EVALUATION OF THE RELATIONSHIP BETWEEN SCAPULAR DYSKINESIS AND ACROMIOHUMERAL DISTANCE

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Ariel Dannielle Ives

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Advanced Athletic Training

April 2022

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Dr. Kara Gange
Chair

Dr. Laura Dahl

Dr. Ashley Roseno

Approved:

04/22/2022	Dr. Yeong Rhee
Date	Department Chair

ABSTRACT

This study analyzed the interaction between scapular dyskinesis (SDK) and acromiohumeral distance (AHD). Diagnostic ultrasound (DUS) was used to measure AHD of 33 participants between 10 and 120^o of weighted arm elevation in the scapular and frontal planes. Images were collected every 10^o as the participant raised and held the weight at each increment. This process was completed bilaterally prior to completion of the Scapular Dyskinesis Test (SDT) to diagnose the presence of SDK. Intra-rater reliability was assessed with ICC (3,1) and four multilinear regressions were used to evaluate the relationship between AHD and SDK. Results indicated nearly perfect inter-rater reliability and a significant, positive relationship between AHD and SDK of the non-dominant arm in the scapular and frontal plane of movement.

ACKNOWLEDGEMENTS

First, I would like to express my sincere gratitude to my advisor Dr. Kara Gange for the continuous support and encouragement throughout the entirety of this research. Her guidance and patience helped me both personally and professionally. She has inspired me to push through the challenges I faced, which has made me a better student, athletic trainer, and person overall.

Dr. Laura Dhal has been incredible in this process. She became a committee member on short notice. Without her I would not have progressed in this process. I appreciate her commitment and time to not only helping me with statistics and providing feedback, but also teaching me the statistics behind research and how to apply them effectively.

Additionally, I would like to recognize Dr. Ashley Roseno for also serving as a committee member. She was incredibly flexible throughout this process and offered a unique and instrumental perspective, which I feel greatly improved the quality of my thesis.

All three of these individuals were vital to my success with this project and I am eternally grateful for their adaptability and contributions.

Besides my committee members I would like to acknowledge my supervisors John Haugrud, Gregory Martodam, Tessa Martin, and Essentia Health for the opportunity to further my education while gaining experience as an athletic trainer as a graduate assistant.

Lastly, I would like to thank my family, boyfriend, friends, and mentors: Chastity Ives, Jean Velasquez, David Hall, Elaine and Leroy Aragon, Jayson Shirley, Brianna King and family, Susan McGowan, and Melissa Loiacono-Lee. Without these individuals I would not have made it to this point in my education or career. Thank you for encouraging me and keeping me positive throughout my life.

DEDICATION

I dedicate this thesis to my Great Grandmother, Esther Velasquez, who has and always will be an inspiration to be courageous and overcome any limitation I might face.

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LIST OF ABBREVIATIONS

SDK	Scapular Dyskinesis
SDT	Scapular Dyskinesis Test
DUS	Diagnostic Ultrasound
AHD	Acromiohumeral Distance
SC	Sternoclavicular
AC	Acromioclavicular
CC	Coracoclavicular
GH	Glenohumeral
LHBT	Long Head of the Biceps Tendon
OSTRC	Oslo Sports Trauma Research Center
ANOVA	Analysis of Variance
sEMG	Surface Electromyogram
MVIC	Maximal Voluntary Isometric Contraction
SAT	Scapular Assistance Test
NDSU	North Dakota State University
VAS	Visual Analogue Scale
GPAQ	Global Physical Activity Questionnaire
WHO	World Health Organization
MET	Metabolic Equivalent Unit
ACSM	American College of Sports Medicine
IRB	Institutional Review Board

1. INTRODUCTION

Scapular dyskinesis (SDK) is a malposition in static and dynamic scapular posture, which commonly results in abnormal scapular movement.[1–4] Typically, SDK develops because of uncoordinated or abnormal activation of scapular stabilizing musculature. These deficits directly impact the ratio between scapular and humeral movement, known as scapulohumeral rhythm.[3,5] Therefore, visible abnormalities in scapular position throughout movement become apparent during upward and downward rotation of the scapula. During downward rotation, SDK becomes more obvious as alternative neuromuscular control is required to maintain activation in scapular stabilizing musculature as the muscles elongate.[3,6]

The most common test is the Scapular Dyskinesis Test (SDT) where patients are required to lift light weights bilaterally overhead for five repetitions in multiple planes of movement. While the patient completes the test, an examiner visually evaluates scapular movement and rates patterns as having normal movement, subtle abnormality, or obvious abnormality.[7,8] Other researchers have created more advanced classification systems for SDK, such as the Four Type Method,[9,10] but research indicates simple, dichotomized methods of diagnosis have similar reliability and validity.[11,12]

Diagnostic ultrasound (DUS) is a non-invasive imaging technique which uses sound waves to visualize tissues under the skin to identify pathology.[13] Sound waves are projected from a device known as a transducer and reflected by body tissues creating a live, on-screen image. This can be used to observe body tissue at rest and during movement while also allowing clinicians to freeze and measure points on an image. Use of DUS is becoming common practice in various health care settings due to its portability, minimal invasiveness, and low cost. As such, DUS may be a valid and reliable tool during assessment of scapular posture at rest and throughout movement, in addition to other associated benefits.

1.1. Statement of the Problem

Research on scapular dyskinesis (SDK) has increased in popularity within the last decade; however, little consensus exists on the clinical importance of abnormal scapular movement patterns, assessment of this condition, and diagnostic parameters. Scapular dyskinesis is well documented in athletic populations as a co-existing condition in those with shoulder injury,[2,6,10,14–17] but current studies often exclude members of the general population who also suffer from a high incidence of shoulder pathology.[18]

Multiple diagnostic tools have been used to identify and assess SDK in research including 3D motion analysis, the Four Type Method[19] and Scapular Dyskinesis Test (SDT)[8,14] Yet none are both reliable and objective. For example, studies that used 3D motion systems rely on surface-based sensors. This does not give an accurate depiction of scapular kinematics because skin movement is not equal to scapular movement in this area of the body. The SDT is one of the most common clinical tests; however, it has not been applied consistently throughout the literature. A lack of existing research that utilizes accurate, objective measurement techniques as a comparison tool to clinical diagnostic methods limits the interpretation of results.

Normative values for AHD and interactions between AHD and SDK have not been thoroughly defined.[20,21] Existing normative values for AHD were collected through several methods including x-ray and fluoroscopy,[18,22] but studies focused solely on DUS do not use the same landmarks for measurement. Therefore, documented norms for AHD cannot be compared to previous studies. Overall, several gaps exist in the current literature on the nature of SDK and the impact it has on shoulder health. Additionally, previous research methodologies vary, which severely limits the ability to make comparisons and clinical decisions regarding these topics.

1.2. Purpose of the Study

The purpose of this study was to compare AHD throughout shoulder range of motion to those with and without SDK in the general population.

1.3. Research Questions

1. How reliable is DUS in measuring AHD throughout shoulder range of motion, specifically above 90º?
2. What is the difference in AHD measurements between those with and without SDK?

1.4. Definition of Terms

Scapular Dyskinesis (SDK): An all-encompassing term that relates scapular postural malposition to resulting alterations in shoulder biomechanics.[1–3,23]

Acromiohumeral Distance (AHD): The space between the humeral head and the acromion process of the scapula.[24]

Scapular Dyskinesis Test (SDT): A diagnostic test which involves five bilateral, weighted arm raises in the sagittal and frontal planes while an examiner assesses scapular movement.[8,14]

Diagnostic Ultrasound (DUS): A non-invasive imaging technique which uses sound waves to visualize tissues under the skin to identify pathology.[13]

Transducer: Handheld piece of equipment, which houses a piezoelectric crystal. The transducer allows electrical signal to be converted to ultrasonic energy and back to create an image.[13]

Transducer Array: Arrangement of the transducer can be linear or curvilinear. This changes the propagation of the sound wave into the tissue.[13]

Echogenicity: The brightness of structures on DUS images. Structures can be hyperechoic, hypoechoic, or anechoic.

Hyperechoic: Describes a structure on DUS images that is brighter than overlying tissue.

Hypoechoic: Describes structures on DUS that are darker in comparison to surrounding tissue or structures.

Anechoic: Describes a structure that has a lack of echogenicity on DUS images.[25]

Plane of Movement: Three planes of motion are used to describe three-dimensional movement of the body. The frontal plane cuts the body into front (anterior) and back (posterior) halves while the sagittal plane divides the body into right and left halves. The transverse plane divides the body into upper and lower halves.[22]

Scapular Plane: Shoulder movement upward and downward in a plane that remains in 30° of forward shoulder flexion from the frontal plane.[21,26]

Abduction: Movement away from the midline of the body.[27]

Lateral: Describes a location of a point of interest to the side of another referenced point.[22]

1.5. Importance of the Study

This study aimed to apply the STD according to recommendations by the original author apart from one change. Originally, the SDT was conducted in the sagittal and frontal planes, but focus on the scapular and sagittal planes is indicated by other authors.[7,21] Apart from this modification, participants were required to actively lift weights overhead bilaterally for five repetitions based on the original methodology.

Several discrepancies exist in methodologies involving DUS measurements of AHD including the use of various landmarks and subjective determination of these points. To make this process more objective, the examiner placed a horizontal line at the lowest visible point on the humeral head and a vertical line from the most lateral point of the acromion process. These measurements were compared to the diagnosis of SDK. Reliability of AHD measurements from 10 – 120° were also investigated as few studies have utilized DUS to measure AHD above 90 degrees.

1.6. Limitations of the Study

This study was not completed without limitations primarily related to the experience of the examiner. This individual was trained in DUS and practiced the procedure but reliability of DUS is dependent on the experience of the examiner. As such, the time required to obtain quality images varied throughout data collection. For example, during movement greater than 90°, structures became difficult to image and require the participant to raise and hold the weight for longer periods of time. The SDT was conducted after DUS images were collected to reduce bias during imaging. However, requiring the participants to raise and hold the weights may have increased fatigue during the SDT, which can make SDK more apparent. Future research with an experienced or expert in DUS may improve outcome measures for this study.

A convenience sample was utilized to obtain participants rather than a random sample due to accessibility of equipment and testing location. Additionally, weight was self-reported by the participants. This information was used to determine the size of dumbbells utilized in testing. As a result, those reporting a lower weight than their true weight received a smaller dumbbell. This may have also impacted the occurrence of muscular fatigue and alter the results of the SDT. The final limitation of this study was the exclusion of a full shoulder evaluation. The decision to forgo diagnosis of other shoulder pathology limits the ability of the examiner to relate changes in scapular movement solely to SDK.

1.7. Delimitations of the Study

The sample population of this study was limited to students and staff at North Dakota State University and the Fargo-Moorhead metroplex in North Dakota and Minnesota, because of convenience and the availability of equipment. The prevalence of SDK and other shoulder injuries in the Fargo-Moorhead area may not accurately represent the commonness in other areas. Additionally, many participants were college age students, which resulted in a low mean age. None of the participants were included or excluded based on level of activity, which may have impacted the prevalence of shoulder pathology and SDK. These factors must be taken into consideration while comparing results of the current study to those of existing and future research.

2. LITERATURE REVIEW

This study aimed to assess acromiohumeral distance (AHD) throughout shoulder overhead movement in those with scapular dyskinesis (SDK). Diagnostic ultrasound (DUS) was used as an objective assessment tool to determine if there is a relationship between SDK and AHD. Additionally, this study evaluated the reliability of DUS throughout shoulder range of motion specifically above 90°. This literature review was written with focus on the following areas: anatomy and kinematics, SDK, and DUS.

2.1. Shoulder Anatomy and Kinematics

2.1.1. Bony Anatomy, Ligaments, and Arthrology

To understand SDK and potential changes to other anatomic structures because of this condition, it is important to have a thorough picture of the anatomy of the shoulder complex. The shoulder girdle is comprised of three bones including the humerus, scapula, and clavicle. These bones form four true articulations: sternoclavicular (SC), acromioclavicular (AC), coracoclavicular (CC), and glenohumeral (GH) joints (Figure 1).[22,27] The SC joint is formed between the clavicular notch on the manubrium of the sternum and the sternal facet of the clavicle. This is a gliding joint, which serves as the only true articulation between the axial skeleton and the upper extremity. Strong ligaments make this joint stable while still allowing the clavicle to move upward, downward, forward, backward, and rotate. Adequate scapular upward rotation is heavily impacted by elevation of the clavicle. As the scapula upwardly rotates, the clavicle must elevate approximately 40° to allow for full scapular upward rotation.[27]

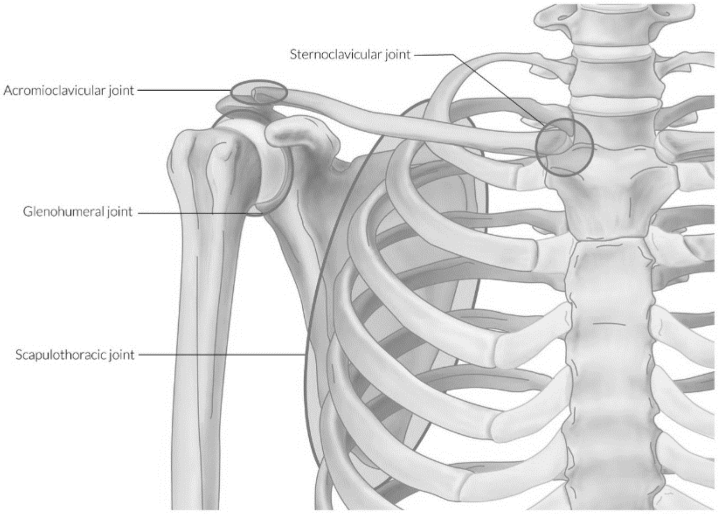

Figure 1: Joints of the shoulder. Image from Google Images.[28]

All other joints of the shoulder involve direct articulation with the scapula. The scapula is a triangular shaped bone, which is typically positioned over the second through seventh ribs approximately 5cm lateral to the spinous processes of the thoracic vertebrae.[27] One of the most prominent landmarks on the superolateral portion of the shoulder girdle is the acromion process, which is commonly referred to as the “tip” of the shoulder.[22,27] Articulation of the lateral end of the clavicle and the acromion process of the scapula via the AC ligament creates the AC joint. This joint is a relatively weak articulation and is commonly injured. As a result, the AC joint relies primarily on adjacent joints for additional support.

Acromioclavicular joint integrity is primarily maintained by the CC joint as it stabilizes the clavicle and reduces movement at the acromial end. The CC joint connects the coracoid process and the clavicle via the CC ligament, which is divided into medial and lateral portions. The lateral portion is referred to as the trapezoid ligament, which prevents lateral translation of the clavicle on the acromion. Similarly, the medial portion of the CC ligament is termed the conoid ligament and resists superior translation of the lateral portion of the clavicle. As the CC ligaments help stabilize the motion of the clavicle, the AC ligament secures the AC joint.

Therefore, both the AC and CC joints perform in unison to maintain the integrity of the AC joint throughout shoulder movement.[22,27]

The AC and CC joints add stability to the GH joint, which is commonly referred to as the shoulder joint. The GH articulation is formed between the humeral head and glenoid fossa of the scapula. This is known as a ball-and-socket joint where the humeral head is synonymous to the ball and the glenoid fossa is the socket. However, the glenoid fossa is relatively shallow in comparison to the size of the humeral head. Therefore, about 25-30% of the humeral head is in contact with the glenoid fossa, like a golf ball on a tee.[22] This relationship increases the mobility and range of motion in the GH joint, but decreases overall stability.

As a result, GH joint integrity relies primarily on soft tissue structures. One of the primary soft tissue structures involved is the glenoid labrum, which is composed of dense, fibrous connective tissue and serves to deepen the concave surface and secure the humeral head.[27] Additional stability is created by the superior, middle, and inferior GH ligaments. The superior GH ligament originates on the glenoid and inserts on the neck of the humerus to limit external rotation and inferior translation of the humeral head. Similarly, the middle GH ligament shares the same origin and insertion as the superior GH ligament, but prevents excessive external rotation and anterior translation of the humeral head.[22,27] Additionally, the inferior GH ligament is divided into anterior and posterior portions, both of which originate on the inferior aspect of the glenoid and insert medial to the lesser tuberosity. Both portions of the ligament limit anterior translation of the humeral head. The anterior portion limits external rotation, superior, and anterior shifting of the humeral head, while the posterior portion limits internal rotation and anterior movement. These ligaments reinforce the GH joint capsule which encompasses the entire GH joint and ligaments (Figure 2).[27]

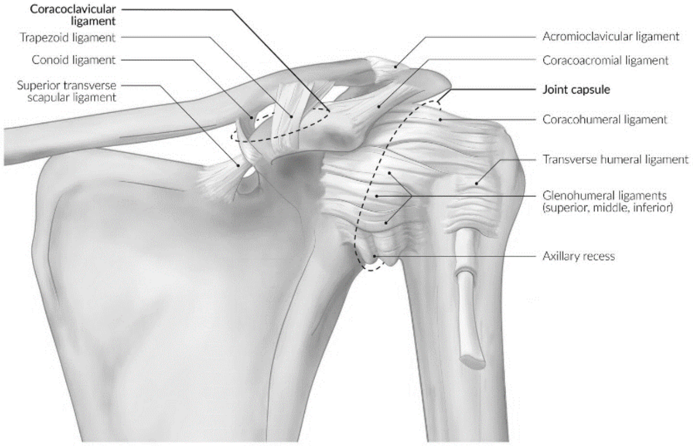

Figure 2: Ligaments of the shoulder. Image from Google Images.[28]

Lastly, the scapula articulates with the rib cage to form the scapulothoracic joint. Although, this is not considered a true joint, it is vital to proper shoulder function.[22,27] The volar aspect of the scapula glides over the thoracic cage to complete several movements, collectively known as five degrees of freedom of movement.[27] This includes rotations around three axes and two translations. Upward and downward rotation occurs around the transverse, otherwise known as the anteroposterior axis; internal and external rotation are also referred to as protraction and retraction and occur around the sagittal, or superoinferior axis; and anterior and posterior tipping occurs around the frontal, or mediolateral axis.[27] Abnormalities such as uncontrolled, dysrhythmic, or aberrant patterns in these movements is commonly recognized as SDK.[8,19,29,30] In all, the shoulder girdle is a complex group of bony and ligamentous structures almost all of which articulate with the scapula.

2.1.2. Soft-Tissue Anatomy

Structural integrity and function of the shoulder girdle is dependent on soft tissue structures, such as muscles, tendons, bursas, and ligaments. Dysfunction of these structures is thought to be a contributing factor in abnormal scapular kinematics, which makes knowledge of these structures and their functions pertinent in understanding SDK.[1,3,4,19,31] Soft tissue is further categorized based on the contractile properties of the structure. Soft tissue non-contractile structures lack the ability to voluntarily shorten and lengthen. Examples include labrum, ligaments, bursas, joint capsule, and tendons.[22,27] On the other hand, soft tissue contractile structures primarily include muscles. Both contractile and non-contractile structures increase the stability of the shoulder girdle.[3,16,19]

For clarity, pertinent ligaments were previously discussed in relation to their associated joint. Additional soft tissue non-contractile structures of the shoulder include the subacromial bursa, subdeltoid bursa, and the long head of the biceps tendon (LHBT). The subdeltoid bursa is positioned superior to the insertion of the supraspinatus and deep to the deltoid muscle. Medial to the subdeltoid bursa, under the acromion process of the scapula, is the subacromial bursa. These structures act to reduce friction and prevent damage to other structures in the subacromial space during movement.[27] The LHBT provides additional support to the GH joint as it extends from the biceps muscle belly and crosses the GH joint to its insertion point on the superior aspect of the glenoid labrum.[22] Many muscle tendons cross the GH joint; however, this structure is unique because of its position and insertion which reduces translation of the humeral head within the glenoid fossa of the scapula. All of these structures maintain the static and dynamic integrity of the shoulder girdle and impact normal scapular movement.[8,14,19]

Numerous muscles, also known as soft tissue contractile structures, serve to move the arm through a range of motion in addition to providing dynamic stability to the shoulder girdle. One of the primary muscle groups involved is collectively known as the rotator cuff.[2,22,27] This muscle group includes the supraspinatus, infraspinatus, teres minor, and subscapularis muscles. The supraspinatus originates in the supraspinous fossa and rests within the subacromial arch. Similarly, the infraspinatus originates from the infraspinous fossa, below the spine of the scapula. Inferior to the infraspinatus rests the teres minor, which originates from the upper portion of the axillary border of the shoulder blade.[13,20,21] All three of these muscles share a similar insertion on the greater tuberosity of the humerus and all act to externally rotate the GH joint.[2,22] Lastly, the subscapularis originates in the subscapular fossa and axillary border on the anterior aspect of the scapula. This muscle passes through the axilla, medial to the humerus and lateral to the rib cage, to its insertion on the lesser tuberosity on the humerus. Due to the path of the muscle and its insertion, the subscapularis muscle is the primary internal rotator of the GH joint.[13,22]

In addition to the rotator cuff muscle group, the deltoid muscle is a primary stabilizer of the shoulder girdle.[22] This is a multipennate muscle with three parts: anterior, middle, and posterior, all of which insert on the deltoid tuberosity. The anterior portion originates on the most lateral 1/3 of the clavicle and assists in GH flexion in the sagittal plane, abduction, and horizontal adduction. Immediately posterior to the anterior deltoid, the middle deltoid originates on the acromion process and abducts the GH joint. Finally, the posterior deltoid originates on the spine of the scapula and extends and horizontally abducts the shoulder.[7,32] Several additional muscles provide secondary dynamic stabilization of the shoulder girdle because of the origin, insertion, or path of the muscle.[22,27] Muscle names, actions, origins, and insertions are displayed in Table 1.

Strength and function of several muscles directly impact scapular movement patterns, stabilization, and proper posture of the scapula. These muscles primarily include the trapezius, rhomboids, serratus anterior, and levator scapulae. The complex relationship between these structures and SDK is discussed in detail in the etiology portion of this literature review.

Table 1: Origin, Insertion, and Action of Shoulder Muscles[22,27]

Muscle	Origin	Insertion	Action
Teres Major	Inferior angle of scapula, lower 1/3 of the axillary border of the scapula	Medial lip of the bicipital groove	GH extension, internal rotation, adduction
Latissimus Dorsi	Spinous process of T6-T12, lumbar vertebrae via the lumodorsal fascia, posterior iliac crest	Intertubecular groove	GH internal rotation, extension, adduction
Pectoralis Major	Medial ½ of the clavicle, anterolateral portion of the sternum	Greater tuberosity and lateral lip of bicipital groove of the humerus	GH adduction, horizontal adduction, flexion, internal rotation
Sternocleidomastoid	Sternal end of the clavicle and part of the manubrium	Mastoid process of the occiput	neck lateral flexion and rotation
Triceps	LH: infraglenoid tuberosity Lateral Head: Posterolateral Surface of the proximal ½ of humeral shaft MH: Posteromedial surface of the humerus	Olecranon process	GH extension
Biceps	LH: Supraglenoid tuberosity of scapula SH: Coracoid process of scapula	Radial tuberosity	GH flexion
Coracobrachialis	Coracoid process	Adjacent to the deltoid tuberosity of the humerus	GH flexion and adduction

One of the largest muscles that influences shoulder health and function is the trapezius. This is a flat, triangular, multipennate muscle, which is divided into upper, middle, and lower portions.[27] The upper trapezius originates at the occipital protuberance, superior nuchal line of the occiput, superior ligamentum nuchae, and C7 spinous process. This portion of the muscle inserts on the lateral 1/3 of the clavicle, acromion process, and scapular spine. Inferior to the upper trapezius is the middle trapezius, which originates from C7 spinous process to T5 spinous process and inserts on the acromion process and scapular spine. Adjacent to the middle trapezius, the lower trapezius originates on T8 spinous process through T12 vertebrae and inserts on the medial portion of the scapular spine.[19,22,27,33] Anatomical positioning of each portion of the trapezius allows for several actions.[22,27] Activation of the upper trapezius elevates and upwardly rotates the scapula, while the middle trapezius retracts the scapula and the lower trapezius assists in retraction and depression of the scapula.

Retraction of the scapula and prevention of scapular winging is primarily performed by rhomboid major and minor muscles.[2,22,27,34] The rhomboid minor originates from the inferior ligamentum nuchae and spinous processes of C7 and T1 vertebrae and inserts on the medial border of the scapula. Inferior to the rhomboid minor, rhomboid major originates on T2 through T5 spinous processes and inserts on the lower 2/3 of the medial scapular border. These muscles perform simultaneously to move the scapula towards the spine and improve should dynamics during scapular rotation.[27]

Similarly, the levator scapulae originates on the transverse processes of C1-C4 and inserts on the superior medial angle of the scapula. This muscle has comparable actions to the upper trapezius, but primarily elevates the scapula. One of the primary scapular postural muscles is the serratus anterior, which originates on the anterior aspect of ribs 1-8 and inserts on the costal surface of the entire medial scapular border and the superior and inferior angles of the scapula.

Lastly, the pectoralis minor originates on the costal cartilage of ribs 6-7, the anterior surface of ribs 3-5 and inserts on the coracoid process. As the pectoralis minor contracts, the scapula moves into an anterior tilt.[22] Many muscles in the shoulder either originate or insert on the scapula. Therefore, muscular activation greatly impacts scapular posture and movement and vice versa. For instance, if the scapula is positioned in an anterior tilt, the origin moves further away from its insertion, which may impact muscle movement. In all, movement of the shoulder is influenced by scapular posture because of numerous muscle origins and insertions.

2.1.3. Subacromial Space

As previously discussed, the acromion is one of the major bony landmarks on the anterior, superior portion of the scapula. The acromion and coracoid processes are connected via the coracoacromial ligament to form the coracoacromial arch. This articulation acts as the roof of the subacromial space, which is defined as the space between the coracoacromial arch and the humeral head.[18,22] Structures, in order from deep to superficial, within the subacromial space include the following: long head of the biceps tendon, supraspinatus tendon, and subacromial bursa. These structures are subject to impingement and irritation as they move under the acromion and coracoid processes.[2,18,21] The ideal subacromial distance in asymptomatic individuals is suggested to be approximately 9-10 mm measured by radiographs.[27] Numerous studies have noted the importance of the subacromial space and rotator cuff injury. A relationship between a decrease in area under the acromion correlates to an increase in cases of supraspinatus impingement under the acromion process.[18,21,35,36] Although current research is limited, SDK may alter the position of the acromion, which can increase the likelihood of subacromial impingement.

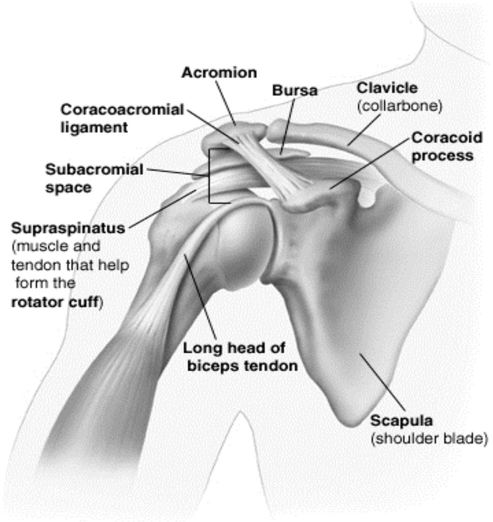

Figure 3: Anatomy of the subacromial space. Image from Google Images.[37]

2.1.4. Kinesiology and Mechanics

Normal scapular kinematics are dependent on proper function of scapular stabilizing muscles including the trapezii, rhomboids, levator scapulae, and serratus anterior due to the lack of bony articulation between the scapula and the thorax.[10,16,27] Movements of the scapula include approximately 60° of upward and downward rotation, 25° of protraction and retraction, 55° of elevation and depression, as well as slight anterior and posterior tilt.[38] Upward and downward rotation of the scapula are the most complex movements of the scapulothoracic joint. To achieve this movement, scapular stabilizing muscles must coordinate concentric and eccentric phases of activation to produce smooth, rhythmic, rotation around the sagittal axis.[6,10] These muscles have been termed force couples due to the relationship they have in producing complex rotation of the scapula.[27] For example, the serratus anterior contracts to move the scapula into protraction while the rhomboids oppose this movement. Meanwhile, the lower trapezius depresses the scapula as the upper trapezius and levator scapulae elevate the scapula. Although these muscles move the scapula in opposite directions, the result of this synchronous activation is upward rotation.[3,38]

Rotation of the scapula is necessary to achieve maximum GH abduction and return to a neutral position. The relationship between rotation of the scapula and humeral abduction or adduction is known as scapulohumeral rhythm. This is characterized by one degree of upward rotation of the scapula for every two degrees of humeral movement for a maximum of 60° from its neutral position.[38] Upward rotation of the scapula occurs as the GH joint is abducted from a neutral position after the first 30°-60° of humeral abduction.[39] Scapular downward rotation begins as the arm is adducted back to a neutral position at the side of the body until the humerus reaches 30°-60° of abduction. At this point the scapula remains in a neutral position while the humerus completes the range of motion.

2.2. Scapular Dyskinesis (SDK)

2.2.1. Definition

The literature commonly recognizes SDK as an all-encompassing term that relates scapular postural malposition to resulting alterations in shoulder biomechanics.[1–3,19,23] However, alternative terms such as scapular winging,[5,19,23,40] scapular dyskinesia,[2,19,34] and scapula alata[2,5,6,32,34] have been used interchangeably. Each of these terms describes abnormalities in scapular positioning or movement but have slightly different meanings which fail to fully incorporate the dynamic, multifactorial nature of SDK. Scapular winging and scapula alata are similar terms which describe medial and inferior scapular border prominence in either a static or dynamic position.[2,5,6,32,34] Additionally, scapular dyskinesia is associated with abnormally increased voluntary motion specifically caused by neurological pathology.[19] Although the aforementioned terms identify various components of SDK, other factors that alter scapular posture and kinematics, such as pathology to bony and soft tissue structures around the scapula, are excluded. Therefore, SDK is the most appropriate terminology due to the broad nature of the term.[19]

Some phrases have been used to describe conditions which involve SDK as a symptom or contributing factor; however, these terms cannot be used to define SDK itself. In other words, abnormalities in force couples which lead to SDK should not be confused with specific injuries or pathologies. For example, SICK scapula syndrome, an acronym coined by Burkhart et al,[5] stands for scapular malposition, inferior medial border prominence, pain and malposition of the coracoid, and dyskinesis of scapular movement. Although SDK and scapular malpositioning is involved in this syndrome, SICK scapula does not describe SDK. The primary difference between these two terms is the inclusion of coracoid pain in the diagnostic criteria for SICK scapula syndrome, which limits etiology to tightness in the pectoralis minor or short head of the biceps brachii due to the attachment of these structures to the coracoid process.[2,5,19] The inclusion of coracoid pain neglects other significant factors including, but not limited to, force couple imbalances, acromial abnormalities, soft tissue non-contractile laxity, or GH joint capsule tightness.[1,3,6] In essence, SICK scapula syndrome and similar pathologies or combination of symptoms should not be used to identify or diagnose SDK.

2.2.2. Etiology

Development of SDK commonly occurs due to uncoordinated or abnormal activation of scapular stabilizing musculature and presents as abnormal scapulothoracic rhythm, particularly during downward rotation.[3,10] As the scapula moves through downward rotation, scapular stabilizing muscles activate eccentrically, which requires alternative neuromuscular control and causes abnormal kinematics to become more apparent.[6,10] Inefficient energy transfer from the torso to the upper limb via the kinetic chain has also been reported to result in a loss of controlled, voluntary movement in the direction of retraction, protraction, and elevation. These deficits are observable during assessment for SDK.[10] Recognition of movement patterns aids the clinician in making a diagnosis. However, a lack of research of scapular kinematics outside of athletic populations restricts the clinician's ability to apply diagnostic information to population subsets.[19,31]

Scapular position and movement are vital to GH joint integrity and injury risk reduction. Clinicians need to recognize where restrictions in scapular motion occur as movement patterns can be specific to the structures impacted by the injury.[1,4–6,10,19,23,29,34,40] For example, the deceleration forces during throwing are amplified, which can alter the integrity of the GH joint if scapular protraction is not well controlled. Additionally, this can create an anteversion of the glenoid, which predisposes patients to labrum and GH ligament injury.[5] On the other hand, an increase in protraction is associated with increased anterior tilt and can lead to compression, also known as impingement, of the rotator cuff muscles and brachial plexus. Decreased elevation control can reduce the acromiohumeral distance (AHD), resulting in impingement, rotator cuff tendonitis, and GH joint instability.[10,21,35] This can be attributed to serratus anterior and lower trapezius weakness, potentially leading to more severe symptoms and pathologies. Examples include damage to the long thoracic nerve, thoracic outlet compression syndrome, or damage to the long thoracic nerve impingement of the rotator cuff.[6] As previously discussed, these altered scapular kinematics also directly affect the loss of kinetic chain function as the force generated from the trunk is not effectively transferred to the upper limb.[6,10]

Information on the etiology of SDK is presented comprehensively in the most recent consensus statement,[19] which organizes causes according to the type of tissue impacted: bony, joint, neurological, and soft tissue. Bony structures that influence scapular kinematics include thoracic kyphosis or abnormalities in the clavicle due to a previous fracture. Etiology related to joints occurs primarily because of instability in the AC or GH joints caused by prior injury. Neurologic causes involve long thoracic or spinal accessory nerve palsy. Tightness, inflexibility, and stiffness in the pectoralis minor and short head of the biceps, and global weakness of the parascapular muscles are contributing factors to SDK.[19]

Other researchers divide causes into two categories based on the proximity of the structures to the scapula.[30] Structures closer to the scapula are proximal causes and primarily involve neurological, bony, or soft tissue structures directly connected to the scapula. Distal causes are related to injury or abnormality of areas surrounding the scapula, such as the GH and AC joints.[30] Both of these organizational styles recognize similar causes of SDK; however, simply categorizing contributing factors based on proximity to the scapula lacks specificity to the underlying etiology.

Although many contributing factors may result in SDK, it is unclear whether shoulder pathology causes the condition or vice versa. Rather than investigating this relationship, most researchers recognize the lack of evidence but identify SDK as a precursor to shoulder pathology.[12,19,23,26] Based on this assumption, research on the etiology of SDK is focused primarily on muscle function and abnormal movement patterns. Using a cross-sectional design, other researchers further investigated the role of improper or inadequate scapular stabilizing musculature function.[41] This study design focused on a subset of a population at a specific point in time with no intervention from the investigator. Researchers used a convenience sampling method from an outpatient clinic, university hospital, and local Internet media to recruit a total of 82 volunteers (m=65, f=17, age=22.9±3.3 years) with SDK. Subjects were included if they were 18-50 years old, had unilateral shoulder pain in the shoulder girdle, and had a confirmed diagnosis of SDK. Exclusion criteria included the following: history of shoulder dislocation, fracture, or surgery within one year; injury to the neck or upper extremities within one month; those with scoliosis or kyphosis; neurologic disorders; or pain >3 on a visual analog scale during testing procedures.[41] Although the exact number was not reported, it is essential to note that many subjects were said to be active participants in overhead sports. Researchers visually assessed scapular movement while palpating the scapula to categorize the type of SDK. In this study, researchers acknowledged Types I-IV of SDK but modified the criteria by adding a fifth type to identify those with multiple patterns of SDK.

Testing began with assessing the type of SDK with subjects standing, arms at their sides, elbow in full extension, and shoulder in a neutral position. Subjects were then asked to perform the Scapular Dyskinesis Test (SDT)[8] by abducting their arms to the end range of motion over a three-second count using a metronome while holding weights in both hands with their thumbs up.[41] Next, participants were instructed to lower their arms in the same position at the same rate until they returned to the starting position. The rising and lowering phases were repeated six times during this assessment. Scapular kinematics during the rising and lowering phases were categorized independently. Therefore, participants could be classified as having one variety of SDK during the rising phase and another during the lowering phase. Of the total sample population, the first 15 individuals with a prominence of the inferior angle or medial border of the scapula were used as the comparison group. Next, 3-D kinematic data of the scapula and muscle activation were collected simultaneously. Skin sensors were placed on the sternal notch, xiphoid process, C7, C8, AC joint, the root of the spine of the scapula, inferior angle of the scapula, and the lateral and medial humeral epicondyles to create a 3-D representation of the shoulder girdle.[41] In addition, surface electromyogram (sEMG) sensors were placed over the middle portions of the upper, middle, and lower trapezius, serratus anterior, and clavicle on the same laterality. Subjects were asked to complete five repetitions using the same weight and positioning to assess SDK patterns. Finally, each muscle was tested for maximal voluntary isometric contractions (MVIC) to normalize the sEMG data.

The researchers used the Shapiro-Wilk test to confirm a normal distribution of kinematic and sEMG data before performing a two-way ANOVA to determine differences between group, GH angle, and sEMG data.[41] Low significance levels were set for both kinematic data ($\alpha=0.0125$) and sEMG data ($\alpha=0.01$). Significant differences were identified between upper trapezius activity during the lowering phase with both group and angle interaction effect ($p=.028$). Researchers then analyzed data collected at each angle of GH adduction, which revealed a 14% increase in activity of the upper trapezius was reported at >120° during the lowering phase in those with type II dyskinesis when compared to the control group ($p=.01$). Additionally, activation of both the lower trapezius (5%, $p=.025$) and serratus anterior (10%, $p=.004$) was significantly lower in those with type I and II dyskinesis during the descending phase. In this study, the effect size was assessed to determine clinical differences in the sEMG data, which confirmed the significance of the original statistics.[41] More specifically, increased upper trapezius activation was found in subjects with type I and II dyskinesis (effect size=0.67-0.94). Decreased serratus anterior activation was identified in type I dyskinesis (effect size=0.56-0.81) and type II dyskinesis (effect size=0.50-1.10) compared to the control group.

Results of this study were used to support the claim that abnormalities in soft tissue contractile activation have a considerable impact on SDK. Based on the high α, low p-values, and significant effect sizes, two conclusions can be made with confidence: SDK is more prominent during eccentric activation of scapular stabilizing muscles, and abnormal force couple activation has a significant impact on scapular kinematics.[41] However, there are several limitations to this study. Despite sampling the general population, most participants were athletes in overhead sports, which narrows the pertinence of the results to other demographics. Additionally, data were only collected to 120° of GH flexion for four muscles. This delimitation neglects the impact of other soft-tissue contractile structures and muscle activation during GH abduction in other planes of movement. Lastly, the impact of muscle fatigue was not considered in this study. Participants were asked to complete practice trials, six repetitions to categorize the type of SDK, and five trials to collect sEMG data, followed by isometric muscle testing with minimal breaks. Furthermore, the order in which the tests were completed was not randomized. As a result, researchers placed a high demand on the muscles they were investigating without allowing adequate rest time, which may skew results. This study also neglected scapular posture at rest, which other authors indicated had a significant impact on scapular mechanics during movement.[19,31,41] Thus, further research on the impact of other scapular stabilizing muscles on scapular kinematics in the general population is necessary.

More information on abnormal scapular posturing at rest and its impact on scapular kinematics throughout movement was provided in a quasi-experimental study on scapulothoracic movement during active and passive GH elevation.[7] Researchers used an undisclosed sampling method to recruit a total of 17 subjects (m=9, f=8, age=22.5 years, age range 18-30 years). Subjects were included if they were at least 18 years of age and could achieve a minimum of 120° of humeral flexion, while exclusion criteria were not reported. No standard deviation data was reported for demographic data in this study. Testing of dominant versus non-dominant arm was assigned randomly for all but two subjects who reported shoulder injury on their non-dominant arm. These subjects were tested on their dominant side.

Various muscles were studied using sEMG, including the upper and lower trapezius, serratus anterior, anterior and posterior deltoid, and infraspinatus. Resting sEMG was determined over two seconds before MVIC trials.[7] Kinematic electrode placement was similar to the study above except for the use of a scapular tracking device placed over the spine of the scapula and the superior surface of the acromion. Kinematic and sEMG data were collected simultaneously with the subject seated. Arm elevation trails were performed in the scapular plane approximately 40° (± 10°) anterior to the frontal plane over an eight-second count. During active trials, subjects were asked to raise and lower their arm with the thumb up. No other instruction was provided to control elbow movement.[7] Passive range of motion was achieved using a splint attached to an overhead pulley system, which the examiner used to elevate the subject's arm in a relaxed state and was only included if EMG values during this process were under 10% MVIC for all muscles except the serratus anterior.

Researchers reported a significant effect of muscle condition on scapular upward rotation (df = 1, $F = 38.09$, $P < 0.001$) and humeral elevation angle (df = 1.9, $F = 22.40$, $P < 0.001$).[7] Additionally, a significant difference in scapular upward rotation at 90° (df = 16, $t = 4.12$, $P < 0.001$), 120° (df = 16, $t = 9.80$, $P < 0.001$), and maximal active GH elevation (df = 16, $t = 3.75$, $P < 0.002$) was reported after a paired *t*-test. Similarly, muscle condition and humeral elevation was reported to have an impact on scapular retraction (df = 2.1, $F = 8.06$, $P < 0.001$). After subsequent paired *t*-tests, researchers reported increased scapular retraction during active GH elevation (df = 16, $t = 2.9$, $P = 0.01$). Based on these results, muscle activation has a direct impact on scapular kinematics.[7] Despite relatively low p-values, the sample size in this study was small which threatens the significance of reported results. Additionally, potential influence of the short head of the biceps was not assessed or controlled during active arm elevation despite its direct attachment to the scapula. There was no mention of ROM measurements to ensure joint angle, but researchers reported these values with a rather larger standard deviation (±10º).

Similar to the previous study,[41] only two true scapular stabilizing muscles were assessed (upper trapezius and serratus anterior), which results in two limitations across the existing literature: lack of understanding on the impact of other scapular stabilizing muscles on shoulder kinematics and inability to determine true relaxation of musculature during passive arm elevation. Both of these studies come to a common conclusion that scapular stabilizing muscular imbalances may result in SDK during active range of motion.[7,41] These authors produced objective evidence to support the consensus of the existing literature that the proper function of soft-tissue contractile structures surrounding the scapula impacts scapular kinematics.[5,17,41,42] Activation of muscles both individually and as part of a force couple is vital to normal scapular movement and overall shoulder health. Abnormal activation of these structures may cause SDK, resulting in subsequent injury.

Furthermore, as the scapula moves through an abnormal pattern, the potential for injury increases.[7,19,41] Some examples of these injuries include subacromial impingement syndrome, long thoracic nerve impingement, GH luxation or subluxation, rotator cuff injuries, and labral pathologies.[6,10,30] Therefore, the relationship between soft tissue contractile imbalances and subsequent shoulder pathology emphasizes the importance of proper assessment of scapular kinematics.

2.2.3. Scapular Dyskinesis and Shoulder Injury

Abnormalities in scapular kinematics have been associated with shoulder pain and a broad spectrum of shoulder injuries.[1,2,11,19,23,40] Based on a meta-analysis devoted to SDK, those who have the condition during baseline testing have a greater risk of developing shoulder pain.[23]

Two researchers analyzed a collection of articles based on inclusion and exclusion criteria (Table 2). Researchers then used an undisclosed standardized form to extract data from the five studies reviewed in the meta-analysis. Next, the studies were issued quality assessment scores using a modified Downs and Black Checklist. The authors used data collected from the studies on shoulder pain to generate forest plots, risk ratios, and a 95% CI to analyze the raw data. Outcome measures for the five studies included any questionnaires, scales, or tools that measured patient perceptions of shoulder pain.[23] In addition, any measurement tool used to assess SDK, which resulted in dichotomized data, was accepted. Researchers assessed for heterogeneity of the combined population using visual analysis of forest plots and the I^2 test; studies with greater than 50% of consistency were deemed to have significant heterogeneity. This data indicates a general relationship between SDK and shoulder pathology may exist and calls for future research.

Table 2: Inclusion and Exclusion Criteria for Meta-Analysis

Inclusion Criteria	Exclusion Criteria
Prospective studies	Other study designs
Athletic population	Pain at baseline
No shoulder pain at baseline	Non-musculoskeletal cause of SDK
Yes/no dichotomization for SDK	Non-shoulder musculoskeletal pathology
Patient ratings for pain during follow-up	No dichotomization for SDK

The combined characteristics of the five studies included a total of 419 participants (range of mean ages: 14-39). Most subjects participated in overhead sports and had various experience levels, ranging from recreational to elite. Participants were surveyed regarding shoulder pain in sessions conducted one season, one year, or two years after researchers completed the introductory study.[23] Authors used various methods to survey participants; outcome measurements ranged from validated patient-rated outcome questionnaires to interview questions created by the researcher. Each of the five studies defined significant shoulder pain using unique terms, which substantially affects results and does not allow adequate comparison. Overall, patient demographics were homogenous, and general methodologies were similar and replicable.

Researchers combined the data from the total number of subjects across the five studies in their reported results of this meta-analysis to assess participant demographics among all subjects.[23] Pooled data were dichotomized as 'SDK' and 'no SDK' to ease analysis. Across all participants, 38% (160/419) were diagnosed with SDK. Although both the SDK and no SDK groups reported shoulder pain in follow-up sessions [SDK=35% (56/160), No SDK=25% (65/259)], those with SDK at baseline were at 43% greater risk of developing shoulder pain (RR=1.43, 95% CI 1.05-1.93, I^2=40%). Based on these results, researchers reported a formidable connection between SDK and generalized shoulder pain.[23]

Several limitations occurred throughout this study involving the sample population and statistic criteria used by researchers. The homogeneity of study populations throughout all five studies is beneficial to the purpose of a meta-analysis but limits the applicability of the information to non-athletic groups. Additionally, it is difficult to objectively determine how similar the groups were since no standard deviations were reported. Conclusions made using this data are also clouded by statistic and sampling criteria, including a broad range in CI, loose inclusion criteria for diagnosis of SDK, and inconsistencies in shoulder pain parameters. The limitations of this study impeded reliable comparison of the included articles and may have reduced the accuracy of deductions made using this data.

Similarly, claims regarding the relationship between abnormal scapular mechanics and increased risk for shoulder injury in the previous study were substantiated in a prospective cohort study on SDK as a risk factor of shoulder injury in elite male handball players.[26] A total of 206 participants (age: 24.0 ± 4.0 years) participated in the study after being recruited by researchers using a convenience sampling method. Participants had an average of 14.0 ± 5.0 years of experience playing handball and were on the elite team for an average of 4.0 ± 4.0 years. A mix of player positions was represented in the population, including back (86/206, 42%), wing (48/206, 23%), line (30/206, 15%), and goalkeepers (29/206, 14%). The remaining 15 players (15/206, 6%) filled multiple positions.

A mixed-methods approach was used to describe risk factors for shoulder injuries,[26] which followed the same group of people over time to determine injury outcomes. Qualitative measures included the Oslo Sports Trauma Research Center (OSTRC) Overuse Injury Questionnaire, a modified Fahlstrom Questionnaire, and visual observation of SDK. These methods involved participant or examiner biases and did not yield objective, unit measures. Instead, all three methods relied on subjective interpretation of the severity of symptoms and SDK diagnosis. In addition, quantitative measurements were collected using a digital inclinometer to measure GH range of motion and a digital handheld dynamometer to measure the minimum muscle strength change in pounds or kilograms.[26] Initially, each participant was given the modified Fahstrom questionnaire to identify those with shoulder injuries. Then, researchers used the OSTRC bi-weekly for nine months to monitor patient-reported outcomes on current shoulder injuries.

Additionally, an examiner measured scapular control via live visual analysis of scapular movement. The subject completed five GH abduction repetitions followed by five GH flexion repetitions with a 5-kilogram weight in hand. Then, subjects were categorized on a normative scale based on the presence of SDK: normal scapular control, slight SDK, or obvious dyskinesis. Furthermore, internal and external GH ranges of motion were measured while subjects were lying supine and the examiner palpated for scapular movement.[26] Examiners noted the point at which scapular movement began and then marked the end range of motion. Additionally, minimum muscle strength change during internal and external rotation was measured with the subject lying supine, the shoulder in a neutral position, and the elbow flexed to 90°. Lastly, subjects were asked to stand with the shoulder abducted to approximately 30° in the scapular plane to test minimum muscle strength change during GH abduction. The data collected using these methods were then compared in Post Hoc Receiver Operator Characteristic curve analyses.[26] Those categorized as having obvious SDK were reportedly at higher risk of shoulder injury (P= 0.02; OR 8.41, 95% CI 1.47-48.1) and a 28% higher risk of shoulder pain (RR=1.28, CI 0.93 to 1.76, I^2=17%).

Compared to the meta-analysis mentioned above,[23] the results reported by Clarsen et al[26] are similar in that both studies support the hypothesis that SDK increases the risk of shoulder pain and is highly prevalent. However, the current study reported a much higher prevalence rate, with 72% (149/206)[26] of participants having various degrees of SDK compared to 38% (160/419).[23] Additionally, due to the prospective nature of this study, the evidence gathered supports the hypothesis that SDK not only impacts shoulder pain but may also augment the risk of injury.[26] Although researchers found evidence reflecting a high prevalence of SDK and its involvement in shoulder injury, the results of this study do not apply to other athletic populations or the general population due to the homogeneity of the sample population.

While substantial evidence supports the importance of ruling out SDK in shoulder pathology patients, the significance of symmetrical scapular kinematics bilaterally is doubted. Uhl et al[12] studied SDK in the general population using a mixed-methods design with two purposes: to compare reliability and validity of clinical assessment methods and to assess the prevalence of asymmetry in scapular motion in injured versus uninjured shoulders. A total of 56 participants (Table 3) were used in this study. Symptomatic participants, patients of an orthopedic surgeon (n=35), and asymptomatic patients (n=21), members of the local community,[12] were recruited using convenience and snowball sampling. Next, subjects were surveyed and evaluated for previous injuries using an undisclosed standard orthopedic shoulder examination and imaging. The subjects were diagnosed with the following conditions: rotator cuff strain (n=13), labral pathology (n=7), unidirectional anterior GH instability (n=6), and periscapular muscle weakness (n=9).[12] Those with bilateral shoulder pain; bony pathology to the shoulder girdle; neuropathology to the long thoracic, spinal accessory, or cervical root nerves; or rupture of the rotator cuff were excluded from the study.

Table 3: General Population Demographics

	Asymptomatic	Symptomatic	P Value
Age (yr)	24 (3)	32 (11)	< .001
Number of subjects	m=11, f=10	m=24, f=11	.26
Hand dominance (right or left)	R=19, L=2	R=30, L=5	.7

Two clinicians performed a visual analysis of scapular movement while each participant performed three to five repetitions of arm elevation in the sagittal and scapular planes. After observing scapular kinematics, the clinicians were asked to categorize scapular motion using a normative scale known as the Four-Type Method[9], which is described in detail in the definition section of this literature review. Types I, II, and III identify three varieties of SDK, while type IV describes no asymmetries in scapular movement. Then, the results were dichotomized into those with SDK and those without ("yes/no"). Those with types I, II, and III were categorized as "yes" while type IV was relabeled as "no."[12] The two clinicians performing the visual analysis of the participants were reportedly blinded; however, the variables they were blinded to were not disclosed. Next, three-dimensional (3D) kinematic analysis was performed bilaterally with receivers placed on the skin over the sternum and both acromion processes. The first five seconds of analysis were recorded with the participant standing in a normal posture, arms relaxed along the torso, and thumbs pointing forward, referenced as the resting position. Then subjects were asked to perform eight repetitions of arm elevation in the sagittal plane at a constant rate of 75°/s set by a metronome.[12]

Eight patients were identified as having typical bilateral scapular mechanics without pathology. Researchers used these eight subjects as the control group and used data collected to set normative values. As a result, a difference of 7-8° of flexion and scaption and 8-9° of protraction and posterior tilt during bilateral comparison was deemed symmetric.[12] During GH flexion in neutral and scaption, a 1.6 cm translation of the scapula superiorly was deemed normal. Subjects that did not surpass these three criteria were classified as having symmetrical scapular kinematics. A Pearson χ^2 analysis with significance set at $P \leq .05$ was performed to compare the presence of asymmetries in the 3D kinematic analysis data between symptomatic and asymptomatic groups.[12] Researchers reported mixed results in terms of prevalence with an increased frequency of multiple-plane asymmetries in the symptomatic group during GH forward flexion (Table 4). However, the prevalence of bilateral asymmetries was the same between the symptomatic and asymptomatic groups when subjects performed the same action in the scapular plane.

Table 4: Pearson χ^2 Frequency Results for Asymmetries in Scapular Movement

	Symptomatic group (n=35)	Asymptomatic group (n=21)	p-value
Multiple-plane	53.3%	14.3%	.002
Single-plane	17.1%	57.1%	.002
Prevalence in scaption	76%	77%	.87
Prevalence in flexion	71%	71%	.66

Several limitations within this study detracted from the applicability of the results. The primary limitation of this study involved the control group and the methods used to identify normative data. Despite pre-existent normative data on scapular kinematics, only eight subjects were included to create the parameters used as a control. The use of a small subpopulation as a control group allowed for a high CI (95%) but may not accurately reflect the actual normative values of the general population. Additionally, a lack of proper blinding of pathology information to evaluators created bias.[12]

Like other authors, these researchers recognized the high prevalence of SDK in symptomatic patients and acknowledged this diagnosis as a contributing factor in general shoulder dysfunction. Overall, the prevalence of SDK has been reported to be 38% or higher in various populations.[12,23,26] Reported data in all three studies examined thus far also indicate a correlation between SDK and subsequent shoulder pain.[12,23,26] However, Uhl et al[12] indicated bilateral comparison might be inconclusive, which is essential to consider during clinical shoulder evaluation.

Although a substantial body of evidence supports the claim that SDK impacts generalized shoulder pain, some question the negative stigma associated with SDK and its involvement in shoulder injury. Instead, these individuals suggest SDK is a natural, beneficial adaptation to unique shoulder mechanics in healthy individuals rather than a precursor to injury.[16,23,31] Those who adopt this perspective suggest abnormal scapular kinematics should not be routinely associated with shoulder pathology and are more accurately a result of individualistic movement patterns.[16,23,31] Additional information was provided by researchers who focused on scapular kinematics, shoulder strength, and flexibility in elite adolescent tennis players using a mixed-methods approach.[16] A total of 35 participants (m=19, age=13.6±1.4 years; f=16, age=12.6 ± 1.3

years) were recruited using a convenience sampling based on their national ranking in tennis by the Swedish Tennis Federation. On average, subjects reported playing tennis for 7.1 ± 1.4 years for 13.9 ± 2.4 hours per week. Similar to Clarsen et al,[26] upward scapular rotation and isometric muscle strength of the upper, middle, and lower trapezius; and serratus anterior were measured. Scapular upward rotation was assessed at 0^{o}, 90^{o}, and 180^{o} of GH abduction. Additionally, the anthropometric length of the pectoralis minor was measured based on the distance between the medial-inferior angle of the coracoid process and the sternocostal junction of the fourth rib using a Vernier caliper.

Data collected on upward scapular rotation was analyzed using an analysis of variance (ANOVA) for three-way and two-way interactions between each variable. Researchers reported no significant differences in this analysis. However, significant differences were found between right and left sides ($P<0.001$, $\alpha=0.05$) and level of GH abduction ($P<0.001$, $\alpha=0.05$), which reflected a high prevalence of asymmetrical scapular kinematic abnormalities.[16] Further statistical analysis was conducted using posthoc tests performed on the three points of GH abduction. A significant increase in upward scapular rotation occurred bilaterally for both genders ($P<0.001$).

Based on these results, the authors support Uhl et al[12] in the theory that asymmetrical scapular movement is beneficial to produce optimal scapulohumeral kinematics.[12,16] Although this study was well structured and used appropriate statistical analysis tests, the size of the sample population and homogeneity of participants restrict the applicability of this research to other populations. As with most of the existing research on SDK, the sample population was comprised mostly of athletes who participated in overhead sports. It is also important to note that data in this study was only collected and analyzed for upward scapular rotation. At the same time, the literature consensus suggests SDK is primarily recognized during downward rotation.[1,2,40,4–6,10,19,23,29,34]

While the literature does not indicate a true consensus on the relationship between SDK and shoulder injury, most researchers recognize SDK as a precursor to many shoulder pathologies. More research is necessary to fully substantiate this claim and gain clear insight into the dynamic between pathology and abnormal kinematics. Generally, these studies have been conducted on athletes or those with an athletic background, leading to multiple limitations. As previously stated, this knowledge would only apply to fields where patients are primarily athletes, such as athletic training and sports medicine. However, the existence of this relationship in the general population is not known. More specifically, these studies have been primarily conducted on athletes in overhead sports, which negates the application of this research to other athletic populations. Overall, the need for more research in various populations is prevalent and would provide a more fluid understanding of SDK and its relationship to shoulder pathology.

In short, despite a lack of consensus on the implications of SDK on shoulder pathology, early recognition of SDK has been consistently identified as a risk factor to subsequent shoulder pathology.[23,26] Therefore, more research is needed to understand this relationship in its entirety. The high prevalence of SDK in an athletic population has been well documented,[16,19,23,26] but there is a lack of existing research to describe this relationship in the general population.

2.2.4. Diagnostic Tools and Clinical Assessment Methods

Clinical shoulder assessment typically begins in a subjective manner involving questions from a clinician to a patient about injury history, signs, and symptoms. Signs of SDK are assessed based on static scapular posture and functional movement of the scapula to make an appropriate diagnosis.[5] Presence of generalized shoulder pain, the early elevation of the scapula during arm abduction, painful and decreased ROM in the direction of GH abduction and flexion, irregular or uncontrolled downward rotation, scapular winging, and abnormal static and dynamic scapular posture are all taken into consideration.[1,2,40,4–6,10,19,23,29,34] Ideally, this would be tested using bone-in three-dimensional (3D) movement analysis, as it is currently the gold standard.[19] However, utilization of this technology is not practical outside of a lab setting as it is not usually readily accessible to most clinicians. Additionally, these systems are expensive to purchase and maintain. Although clinical methods remain subjective, other methods have been developed to diagnose SDK.

One of the most referenced techniques used to assess scapular kinematics is the SDT. This test consists of a visual analysis of scapular movement during repeated, weighted GH flexion and abduction. The SDT was created and assessed for reliability and validity in a two-part study. The first part of the study[8] focused on the interrater reliability of SDT in college athletes who participated in repetitive overhead activities as part of the National Collegiate Athletic Association. Participants (N=142, m=111, f=31) were recruited from a variety of sports, including water polo (n=89), swimming (n=19), baseball and softball (n=28), and other sports (n=6) due to the prevalence of shoulder injury within this population. Exclusion criteria included pain rated at a 7 or higher on an 11-point visual analog scale, history of a rotator cuff or glenoid labral tear, shoulder dislocation, fracture, or shoulder surgery within the previous year.[8] Participants with injury to the neck or upper extremities less than 30 days before the study, an allergy to adhesives, or body mass index over 30.0 were also excluded. Subjects were included in the study if they were Division I-II athletes and could complete all test movements.

Before conducting the study, all examiners were given standardized training on identifying abnormal scapular movement.[8] Participants stood two to three meters from the camera to capture each subject's waist, head, and elbows throughout the range of motion. Each subject was evaluated by a certified athletic trainer who completed special tests, range of motion, and isometric strength measurements of each shoulder. Subjects then completed the SDT, which included five bilateral, weighted GH flexion and abduction repetitions. Each repetition began with arms at the side and thumbs up while holding dumbbells. The weight of the dumbbell was determined based on the subject's body weight.[8] Participants were instructed to elevate their arms as far as possible then lower their arms. Each motion was conducted over a three-second count. Two investigators evaluated subjects in real-time and recorded sessions. Interrater reliability was assessed using the κ coefficient for live raters (κ=0.57) and those who watched recorded videos (κ=0.54), indicating moderate interrater reliability in both settings.

Although the results for interrater reliability of this study were promising, the methodology of this study raised several concerns. A total of five individuals conducted live evaluations in groups of two per subject. Each pair of examiners consisted of a certified athletic trainer and a physical therapist or physical therapy student.[8] Evaluation procedures were unclear and did not describe how many participants were evaluated by each rater and if the athletic trainer in each group also conducted pre-experimental musculoskeletal exams. During live sessions, evaluators were not blinded to the diagnosis of their co-investigator. Three pairs of certified athletic trainers and licensed physical therapists were assigned to 30 recorded sessions per group.[8] Therefore, only 90 of the 142 recordings were reviewed, and each group did not evaluate the same participants. No discussion was permitted while recordings were reviewed, which ensured that raters were blinded to all other diagnoses.

Despite the inconsistencies of this study, researchers adopted a unique approach to improve interrater reliability by providing standardized training to all evaluators before conducting scapular movement analysis.[8] This training consisted of videotaped examples of normal and abnormal scapular movement. Additionally, this study relied on a generalized classification system to diagnose SDK. All participants were rated as having normal motion, subtle abnormality, or obvious abnormality based on scapular dysrhythmia and winging severity. Scapular dysrhythmia was defined as an early or excessive, uncoordinated, or uncontrolled scapular movement.[8] This system was not as simple as a dichotomized "yes" or "no" diagnosis as seen in other studies[11,12] but was also less restrictive than the Four Type Method.[9] These adaptations to previous methodologies may have improved the reliability of the current research, but the lack of blinding and discrepancies in data collection throughout the methodology reduces the accuracy of reported results.

The second part of this study focused on the validity of the SDT using a portion of the participants (n = 66) from part one of the study.[14] Those with normal motion or obvious dyskinesis by both live examiners were invited to participate in 3D testing. Subjects were excluded if they had slight abnormalities, or the examiners disagreed on the severity of SDK. The methodology of part one of the study was repeated. Each participant first completed the SDT while being evaluated by a pair of examiners before collecting 3D kinematic data and a second video recording. Sensors were placed on the skin over the manubrium, scapula, and distal humerus.[14] The scapular sensor was adhered to the skin using a custom plastic tracking jig. Although data was collected bilaterally, only more painful or dominant shoulder data were studied per subject. A nonparametric ANOVA was used to analyze data in addition to post hoc and odds ratios.[14] Significant differences were identified for upward scapular rotation at rest ($P < 0.001$), 30º ($P = .001$), and 60º ($P = .01$), with the obvious SDK group having decreased upward rotation. Scapular posture of those with SDK was also significantly more protracted at rest ($P =$

.02), 30° (P = .03), 60° (P = .008), 90° (P = .002), and 120° (P = .03). Clavicular elevation (P < .001) and clavicular protraction (P < .04) were also substantially different.

The results of this study were compelling but failed to support the validity of the SDT as a viable, standardized test compared to surface 3-D motion analysis.[14] First, the results did not mention scapular winging, which is critical to diagnosing obvious SDK during visual analysis. Scapular winging may have been excluded due to the challenges of measuring scapular movement with surface sensors. Additionally, validity measures such as sensitivity, specificity, likelihood ratios, and predictive values were not assessed or reported. In all, the SDT is clinically applicable and has been used across many studies, but the reliability and validity of this test is questionable based on current literature.

An alternative special test related to SDK is the scapular assistance test (SAT).[17] More specifically, the SAT is used to determine if low acromial elevation is the cause of shoulder impingement. To perform this test, the examiner applies pressure in an upward and lateral direction over the medial border and inferior angle of the scapula to mimic the actions of the serratus anterior and lower trapezius muscles. The force by the examiner is maintained as the patient moves through active, dynamic arm elevation. A positive test is indicated if symptoms of impingement syndrome are relieved as the examiner applies pressure.[17] This was later modified to include examiner hand placement over the clavicle and scapular spine while applying a downward, posterior force to create posterior tipping of the scapula while maintaining an upward, lateral force with the opposite hand.[43] The modified SAT was assessed for interrater reliability amongst 46 physical therapy patients (male = 30, female = 16, age = 44.5 ± 14.3 years, onset = 32.2 ± 58.7 months). Subjects were included if they were 18 years or older, were referred to physical therapy, and had increased pain with GH elevation in either the scapular or sagittal plane. Exclusion criteria consisted of inability to elevate the arm to 90° or if arm elevation was contraindicated. Eleven examiners were involved in the study with experience in physical therapy ranging between 2-20 years. All examiners were given standardized training and were assessed for competency in performing the modified SAT before data collection.[43]

The evaluation began with a patient-rated pain level on an 11-point ordinal scale where 0 indicated no pain and 10 represented the worst pain imaginable. Participants were asked to elevate their arm in the scapular plane on their own and provide an additional pain rating. The examiner then recorded a third pain rating while performing the modified SAT.[43] A difference of two or more in patient-rated perceived pain was considered a positive test while no change or an increase in pain indicated a negative test. This process of arm elevation with and without the SAT was then repeated in the sagittal plane. A second examiner who was blinded to the results of the first examiner immediately repeated the entire procedure after the first assessment was concluded. One pair of evaluators conducted testing on most of the participants ($n = 22$) and were compared to the primary investigator in the scapular plane ($\kappa = 0.51$, 76%) and sagittal plane ($\kappa = 0.66$, 84%). The lead examiner was also compared to all other examiners in both planes (scapular plane: $\kappa = 0.54$, 77%; sagittal plane: $\kappa = 0.58$, 79%), which indicated moderate interrater reliability.[43]

Many factors and limitations may have contributed to the lack of significant findings in this study. First, participants were not excluded based on adjacent or systemic pathology. For example, patients are commonly excluded from similar studies due to systemic musculoskeletal diseases or cervicogenic symptoms.[9,23,32,36] Additionally, immediate repetition of the testing procedure without a rest period may have introduced a bias due to muscular fatigue. Third, studies on the SDT emphasized the importance of using weights during scapular kinematic assessment, which was not applied in this methodology.[8,14] Lastly, kappa coefficients were determined based on subjective measures, limiting the objectivity of these results.

A more specific classification of SDK was created by Kibler et al[9] using a system he called the Four Type Method. This categorization system is a nominal scale (Table 5) which was and tested for intra-rater and interrater.[9] Participants (N=26, age=29.5±9 years) in this quantitative study were separated into groups: with injury (n=20) and those without (n=6). Those with injuries were recruited by the senior author of this study in his private clinic. Subjects were excluded if they had symptoms in bilateral shoulders, previous history of shoulder surgery, shoulder fracture, or adhesive capsulitis.

Table 5: Four-Type Method Descriptions

Type	Pattern	Definition
Type I	Inferior Angle	Medial scapular border prominence at rest and through movement. An anterior tilt of the scapula causes malpositioning around the transverse axis.
Type II	Medial Border	"Scapular winging" occurs when the scapula moves laterally about the vertical axis in the frontal plane, causing prominence of the entire medial scapular border.
Type II	Superior Border	Superior and anterior translation of the scapula in the sagittal plane causing superior medial border prominence. May present as a shoulder shrug without significant scapular winging.
Type IV	Symmetric Scapulohumeral	Normal scapular posture and fluid movement bilaterally.

Before this, a pilot study was conducted to identify common movement patterns among symptomatic individuals.[9] This information was used to describe the four unique movement patterns used in this study. All subjects were then videotaped while standing in normal posture. Participants were also videotaped during arm elevation trials, where they were asked to align their first metatarsophalangeal joint with an adjustable backdrop. Subjects then completed three repetitions of bilateral arm elevation in neutral and scaption, which was counterbalanced to limit the effect of fatigue. Arm elevation repetitions were completed at a rate of 45°/s, which was practiced using a stopwatch before the recorded trials. The video data was recorded onto VHS tapes, randomized, and given to two physicians and two physical therapists. These individuals were blinded to the subjects' previous history of shoulder pathology. Before evaluators viewed these recordings, they were educated on the four-movement patterns with a 10-minute presentation that included examples of each abnormal pattern.[9] They were also given a written table with definitions of the four movement patterns to reference while analyzing the video recordings. After reviewing the videos, examiners were asked to categorize the subjects by scapular movement patterns.

Researchers compared physicians ($\kappa=0.31$, $p<.01$) and physical therapists ($\kappa=0.42$, $p<.001$) separately in terms of interrater reliability. Intra-rater reliability data was only analyzed for one physician ($\kappa=0.59$, $p<.001$) and one physical therapist ($\kappa=0.49$, $p<.001$). Researchers concluded that the Four Type Method[9] is a reliable approach to categorizing and defining SDK based on these results. However, this study has significant delimitations, including sampling bias, because all symptomatic participants were recruited from a clinic owned by one of the examiners. Additionally, video versus live observation of the subject prevents clear visualization of the scapula throughout the movement pattern. Technological advances in video clarity and quality of recordings may improve these results and should be investigated in future research. Researchers do not report many patient demographics, which limits the understanding of the patient population and the applicability of the results of this study.

A third method used to identify SDK is a dichotomized "yes" or "no" diagnosis of the condition. A dichotomized approach simplifies the Four Type Method and has also been assessed for reliability and validity.[12] In the previously discussed study on the clinical assessment methods for SDK, researchers compared the Four Type Method and dichotomized results to 3D kinematic to determine the validity of these approaches (Table 6). Researchers also assessed the raw data for inter-rater reliability (Four Type: 61%, κ=0.44, P < .01; yes/no: 79%, κ=0.41, P < .01) using a κ correlation. The dichotomized method yielded a slightly higher agreement between evaluators but generally had lower validity in several aspects. The inter-rater reliability and positive predictive value were higher for the dichotomized method indicating a high level of agreement between evaluators and decreased risk of false-negative results. However, the specificity of this method was higher than the Four Type Method, suggesting an increased risk of false-positive results. Overall, based on this study, researchers recommend the dichotomized method rather than the Four Type Method of assessment for SDK.[12]

Table 6: Validity of Four-Type and Yes/No Methods Versus 3D Kinematic Analysis

		Type I	Type II	Type III	Type IV	Yes/No Method
Scaption						
	Accuracy	54	45	61	64	64
	Sensitivity	47	85	13	31	74
	Specificity	62	43	80	74	31
	Positive Predictive Value	58	45	20	27	78
	Negative Predictive Value	50	45	70	78	27
Flexion						
	Accuracy	61	61	64	64	66
	Sensitivity	54	20	22	38	78
	Specificity	67	94	84	78	38
	Positive Predictive Value	58	71	40	40	76
	Negative Predictive Value	63	59	70	76	40

Although multiple approaches to diagnosing SDK exist, the dichotomized method is a more valid and reliable clinical assessment method when compared to the Four Type Method. Dichotomization reportedly has similar sensitivity, specificity, diagnostic accuracy, and interrater reliability levels to other clinical assessment methods used to diagnose various shoulder pathologies.[12] This was supported in a cross-sectional study by Rossi et al,[11] who assessed the three previous diagnostic tests, including the SDT, Four Type Method, and dichotomized method for intrarater and interrater reliability based on recommendations made by the original authors.[8,9,14] Subjects were recruited during a sporting event and were assessed by a blinded physical therapist for demographic data and body anthropometrics (N=75; m=45, age=23.7±7.0 years, BMI=25.3±3.8 kg.m^2; f=30, age=17.6±5.7 years, BMI=22.8±3.0 kg.m^2), sport including: baseball (n=11), judo (n=5), taekwondo (n=6), volleyball (n=8), basketball (n=21), jiu-jitsu (n=23), and swimming (n=1), and skill level: professional (n=9), amateur (n=57), and recreational (n=9).[11] Participants were included if they had full shoulder range of motion with pain intensity between 1 and 4 on a numeric pain scale. Exclusion criteria included a history of shoulder surgery, fracture of the scapula, humerus, or clavicle, visual misalignment of the thoracic spine, and systemic diseases.

Two physical therapists completed nine hours of training on classifications by previous authors.[11] Analysis was practiced via video and live assessment followed by discussion of results between both physical therapists. After training was completed, the methods of this study were like other studies where participants were asked to complete weighted arm raises for 8-10 repetitions bilaterally. The evaluators were only allowed to visually analyze scapular kinematics without palpation and were blinded to previously collected demographic data and the determinations made by the other rater. For each participant, examiners determined SDK first with the dichotomized method, then the Four Type Method followed by the SDT classification.[11] Participants were given a three-hour rest period before repeating the evaluation protocol to determine the intrarater reliability. Both arms were evaluated, but the only assessment of the dominant arm was included in statistical analysis. Interrater results (Table 7) ranged from 80% to 95.9%, with nearly perfect reliability ($\kappa > 0.81$), low prevalence, and bias index scores for the Yes/No method. Results for intrarater reliability were substantial for both raters ($\kappa = 0.66\text{-}0.81$); the CIs reflected reliability for the sample population were between moderate and almost perfect for all testing methods; however, only the dichotomized method showed almost perfect interrater reliability in all three test positions.[11]

Table 7: Interrater and Intra-rater Reliability of Yes/No Method

	Interrater Reliability							
	P (%)		κ (95% CI)		Prevalence Index		Bias Index	
Rest	95.9		0.91 (0.82-1.00)		-0.19		0.01	
Flex	95.0		0.89 (0.79-1.00)		0.07		0.00	
Abd	90.7		0.81 (0.68-0.94)		-0.11		0.07	
	Intrarater Reliability							
	P (%)		κ (95% CI)		Prevalence Index		Bias Index	
	PT$_1$	PT$_2$	PT$_1$	PT$_2$	PT$_1$	PT$_2$	PT$_1$	PT$_2$
Rest	85.7	88.9	0.70 (0.52-0.88)	0.77 (0.60-0.94)	-0.21	-0.19	0.03	0.00
Flex	89.3	85.7	0.79 (0.63-0.95)	0.71 (0.53-0.90)	0.04	-0.11	0.03	0.00
Abd	87.7	86.0	0.73 (0.54-0.91)	0.70 (0.52-0.89)	-0.32	-0.25	0.00	0.02

Overall, the current study was well designed with several unique adaptations to methodologies used in the previous studies.[8,9,12,14] Suggestions made by original authors were applied in the current study to improve reliability results. Some of these changes included increased repetitions, added resistance during testing, and standardized training of evaluators before conducting the study.[11] This was the only study that considered bias and prevalence index scores. The bias index for all evaluation methods for this study was close to zero, which indicates no difference in the proportion of positive cases between the two examiners or two evaluations. Prevalence index scores were also small or negative for all evaluation methods and testing positions throughout the study, suggesting no prevalence effect. Examiners were also double-blinded to patient demographic information and the results of the other examiner. The combination of these adaptations compared to previous studies improves the accuracy and confidence of the results reported in the current study.

Results of the study by Rossi et al[11] and original authors[8,9,12,14] indicate the dichotomized method is an efficient, reliable, and valid evaluation tool without the disadvantages of other methods. For example, the Four Type Method requires the evaluator to assess scapular kinematics by identifying and classifying abnormal movement in multiple planes based on visualization of bony landmarks. These structures can be difficult to visually follow throughout the movement but are critical in categorizing the type of dyskinesis when using the Four Type Method.[12,19] The dichotomized method does not emphasize the type of existing SDK, which increases efficacy and enhances the clinical pertinence of this test. Therefore, the dichotomized method is a preferred clinical assessment tool based on statistical analysis and clinical applicability.

2.3. Diagnostic Ultrasound

2.3.1. Definition

Diagnostic ultrasound (DUS) is a non-invasive imaging technique that uses sound waves to visualize tissues under the skin to identify pathology.[13] Sound waves are generated at a frequency above the threshold of human hearing via a piezoelectric transducer. More specifically, electricity interacts with a crystal in the transducer head, creating mechanical stress on the crystal. In response, the crystal expands and contracts to create sound waves that move through the tissue when the transducer is placed on the skin.[13] Penetration of ultrasound waves is aided by a layer of water-based gel between the transducer and the skin. Ultrasound waves interact with tissue and are absorbed or reflected at various frequencies to generate an image with few contraindications.

Diagnostic ultrasound transducer properties range in size, array, and frequency, each of which aims to image different tissue depths and areas of the body. Small size or footprint arrays allow the user to conduct imaging in narrow or otherwise tricky areas, such as the hand or ankle. Large footprint transducers work well in broad, flat areas of the body like the quadriceps. Transducers are primarily curvilinear or linear in shape.[13] Curvilinear transducers increase the field of view, allowing for evaluation of deeper structures, while the linear array is best for imaging flat structures as the sound wave remains parallel to the tissues being imaged. A single transducer can produce a range of sound wave frequencies that influence image quality. High-frequency ranges are best for superficial structures and provide a higher resolution, while low frequency has reduced overall resolution but can penetrate deeper into tissue.[13,25]

With DUS imaging, tissues can be differentiated by their echogenicity and texture.[13,25] Normal tendons and bone are echogenic and slightly hyperechoic meaning they appear brighter than the overlying muscle. However, normal bone appears smooth while tendons have a fibrillar echotexture. Ligaments are also hyperechoic and striated, like tendons, but can be differentiated as they tend to be more compact and connect one bone to another bone. Healthy muscle tissue is generally hypoechoic with small, hyperechoic spots. Structures closer to the surface including the epidermis and the dermis appear generally hyperechoic as well and have no patterned texture.[13]

2.3.2. Diagnostic Ultrasound Assessment of Subacromial Space

Normal, optimal subacromial space is suggested to be approximately 9-10mm but methods used to obtain this measurement were not disclosed.[27] A study which utilized fluoroscopy reported minimum AHD measurements of 2.6 ± 0.8 mm in the scapular plane and 1.8 ± 1.2 mm during forward flexion.[35] One of the first studies to use DUS was conducted in 2008 on junior elite tennis players and focused on subacromial space measurement.[20] A total of 53 participants (age = 14.8 years, age range = 11-18 years, m = 31, f = 22) were members of a local tennis club who practiced for 11.4 hours per week. Twenty individuals with similar demographics (age = 14.6 years, age range = 11-17 years, m = 9, f = 11) were used as a control group, but the activity level was not reported for this cohort. Standard deviation data was not reported in this study for demographic and reported activity level. Participants were included if they were members of the Brazilian Tennis Confederation and involved in competition.[20] Subjects were excluded if they had a shoulder injury, surgery, or treatment within six months before the study. Although pain was not a factor in inclusion and exclusion criteria, all participants were asymptomatic.

An orthopedic surgeon conducted a clinical evaluation for SDK while the patient completed bilateral, forward and lateral arm raises. This study used the dichotomized classification of SDK, and the criteria for diagnosis included static or dynamic scapular winging or abnormal movement during the ascending or descending phase of arm raises.[20] Diagnostic ultrasound was conducted by a radiologist who was blinded to the clinical evaluation results and any demographic information. A 7-12 MHz linear transducer was used to measure AHD at 0° and 60° of abduction. The forearm was pronated, and the humerus was internally rotated. The transducer was placed along the coronal plane, and measurement was taken at the point where AHD was the smallest.[20] Researchers used a student *t*-test to compare quantitative variables and a χ^2 test to analyze quantitative variables.

Amongst tennis athletes, the apparent prevalence of SDK (43%; 23/53) was similar to a study on handball athletes.[26] In the current study, most SDK patients were affected bilaterally (82.6%; 19/23) or presented with SDK of the dominant shoulder (13%; 3/23).[20] The control group was observed to have about half the apparent prevalence of SDK (20%; 4/20). Statistically significant differences were found for AHD between tennis players (8.79 ± 1.52mm, P <0.001) and the control group (9.80 ± 1.40mm, P <0.001) at 0°. There was also a significant difference in AHD reduction between the two groups (tennis players: 1.60 ± 0.89mm; control: 2.18 ± 1.14mm; P = 0.001) and those with SDK (n = 42, 1.93 ± 0.83mm; P = 0.002) or without SDK (n = 64, 1.38 ± 0.87mm; P = 0.002). Therefore, a 21.4 ± 0.92% (P = 0.007) difference in AHD reduction between the two groups.[20]

Although these results indicate a relationship between SDK and reduction in AHD, the measurement of AHD was subjective. No standardization of points used to measure AHD were set in this study. Instead, the examiner was asked to identify where AHD was the shortest. Additionally, the average age of the sample used in this study is lower than most other studies. Specifically, a relationship between age and SDK has not been investigated and remains unclear.

Seitz et al[21] conducted a study with a similar methodology to determine the effects of SDK on AHD. Participants were recruited for the study if there were 18-70 years old and were free from shoulder or upper arm pain for six months before the study. They were excluded if they expressed symptoms of cervical spine motion, systemic connective tissue disease, or previous shoulder fracture, surgery, or pathology. Researchers recruited participants from a local university and screened them for inclusion and exclusion criteria. A total of 42 participants (male = 18, female = 22, age = 26.6 ± 6.0 years) with no significant differences in reported characteristics (P > .05) were scheduled for testing. Participants were examined by a physical therapist with 15 years of previous experience and an athletic trainer independently with 3 years of experience. Both examiners received standardized training on SDK and were blinded to the results of the screening process and observations of the other examiner. If both examiners agreed on the diagnosis, patients were assigned to the SDK group (n = 11/20, 55%) or normal group. Researchers then matched each participant according to age, gender, and arm dominance. Testing began with the subject seated while performing a series of static arm raises at rest, 45°, and 90° in the scapular plane, defined as 30° anterior to the frontal plane.[21]

Arm raises were completed with the thumb up and held at the predetermined angles (0°, 45°, or 90°) in a suspension harness. This process was repeated twice at each arm elevation angle while being assessed with 3-D kinematic receivers and DUS to obtain measurements with and without the SAT in random, sequential order. Kinematic data were collected using receivers placed on the T3 spinous process, posterolateral acromion, and distal, posterior portion of the humerus. Scapular upward rotation, poster tilt, and protraction were defined as positive values. DUS data was collected using a 5-12 MHz linear array set at 8.0 MHz. Acromiohumeral distance was defined as the shortest measured distance between the humeral head and the inferior anterior tip of the acromion.[21]

Intrasession test-retest reliability for kinematic data (ICC = 0.98-0.99), DUS (ICC = 0.88 – 0.96), and application of the SAT (ICC = 0.97-0.99) were all excellent. Kinematic data and AHD were compared between groups using multiple mixed methods ANOVAs. The first compared group (dyskinesis and normal) and arm angle (0°, 45°, or 90°) to interactions (kinematic data and DUS).[21] Results of the SDK group revealed no significant differences with any scapular kinematic data or AHD. The second considered the SAT and compared results to group, arm angle, and interactions and did not reveal any significant differences. The 2-way interaction between SDK and the SAT was significantly different, indicating the presence of SDK influenced the efficacy of the SAT. More specifically, those with SDK experienced significantly greater upward rotation while the SAT was applied.[21]

Results of this study contradict conclusions of other studies[20,35,36] on the impact of SDK on AHD. It is essential to note that the measurement of AHD in this study differed from the study by Silva et al.[20] In the current study, the transducer placement was standardized and measured the anterior aspect of the acromion while other studies assessed the lateral aspect of the acromion.[21] However, several limitations existed throughout the methodology of this study which may have influenced the results. First, patients were not asked to raise their arm above 90° of GH abduction, whereas other researchers indicated significant differences at elevations up to 120° of GH abduction.[12,41] Perhaps the most significant limitation of this study was the lack of active GH abduction using weights. Previous studies have indicated SDK results from muscular imbalances[5,17,27]; therefore, the condition is made more apparent while the patient holds weight during testing.[8,14] The use of a suspension harness to maintain arm elevation further limited activation of the musculature, which may have led to the lack of significant findings within the SDK group. Additionally, examiners for DUS were not blinded to SAT application which may have created a bias.

A third study on the impact of shoulder kinematics focused on changes in AHD caused specifically by upward rotation.[18] Participants (N = 60) were included if they were between 21-60 years old, had shoulder pain at the time of the study for more than four weeks, had symptoms aggravated by active shoulder motion, and had at least ≥120° of GH abduction. Subjects were excluded for cervicogenic pain, radiating pain, ≥25% decrease in GH internal rotation, shoulder trauma or surgery, positive apprehension test, scoliosis, joint disease, allergy to adhesives, or contraindications of MRI. After screening all subjects for eligibility, they were matched based on age, sex, and hand dominance after being split into symptomatic and asymptomatic groups. Kinematic data were gathered using a fluoroscope and camera motion-capture system with the participant's arm at rest and throughout dynamic scapular plane GH abduction. Magnetic resonance scans were also collected to create 3-D bone models of the scapula and proximal humerus.[18] The 3-D models were matched with the other imaging results to create a dynamic 3-D model of each participant's bony anatomy. Subacromial distances were defined as the space between the coracoacromial arch and the greater tubercle of the humerus, quantified at every 10° of GH abduction. Minimum distances were normalized to the subject's rotator cuff thickness and expressed the subacromial distances as percentages. This information was then used to identify five dependent variables, including the smallest normalized minimum distance, contact between the rotator cuff and coracoacromial arch when minimum distances were less than 120%, the surface area of rotator cuff insertion in proximity to the coracoacromial arch, absolute minimum distance, and position of the humerus at absolute minimum distance. Each subject was ranked based on their recorded scapular upward rotation.[18] The top 20 individuals with the highest amount of upward rotation were assigned to the high upward rotation group (n = 20, age = 32.9 ± 7.3 years, male = 30%, asymptomatic = 50%, rotator cuff thickness = 5.3 ± 1.2mm) while the 20 participants with the lowest measurements were assigned to the low upward rotation group (n = 20, age = 32.0 ± 8.7 years, male = 55%, asymptomatic = 35%, rotator cuff thickness = 5.6 ± 0.9mm) regardless of their expressed symptoms.

Data of this study were assessed using a 2-sample independent *t*-test, Mann-Whittney *U* test, or chi-square test for comparisons between groups and cohorts. Proximity measures and covariates were assessed using Pearson’s correlation which revealed no moderate or high correlation.[18] The low and high upward rotation groups showed a 10.0° difference at 30° GH abduction. The normalized minimum distance was lowest in both groups during ROM below 70° of GH abduction. The interaction between the amount of upward rotation and normalized minimum distance depended on the angle of GH abduction ($P = 0.049$, $F = 2.71$). Furthermore, those with low upward rotation had a significantly smaller normalized minimum difference at rest ($P = 0.049$, $t = 1.99$, $df = 113$, mean difference = 34.8%). However, the subacromial proximity areas were not significantly different from the upward rotation groups. Contact between the rotator cuff tendons and coracoacromial arch occurred in 45% of all participants, 32.5% of which occurred at 60° of GH abduction.[18] The level of arm elevation significantly impacted absolute minimum distance the low upward rotation group versus the high upward rotation group ($P = 0.07$, $t = -1.82$, $df = 38$), but the magnitude of the distances was not significantly different ($P = 0.41$, $t = 0.83$, $df = 32$; mean difference, 5.4%). More specifically, the low upward rotation group reached absolute minimum distance at $51.5 \pm 11.8°$ while the high upward rotation group reached the same values at $60.4 \pm 18.4°$. Therefore, those with low scapular upward rotation experience a maximum decrease in subacromial space earlier than those with high upward rotation, but the area remains statistically the same for both groups. Overall, researchers found subacromial distances are smallest between 50° and 70° of GH abduction but are dependent on the amount of upward scapular rotation.[18]

This study had multiple limitations, which may have impacted the results and conclusions presented by researchers. First, the rotator cuff thickness was measured at the articular margin, which may not reflect the actual thickness of the muscles. Multiple variables were dependent on rotator cuff thickness measurements and may have produced inaccurate results. Another limitation of the study is measuring scapular upward rotation at 30° of GH abduction to determine low and high upward rotation groups. Researchers chose this point as it is within the ROM, where subacromial proximities are suggested to be the smallest, but the literature on validated classification of upward rotation during clinical evaluation is limited. Lastly, this study focused strictly on upward scapular rotation rather than SDK. Previous research indicates that SDK may be more apparent during downward rotation.[3,10]

Although the conclusions on the relationship between SDK and AHD are uncertain, DUS is a reliable tool in measuring AHD. Pijls et al[36] investigated the interrater and intrarater reliability of DUS to evaluate AHD in symptomatic patients. Participants were included in the study if they were diagnosed with subacromial impingement syndrome by an orthopedic surgeon and had pain for greater than six months prior. They were excluded if they expressed symptoms associated with shoulder instability, adhesive capsulitis, AC pathology, a history of systemic musculoskeletal disorders, upper extremity fracture, or shoulder surgery. A total of 43 participants were divided into a neutral position group (n = 21, male = 9, female = 12, age = 51 ± 11 years, right = 9, left =16) and a 60° GH abduction group (n = 22, male = 10, female = 12, age = 52 ± 10 years, right = 9, left =16) without randomization. One experienced radiologist and one novice orthopedic surgeon examined participants and completed practice sessions on volunteers who were not included in the study and were blinded to their measurements as well as the values obtained by the other clinician.[36]

A 5-12 MHz linear array transducer was set at a frequency of 7.5 MHz during this study to assess AHD. Participants were seated and asked to hold a wooden rod in supination to ensure the shoulder was in a neutral position. In this study, AHD was defined as the shortest distance between the acromion process at the inlet of the subacromial space and the most superior point of the humerus.[36] Subjects in the GH abduction group were seated in a custom-made "abduction chair," which only allowed them to raise their arms in the scapular plane. Participants were asked to raise their arm to 60° of GH abduction, which was confirmed using a goniometer. The patient actively maintained this position while DUS data was collected. Examiners took three independent measurements for each subject regardless of group allocation, which resulted in a total of 150 measurements in both the neutral and abduction groups. Reproducibility was also assessed by randomly selecting 25 of the images collected in the study and asking the examiners to reselect points for measurement. After six months, the same 25 images were given to the examiners, and the process was repeated.[36] A total of 300 AHD measurements were completed on 50 shoulders in 43 participants (Table 8).

Table 8: Results for AHD Measurements, Intrarater, and Interrater ICC Values

AHD Measurements				
	Experienced Examiner (mm)	Novice Examiner (mm)	Difference	P
Neutral Position	9.3 (1.7)	9.0 (1.4)	0.3 (1.1)	0.05
Abduction Position	6.7 (1.7)	6.7 (1.4)	0.05 (1.3)	0.05
Interrater Reliability				
	ICC for measurement of AHD		ICC for Replicability	
Neutral Position	0.70 (0.43–0.86)		0.50 (0.26–0.68)	
Abduction Position	0.64 (0.33–0.82)		0.77 (0.64–0.87)	
Intrarater Reliability				
	ICC for measurement of AHD		ICC for replicability	
	Experienced Examiner	Novice Examiner	Experienced Examiner	Novice Examiner
Neutral Position	0.94 (0.89–0.97)	0.92 (0.85–0.96)	0.56 (0.22–0.77)	0.57 (0.24–0.78)
Abduction Position	0.90 (0.82–0.95)	0.87 (0.77–0.94)	0.82 (0.61–0.91)	0.85 (0.69–0.93)

ICC, interclass correlation coefficient; (95% CI). ICCs were significant (P < 0.0001).

Cumulative ICC values for AHD measurement in neutral position (ICC = 0.78 (0.65–0.88)), abducted position (ICC = 0.71 (0.52–0.88)) were significant ($P < 0.0001$) and reflect a moderate reliability. Replicability in abducted position were also relatively high (ICC = 0.82 (0.70–0.90), $P < 0.0001$). However, this was not reflected in replicability values in neutral position (ICC = 0.52 (0.32–0.71), $P < 0.0001$). Intrarater consecutive measures on the same participant had an accuracy of about 1.1 mm (95% CI 0.7–1.5 mm) in a neutral position and 1.4 mm (95% CI 0.8–2.0 mm) in an abducted position.[36] Generally, the intrarater reliability of the experienced evaluator was only slightly better than the novice examiner, which indicates DUS is easily learned and does not require much experience to achieve consistent results. Seitz et al[21] reported slightly higher intrarater ICC values, which a difference in participant demographics may cause. More specifically, the subjects in this study were all symptomatic and were older than those in the previous study. However, the difference in ICC values for interrater reliability indicates some discrepancies between examiners.[36] These measures fell within the suggested optimal range of 9 – 10 mm range but were relatively low when compared to other studies.[27]

Overall, diagnostic protocols using DUS in evaluation for SDK by assessing subacromial proximities vary throughout the literature in several ways. First, none of the studies used standardized definition or methodology for measuring subacromial proximities. Some studies investigated AHD using DUS but used different aspects of the acromion (lateral and anterior) to obtain measurements. Other researchers used alternative imaging such as fluoroscopy and magnetic resonance imaging to measure the space between the coracohumeral arch and the greater tuberosity.[18,20,21] Additionally, previous studies have concluded that SDK effects are made more apparent while the subject is holding weight during completing dynamic movement.[8,14] None of the researchers who used diagnostic imaging to measure subacromial proximities in those with SDK required the patient to hold weight during the examination.

Lastly, based on previous studies, researchers suggest SDK may exist throughout shoulder movement and is dependent on arm position. Several authors have noted the occurrence of SDK after approximately 70° GH abduction, which becomes more apparent during downward rotation.[2,4,5,18,23] However, researchers using DUS conclude significant differences may occur in a much smaller range between 45° and 90°.[18,20,21] This assumption may be inaccurate due to the lack of research on AHD in arm elevations greater than 90° of GH abduction. Some researchers instructed patients to conduct arm elevation with the forearm pronated and GH internally rotated.[20] In contrast, most researchers, opted for a "thumb up" position[8,9,14,17,18,20,21] as the alternative may exacerbate shoulder impingement symptoms and intentionally create a more significant decrease in subacromial space. In conclusion, more research based on previous authors' suggestions that utilizing objective and standardized measures throughout GH abduction in the scapular plane is necessary to fully understand the relationship between subacromial proximities and SDK.

2.4. Conclusion

Overall, a substantial body of research exists on various aspects of SDK, but several gaps remain in the literature. Based on the reviewed articles, SDK is assumed to impact the etiology of other shoulder pathologies, yet the cause of specific patterns of SDK remains unclear. The prevalence of SDK in athletic subjects has been thoroughly investigated, but studies focused on the general population are limited. Furthermore, the diagnostic tools and classification methods for SDK lack validity, reliability, and objectivity. The SDT is the most referenced and effective test, while the dichotomized classification of SDK is the most reliable. Utilization of DUS may be a clinically practical, objective, and efficient assessment tool in diagnosing SDK but requires further research to confirm clinically relevant areas of interest and normative measurements of these areas. In all, a clinician's ability to objectively evaluate and diagnose SDK is currently limited, which warrants additional research.

3. METHODOLOGY

The purpose of this study was to compare AHD throughout shoulder range of motion to those with and without SDK in the general population. Reduction in AHD has been associated with shoulder injury and is thought to be a primary cause of impingement of the supraspinatus tendon.[44,45] The results of this study provided information on the accuracy of objective and subjective diagnostic tests for SDK. Although the Scapular Dyskinesis Test (SDT) is a reliable and moderately valid diagnostic tool, it is based on subjective observation of shoulder mechanics.[8,14] Other objective measures of SDK have not been extensively explored. This study also focused on the accuracy of diagnostic ultrasound (DUS) as an unbiased, clinically applicable, and non-invasive method of diagnosing SDK, which fills an essential gap in the current literature. Overall, results of this study will improve clinical diagnosis of SDK through evidence-based practice. The following research questions were investigated in this study:

1. How reliable is DUS in measuring AHD throughout shoulder range of motion, specifically above 90°?
2. What is the difference in AHD measurements between those with and without SDK?

This chapter focuses on the experimental design, population of the study, instruments for data collection, procedures, and data analysis procedures of the current study.

3.1. Experimental Design

This study was a quasi-experimental design. Participants were allocated to groups based on a diagnosis of SDK rather than random assignment while exploring the relationship between AHD and SDK. The independent variable of this study was the diagnosis of SDK and the dependent variable was AHD.

3.2. Population of the Study

A convenience sample of 30 participants were recruited from the Fargo-Moorhead area through email and word-of-mouth. North Dakota State University (NDSU) listservs were used to recruit students and staff, while word-of-mouth was utilized in professional settings throughout the Fargo-Moorhead metroplex. Subjects were included in this study if they were between the ages of 18 and 50 and could achieve at least 120^{o} of shoulder abduction. Exclusion criteria included any non-shoulder musculoskeletal pathology such as cervicogenic shoulder pain, systemic musculoskeletal disease, or spine malalignment such as scoliosis or kyphosis of the thoracic spine. Participants were also excluded if they experienced any shoulder trauma, pathology, surgery, or treatment for these conditions within six months prior to the study. Shoulder pathology is defined as those with chronic conditions such as adhesive capsulitis, confirmed rotator cuff injury, or glenoid labrum tears as well as acute conditions like shoulder fracture, glenohumeral dislocation, or acromioclavicular injury based on methodologies of previous studies.[8,20,41] If at any point participants reported cognitive disability (i.e. memory loss, Alzheimer's disease, or developmental disorders), neurological impairment (i.e. Multiple Sclerosis, nerve entrapment, Parkinson's disease, or paresthesia), or history of musculoskeletal disease (Rheumatoid Arthritis, osteoarthritis, Lyme disease, fibromyalgia) they were excluded from the study as these conditions may impact the provision of informed consent or shoulder range of motion. Participants were required to wear clothing that allowed both scapulae to be visualized such as a racerback tank top. Each participant provided informed written and verbal consent prior to data collection and conclusion of any part of the study.

3.3. Instruments for Data Collection

Two patient-rated outcome measures were used in this study, including an 11-point Visual Analogue Scale (VAS) and the Global Physical Activity Questionnaire (GPAQ)[46] (Appendix A). The VAS was administered verbally pre- and post-test. First, to determine current pain level upon arrival then at the end of testing to reflect pain with movement. Zero was defined as no pain at all while 10 was described as the worst pain imaginable. Each participant also completed the GPAQ prior to data collection to determine each subject's level of activity. This questionnaire was ideal based on its ability to measure multiple components of physical activity including intensity, duration, and frequency with supplemental visual examples (Appendix Figure A). It was created by the World Health Organization (WHO) and categorizes levels of activity to either work, travel, or recreational activities. Physical activity information collected with this tool can also be converted to Metabolic Equivalent Units (METs).[46]

The calculated MET value is a standardized measure of energy expenditure based on oxygen requirement of physical activity (Appendix Figure B). This value can be compared to standards set by the Center for Disease Control and American College of Sports Medicine (ASCM) to determine level of activity.[47,48] The ASCM categorizes physical activity into light (<3 METs), moderate (3-6 METs), and vigorous (>6 METs) levels based on the METs required to complete the task.[48] Categorization of energy expenditure using the GPAQ data follows similar guidelines to the ASCM and suggests either moderate (4.0 METs) or vigorous (8.0 METs) values in work and recreation settings should be assigned.[46] A MET value (4.0 METs) was only assigned to the transportation section of the questionnaire if the individual reported cycling or walking. For this study, overall energy expenditure was calculated from the GPAQ and compared to the WHO recommendations, which advise a minimum of 150 minutes of moderate-intensity physical activity, 75 minutes of vigorous-intensity physical activity, or an equivalent combination of both intensity levels to achieve at least 600 MET-minutes.[46] Additionally, AHD was measured using DUS. Diagnostic ultrasound is a noninvasive method of imaging the musculoskeletal system. The Terason uSmart® 3300 Diagnostic Ultrasound (MedCore LLC., Tampa, FL) with a 15L4 transducer (4.0-15.0 MHz) and Aquasonic® ultrasound gel (parker Laboratories, Inc, Fairfield, NJ) was used. This device has internal storage, which was used to save DUS images.

3.4. Procedures

Prior to participant enrollment and data collection, this research study was approved by the NDSU Institutional Review Board (IRB). Recruitment was conducted through email at NDSU and in-person communication at NDSU and the Fargo-Moorhead area. The NDSU listserv was used to contact students and staff who may be interested in participating in this study. Those who met inclusion and exclusion criteria were deemed eligible for participation in the study. Both shoulders were examined in every participant and evaluated independently from the contralateral shoulder. Recruitment continued until data was collected on a minimum of 30 shoulders with normal scapular control and 30 with SDK. Since a single subject can have SDK on one side and no SDK on the other, the minimum number of participants was 30. Before meeting for data collection, the informed consent sheet, instructions on SDT, examples of required range of motion, and supplemental information including testing attire and directions to the testing location were emailed to each participant. Based on recommendations by previous researchers, the examiner for this study completed standardized training on SDK.[8,14] This included picture examples (Appendix C) of SDK and a written description of diagnostic criteria (Appendix D). The examiner was also trained in DUS and practiced imaging, recording, and measuring AHD prior to collection data for the study.

After preliminary information was obtained and examiner training was concluded, data collection began. Testing was completed in the Benson Bunker Fieldhouse on the NDSU campus, room 24 where subjects attended a single, one-hour session. Upon arrival, the informed consent was reviewed with the participant and signed after all participant questions have been answered. The VAS was administered verbally, and participants completed the GPAQ followed by a review of the testing procedure information. Demographic information including age, height, weight, and hand dominance was also recorded at this time. Body weight was self-reported and collected to determine the mass of hand weights used. Those who weighed less than 68.1 kg (150 lbs) used a 1.4 kg (3 lbs) dumbbell, while those weighing 68.1 kg (150 lbs) or more used a 2.3 kg (5 lbs) dumbbell based on suggestions by the original author.[8,14]

A goniometer was used to measure glenohumeral (GH) elevation in flexion and abduction, throughout the testing procedure. To improve efficiency during DUS imaging, goniometry took place prior to testing and weights were not used in this step. Participants were seated in a backless chair with their arms at their sides, thumbs up, and elbows extended. While the examiner faced the participant from the side, the axis of the goniometer was placed over the lateral aspect of the humeral head, the movement arm followed the midline of the humerus throughout shoulder motion, and stationary arm remained aligned with the mid-axillary line. Participants were then be asked to raise their arms 10° (confirmed with goniometry). This point was marked on a stationary PVC pole. This process was repeated for every 10° until 120° is attained. These markers were used while DUS images are collected to maintain participant positioning during arm elevation.

The DUS data were collected first to prevent bias in diagnosing SDK. Diagnostic ultrasound frequency settings were manipulated to ensure image quality based on the individual's anatomy. For example, frequency and focal zone were changed for those with more adipose tissue. With subjects in position with their arms at their sides, holding dumbbells, Aquasonic® ultrasound gel was put on the transducer prior to positioning it obliquely over the anterolateral aspect of the shoulder until both the acromion process and greater tuberosity were in view. Marks were made on the skin in line with the proximal and distal aspect of the transducer to improve consistency of transducer placement as arm elevation increased. Participants were asked to raise and hold the weight in 10° increments, following the markers on the PVC pole, until 120° of GH flexion is achieved. When an optimal image was created, the screen was frozen and saved for later analysis. Images were saved for each increase in movement and labeled with the associated participant number, field of movement, and degree of elevation. A 30 second rest period was observed between each increase in arm elevation to prevent fatigue. This process was repeated on the contralateral side.

After testing in the frontal plane was concluded, the same testing procedure was repeated in the scapular plane, which was defined as 30° of GH movement toward the midline of the body from the frontal plane.[21,26] During a one minute rest period, a goniometer was used to verify the scapular plane. Participants were asked to abduct their arms to approximately 90° with their elbows flexed. The axis of the goniometer was placed over the acromion process with the movement arm over the mid-line of the humerus and the stationary arm parallel to the floor. Each subject was asked to raise their arm to approximately 90° of abduction. Then they were instructed to adduct their arm until 30° of forward movement was achieved. The stationary PVC poles were also utilized in this position and placed against the inside of the participant's arm to maintain the scapular plane and appropriate arm elevation. All DUS images were collected using the same process described for the frontal plane. Goniometry to identify the scapular plane and testing procedures were repeated on the contralateral arm.

After DUS imaging was completed, a three-minute rest period was observed during which the SDT was reviewed with participants. This test is a valid and reliable[8,14] subjective assessment of SDK, but a methodology has not been consistently utilized in the literature. This study applied recommendations from the original author of the SDT including training of the examiner, arm positioning, and weighted, bilateral arm raises.[8,14] For this study, SDK was defined as any abnormalities in scapular kinematics during either upward or downward scapular rotation. The Yes/No dichotomized method was utilized in this procedure rather than the Four-Type diagnostic criteria (Appendix D). These techniques have similar validity and reliability,[9,11,12] but the dichotomized approach combines types I-III as a "yes" diagnosis of SDK, while type IV indicates a "no." The examiner recorded any observed, specific pathomechanics and aberrant movement patterns (i.e. winging or inferior pole prominence) during upward and downward rotation separately, in addition to their dichotomized diagnosis of SDK (Appendix E). The SDT was completed in both the frontal and scapular planes and the order was randomized to prevent bias. To conduct the SDT, participants were placed in the original testing position with weights and asked to raise their arms bilaterally, as far as possible over a three second count then lower their arms to the starting position in one of two planes (scapular and frontal) for a total of five repetitions. To prevent fatigue, the subject rested for three minutes before completing the second set of arm raises in the second plane. This was decided based on the recommendation that shorter rest periods (30-90 seconds) increase levels of anabolic hormones while longer rest intervals (2-5 minutes) allow for recovery while maintaining force production and rate of force development.[49]

After all data was collected for all participants, DUS images were randomly re-numbered by the supervising researcher to create blinding of the examiner. Due to the inconsistencies in the literature on AHD measurements, an additional step was utilized to create a more objective, consistent approach to this process. Previous studies have assessed AHD using the most lateral point of the acromion to various landmarks including the greater tuberosity of the humerus, point of entry of supraspinatus tendon to humeral head, tangential distance, and shortest distance to the humeral head (Figure 4). In the current study, the examiner drew a horizontal line across the image in line with the humeral head. A second line was made vertically from the most lateral point of the acromion process to the humeral head, like number two in the figure below. The designated points at which AHD was measured consisted of the most lateral portion of the acromion process and the point indicated by the intersection of the two lines. To assess intra-rater reliability, the examiner was blinded to their measurements by saving a copy of the image with the measurement and re-opening the original to perform subsequent measurements. This process was repeated a total of three times for each original image.

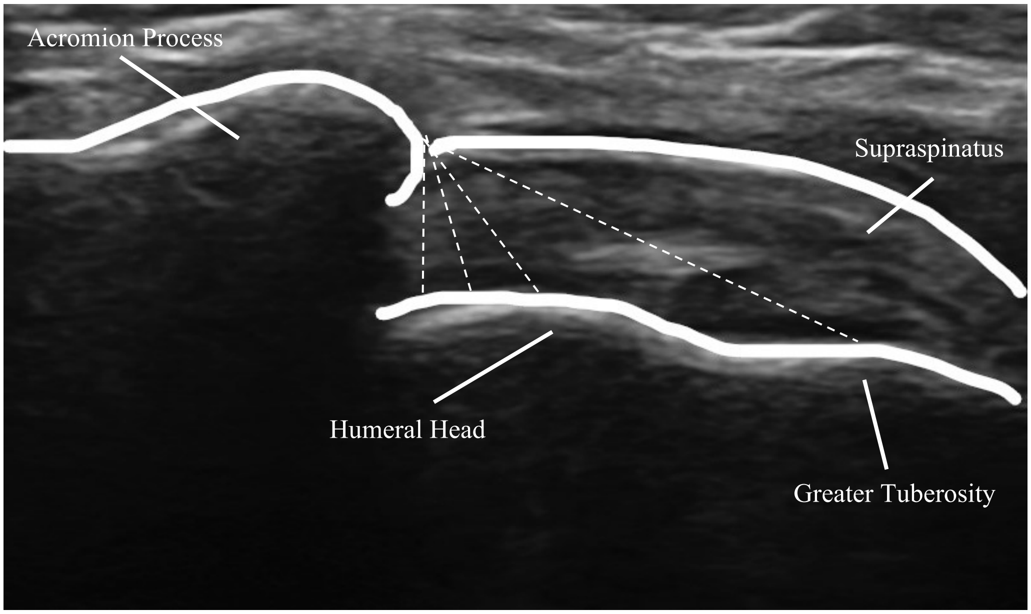

Figure 4: Various methods used to measure AHD indicated by dashed lines.

3.4.1. COVID-19 Procedures

North Dakota State University IRB approved precautions was applied to prevent the transmission of COVID-19 during the testing procedure. COVID-19 screening questions and expectations was communicated to the participant prior to arrival for data collection. For example, facemasks were required for the examiner and all participants for the duration of the study. When possible, the examiner maintained a minimum of 6 feet of distance between themselves and the participant. This included during examiner guided instruction of procedures and completion of paperwork. Tools and surfaces including the DUS machine, chairs, and tables were cleaned with disinfectant between participants. In the event COVID-19 symptoms or diagnosis were reported, the subject was asked to reschedule their session with the examiner.

3.5. Data Analysis Procedures

Demographic information was assessed to obtain descriptive statistics including means and standard deviations. Intra-rater reliability of AHD measurements from DUS images were assessed using interclass correlation coefficients (ICC). For this study, an ICC (3,1) was used to determine the consistency of one examiner in a two-way mixed-effects model. Changes in AHD in those with and without SDK was assessed with a multiple regression analysis. All assumptions were tested to ensure this analysis was appropriate. Due to limited research on etiology of SDK, interactions of sex, height, and weight were controlled during data analysis. One of the only factors identified in the literature as having an impact on the occurrence of SDK is overhead activity.[14,16,50] Results were clustered by subject number across four outcomes: dominant arm in scapular plane, non-dominant arm in scapular plane, non-dominant arm in frontal plane, and non-dominant arm in frontal plane. All data analysis was completed using the Statistical Package for Social Science (SPSS) 27.0.

4. MANUSCRIPT[1]

4.1. Abstract

[Background] Scapular dyskinesis (SDK) is defined as abnormal posture or movement of the scapula. SDK is related to increased shoulder pain and injury. Current literature on the relationship between SDK and shoulder pathology is limited and employs inconsistent, subjective diagnostic tests and criteria.

[Hypothesis] Individuals with SDK experience a decrease in subacromial space, which could be objectively measured using diagnostic ultrasound (DUS).

[Study Design] Quasi-experimental; Level of evidence, 3

[Methods] A convenience sample of 33 individuals (m=12, f=21, age 26 ± 6.46) were evaluated in the study. Upon arrival to testing, participants completed participant-rated outcome measures and provided demographic information. Acromiohumeral distance (AHD) measurements using DUS were collected bilaterally, as participants raised and held dumbbell weights throughout the range of motion in the scapular and frontal planes. Goniometry was completed to verify movement plane and 10^{o} increments of arm elevation. The Scapular Dyskinesis Test (SDT) was conducted in the scapular and frontal planes, while scapular movement was evaluated during upward and downward rotation. The AHD was measured from the most lateral point of the acromion to the humeral head. Subject numbers were randomized by a second researcher and then AHD was reassessed to determine reliability.

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[1] This chapter was co-authored by Ariel Ives, Dr. Kara Gange, and Dr. Laura Dahl. Ariel Ives collected DUS images, measured AHD, and conducted the SDT. Ariel Ives developed the conclusions discussed in this chapted. Dr. Kara Gange served as proofreader and assisted with development of the methodology. Dr. Laura Dahl assisted with development of statistical analysis methodology and interpretation of results of the statistical analysis.

[Results] Across all measurements, the ICC (3,1) was .933 (95% CI, .912-.951). Shoulders were examined bilaterally in all participants. A total of 31 were diagnosed with SDK shoulders (right: n=14/33, 42.4%; left: n=17/33, 51.5%). Results of a multilinear regression between SDK and AHD only reflected significance on the non-dominant arm in the frontal (b=.013, p<.05) and scapular (b=.002, p<.05) planes.

[Conclusions] Diagnostic ultrasound is a reliable tool, which can be used to assess AHD. Additionally, a significant relationship exists between SDK and AHD in non-dominant shoulders.

[Clinical Relevance] These results may be used to improve objective clinical diagnosis of SDK. With more research, these results may also improve preventative treatment for injuries associated with SDK and shortened AHD.

[Key Terms] Shoulder, Diagnostic Ultrasound, Biomechanics, Motion Analysis

4.2. Introduction

Scapular Dyskinesis (SDK) is a condition characterized by abnormal posture and movement of the shoulder blade, which is typically caused by unbalanced muscular contraction. Usually, this condition presents as protrusion of the superior, medial, and inferior borders of the scapula and disruption of scapulohumeral rhythm.[2,10] Muscles, which act to move the scapula, work synchronously as force couples to create a rotation during shoulder abduction and adduction.[1,6,10] Inefficiency in one or more of these muscles can lead to the visible abnormalities associated with SDK. For example, downward and upward rotation requires synchronous activation of the upper, middle, and lower trapezius, rhomboid major and minor, serratus anterior, and levator scapulae.[34,41] If one of these muscles is underactive or overactive, posture and movement of the scapula will be affected.[3,38] Previous research has indicated a high prevalence of SDK in both athletic and general populations.[12,18] Additionally, a relationship between SDK and increased risk of shoulder pain and injury has been documented.

Diagnostic criteria and testing methods for SDK vary significantly throughout the literature. One of the most common classification systems utilized in previous research is the Four-Type Method,[9] but recent studies support a dichotomized approach has resulted in more reliable and valid recognition of SDK.[11,12] The Scapular Dyskinesis Test (SDT) is frequently used to assess scapular movement and scapulohumeral rhythm.[8,14] This test consists of five repetitions of weighted glenohumeral abduction in multiple planes of movement. Although this is the most common diagnostic test used, many studies to not employ procedures recommended by the original author. These inconsistencies limit the accuracy and applicability of results in both clinical and educational settings.

Previous authors have presented mixed results on changes in acromiohumeral distance (AHD) in those who present with SDK when measured with diagnostic ultrasound (DUS). The most lateral point of the acromion process is used throughout the literature as the first, most superficial reference point. However, the second point of interest is inconsistent in previous research and included several points between the humeral head and greater tuberosity.[24] In general, DUS is a reliable and valid method of assessing AHD, but previous study results can not be compared due to vast differences in methodologies.[20,36,51]

4.3. Methods

For this study, a convenience sample of the university area via email and word-of mouth was employed. Recruitment continued until a minimum of 30 samples were collected on shoulders with SDK and without SDK. A total of 33 participants were included in the study after meeting inclusion criteria, which consisted of being between the ages of 18-50 years and overhead arm movement to a minimum of 120°. Participants were excluded if they had any non-shoulder musculoskeletal disease or spine malalignment; shoulder trauma, injury, disability, surgery, or treatment for these conditions within six months prior to the study; or pain which inhibited overhead shoulder movement to at least 120°. All data was collected during a single session for each participant. Upon arrival, the informed consent was signed, demographic information was collected, and the Global Physical Activity Questionnaire (GPAQ)[46] was completed. Participants were also asked to rate their current level of pain in each shoulder using the Visual Analogue Scale (VAS).

The participants were then seated in a backless, armless chair and asked to refrain from moving their body as much as possible for the duration of the study. Data were collected in two fields of movement including the scapular and frontal planes, which were randomized during DUS imaging and the SDT. The first plane in which data were collected was randomized for each participant. The frontal plane was measured as 0° of glenohumeral flexion while the arm was abducted, while the scapular plane was measured at 30° of glenohumeral flexion. Two PVC poles were used to maintain arm movement in the designated plane. After the plane of movement was confirmed with goniometry, the first pole was placed posterior to the elbow and the second was placed posterior to the wrist while the arm was extended at approximately 90° of GH abduction.

Arm elevation was then measured in 10° increments using a goniometer and marked on the PVC poles. Next, participants were given either a 3lb or 5lb dumbbell based on their reported body weight.[8,14] Ultrasound gel and the linear transducer were placed on the skin to visualize the acromion process and humeral head. The position of the transducer was marked on the skin to ensure the same area was measured throughout the range of motion. Participants then raised the weight to the first mark and maintained this elevation while an image was taken using DUS. The weight was then lowered, and the participant was allowed to rest for 30 seconds prior to raising the weight to the second mark. This process was repeated for the remaining marks until 120° was achieved. Goniometer measurements to confirm the plane of movement and elevation were repeated for the second plane on the same arm and for the scapular and frontal planes on the contralateral side.

After DUS imaging was complete, a three-minute rest period was observed and the participant was given instructions on the SDT. For this study, SDK is defined as any abnormalities in scapular kinematics during either upward or downward scapular rotation using a yes/no dichotomized approach to diagnosis. To complete the SDT, participants were placed in the original testing position with weights and were asked to raise and lower their arms bilaterally, as far as possible over a three second count in one of two planes (scapular and frontal) for a total of five repetitions. To prevent fatigue, the subject rested for three minutes before completing the second set of arm raises in the second plane. Observed abnormalities were recorded on paper by the examiner. At this point data collection was complete and participants were dismissed.

Measurement of AHD was completed using the most lateral point of the acromion process as the first point of interest. While using an onscreen caliper, a horizontal line was made parallel to the humeral head. Then, a vertical line was drawn from the acromion process downward until the lines intersected. The distance of this line was recorded as an objective approach to AHD measurement (Figure 5). Once all measurements were completed a second researcher randomized all subject numbers, the first examiner was blinded to this process. After randomization was complete, the first examiner re-measured all images taken at 30°, 60°, 90°, and 120° of arm elevation three times per image. The examiner was also blinded to their measurements by saving a copy of the image and re-opening the original to perform subsequent measurements. Measurements collected after randomization were used to assess intra-rater reliability.

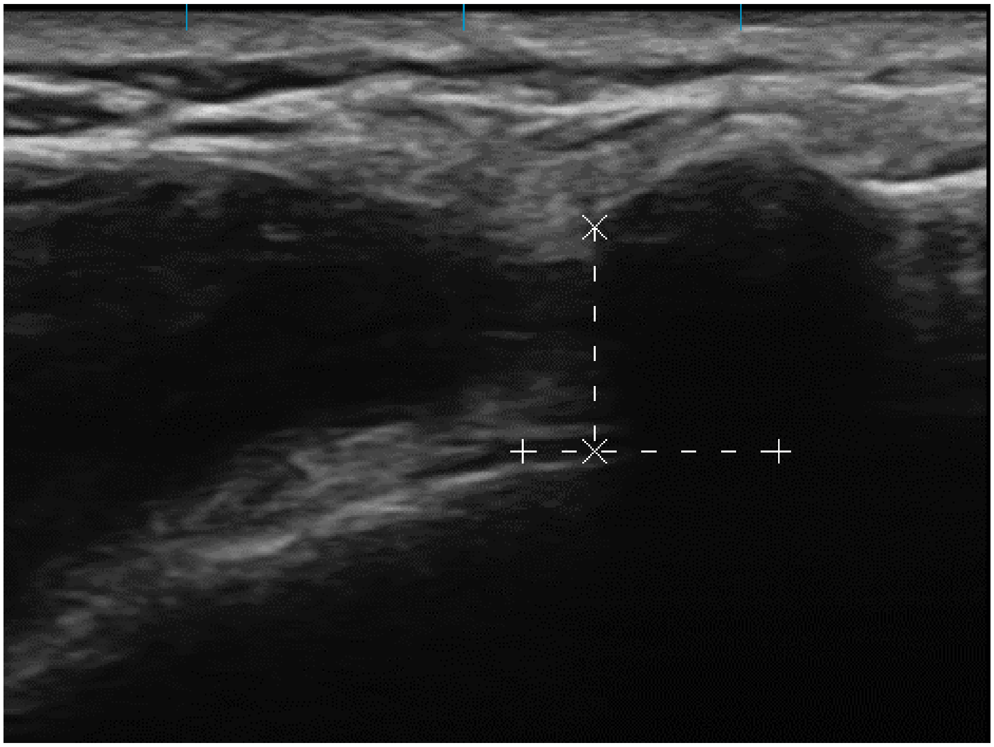

Figure 5: Standardized measurement of AHD on DUS.

4.3.1. Statistical Anlaysis

Data collected after randomization was used to assess reliability of DUS and AHD measurement techniques. This data was analyzed using an ICC (3,1) to determine the consistency of one examiner in a two-way mixed-effects model. In addition, four multilinear regressions with standard errors clustered by participant were utilized to examine the relationship between SDK and AHD for each arm and movement plane (dominant arm, frontal plane; dominant arm, scapular plane; non-dominant arm, fontal plane; and non-dominant arm, scapular plane). Each of the four regression models controlled for participant sex (male or female), weight (in kg), MET (as measured by the WHO GPAQ), and average overhead activity (as measured by participant estimated minutes per day). All regression analyses were tested for multicollinearity, normality of residuals, and homoscedasticity of variance. No assumptions were violated.

4.4. Results

A total of 33 participants were examined in this study, 21 (63.6%) were female and 12 (36.4%) were male, with a mean age of 26 ± 6.46 years. Other demographic data including height, weight, overhead activity, and VAS scores are reported in Table 9. Most participants were righthanded (n=30, 90.9%) while only 3 (9.1%) participants reported left hand dominance.

Table 9: Participant Descriptive Statistics

	Age (years)	Height (in)	Weight (lbs)	OH (min)	VAS Right	Vas Left
Mean	26.0	67.21	170.30	39.91	.30	.12
SD	6.46	3.66	37.51	93.48	1.02	.48
Min	18	61.0	105.0	.0	.0	.0
Max	41	77.0	260.0	540.0	4.0	2.0
			Female			
Mean	26.24	65.57	160.9	22.86	0.38	.1
SD	7.12	2.6	48.55	22.89	1.2	.44
			Male			
Mean	25.58	70.08	176.25	69.75	.17	.17
SD	5.38	3.55	41.69	151.47	.58	.58

OH, overhead activity; VAS, visual analogue scale; SD, standard deviation

4.4.1. Global Physical Activity Questionnaire

Data collected from the GPAQ revealed 18% (n=6/33, f=3, m=3) of participants were not meeting minimum activity levels when compared to standards set by the World Health Organization (WHO). In general, most vigorous activity was reported during recreational activity. The lowest level of activity was reported in the transportation category. Means for GPAQ data are reported in Table 10.

Table 10: Average Global Physical Activity Questionnaire Results in MET Values

	Work V.	Work M.	Transport	Recreational V.	Recreational M.	Weekly Avg.	Daily Avg.
All	389.58	683.64	142.55	1540.61	661.21	3417.58	488.23
Male	614.67	993.33	332.0	1630.0	785.0	4355.0	622.14
Female	260.95	506.67	34.29	1489.52	590.48	2881.91	411.70

V, Vigorous; M, Moderate

4.4.2. Scapular Dyskinesis Test

Both shoulders were examined on each participant; therefore, data was collected on a total of 66 shoulders in this study. Scapular dyskinesis was diagnosed in 42.4% (n=14/33, f=10, m=4) of right shoulders and 51.5% (n=17/33, f= 10, m=7) of left shoulders. Overall prevenance of SDK without consideration of the subject's hand dominance was 46.97% (31/66). Diagnosis of SDK is reported according to laterality, plane of movement, and direction of arm movement and displayed in Table 11. In most cases, SDK was observed during the downward phase of scapular rotation.

Table 11: SDK Diagnosis

Plane of Movement	Frontal				Scapular			
Arm Movement	Upward		Downward		Upward		Downward	
Laterality	Right	Left	Right	Left	Right	Left	Right	Left
Total No	25	21	20	17	23	20	19	17
Total Yes	8	12	13	16	10	13	14	16

4.4.3. Diagnostic Ultrasound

Diagnostic ultrasound images were collected at 12 points of arm elevation in two planes of movement for each arm. Thus, 48 measurements were collected from each participant, which resulted in a total of 1584 measurements across all subjects. Mean AHD measurements for both planes of movement at each point of arm elevation are listed in Table 12. Additionally, AHD measurements for each participant are displayed in Figure 5. Results for ICC for a single rater across three measurements after randomization of subject number was near perfect (.933, 95% CI, .912-.951) with a Cronbach's Alpha of .933.

Table 12: Mean AHD Measurements

Plane of Movement	Frontal						Scapular					
	Dominant			Non-Dominant			Dominant			Non-Dominant		
Arm Elevation	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
10	1.08 (.20)	1.63	0.74	1.02 (.25)	1.53	0.73	1.09 (.20)	1.99	0.52	1.05 (.20)	1.33	0.65
20	.97 (.18)	1.32	0.59	.97 (.25)	1.34	0.71	1.0 (.17)	1.99	0.52	.98 (.20)	1.4	0.65
30	.86 (.21)	1.29	0.52	.86 (.25)	1.55	0.55	.96 (.23)	1.29	0.41	.98 (.23)	1.43	0.48
40	.86 (.26)	1.42	0.5	.89 (.26)	1.42	0.47	.94 (.26)	1.52	0.46	.98 (.25)	1.37	0.48
50	.89 (.34)	1.71	0.33	.94 (.28)	1.6	0.48	.89 (.30)	1.6	0.47	.95 (.34)	1.6	0.41
60	.91 (.35)	1.86	0.46	.9 (.33)	1.65	0.5	.91 (.28)	1.55	0.43	.88 (.31)	1.53	0.48
70	.92 (.34)	1.93	0.45	.91 (.31)	1.64	0.44	.88 (.31)	1.62	0.38	.9 (.32)	1.63	0.41
80	.97 (.36)	1.91	0.39	.92 (.37)	1.8	0.56	.95 (.34)	1.87	0.49	.86 (.31)	1.7	0.47
90	.96 (.37)	2.08	0.54	.94 (.37)	1.82	0.58	.96 (.32)	1.98	0.47	.92 (.35)	1.83	0.47
100	1.01 (.34)	2.14	0.66	.94 (.26)	1.83	0.53	1.0 (.33)	1.86	0.63	.96 (.34)	1.87	0.48
110	1.0 (.32)	1.96	0.65	1.0 (.29)	1.63	0.51	1.04 (.30)	1.95	0.67	.97 (.26)	1.6	0.54
120	1.09 (.38)	2.3	0.57	1.12 (.32)	1.99	0.4	1.07 (.33)	1.96	0.65	1.06 (.32)	2	0.6

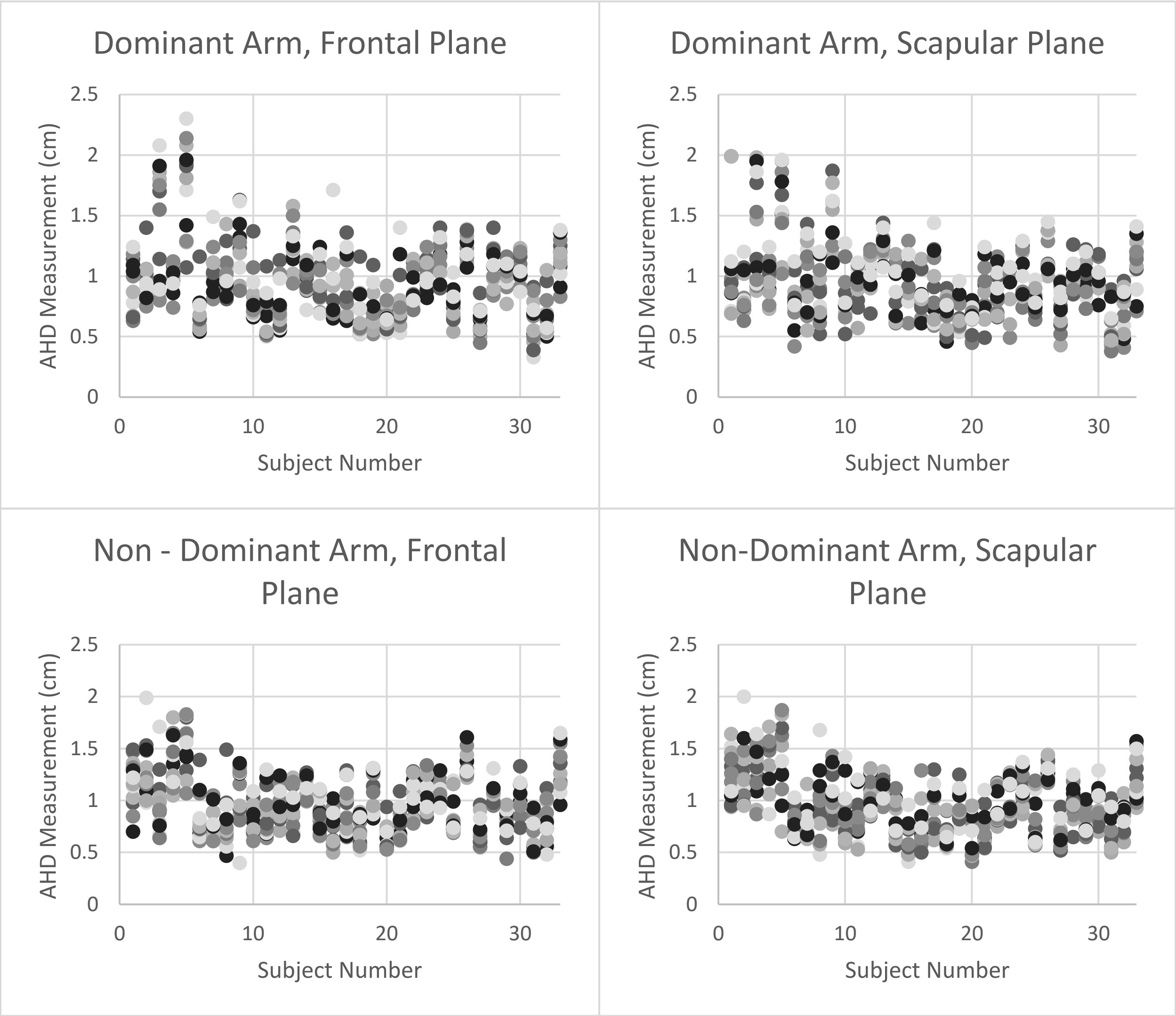

Figure 6: AHD measurements by subject number

Results indicated no significant relationship between SDK and AHD in the dominant arm in the frontal and scapular planes (see Table 13). However, a significant, positive relationship was revealed for the non-dominant arm in the frontal (b=.240, p<.05) and scapular (b=.273, p<.05) planes.

Table 13: Multilinear Regression Results

	Dominant Arm, Frontal Plane			Dominant Arm, Scapular Plane			Non-dominant Arm, Frontal Plane			Non-dominant Arm, Scapular Plane		
Predictor	b	SE	sig	b	SE	sig	b	SE	sig	b	SE	sig
Sex (M=0, F=1)	-0.262	0.094	**	-0.248	0.077	**	-0.070	0.073		-0.140	0.064	*
Weight	-0.001	0.001		-0.000	0.001		0.002	0.001		0.002	0.001	*
MET	0.000	0.000		0.000	8.71e-06		0.000	0.000	*	0.000	0.000	***
Average OH	0.000	0.000		-0.001	0.000	*	0.000	0.000		-0.001	0.000	**
SDK	0.008	0.087		-0.040	0.069		0.240	0.091	*	0.273	0.082	**
Constant	1.195	0.200		1.160	0.177		0.507	0.228		0.479	0.189	
Variance Explained	0.174			0.167			0.130			0.230		

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

4.5. Discussion

4.5.1. Research Question 1: Reliability of DUS Methods

Intra-rater reliability for DUS in this study was determined to be nearly perfect (.933, 95% CI, .912-.951). These results were slightly higher, but similar to previous studies on SDK and AHD measurements;[21,36,52] More specifically, Seitz et al[21] reported (ICC$_{3,2}$ = 0.88-0.96) for AHD measurements and utilized a similar methodology with measurements at rest, 45°, and 90° of static active arm elevation. Pijls et al[36] completed measurements at neutral and 60° of active arm elevation and also produced similar ICC values. At neutral, intra-rater reliability was 0.92 for the novice and 0.94 for experienced examiner. At 60° the intra-rater ICC values slightly decreased (novice = 0.87, experienced = 0.90), but interrater reliability remained relatively similar in both positions (neutral = 0.70, 60° = 0.64). Furthermore, Mackenzie et al[52] completed an ICC$_{2,1}$ of 0.88 in neutral and 0.68 during 60° of active arm elevation. Although this type of ICC indicates some differences in methodology compared to the current study, reported statistics were similar across all four articles, including the current study.

However, many of these studies did not investigate active arm elevation up to 120°. Therefore, our results support using DUS throughout normal arm range of motion without decreasing intra-rater reliability. Additionally, several points of interest on the humerus have been used to measure AHD in the past.[24] To address this, probe placement and measurement of AHD was standardized in the current study by using a horizontal line across the humeral head and vertical line from the acromion process. More research is needed to determine the impact this process had on reliability, but it is likely that intra-rater reliability remained high as a result.

4.5.2. Research Question 2: Relationship Between AHD and SDK

Typically, clinical examination involves bilateral comparison to distinguish between normal anatomy and pathology. However, previous research has indicated that scapular mechanics should not be assessed in the same way.[12] The results of this study indicated a significant, positive relationship exists between AHD and SDK on the non-dominant arm in both planes of movement. Increases in AHD on the dominant arm has been documented in athletic populations by other researchers.[53] In a previous study,[53] the AHD in the dominant arm was significantly smaller with the arm at neutral (-0.4 ± 0.6 mm), 45° (-0.5 ± 0.8 mm), and 60° (-0.6 ± 0.7 mm) of active abduction compared with the non-dominant side. Although the current study did not compare changes in AHD bilaterally, smaller AHD measurements were noted in the dominant arm (frontal plane: $b = 0.008 \pm 0.087$; scapular plane: $b = -0.040 \pm 0.069$) compared to the non-dominant arm (frontal plane: $b = 0.240 \pm 0.091$; scapular plane: $b = 0.273 \pm 0.082$). Similar trends have been noted in scapular mechanics.[12] The primary focus of the study by Uhl et al[12] was to investigate clinical assessment methods of SDK. In this process, a significant difference in bilateral asymmetries was noted in those with symptomatic shoulders (54.3%, n=19, $P = .002$) versus those that were asymptomatic (14.3%, n=3, $P = .002$) during shoulder flexion. Overall, the incidence of symmetry ranged between 71% and 77% for all subjects despite symptoms, which authors related to healthy adaptations in scapular mechanics. The current study supports the conclusion that a difference exists in AHD in dominant versus non-dominant arms. Therefore, highlighting the importance of limiting bilateral comparison of scapular mechanics.

The positive relationship between AHD and SDK indicates that those with SDK on average had an increase in AHD in the non-dominant arm (scapular plane = .273 ± 0.082, frontal plane = 0.240 ± 0.091). These results are different compared to other researchers who indicated either no change[21] or decrease in AHD[20] in those with SDK. Seitz et al[21] documented no significant interaction (*P* = .491) or main effect (*P* = .754) of dyskinesis on AHD. This study focused on comparison of AHD to 3D kinematic data with the arm at rest, 45°, 60°, and 90° of active arm elevation in the scapular plane.[21] Researchers utilized a suspension harness to maintain arm elevation in this study, which limits muscular activation and may have contributed to the lack of significant findings. Conversely, Silva et al[20] noted a significantly greater decrease in AHD in subjects with SDK between 0° (n = 42, 19.3mm, p = 0.002) and 60° (n = 64, 13.8 mm, p = 0.002) with active arm elevation. Therefore, a 21.4 ± 0.92% (P = 0.007) difference in AHD reduction between the two groups.[20] During data collection the forearm was pronated and the humerus was internally rotated, creating a more durastic decrease in AHD.

Several reasons exist for noted differences between the existing literature and the current study including muscle activation and statistical analysis in the current study. A unique approach was utilized to assess the relationship between SDK and AHD in this study as utilization of multilinear regressions is uncommon in studies within this field. Multilinear regressions were used because of the continuous dependent variable and multiple variables. The data was clustered to account for the violation of independence that would otherwise occur. Although this approach satisfied all assumptions, some oddities were identified in the data. Multiple coefficients had b scores close to zero indicating no relationship exists, yet some variables still had significance (Table 12). However, this was accompanied by very low standard deviations. This means even small changes in the data are significant. Typically this would call for rescaling of the variable, but this may not be indicated since MET values are considered to be a unique unit.

4.5.3. Other Observations

In terms of overall prevalence, this study reflects similar results to previous studies conducted in both athletic and general populations (Table 14).[12,23,26] Demographic statistics of the current study differed in that over half of the participants in the current study were female, which is uncommon in previous studies. Additionally, some of the most quoted studies on SDK and AHD had younger [14.8 years (range 11 to 18 years)][20] or older (control: 50 ± 7 years, injured: 57 ± 14)[43] sample populations compared to the current study (26.0 ± 6.46 years). While collecting demographic data, participants were asked to estimate time spent performing overhead activity in a day in addition to physical activity levels estimated using the GPAQ. This was not completed in previous studies and may be a solution to improve objective comparison between research on non-athletic and active populations.

Table 14: Prevalence of SDK in the Existing Literature

Author	Population	N	Prevalance of SDK
Uhl 2009	General population	56	71% - 77%
Hickey 2018	Asymptomatic athletes	160	35%
Clarsen 2014	Elite handball players	206	42% slight SDK in flexion 21% slight SDK in abduction 7% obvious SDK in flexion 2% obvious SDK in abduction

Other interesting findings involve VAS pain scores, level of activity and diagnosis of SDK. Four participants in the study reported pain on the VAS yet, only one of these participants had SDK. Previous studies indicated that those with SDK are at a greater risk of experiencing shoulder pain;[23,26] however, a similar trend is not grossly obvious in the current study. Level of activity, specifically overhead activity, has also been reported to be risk factor for developing SDK and shoulder pathology.[23,26] In the current study 18% (n=6/33, f=3, m=3) were inactive based on GPAQ results. Of these individuals, one female and two males were diagnosed with SDK. Additionally, those deemed inactive with SDK reported well below the mean time spent doing overhead activity reported by all subjects. This suggests that SDK in the general population may not be related specifically to activity or overhead movement.

Previous studies only investigated AHD at 0° of arm movement with no muscle activation. When arm abduction was included, the highest point reported was 90° of passive arm elevation.[52,54,55] Measured AHD of the current study cannot be accurately compared to other research that reported AHD at 0° of passive arm movement due to the use of weights and the first measurement taken at 10° of arm abduction. Studies that required active arm elevation reported similar mean AHD measurements at 45° (8.3 ± 1.9 mm) and 60° (7.6 ± 1.7 mm)[55] when compared to the current study at 40° (dominant arm: frontal plane = 0.86 ± 0.26, scapular plane = 0.94 ± 0.26; non-dominant arm: frontal plane = 0.89 ± 0.26, scapular plane = 0.98 ± 0.25) and 60° (dominant arm: frontal plane = 0.91 ± 0.35, scapular plane = 0.9 ± 0.33; non-dominant arm: frontal plane = 0.91 ± 0.28, scapular plane = 0.88 ± 0.31). Conversely, other authors reported smaller AHD measures in non-athletic and uninjured subjects at 90° of passive arm movement than the current study, as noted previously.[54] The current results support arguments made by others regarding the increase in AHD with muscle activation.

Studies that have collected AHD measurements with passive arm elevation consistently report lower AHD compared to studies with active arm elevation.[54] For example, Wang et al[54] was one of the few studies to measure AHD in the frontal and scapular planes of movement, but measurements were only collected at 0° and 90° with passive arm elevation. In this study mean AHD ranged from 5.6 ± 1.5mm to 9.6 ± 3.1mm in the dominant arm and 5.2 ± 1.6 to 9.6 ± 3.3mm in the non-dominant arm. In the current study, AHD measurements ranged from 0.86 ± .21cm to 1.09 ± 0.38cm in the dominant arm and .86 ±.31cm to 1.12 ± .32 in the non-dominant arm. Additionally, Mackenzie et al[52] assessed percent changes in AHD in non-athletic controls verus athletes and documented a greater percentage reduction in the non-dominant shoulder (Δ=5.90% ± 2.50%, p = 0.02) in men. Significant changes in AHD were noted bilaterally in women (dominant shoulder: Δ=10.76% ± 0.06%, p=0.01; non-dominant shoulder: Δ=15.54% ± 0.07%, p=0.02). This information indicates AHD may be influenced by muscular activity and endurance. This study may exacerbate the occurancce of this phenominon due to added resistance via dumbbell weights.

Although this study supplements knowledge regarding SDK and AHD, several gaps in the literature remain. Studies relating demographic information to risk factors of SDK and changes in AHD are scarce. The current study suggests that SDK is more common in females, but this may be due to sample population demographics and small sample size. Additionally, more information is needed on normal AHD measurements. Authors have indicated that DUS assessment of AHD is similar to radiographs but normal ranges are rarely reported in the literature. Lastly, prospective and longitudinal studies are needed to determine the association between SDK, changes in AHD, and risk of shoulder injury. The relationship between SDK and AHD have been related to an increased prevalence of shoulder pain and pathology individually;

however, these factors have not been studied together. After this information is obtained, the impact of rehabilitation for SDK on AHD and reduction of injury risk can be conducted to improve evidence-based practice.

4.6. Conclusion

In this study, reliability of DUS measurements of AHD were nearly perfect despite requiring active arm elevation well above 90º of movement. More specifically, ICC values were higher than previously reported results, which may be due to the standardization of probe placement and measurement processes. A significant relationship between AHD and SDK was found in the non-dominant arm. Clinically, this highlights the importance of limiting bilateral comparison of scapular mechanics, which is a rare occurrence in medicine. Lastly, this study suggests those with SDK experience an increase in AHD.

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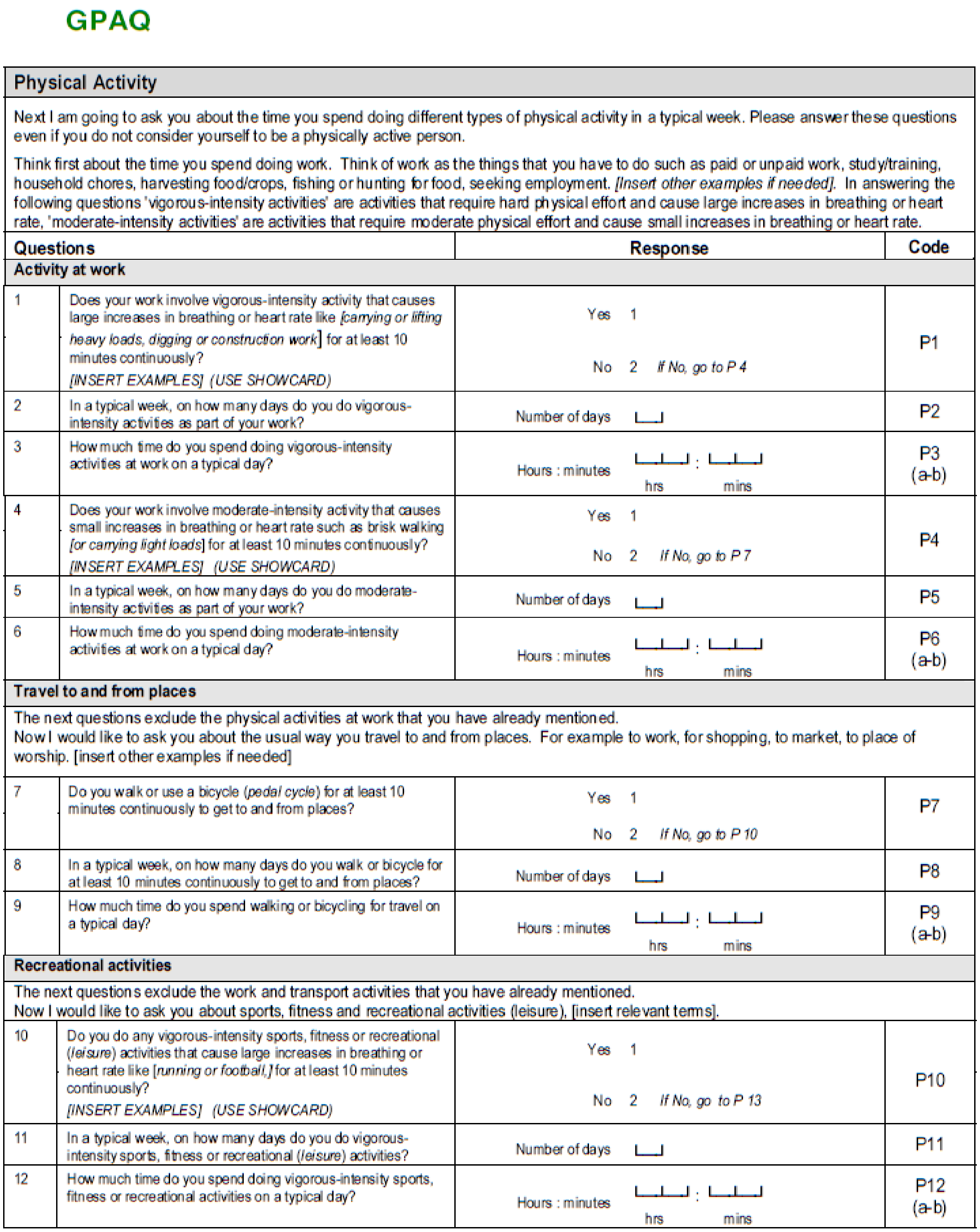
APPENDIX A: GLOBAL PHYSICAL ACTIVITY QUESTIONNAIRE AND VISUAL EXAMPLES



GPAQ

Physical Activity

Next I am going to ask you about the time you spend doing different types of physical activity in a typical week. Please answer these questions even if you do not consider yourself to be a physically active person.

Think first about the time you spend doing work. Think of work as the things that you have to do such as paid or unpaid work, study/training, household chores, harvesting food/crops, fishing or hunting for food, seeking employment. *[Insert other examples if needed].* In answering the following questions 'vigorous-intensity activities' are activities that require hard physical effort and cause large increases in breathing or heart rate, 'moderate-intensity activities' are activities that require moderate physical effort and cause small increases in breathing or heart rate.

	Questions	Response	Code
	Activity at work		
1	Does your work involve vigorous-intensity activity that causes large increases in breathing or heart rate like *[carrying or lifting heavy loads, digging or construction work*] for at least 10 minutes continuously? *[INSERT EXAMPLES] (USE SHOWCARD)*	Yes 1 No 2 *If No, go to P 4*	P1
2	In a typical week, on how many days do you do vigorous-intensity activities as part of your work?	Number of days └┘	P2
3	How much time do you spend doing vigorous-intensity activities at work on a typical day?	Hours : minutes └┴┘ : └┴┘ hrs mins	P3 (a-b)
4	Does your work involve moderate-intensity activity that causes small increases in breathing or heart rate such as brisk walking *[or carrying light loads*] for at least 10 minutes continuously? *[INSERT EXAMPLES] (USE SHOWCARD)*	Yes 1 No 2 *If No, go to P 7*	P4
5	In a typical week, on how many days do you do moderate-intensity activities as part of your work?	Number of days └┘	P5
6	How much time do you spend doing moderate-intensity activities at work on a typical day?	Hours : minutes └┴┘ : └┴┘ hrs mins	P6 (a-b)
	Travel to and from places		
	The next questions exclude the physical activities at work that you have already mentioned. Now I would like to ask you about the usual way you travel to and from places. For example to work, for shopping, to market, to place of worship. [insert other examples if needed]		
7	Do you walk or use a bicycle (*pedal cycle*) for at least 10 minutes continuously to get to and from places?	Yes 1 No 2 *If No, go to P 10*	P7
8	In a typical week, on how many days do you walk or bicycle for at least 10 minutes continuously to get to and from places?	Number of days └┘	P8
9	How much time do you spend walking or bicycling for travel on a typical day?	Hours : minutes └┴┘ : └┴┘ hrs mins	P9 (a-b)
	Recreational activities		
	The next questions exclude the work and transport activities that you have already mentioned. Now I would like to ask you about sports, fitness and recreational activities (leisure), [insert relevant terms].		
10	Do you do any vigorous-intensity sports, fitness or recreational (*leisure*) activities that cause large increases in breathing or heart rate like [*running or football,]* for at least 10 minutes continuously? *[INSERT EXAMPLES] (USE SHOWCARD)*	Yes 1 No 2 *If No, go to P 13*	P10
11	In a typical week, on how many days do you do vigorous-intensity sports, fitness or recreational (*leisure*) activities?	Number of days └┘	P11
12	How much time do you spend doing vigorous-intensity sports, fitness or recreational activities on a typical day?	Hours : minutes └┴┘ : └┴┘ hrs mins	P12 (a-b)

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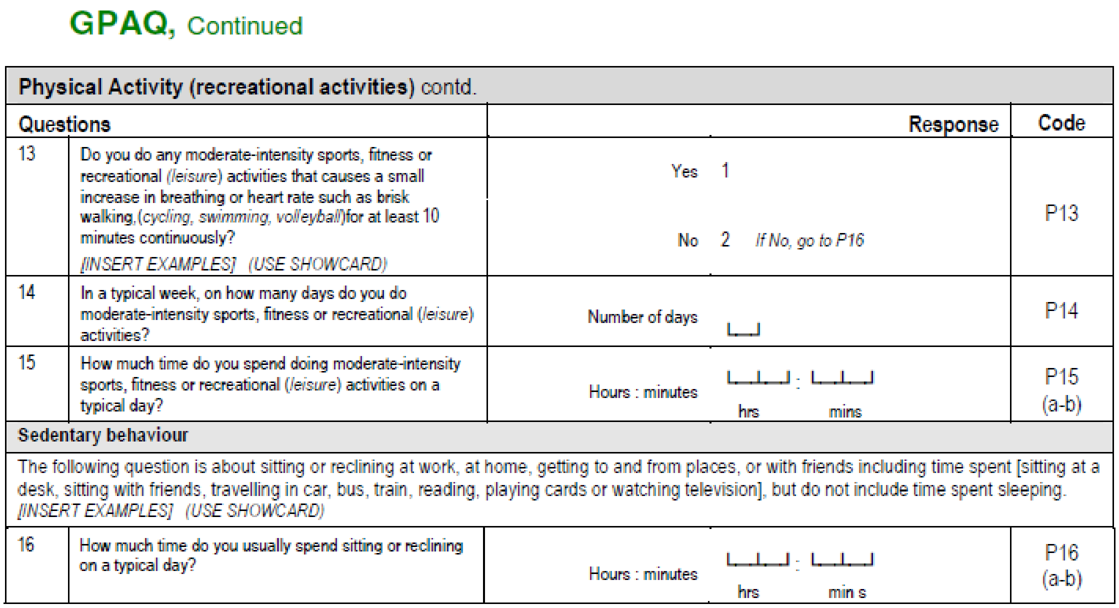


GPAQ, Continued

Physical Activity (recreational activities) contd.			
Questions		**Response**	**Code**
13	Do you do any moderate-intensity sports, fitness or recreational *(leisure)* activities that causes a small increase in breathing or heart rate such as brisk walking,(*cycling, swimming, volleyball*)for at least 10 minutes continuously? *[INSERT EXAMPLES] (USE SHOWCARD)*	Yes 1 No 2 *If No, go to P16*	P13
14	In a typical week, on how many days do you do moderate-intensity sports, fitness or recreational (*leisure*) activities?	Number of days └─┘	P14
15	How much time do you spend doing moderate-intensity sports, fitness or recreational (*leisure*) activities on a typical day?	Hours : minutes └─┴─┘ : └─┴─┘ hrs mins	P15 (a-b)
Sedentary behaviour			
The following question is about sitting or reclining at work, at home, getting to and from places, or with friends including time spent [sitting at a desk, sitting with friends, travelling in car, bus, train, reading, playing cards or watching television], but do not include time spent sleeping. *[INSERT EXAMPLES] (USE SHOWCARD)*			
16	How much time do you usually spend sitting or reclining on a typical day?	Hours : minutes └─┴─┘ : └─┴─┘ hrs min s	P16 (a-b)

Vigorous Physical Activity at Work

Examples for vigorous activities at WORK

VIGOROUS Intensity Activities
Make you breathe <u>much</u> harder than normal

Other examples for VIGOROUS activities at WORK

- Forestry (cutting, chopping, carrying wood)
- Sawing hardwood
- Ploughing
- Cutting crops (sugar cane)
- Gardening (digging)
- Grinding (with pestle)
- Labouring (shovelling sand)
- Loading furniture (stoves, fridge)
- Instructing spinning (fitness)
- Instructing sports aerobics
- Sorting postal parcels (fast pace)
- Cycle rickshaw driving

Moderate Physical Activity at Work

Examples for MODERATE activities at work

MODERATE Intensity Activities

Make you breathe somewhat harder than normal

Other examples for MODERATE activities at WORK

- Cleaning (vacuuming, mopping, polishing, scrubbing, sweeping, ironing)
- Washing (beating and brushing carpets, wringing clothes (by hand)
- Gardening
- Milking cows (by hand)
- Planting and harvesting crops
- Digging dry soil (with spade)
- Weaving
- Woodwork (chiselling, sawing softwood)
- Mixing cement (with shovel)
- Labouring (pushing loaded wheelbarrow, operating jackhammer)
- Walking with load on head
- Drawing water
- Tending animals

Vigorous Physical Activity during Leisure Time

Examples for VIGOROUS activities during LEISURE TIME

VIGOROUS Intensity Activities
Make you breathe <u>much</u> harder than normal

Other examples for VIGOROUS activities during LEISURE TIME

- Soccer
- Rugby
- Tennis
- High-impact aerobics
- Aqua aerobics
- Ballet dancing
- Fast swimming

Moderate Physical Activity during Leisure Time

Examples for MODERATE activities during LEISURE TIME

MODERATE Intensity Activities

Make you breathe somewhat harder than normal

Other examples for MODERATE activities at WORK

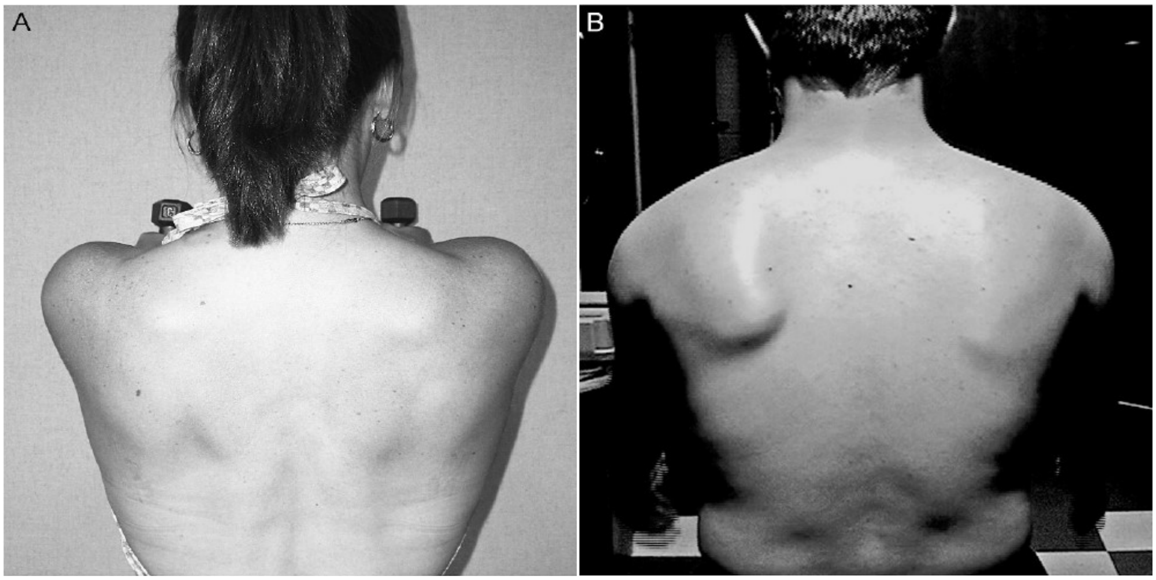
- Cycling
- Jogging
- Dancing
- Horse-riding
- Tai chi
- Yoga
- Pilates
- Low-impact aerobics
- Cricket

APPENDIX B: METABOLIC EQUIVALENT UNITS EQUATION

Divide VO_2 in exercise ($mL.kg^{-1}.min^{-1}$) by VO_2 in rest ($mL.kg^{-1}.min^{-1}$)

Calculation used to determine MET values of exercise by the ACSM[48]

APPENDIX C: SCAPULAR DYSKINESIS TRAINING MATERIALS



A was recorded as normal scapular movement in both shoulders. In B SDK is noted bilaterally.[14]

Training materials website:

http:// www.arcadia.edu/academic/default.aspx7id515080

APPENDIX D: SCAPULAR DYSKINESIS CLASSIFICATION

Dichotomized	Four-Type		
	Type	Pattern	Definition
Yes	Type I	Inferior Angle	Medial scapular boarder prominence at rest and through movement. Anterior tilt of the scapula causing malpositioning around the transverse axis
	Type II	Medial Boarder	“Scapular winging” occurs when scapula moves laterally about the vertical axis in the frontal plane causing prominence of the entire medial scapular boarder
	Type II	Superior Boarder	Superior and anterior translation of the scapula in the sagittal plane causing superior medial border prominence. May present as a shoulder shrug without significant scapular winging.
No	Type IV	Symmetric Scapulohumeral	Normal scapular posture and fluid movement bilaterally.

Definitions of Dichotomized and Four-Type methods of diagnosing SDK.

APPENDIX E: SCAPULAR DYSKINESIS TEST DOCUMENTATION FORM

Observed Scapular Pathomechanics		
	Right	Left
Upward Rotation		
Presence of SDK (Y/N)		
Downward Rotation		
Presence of SDK (Y/N)		

This table was utilized for data collection during the SDT.