4</td>
<td>ER</td>
<td>IR</td>
<td>ABD</td>
</tr>
<tr>
<td>5</td>
<td>ER</td>
<td>IR</td>
<td>ABD</td>
</tr>
<tr>
<td>6</td>
<td>ER</td>
<td>IR</td>
<td>ABD</td>
</tr>
<tr>
<td>7</td>
<td>ER</td>
<td>IR</td>
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<tr>
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<td>9</td>
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<td>IR</td>
<td>ABD</td>
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**Right Shoulder**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Condition</th>
<th>Pain (0-10)</th>
<th>Force (lbs.)</th>
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<td>1</td>
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<td>IR</td>
<td>ABD</td>
</tr>
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<td>ABD</td>
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Ultrasound Imaging Rotator Cuff Tendon & Muscle Characteristics

Subject ID number: ___________________________ Date: ___/___/____

US Imaging Rotator Cuff Tendon & Muscle Characteristics

**Right Shoulder** File name (on US machine): ___________________________

A. **Bicep tendon cross section** (arm on thigh, mm) Image 1 Image 2
   a. Right shoulder, image# _______ _______

B. **Supraspinatus Tendon Images** : B-mode, modified Crass position

   1. Tendon x-section thickness in mm(thickest portion): Image 1 Image 2
      Right shoulder, image# _______ _______
   2. Tendon longitudinal thickness in mm Image 1 Image 2
      Right shoulder, image# _______ _______

C. **Acromial Humeral Distance**

   1. Right shoulder (posterior, mm) Image 1 Image 2
      a. Resting position, image# _______ _______
      b. Mid bow 1st string, image# _______ _______
      c. Mid bow 4th string, image# _______ _______

**Left Shoulder** File name (on US machine): ___________________________

A. **Bicep tendon cross section** (arm on thigh, mm) Image 1 Image 2
   a. Left shoulder, image# _______ _______

B. **Supraspinatus Tendon Images** : B-mode, modified Crass position

   1. Tendon x-section thickness in mm(thickest portion): Image 1 Image 2
      a. Left shoulder, image# _______ _______
   2. Tendon longitudinal thickness in mm Image 1 Image 2
      a. Left shoulder, image# _______ _______

C. **Acromial Humeral Distance**

   1. Left shoulder, Image 1 Image 2
      a. Resting position, image# _______ _______
      b. Third finger 1st string (posterior, mm) _______ _______