THE EVALUATION OF SCAPULAR KINEMATICS AND MUSCULAR CHARACTERISTICS OF THE SCAPULAR STABILIZERS IN OVERHEAD ATHLETES PRESENTING WITH SCAPULAR DYSKINESIS COMPARED TO HEALTHY CONTROLS

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Proper scapular motion is essential to the performance of efficient and injury free overhead activities and altered scapular motion is known to be associated with shoulder pathology. Intervention strategies addressing scapular dyskinesis have yielded inconsistent results. The purpose of this study was to determine if differences were present in scapular kinematics, muscular strength and activation patterns between a healthy control and a dyskinesis group. Thirty-four overhead athletes subjects (Normal group: n=17, Obvious dyskinesis group: n=17) participated in this study. A surface infrared optical capture system was used to measure scapular kinematics during weighted humeral elevation and depression during flexion and abduction. Muscle activation patterns of the scapular stabilizers were assessed using surface and indwelling electromyography. Isometric strength of the pectoralis minor, rhomboid major, serratus anterior, upper, middle, and lower trapezius was assessed using hand-held dynamometry and normalized to body weight (%BW). Independent t-tests or Mann-Whitney U tests, for data that violated normality, were used to assess for mean differences in scapular upward/downward rotation (UR/DR), internal/external rotation (IR/ER), and anterior/posterior tilt (AT/PT) at 30°, 60°, 90° and 120° of humeral elevation/depression, %MVIC, on/off activation, and isometric strength (%BW) of each of the scapular stabilizers. A significance level was set *a priori* at alpha = 0.05. The dyskinesis group demonstrated significantly less scapular UR at 30° humeral elevation

(p=0.012) and depression (p=0.004), increased %MVIC of the pectoralis minor 90-120° humeral elevation(p=0.038), decreased activation of the upper trapezius from 30°-60° of humeral elevation (p=0.045) and decreased activation of the rhomboid major from 120°-30° humeral depression(p=0.011-0.034). Delayed de-activation of the pectoralis minor (p=0.020) and serratus anterior (p=0.031) was also observed. No differences in isometric strength were found between groups. Overhead athletes with obvious scapular dyskinesis demonstrated decreased scapular UR, decreased activation of the upper trapezius and rhomboid major, and increased activation of the pectoralis minor. When clinicians clinically identify the presence of obvious scapular dyskinesis, rehabilitation strategies should aim to increase activation of the of the scapular upward and external rotators while addressing potential hyper-tonicity of the pectoralis minor in order to re-establish coordinated muscular control of dynamic scapular motion.

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PREFACE

Great educators teach us to think critically, to question what seems absolute. Curiosity and a quest for discovery drive us forward as individuals, as communities, as a species. If my education has taught me anything it is how little I still know and how much more there is still to learn. This dissertation is just a brick in the wall of knowledge. So, here is to a life and career of continued learning and discovering the answers to the unanswered questions.

1.0 INTRODUCTION

The scapula is the base of support for all shoulder function and serves as the link in the kinetic chain between the upper extremity and the trunk. Proper scapular motion is essential to the performance of efficient and injury free overhead activities. Characteristics of scapular motion, known as scapular kinematics, are especially important in populations with high demands of repetitive overhead motion (construction workers, military operators, and overhead athletes). Altered scapular motion is known to be associated with shoulder pathology. Inefficient or altered scapular motion, termed scapular dyskinesis, may adversely affect overhead function, the development of shoulder injury, and recovery from shoulder pathologies. However, the relationship between scapular dyskinesis and these factors are currently unknown. To better understand how scapular dyskinesis contributes to altered overhead function or pathology, research is needed to investigate the underlying characteristics that contribute to altered dynamic scapular motion such as muscular activation patterns and strength of the scapular stabilizers.

1.1 SCAPULAR FUNCTION

1.1.1 Normal Scapular Function

The scapula serves as the link between the upper extremity and the trunk, and is the foundation for upper extremity motion. The glenohumeral joint which is the articulation between the glenoid fossa of the scapula and the humeral head, possess greater mobility compared to any other joint in the body. Efficient motion of the scapula is necessary for increased range of motion (ROM) of the humerus to allow for the performance of basic activities of daily living as well as more complex and sport specific tasks. To facilitate optimal overhead motion the scapula serves several important functions: 1. it maintains glenohumeral joint congruency; 2. it elevates the acromion; 3. it serves as a base for muscular attachments; and 4. it serves as a link in the kinetic chain for energy transfer from the lower extremity and trunk to the upper extremity.[19, 20, 67] As mentioned previously, proper scapular motion is integral to having full range of motion of the arm for the performance of daily as well as athletic activities. In order to identify if alterations or abnormalities are present with regard to scapular motion it is necessary to first understand normal kinematics and healthy shoulder function. The scapula is oriented at about 30° anterior to the frontal plane and rotates about three axes: upward/downward rotation occurs about an axis perpendicular to the body of the scapula. Anterior/posterior tilt occurs about an axis parallel to the spine of the scapula. Internal/external rotation occurs about the vertical axis relative to the body.[99] For normal overhead function the scapula must upwardly rotate, externally rotate, and posteriorly tilt. These motions as mentioned before maintain glenohumeral joint congruency and elevation of the acromion to allow for overhead motion. During dynamic motion there is a shift of the center of rotation; below 60°-90° the center of rotation is about the root of the spine of the scapula, however as the arm elevates beyond 60°-90° the center of rotation shifts to the acromioclavicular joint. This shift in the center of rotation is important when considering the scapulohumeral rhythm. Historically, the scapulohumeral rhythm was agreed to be 2:1 throughout elevation of the arm.[59] However, it has been shown that the contribution of the scapula to humeral elevation varies throughout elevation.

1.1.1.1 Considerations in the Overhead Athlete The overhead athlete constitutes a unique population in regards to shoulder and scapulothoracic characteristics. This is largely due to the unique demands of overhead sport which often require repetitive motion and potentially large forces to be produced and absorbed throughout the upper extremity. Unique shoulder complex characteristics have been observed between different sports, and have carried through into differences is scapular kinematics between overhead sports and compared to non-overhead athletic populations.[112] Furthermore, research has demonstrated cumulative changes in shoulder complex and scapulothoracic characteristics with increased years of play in specific overhead sports.[147] While there are differences in the demands of different overhead sports, the overhead athletic population, independent of sport, is considered to be at greater risk of developing shoulder pathologies and developing abnormal scapular motion.

1.1.2 Scapular Function and Shoulder Pathology

There is a high prevalence of shoulder pathology specifically in the overhead athletic population. Alterations in normal scapular kinematics have been identified in the presence of shoulder pathologies. Despite the presence of a relationship, the direction and types of scapular alterations identified is inconsistent in the literature, most likely due to differences in pathology definition or methodologies used. Pathologies most associated with overhead sport include overuse injuries such as rotator cuff disease, impingement syndromes, and glenohumeral joint instability. In the presence of rotator cuff disease or impingement decrease upward rotation, and posterior tilt have been most often found.[35, 72, 79, 84, 86, 88, 147] Decreased scapular upward rotation, greater scapular internal rotation and a greater scapulohumeral rhythm have been observed in the presence of glenohumeral joint instability.[43, 44, 49, 58, 86, 164] Altered scapular internal rotation and anterior tilt may also play a role in the development of labral pathologies.[9, 48, 67, 72, 164] It is evident that alterations in scapular kinematics and shoulder pathology are related, though causation has yet to be determined in this relationship. Further understanding of the underlying cause of altered scapular motion may provide insight in prevention or recovery from shoulder pathology.

1.2 SCAPULAR DYSKINESIS

1.2.1 Definition of Dyskinesis

Scapular dyskinesis is defined as altered positioning and movement of the scapula.[71] Dyskinesis can be identified by alterations in a single plane or across multiple planes. Alterations include: prominence of the inferior angle, medial border prominence (winging), and dysrhythmia. Prominence of the inferior angle is indicative of excessive anterior tipping of the scapular and may be a result of tightness/dominance of the pectoralis minor and weakness of the serratus anterior. Medial border prominence (winging), is indicative of excessive protraction of the scapula, and may be a result of tightness/dominance of the pectoralis minor or serratus anterior and weakness of the retractors which include the middle trapezius and rhomboid muscle group. Lastly, dysrhythmia indicates a more general lack of dynamic control of the scapula and is visible with early shrugging during humeral elevation and/or rapid downward rotation during humeral lowering.[71] The potential weakness or lack of coordinated firing patterns as a potential cause for dyskinesis is only speculation based on the known functions and muscular roles for normal kinematics. Research has yet to comprehensively investigate the cause and/or muscular alterations present in conjunction with scapular dyskinesis.

1.2.2 Dyskinesis and Shoulder Pathology

While the cause of dyskinesis is still only speculation, it has been observed in the presence of multiple shoulder pathologies including shoulder impingement syndromes, instability, and rotator cuff dysfunction. Case-control studies have identified dyskinesis in conjunction with pathologies; however, causation has yet to be determined. It is shown that decreases in upward rotation, and increases in anterior tilt and protraction are associated with shoulder pain, decreased subacromial space and increased strain on the anterior inferior glenohumeral ligament (IGHL).[45, 67, 145] However, other researchers have identified increases in upward rotation in the presence of shoulder pathology and have justified this as a compensation to avoid further degradation the impinged structures.[82] Before the contributions of dyskinesis in the development of shoulder pathology can be determined, better understanding of the underlying mechanisms for dyskinesis need to be evaluated.

1.3 MUSCULAR CHARACTERISTICS AND SCAPULAR DYSKINESIS

Muscular characteristics have been evaluated with regard to specific shoulder pathologies or altered shoulder posture. Indirect inference has been made as to muscular contributions to dyskinesis, though no studies have been found that have directly evaluated muscular characteristics directly to altered scapular kinematics.

1.3.1 Muscular Strength

Few studies have investigated strength of the scapular stabilizers relative to the presence of dyskinesis. However, in the general population decreased shoulder strength has been demonstrated in the presence of altered shoulder postures.[141, 142] Smith et al[142] demonstrated that decreased force production was elicited when the shoulder was either in extreme retraction or protraction compared to its natural resting position. This decreased function of the shoulder elevators may also affect scapular elevation and upward rotation, and in theory could indicate that if scapular position is altered in the transverse plane, muscular strength deficits may occur in other planes of motion by changing the length tension relationship of other muscular couples. Further investigation is warranted with regard to all planes of scapular motion with direct measurement of scapular kinematics compared to isometric strength of the scapular stabilizers.

1.3.2 Firing Patterns and Couplings

Strength is not the only muscular characteristic to consider in regards to scapular control. Activation patterns of the force couples that control scapular motion may be of more importance when considering dynamic scapular motion relative to overhead function, and shoulder pathologies. Upward rotation has been considered to be to most important contributor to healthy overhead function. Therefore, the force couples controlling upward rotation have been deemed by previous literature to be of most importance, and have been the primary focus of previous studies.[73] Muscular activation has been evaluated in rehabilitation exercises, but differences have not been found in healthy individuals compared to those with shoulder pain.[73] This may indicate that while upward rotation is important, dysfunction may be present in other planes or force couples, and assessment of other muscles is warranted.

1.4 DEFINITION OF THE PROBLEM

Multiple authors have found an association with scapular dyskinesis and the presence of shoulder pathology, and suggest shoulder rehabilitation protocols should restore normal scapular motion. However, research has yet to evaluate the cause of scapular dyskinesis. Scapular kinematics and muscular activity has been evaluated in regards to pathology, and intervention strategies have primarily focused on scapular upward rotation, scapular retraction, activation of the trapezius group and serratus anterior,[13, 15-17, 23, 84, 135] yielding inconsistent results.[23, 84, 97, 99, 135, 164 51, 92, 97, 150, 161] This presents several problems. First, evaluation of these muscular characteristics needs to be conducted in a population demonstrating dyskinesis rather than shoulder pathologies. Secondly, assessing characteristics only relative to upward rotation provides limited information in regards to muscular contribution to altered scapular control, specifically in the presence of medial border or inferior angle prominence. Force couples (opposing muscles) must generate equal and opposite forces in order to produce rotation of the scapula in any plane. Sequentially, proper alignment and coordinated activation in one plane will affect position and optimal length tension relationships in the other planes of motion, which will in turn also affect coordinated muscular activity and control through all planes of motion. For protocols to adequately address scapular dyskinesis in rehabilitation or prevention protocols, better comprehensive understanding of the underlying muscular characteristics which contribute to dyskinesis is necessary. This may be accomplished by evaluating muscular firing patterns, and strength of all the scapular stabilizers, as no single muscle group is responsible for scapular control in a single direction.

1.5 PURPOSE

The purpose of this dissertation was to examine the association of scapular dyskinesis with scapular kinematic patterns and muscular characteristics between overhead athletes evaluated, through clinical screening, to have scapular dyskinesis compared to overhead athletes with normal scapular motion. Muscular firing patterns and scapular kinematics were collected during weighted humeral elevation and depression in the sagittal and coronal planes. Isometric strength of the scapular stabilizers was collected using hand-held dynamometry. The primary purpose of this study was to determine if differences were present in scapular kinematics, muscular strength and activation patterns between a healthy control and a dyskinesis group.

1.6 SPECIFIC AIMS AND HYPOTHESIS

Specific Aim 1: To assess if differences are present in scapular kinematics, isometric muscular strength, and muscular activation patterns between normal and dyskinesis groups.

Hypothesis 1a: Individuals with obvious dyskinesis as measured with a qualitative assessment will demonstrate greater decreased scapular upward rotation, increased anterior tilt and increased internal rotation compared to the normal group.

Hypothesis 1b: Individuals with obvious dyskinesis as measured with a qualitative assessment will demonstrate decreased isometric strength in the muscles controlling scapular upward rotation (lower trapezius, serratus anterior), posterior tilt (lower trapezius, serratus anterior) and retraction (middle trapezius, rhomboids) compared to the normal group.

Hypothesis 1c: Individuals with obvious dyskinesis as measured with a qualitative assessment will demonstrate altered muscular firing patterns of the force couples controlling scapular motion compared to the normal group:

1. Altered force couples controlling upward/downward rotation will be demonstrated by delayed/decreased activation of the serratus anterior and/or earlier/increased activation of the rhomboids or pectoralis minor.
2. Altered force couples controlling anterior/posterior tilt will be demonstrated by delayed/decreased activation of the serratus anterior and/or earlier/ increased activation of the pectoralis minor,
3. Altered force couples controlling protraction/retraction will be demonstrated by delayed/decreased activation of the middle trapezius or rhomboids and/or earlier/increased activation of the pectoralis minor or serratus anterior.

1.7 STUDY SIGNIFICANCE

The development of shoulder pathology is a constant concern in the overhead athlete. The identification of scapular dyskinesis in the presence of shoulder pathologies has given rise to intervention strategies which focus on restoring normal scapular position and motion. However these interventions have been limited in their successful restoration of normal scapular kinematics. This study will provide insight as the specific kinematic alteration, muscular coupling patterns, and isometric strength associated with the presence of scapular dyskinesis in overhead athletic. These findings will shed light on muscular deficiencies and loss of optimal force couple control of scapular motion. Clinicians will be able to utilize the findings of this study to more specifically target muscular deficiencies and re-establish coordinated muscular control of scapular position and dynamic scapular motion, which will provided a more thorough rehabilitation of the shoulder complex in the presence of shoulder injury, and when identified early may prevent the development of shoulder injury.

2.0 REVIEW OF THE LITERATURE

This chapter will provide a review of the literature starting with an overview of normal shoulder complex anatomy and function with additional emphasis on the influence of the scapula on normal shoulder complex function. Next a discussion of the unique characteristics and demands of shoulder function in overhead athletes, including biomechanics and muscular activation will be provided. An overview of the epidemiology and burden of shoulder pathology in overhead athletes will be presented followed by a discussion of scapular dyskinesis and associated musculoskeletal alterations, and an overview of the influence of these characteristics relative to the development of shoulder pathology will be presented. Lastly, the methodology of the current study will be presented.

2.1 OVERVIEW OF THE SHOULDER COMPLEX ANATOMY AND FUNCTION

2.1.1 The Shoulder Complex's Function and Musculature

The glenohumeral joint possesses the largest range of motion compared to any other diathrodial joint in the body. However, due to limitations in kinetic and kinematic assessments, shoulder motion is often reported, or assumptions are made, that the shoulder complex functions as a single joint. Shoulder motion occurs from articulation of the sternoclavicular joint, glenohumeral joint and gliding of the scapula on the thorax. The mobility available at the shoulder is due to the six degrees of freedom that each articulation within the shoulder complex possesses. The glenohumeral joint can elevate the humerus 120° and axially rotate 135° with additional ROM from scapulothoracic gliding.[93, 158] The sternoclavicular joint elevates, retracts and rotates the clavicle during humeral motions, and its perpendicular orientation to the scapula results in relatively equal degrees of movement in regards to scapular upward rotation and clavicular axial rotation during humeral elevations.[29, 158] The scapula upwardly rotates, retracts and posteriorly tilts during humeral elevation in coordination with the clavicle.

Mobility is allotted by joint articulation and the large degrees of freedom available in each joint, specifically the glenohumeral joint. It has been found that during humeral motion no more then 25-30% of the humeral head is in contact with the glenoid at any given time.[63, 87, 167] Therefore stability must come from static and dynamic restraints, such as ligamentous and muscular tissue, in order to maintain function and proper alignment throughout the available ranges of motion. The balance of mobility and stability is a delicate equilibrium to maintain. Mobility allows for greater function; however stability protects the shoulder complex from injury. Ligamentous structures such as the joint capsule and the superior, middle, and inferior glenohumeral ligaments provide check-reins to extreme motions, reverse humeral head movement, and maintain glenohumeral head alignment.[63, 87, 158, 167] Intrinsic muscles of the shoulder girdle (rotator cuff) provide stability in the mid ranges of motion. These muscles include the supraspinatus, infraspinatus, teres minor, and subscapularis. Based on muscle orientation and through co-contraction the rotator cuff pulls the humeral head into the glenoid fossa eliciting a compression force that provides stability and counteracts shearing forces generated by the deltoids during motion.[87, 167] Secondary stability comes from extrinsic shoulder muscles: teres major, latissimus dorsi, and the pectoralis major. The co-contraction of the rotator cuff and deltoids throughout shoulder motion has been suggested to operate as a “balance of forces” rather than a true force couple.[167] The last source of dynamic stability comes from the scapulothoracic stabilizers, which include the upper, middle and lower trapezius, rhomboid major and minor, levator scapulae, pectoralis minor, and serratus anterior. These muscles are necessary to maintain the scapula as a stable base of support and to maintain the optimal length-tension relationship for shoulder girdle muscle activation.[87, 167]

2.1.2 Scapular Function and Musculature

Likely through evolutionary development, the human scapula demonstrates a laterally directed glenoid and a long and laterally oriented clavicle. This orientation, compared to other vertebrates species, is thought to be indicative of bi-pedal movement with the upper extremities being used to carry objects rather than locomotion; this orientation of the scapula also allows for greater mobility in the vertical direction.[158] The scapula serves four primary functions: 1. it maintains glenohumeral joint congruency; 2. it elevates the acromion; 3. it serves as a base for muscular attachments; 4. it serves as a link in the kinetic chain for energy transfer from the lower extremity and trunk to the upper extremity.[19, 20, 67] These functions of the scapula do not occur in isolation, and all are necessary for healthy function of the shoulder complex.

In order for the scapula to operate as a stable base and maintain glenohumeral alignment, coordinated activation of the muscles acting on the scapula is necessary. While the scapula is the origin or insertion for 17 muscles, only the muscles that insert on the scapula and control its position in relation to the trunk are referred to as scapular stabilizers. These scapulothoracic muscles include the trapezius (upper, middle, and lower fibers), rhomboids (major and minor fibers), levator scapulae, pectoralis minor, serratus anterior.[87, 119] Authors which have evaluated the scapular stabilizers have focused on the serratus anterior and trapezius as the most important scapular stabilizers, however this may be presumptuous given the nature and complexity of shoulder function.[32, 33, 67, 69, 70, 84] Research remains inconclusive in regards to muscular activity, weakness of scapular stabilizers, and their relationship to pathology or altered scapular motion. This is likely due to the fact that little research has been conducted on scapular stabilizers other than the trapezius and serratus anterior. The scapular stabilizers act as force couples to produce scapular motion. A force couple has been defined by Speer and Garrett[146] as two groups of muscles contracting synchronously to enable a specific motion to occur. This however is not a complete definition of a true force couple. Mechanically speaking, a force couple is an arrangement of equal and opposite forces that result in rotation of an object without translation. Therefore, coordinated activity of all muscles is necessary for smooth scapular motion, disruption of a single muscle in theory could affect all planes of motion. Scapular stabilizers act in such a fashion to achieve rotations and tilt about the thoracic wall. Therefore, coordinated activation of scapular thoracic force couples is necessary to achieve optimal scapular positioning. Scapular upward rotation (UR) (aka. lateral rotation) occurs through activation of the upper and lower trapezius and the serratus anterior.[119] Downward rotation occurs through activation of the rhomboids, levator scapulae and pectoralis minor.[109, 119] Internal rotation (IR) occurs from activation of the serratus anterior and pectoralis minor.[109] Activation of the middle and lower trapezius and rhomboids results in external rotation of the scapula.[109, 119] In the early 90's DiVeta et al[26] found no relationship between resting scapular abduction and isometric strength of the pectoralis minor or middle trapezius muscle. However the limitation to this study is that the middle trapezius is not solely responsible for retraction and the pectoralis is not solely responsible for protraction of the scapula. Furthermore in a resting posture, tightness rather than weakness may also be an issue, and tightness does not necessarily infer strength.[26] Activation of the serratus anterior was found (36-41% MVC) during the performance of isokinetic protraction healthy overhead athletes, while activation of the upper trapezius (37-45% MVC), middle trapezius (24-26% MVC) and lower trapezius (13-18% MVC) was found during isokinetic retraction.[15] Anterior tilt (AT) occurs from activation of the pectoralis minor; while posterior tilt is a result of activation of the lower trapezius, and serratus anterior.[109] Scapular force couples may be agonist muscle in one plane and antagonist muscles in another plane. For example the pectoralis minor and the serratus anterior are agonist muscles in terms of scapular protraction, but are antagonist in regards to scapular tilt. This complexity of coordinated activation and balance of forces makes evaluation of scapulothoracic function difficult, and why it is important to evaluate all scapular stabilizers rather that a select few.

2.1.2.1 Normal Scapular Position and Kinematics Scapular orientation and kinematics have been evaluated in various populations and age groups using a diverse range of methods from clinically accessible techniques such as digital inclinometry and tape measurements to more precise laboratory tools such as radiographs, electromagnetic analysis and infrared video based motion analysis methods. Through qualitative assessment of scapular orientation at rest, the normal scapula orientation should demonstrate the superior angle of the scapula sitting at the level of the second rib, the root of the spine of the scapula at the level of the third rib, the medial border running parallel to the spine, and the inferior angle at the level of the seventh rib.[56, 64]

Kendall has also noted that a normal asymmetry exists with the dominant shoulder demonstrating a depressed scapula compared to the non-dominant side. While this is a simple evaluation tool for assessing scapular position, it is limited in the ability to quantify the presence of an alteration.[64] Further, there is no range for normal variation or reference to the populations used to determine these findings. To better understand the ranges of normal scapular orientation and the influence of population (i.e. age, gender) quantitative analysis is necessary. Qualitative findings for scapular orientation described has been supported by quantitative research in adult females using tape measurements and radiographs.[144] However, one noted difference was the orientation of the inferior angle, which in the studied population of healthy adult females most often corresponded to the eighth and ninth thoracic spinous process, suggesting the scapula to be relatively larger in this population.

In addition to qualitative scapular orientation, quantitative measurements have also been conducted in order to ascertain normal scapular position (Table 1). Scapular abduction (a.k.a. protraction) has been found to range between 8-11cm from the spinous process to the medial border and the dominant scapula resting lower (≥1.91 cm) in the majority of subjects.[26, 115, 144] The limitation to these findings is the specific population, and lack of normalization. In theory the same measurements in a male compared to a female may elicit larger values simply due to body size and therefore falsely indicate an alteration (greater amount of abduction) in an individual with a larger body size. Devita et al[26] acknowledged this limitation within their study and normalized scapular abduction to body size, finding an average of 1.6 normalized scapular abduction in healthy adults. Scapular abduction is the only plane to be measured in distance rather than degrees. Measuring scapular orientation in degrees allows for normalization between body sizes. The use of inclinometers and three-dimensional motion analysis has allowed researchers to ascertain scapular orientation in more planes than just scapular abduction. Three-dimensional analysis of scapular kinematics has been conducted in healthy adults in both static and dynamic arm positions. Most often the task is humeral elevation in the scapular plane. In normal standing posture the scapula sits in a position of IR, AT and UR. Normal scapular IR at rest is 28°-38°and increases with active humeral elevation.[7, 29, 42, 101] Scapular IR seems to closely coincide with the plane of elevation. As the arm moves toward the sagittal plane the amount of scapular IR increases, then as the arm nears the frontal plane in a motion of pure abduction, scapular IR decreases and has even been found to move into a position of ER.[157] Scapular AT at rest is 7°-15° and decreases with humeral elevation.[7, 29, 42, 101] The plane of motion will also affect tilting. During humeral elevation in the sagittal plane there is less demand on tilt and a decreased excursion (posterior tilt) occurs (6°) compared to humeral elevation in the frontal plane (11°).[157] Scapular UR at rest is 0°-8° and increases with humeral elevation. This is the primary motion necessary for maintaining the subacromial space and preventing outlet impingement. The degree of UR that occurs in various planes of motion remains fairly consistent.[157]

Table 1. Normal Scapular Kinematics in Healthy Populations during Humeral Elevation in the Scapular Plane

	Varnell et al, 2014[157]	Varnell et al, 2009[156]	Ludewig et al, 2009[86]	Borstad et al, 2002[7]	McClure et al, 2001[101]	Karduna et al, 2000[61]
Population	Healthy adults	Healthy adults	Healthy adults	Healthy male construction workers	Healthy adults	Healthy adults
Method	Skin based infrared motion analysis system	Skin based active optical tracking system	Skin & bone based electro-magnetic system	Skin based electro-magnetic system	Skin & bone based electro-magnetic system	Skin based electro-magnetic system
Scapular IR (+)						
30°	28°	-	-	-	36°	39°
60°	29°	37°	38°	41°	36°	40°
90°	32°	37°	39°	44°	34°	41°
120°	37°	34°	37°	46°	29°	41
Scapular AT (-)						
30°	-8°	-	-	-	5°	5°
60°	-5°	7°	-7°	-9°	9°	6°
90°	-2°	15°	-3°	-9°	10°	7°
120°	2°	25°	3°	-8°	15°	8°
Scapular UR (+)						
30°	11°	-	-	-	19°	19°
60°	21°	12°	26°	-23°	27°	27°
90°	30°	21°	34°	-	38°	37°
120°	37°	36°	44°	-41°	50°	50°

2.1.3 Shoulder Function in the Overhead Athlete

Overhead athletes undergo sport specific repetitive overhead motion. There is variation as to the specific task, equipment utilized, and the environment of different overhead athletes, yet all overhead athletes appear to utilize similar muscular firing patterns, phases of motion, kinematics, generation of and resistance to kinetic torques and forces (Table 2).

A common characteristic across all overhead sports is repetitive overhead movement of the arm, whether it is for the freestyle stroke, the volleyball serve, throwing or serving a ball. Competitive overhead athletes have been reported to perform a high amount of sport specific overhead tasks per practice, and across the season.[6, 50, 77, 122, 125, 130] Volleyball players can practice upwards of 20 hours per week and perform up to 40,000 spikes in a season.[77, 125] While, swimmers often swim year around, between 6,000-20,000 meters a day, resulting in 40,000-80,000 meters per week depending on competitive level. This results in approximately 18,000 shoulder revolutions per week of which 80% is from freestyle training.[6, 50, 122, 130] Tasks such as serving and throwing, and to an even greater degree pitching or spiking, are demanding overhead tasks. These motions, which can occur at high velocities, have been associated with overuse injuries of the shoulder.[5, 27, 40, 137] Proper biomechanics is necessary to safeguard the shoulder from repetitive trauma and injury. The biomechanical characteristics of these overhead tasks have been well researched.[5, 8, 25, 50, 120, 125]

2.1.3.1 Kinematics and Kinetics in Overhead Athletes The evaluation of shoulder kinematics and kinetics has been conducted in several overhead populations. Overhead tasks such as throwing, pitching, serving, and spiking the ball share similar phases of motion and kinematics. Common phases across these tasks include arm cocking, acceleration and deceleration. During the arm cocking phase the shoulder externally rotates and abducts ending when the shoulder reaches maximum external rotation.[25, 40, 41, 120] The goal of the cocking phase is to achieve as much external rotation as possible in order to have a greater range of motion to accelerate the ball.[120, 125, 133] All of the corresponding forces maintain the shoulder position and transition the motion forward into acceleration.

Arm acceleration occurs through de-rotation of the arm. It is initiated by internal rotation and adduction of the shoulder and elbow extension; the phase is completed at ball release or ball contact.[25, 40, 125, 133]At ball release the shoulder ranges from 48° of internal rotation to 105° of external rotation and 90° of abduction in throwing athletes.[25, 120] While, in volleyball players the shoulder is abducted between 129-133°, horizontally adducted 23-33° and the elbow is flexed between 34-48° at ball contact.[125] During the acceleration phase, throwing athletes generate angular velocities as high as 9,198deg/sec[120], with averages around 7,000deg/sec.[40, 41, 120] Volleyball players have demonstrated angular velocity between 2444-2594°/s with a shoulder proximal force of 358-412N, while the elbow reaches an extension angular velocity of 1535-1666°/s and a proximal force of 277-312N.[125]

Arm deceleration occurs after ball release and the arm continues to extend and internally rotate until the arm reaches 0° of internal rotation. The follow through phase is necessary to continue the deceleration process and occurs through shoulder adduction, horizontal adduction, and elbow flexion. It has been found to be most related to the occurrence of overuse shoulder injuries in throwing athletes.[25, 40, 120]

Table 2. Comparison of Peak Kinematics and Kinetic Parameters across Overhead Sports

	Reeser et al[125]	Reeser et al[125]	Fleisig et al[41]	Dillman et al[25]	Barrentine et al[5]	Werner et al[165]	Elliot et al[35]	Elliot et al[35]
Task	Volleyball Spike	Volleyball Serve	Baseball Pitch	Baseball Pitch	Windmill Pitch	Windmill Pitch	Tennis Serve	Tennis Serve
Skill level	Collegiate	Collegiate	Elite	Collegiate/ professional	Collegiate/ professional	Olympic	Olympic	Olympic
Gender	Female	Female	Male	Male	Female	Female	Female	Male
Kinematics								
Maximum External Rotation(°)	160 ± 10	164 ±11	-	178	-	-	171 ± 8	169 ± 9
Maximum Internal Rotation Angular Velocity(°/s)	2444 ± 608	2505 ± 1005	-	6940	-	-	-	-
Shoulder Abduction at Ball Contact or Release(°)	130 ± 8	129 ± 11	-	95	-	10 ± 13	-	-
Shoulder Horizontal Adduction at Ball Contact or Release(°)	29 ± 14	23 ± 24	-	14	-	-	-	-
Kinetics								
Maximum Internal Rotation torque (Nm)	37 ± 9	40 ± 10	67 ± 11	-	49*	72*	48 ± 16	71 ± 15
Horizontal abduction torque (Nm)	-	-	97 ± 25	-	36*	-	69 ± 14	108 ± 25
Abduction torque (Nm)	-	-	83 ± 26	-	104*	-	-	-
Max anterior force (N)	-	-	380 ± 90	-	242*	-	185 ± 61	292 ± 120
Posterior force (N)	-	-	400 ± 90	-	376*	376*	-	-
Maximum Proximal force (N)	295 ± 63	277 ± 63	-	-	-	-	364 ± 88	608 ± 110
Compression force (N)	-	-	1090 ± 110	-	624*	564*	-	-

*converted from normalized data, based on average weight and height

2.1.3.2 Muscular Firing Patterns during Overhead Tasks In addition to kinetics and kinematics, muscular firing patterns have been evaluated in overhead athletes during sport specific tasks.[73, 122, 133, 135]. Coordinated and sequential activation of extrinsic, intrinsic and scapular stabilizing muscles has been demonstrated during these tasks. During overhead tasks such as swimming, throwing, spiking, and serving activation of the scapular stabilizers occurs first in order to elevate the acromion, upwardly rotate and stabilize the scapula.[68, 122, 133]

For tasks such as throwing, serving, or spiking that have a specified cocking phase, this is followed by activation of extrinsic muscles, the anterior deltoid, which elevates the arm and eccentrically controls horizontal abduction and ER. [68] This eccentric control acts to store energy for the forward swing phase.[68] Further eccentric co-activations of the extrinsic shoulder internal rotators (teres major, latissimus dorsi, and pectoralis major) during the cocking phase has been speculated to protect the anterior shoulder, which in abduction and maximal external rotation is at risk for anterior subluxation.[133] The intrinsic muscles, subscapularis and supraspinatus, couple with the anterior extrinsic muscles in order stabilize the glenohumeral joint and compress the humeral head into the glenoid fossa. At the end of the cocking phase, when the shoulder is elevated above 90° and neared MER the lower trapezius is activated, as it was now in a more efficient position for continuing scapular stabilization during overhead motion.[68] With the arm in this position the teres minor is also in a more efficient position for externally rotating the arm to MER. This was evident by the activation of the teres minor during the cocking phases rather than the infraspinatus.[68, 133] This differentiation of activity between these two muscles has been noted in baseball throwing mechanisms, the volleyball spike/serve and swimming mechanics.[50, 122, 133]

Transition into the acceleration phase is evident by activation of extrinsic muscles (pectoralis major, teres major, latissimus dorsi) to propel the arm forward in to horizontal adduction, extension, and internal rotation. All these muscles together generate the power needed to exert a force onto the ball. Activation of the intrinsic muscles (subscapularis and teres minor) stabilizes and compresses the humeral head.

During deceleration and follow-through the arm is dissipating the excess energy from the acceleration phase. The rotator cuff acts to counter the proximal forces being exerted on the arm by providing compression and depression of the humeral head into the glenoid fossa. Infraspinatus activates as it is now in an optimal anatomical position to assist with humeral head compression and resistance of distraction forces in conjunction with the teres minor.[68, 133] A drop-off in extrinsic activity is present during the deceleration phase.

During follow through muscular activation ceases in a similar pattern as onset during the cocking phase. The anterior deltoid, serratus anterior and upper trap are the first to cease firing, as the arm is no longer accelerating forward and is below 90° elevation. The rotator cuff remains active to compress the humeral head and resist distraction forces, and the posterior deltoid, lower trapezius, and teres minor are the last to turn off in order to eccentrically decelerate the shoulder complex.[68]

2.2 SHOULDER PATHOLOGY IN OVERHEAD ATHLETES

The previous section discussed the demands of overhead sport in various populations. It is evident that while each sport is unique, they demonstrate similar muscular firing patterns, phases of concentric motion and eccentric control, as well as range of motion demands. Therefore it is not surprising that these populations also have similar risks for injury in regards to the shoulder complex. The next section will discuss the burden of shoulder injury in overhead sports as well as the biomechanical considerations, and clinical characteristics associated with shoulder pathology in various overhead sports.

The shoulder is often reported as one of the most common sites for pain and injury in overhead athletes.[1, 24, 34, 55] A review by Ellenbecker et al[34] revealed that shoulder injuries can occur in 4-27% of tennis players of various ages and levels of play. In competitive swimmers shoulder injury prevalence has been reported to be as high as 74%. Incidence has been reported to range from 8-20% of all injuries in collegiate volleyball players.[1, 77, 127, 162] In collegiate baseball players incidence of injury over multiple seasons was found to range from 4.85- 6.64 per 1,000 exposures in games and 1.47-2.34 per 1,000 exposures in practices of which the majority (45-58%) were injuries to the upper extremity and accounted for 75% of the time lost.[24, 102] In baseball players the most common injury site of the upper extremity was reported to be the shoulder with an average of 24.3 days lost from participation.[102] While in softball, the NCAA[94] reported that 33% of game and practice injuries occurred in the upper extremity. Incidence of shoulder injury was reported to range from 5.8% of all injuries during games and 11.3% of all injures during practices, with the most frequent diagnosis of both being muscle-tendon strains.[94]

Of the injuries that have been reported to result in time loss, 27% occurred in the upper extremity.

2.2.1 Shoulder Pain

The shoulder has been reported to be one of the top 3 sites for pain and injury in collegiate volleyball players and is also prevalent across overhead sports.[55] Pain and overuse symptoms can start early and have been reported in 32% of youth baseball pitchers. In youth the incidence of shoulder pain was most associated with increased number of game pitches, decreased cumulative pitches, and arm fatigue.[90] These findings emphasize the importance of proper strength and conditioning early on. Shoulder pain and injury are also common in swimmers with the occurrence and severity generally increasing with age and experience. Prevalence of shoulder pain was present in 9%-91% of competitive swimmers ranging in age from 13 years to elite adults.[103, 104, 136] Additionally, swimming volume and poor biomechanics have also been attributed to the development of shoulder injury. In swimmers, episodes of anterior shoulder pain were initially given the term “swimmers shoulder”.[65, 66]

2.2.2 Swimmers Shoulder

Swimmers shoulder has served as a catch all term for shoulder pain, and is multifactorial in its development.[163] The term does not so much identify the pathology, but more so the etiology of its occurrence. Overuse/fatigue, glenohumeral joint laxity/multidirectional instability, and poor stroke mechanics have all been attributed to the development of swimmers shoulder, as well as other more specific pathologies.[163] Sein et al[136] found 84% of swimmers with shoulder pain had positive signs of impingement, and 69% of those showed positive supraspinatus tendinopathy on magnetic renaissance imaging.

2.2.3 Impingement Syndromes

Impingement syndromes are one of the most common pathologies diagnosed in overhead athletes. In throwing athletes failure of the shoulder complex to maintain glenohumeral alignment during late cocking and early acceleration can result in repetitive shearing and stress of the anterior capsule leading to excessive anterior translations of the humeral head which leads to secondary external impingement.[116] In conjunction with secondary external impingement, during the late cocking phase, players with anterior shoulder instability may also be at risk for posterosuperior impingement, though conflicting findings have been reported.[46, 116, 160] Contact between the undersurface of the rotator cuff and posterior superior labrum has been found in throwers in a position of shoulder abduction and maximum external rotation similar to the late cocking phase. Impingement syndromes and primary instability seem more likely to be elicited during the late cocking and early acceleration phase when the shoulder is in extreme external rotation and abduction. Tennis players are noted to sustain injuries similar to throwing athletes, as the biomechanics of the tennis serve places kinematic and kinetic demands on the shoulder similar to throwing. Therefore, injuries such as impingement syndromes and rotator cuff pathologies are also common shoulder injuries in the tennis population.[155] In swimmers, altered biomechanics of the freestyle stroke may place a swimmer at risk for developing shoulder pain and/or injury. A vulnerable position for the development of impingement is forward flexion with internal rotation, which occurs during the recovery phase just prior to hand entering the water.[170, 171] If the humerus is too internally rotated and adducted it decreases the elbow flexion angle, and the water then causes an upward force on the humerus resulting in the elbow entering the water before the hand and a thumb first entry. The decreased elbow flexion angle results in increased superior translation of the humeral head in turn increasing the potential for subacromial impingement, while a thumb first hand entry position increases stress on the attachment of the long head of the biceps, placing the shoulder at risk for chronic labral pathologies.[159]

2.2.4 Rotator Cuff Disease

Overhead athletes repetitively undergo high velocity movements and commonly suffer similar injuries, including rotator cuff disease, labral pathologies and glenohumeral instability.[5, 34, 39, 40, 54, 155] In the sport of baseball, the most common diagnosis of shoulder injury among this group was rotator cuff tendinitis and muscle-tendon strains.[102] Throwing and pitching were shown to account for 59.5% and 73% of these injuries, respectively. Helm et al[54] found an injury incidence of 70% in youth tennis players with 8% occurring in the shoulder, of which the most common diagnosis was rotator cuff pathology. Overload conditions such as rotator cuff tears and micro-instability result as response to repetitive traction during phases of declaration and follow through.[116] These pathologies do not often occur in isolation and likely one alteration exacerbates the risk of developing others. This creates difficulty in discrete diagnosis and identification of the initial causative factor.

2.2.5 Suprascapular Neuropathy

Despite sustaining similar pathologies and shoulder characteristics to throwing athletes, volleyball players are uniquely prone to sustain suprascapular neuropathy. Suprascapular neuropathy has been noted to occur in up to 45% of elite volleyball athletes and is a pathology rarely seen in other overhead sports.[28, 39, 126, 127, 134] This injury can be sustained as a result of direct trauma, but has also been suggested to develop over time as a result of the repetitive overhead motion such as the spiking maneuver.[28, 126, 127] The suprascapular nerve, which originates from the upper trunk of the brachial plexus, crosses the posterior triangle, runs under the trapezius through the scapular notch below the suprascapular ligament to innervate the supraspinatus, then the nerve curves around the lateral border of the spine of the scapula innervating the infraspinatus. Entrapment often occurs in the scapular notch under the suprascapular ligament, thus affecting both the supraspinatus, and infraspinatus. Clinical presentation of entrapment in this region will illicit an isolated muscle atrophy and decreased strength of both muscles.[129] Isolated hypotrophy of the infraspinatus has also been documented in volleyball players, and results in spinoglenoid notch entrapment of the suprascapular nerve. The extreme ranges of motion, volleyball players demonstrate in shoulder abduction and horizontal adduction are greater compared to other overhead sports. Both these motions that are major components of the volleyball serve and spike, yet they have been identified as positions that can attenuate and compress the nerve. [126, 134] Furthermore a biomechanical comparison by Reeser et al[126] which found increased shoulder abduction and horizontal adduction, noted the influence of the scapula on achieving these extremes in motion. They theorized that scapular dynamics have the potential to be a major risk factor in the development of spinoglenoid neuropathy, which was supported by the findings of previous work evaluating scapular and shoulder girdle mobility.[95, 168] Merolla et al[108] found that volleyball players with scapular dyskinesis demonstrated infraspinatus weakness and inhibition due to pain, but over the course of a 6 month rehabilitation protocol infraspinatus strength increased and pain decreased. The presence of dyskinesis or change in scapular kinematics was never re-assessed. Therefore, biomechanics unique to volleyball, extreme shoulder mobility, as well as scapular position likely contribute to the development of this pathology.

2.3 SCAPULAR DYSKINESIS AND ALTERED SHOULDER COMPLEX CHARACTERISTICS IN OVERHEAD ATHLETES

2.3.1 Scapular Dyskinesis

Dyskinesis is defined as altered motion. Therefore, scapular dyskinesis refers to dysfunctional scapular motion. Scapular dyskinesis is not considered a pathology, but rather a potentially modifiable musculoskeletal characteristic much like posture. While there are currently no standard quantitative thresholds to determine the presence of dyskinesis, much of the work contributing to describing, identifying and evaluating dyskinesis has been performed by Kibler et al. His methods are qualitative in nature for describing types of dyskinesis, the presence dyskinesis in specific populations, and pathologies. A scapular dyskinesis system was developed by Kibler in order to grade the type but not the severity of dyskinesis present.[74] Type 1 is indicated by inferior medial scapular border prominence, eliciting excessive AT during humeral elevation.[74] Type 2 is indicated by entire medial scapular border prominence, eliciting excessive scapular IR during humeral elevation.[74] Type 3 is indicated by an elevated superior border and /or anteriorly displaced acromion, requiring a shoulder shrug to initiate scapular motion during humeral elevation.[74] The difficulty in this assessment method is that dyskinesis must be categorized to one plane of alteration, when realistically more than one type could be present during a screening.

It is speculated that scapular dyskinesis may be the result of muscular imbalance, weakness or lack of coordinated firing patterns of force couples. No studies have been found evaluating muscular firing patterns comparing individuals evaluated to have scapular dyskinesis to controls. Therefore, inference must be used based on previous research that has evaluated the effect of scapular muscle fatigue on scapular kinematics in healthy individuals. Previous studies have investigated and demonstrated that as the upper, middle and lower trapezius muscles fatigued, scapulohumeral rhythm (the ratio of scapular motion contributing to humeral elevation) decreased and scapular UR increased in the mid ranges of humeral elevation.[105] The authors did not evaluate whether dyskinesis was observed, however this study does demonstrate that frequency shifts (the firing rate of electrical signal within the muscle) in scapular stabilizers effects how the scapula moves and contributes to elevation of the humerus. These findings are in agreement with Ebaugh et al[30] who also found that fatigue of the upper trapezius and serratus anterior increased scapular UR and external rotation, and decreased scapular posterior tilt during humeral elevation. These findings are interesting given that in the presence of muscular fatigue the scapula demonstrated favorable compensatory motions: increased scapular UR and external rotation. This may be due to the fact that the lower trapezius, as reported by Ebaugh et al[30], demonstrated resistance to their fatigue protocol and is a primary component to the force couples generating scapular UR and external rotation. Furthermore, the fatigue of the serratus anterior would likely contribute to the increase in external rotation and loss of posterior tilt, as it contributes to both those force couples. The studies conducted by McQuade[105] and Ebaugh[30] evaluated healthy individuals undergoing a single session of shoulder girdle fatigue. The cumulative effects of repetitive fatigue, through tasks such as overhead sport may result in chronic frequency shifts and altered muscle coordination. The effect of shoulder girdle fatigue on muscular firing patterns of scapular stabilizer has yet to be evaluated. However, based on these findings it could be hypothesized that in individuals with scapular dyskinesis, altered muscular firing patterns of the scapular stabilizers would also be present.

2.3.1.1 Scapular Dyskinesis and Shoulder Complex Strength Volleyball players have demonstrated decreased shoulder external rotation strength, increased external rotation ROM, and increased scapular internal rotation in shoulders with spinoglenoid entrapment. Isolated hypotrophy of the infraspinatus results from spinoglenoid notch entrapment of the suprascapular nerve. With isolated spinoglenoid entrapment athletes do not complain of pain and are still able to maintain function despite the loss in infraspinatus strength.[95, 134, 168] In throwing athletes fatigue has also been found to play a role in the development of faulty biomechanics. Fath et al[37] found that after fatigue of scapular stabilizers baseball players demonstrated decreased scapular UR during the late cocking phase and acceleration phase as well as decreased humeral elevation, humeral rotation and ball velocity and accuracy.[37] During late cocking and early acceleration, failure of the shoulder complex to maintain glenohumeral alignment can result in repetitive shearing and stress of the anterior capsule leading to excessive anterior translations of the humeral head which leads to secondary external impingement.[116]

2.3.1.2 Scapular Dyskinesis and Shoulder Complex Range of Motion/Flexibility Shoulder hypermobility and increased shoulder external ROM has been found to be associated with glenohumeral instability.[4] This corresponds with characteristics of the swimming population who have been noted to have greater shoulder mobility. [164] However, while this is also a normal adaptation in this population, hypermobility of the glenohumeral joint has also been found to be a contributing factor to shoulder pain as well as the development of swimmers shoulder and more specific pathologies.[4, 103, 163] Glenohumeral alterations, including both excessive and deficits in ROM, can affect the musculoskeletal characteristics of the shoulder complex, specifically scapular orientation. Deficits in shoulder internal rotation have been associated with increased posterior shoulder tightness and increased scapular AT, while glenohumeral instability has been associated with decreased scapular UR and greater scapular internal rotation. Decreased scapular UR, increased AT, and IR have also been identified in throwing athletes with glenohumeral internal rotation deficit (GIRD).[151] GIRD is the loss of internal rotation compared bilaterally, and has been shown to increase with years of play.[151] The loss of internal rotation is greater than the gain in external rotation of the throwing shoulder, and therefore a loss in the total arc of motion is present. GIRD is thought to occur as a response to deceleration of the arm with repetitive throwing and serving.[8, 67, 155] Eccentric overload of the infraspinatus results in muscle hypertrophy, reduced elasticity of the posterior capsule, and shortening of the inferior glenohumeral ligament (IGHL). This again compromises shoulder stability in the late cocking phase, where the humeral head is shifted in a more posterosuperior location. Baseball players diagnosed with internal impingement have demonstrated significantly greater GIRD and posterior shoulder tightness (PST).[113] Decreased internal rotation range of motion has been found to correlate with increased PST, and both characteristics have been found in shoulders diagnosed to have secondary subacromial impingement syndrome.[152] Decreased glenohumeral IR has also been prospectively identified as a risk factor for the development of shoulder injury in high school baseball players.[140] The presence of GIRD, PST, and altered scapular kinematics seem to be inter-related and likely result in poor biomechanics which place the shoulder at risk for developing pathologies such as superior labral anterior-posterior (SLAP) tears, secondary subacromial and internal impingement syndromes.

2.3.1.3 Scapular Dyskinesis and Altered Posture In addition to alterations in glenohumeral range of motion, forward shoulder posture (FSP) is prevalent in the swimming population.[2, 3, 75,

[91] FSP has been associated with increased scapular IR and AT.[14, 64, 73, 83] Alterations in scapular positioning, such as decreased scapular UR and increased scapular IR likely increase the risk of developing shoulder pathology through reduction of the subacromial space and decreased anterior stability.[84, 99] These findings are supported by Su et al[147] who evaluated isometric strength and scapular UR before and after a swim practice in competitive swimmers with and without shoulder impingement. They found that while there was no difference in characteristics pre-swim, the impingement group demonstrated decreased scapular UR after practice.

2.4 SCAPULAR DYSKINESIS AND SHOULDER PATHOLOGY

While researchers are attempting to define, classify and understand the causative factors for scapular dyskinesis, it is also unknown what the relationship is between the development of shoulder pain or pathology and scapular dyskinesis. The majority of research that has been conducted has been either retrospective or case control studies from which we cannot discern causation. However, these studies do provide insight as to what relationships might be present between certain types of scapular dyskinesis and different shoulder pathologies.

The development of general or localized shoulder pain often precedes diagnosis of overuse shoulder pathology. The presence of pain if identified may illicit signs and symptoms to guide intervention and the prevention of a developing overuse shoulder injury, such as impingement. Lawrence et al[78] evaluated shoulder complex kinematics in individuals symptomatic for shoulder pain and scapular dyskinesis compared to asymptomatic controls without the presence of dyskinesis. The type of dyskinesis was not provided, but significantly less scapular UR was observed at 30° and 60° of humeral elevation/depression in the plane of scaption and abduction. This was accompanied by decreased sternoclavicular posterior tilt and elevation. These findings are similar to those found by Ludewig et al[84] who evaluated scapular kinematics in an impinged population. If similar kinematic alterations are present in a population with generalized shoulder pain and a population with impingement, the continuation of the altered dyskinesis patterns in a population with shoulder pain are likely to contribute to the development of impingement syndrome. Therefore, assessing scapular kinematics and providing an intervention to restore normal scapular UR during initial humeral elevation may be useful in preventing the development of impingement syndrome. Alterations have also been found in clinical characteristics related to altered scapular kinematics. Tate et al[148] evaluated swimmers with and without shoulder pain and found younger athletes with shoulder pain demonstrated greater pectoralis minor tightness, and middle trapezius weakness, both of which are likely to contribute to greater IR (winging) of the scapula.[148]

Weakness and dysfunction of scapular stabilizers has been observed clinically in patients with shoulder instability.[167] Warner et al. identified scapular asymmetry in over half the patients diagnosed with anteroinferior glenohumeral instability through use of Moiŕe topography.[164] It has also been noted that when the scapula is fixed the ability to voluntary sublux the shoulder is lost.[167] This demonstrated the important contribution of the scapula to static stability of the glenohumeral joint in an instability population. Itoi et al[60] evaluated the effect of scapular inclination (UR) on static joint stability in cadaveric specimens and found that the angle of inclination has a significant effect on static stability and humeral head position. In the position of a sulcus test the humeral head was significantly more inferior as scapular inclination decreased and dislocated when the inclination dropped below 0°.[60]

The bulk of work evaluating pathology and scapular kinematics has focused on impingement syndrome.[15, 36, 47, 84, 89, 99, 139, 147, 164] In patients with impingement syndromes, altered scapular position, muscular activation, and kinematics have been found and include: an elevated scapula when compared bilaterally, scapular winging.[15, 36, 47, 84, 89, 99, 139, 147, 164] While alterations in scapular kinematics have been identified, there are conflicting findings as to what specific alterations contribute to impingement. This is likely due to differences in study populations, planes of movement and methodologies used. However, when the studies examining kinematics are evaluated in conjunction with EMG studies we can speculate how function of the scapular stabilizers affects scapular kinematics relative to shoulder impingement.

Cools et al[15] found altered scapular muscle activation and altered isokinetic protraction and retraction strength when comparing overhead athletes with and without impingement. At slower velocities, injured athletes demonstrated a retraction dominant pro/retract ratio while at a higher velocity injured athletes demonstrated decreased protraction strength, a protraction dominant ratio and decreased activation of the lower trapezius during retraction. These studies did not directly assess altered scapular motion; however, there is a known relationship between altered scapular stabilizer activation and altered scapular kinematics. The combined information from these studies do provide a rationale for how scapular kinematics could be altered in the presence of shoulder impingement based on muscular activation, especially at higher velocities, which would more closely relate to a pitching or throwing motion. Other studies which have evaluated scapular kinematics in populations suffering from shoulder impingement syndromes have had similar findings as those of Cools et al[15], specifically in regards to protraction. Increased scapular IR has been demonstrated in individuals with shoulder impingement compared to a normal group.[47, 84]

Studies which have not found significant differences in scapular IR in impingement groups have demonstrated trends of greater scapular IR. These studies also evaluated scapular kinematics during humeral elevation in the scapular plane and unloaded condition, methods, which may not adequately challenge the scapular stabilizers in order to induce dyskinesis like patterns of movement.[36, 89, 99] Herbert et al[47] found that scapular external rotation was the greatest contributor to scapular motion in the plane of abduction. Ludewig et al[84] found that in an unloaded condition there were no scapular IR differences present between controls and subjects with impingement; but in loaded conditions the subjects with impingement demonstrated significantly greater scapular IR.

Subjects with impingement have also demonstrated decreased UR and increased AT.[47, 84] This coincided with increased activation of the upper and lower trapezius and decreased activation of the serratus anterior. Compared to the a normal group, UR was decreased in the initial phase of scapular elevation, where it would primarily be a function of the serratus anterior, however in the last 2 phases similar UR was found. This could be explained by the increased activation of the lower trapezius, which would have a better mechanical advantage to stabilize and upwardly rotate the scapula above 90° of humeral elevation, thus compensation was present to overcome the lack of initial scapular UR.[84] This would likely be identified as a dysrhythmia or stutter during humeral elevation, which would be type 3 scapular dyskinesis.[74]

Subjects with impingement also demonstrated increased AT of the scapula with arm elevation, which may be a result of decreased activation of the serratus anterior. This is supported by the findings of other studies evaluating scapular kinematics relative to shoulder impingement that have found decreased posterior tilt during humeral elevation in flexion and abduction.[47, 89] Herbert et al[47] found that AT contributed most to scapular position during humeral elevation during flexion, and a lag at 90° humeral elevation could identify unilateral shoulder impingement syndrome when compared bilaterally. Interventions aiming to correct scapular position have also been successful in alleviating pain in impingement populations, which is further evidence of a relationship between scapular kinematics and the presence of shoulder pathology. Shaheen et al. found manual interventions such as scapulothoracic taping altered scapular kinematics and reduced pain in subjects with impingement syndromes.[139] While it is still unknown how the mechanism of taping actually works, it does show the re-establishing normal scapular motion can alleviate symptoms in a population suffering from impingement.

Based on previous research there is indirect evidence that dysfunction of the scapular stabilizers results in dyskinesis and is related to the presence of shoulder pain and pathology. However, no single study that has evaluated muscular function has been conducted in a population with scapular dyskinesis. Therefore we can only speculate on the actual relationships between muscular function and scapular dyskinesis, which limits our ability to understand its impact on the development of pain and shoulder injury. Identifying this relationship is necessary for properly treating and evaluating the individuals who are prone to developing dyskinesis and often suffer from shoulder injury, specifically overhead athletes.

2.5 METHODOLOGICAL CONSIDERATIONS

The section will review the methodology historically used to evaluate the parameters chosen for this study and will provide rationale for the chosen methodologies. A detailed description of the protocol and methodologies is provided in chapter 3.

2.5.1 Scapular Dyskinesis Screening Test

Qualitative screening for the identification of scapular dyskinesis is an evaluation tool often used in the absence of precision motion analysis systems. Qualitative screenings however, rather than biomechanical assessments, are historically used for identifying the presence of scapular dyskinesis in the clinical setting. There are two primary qualitative screening scales that evaluate scapular position beyond a single plane of motion.[74, 96] The scale that was utilized in this study was validated to an electromagnetic 3-D motional analysis system and demonstrated moderate inter-rater reliability during live rating bilaterally (k = 0.55-.058). This method provided a more general rating: normal motion, subtle dyskinesis, or obvious dyskinesis.[96] The method by Kibler et al[74] constrains classification of scapular motion based on the predominant plane of abnormality as discussed in section 2.2.3. Often scapular alterations are not isolated to a single plane, but rather occur in conjunction. This method demonstrated less inter-rater reliability (k = 0.31-0.42) compared to McClure's method and has not been validated.

2.5.2 Isometric strength assessment

Isokinetic testing is often used in assessment of gross shoulder strength, specifically glenohumeral internal/external strength; however it is constrained in its ability to assess the scapular stabilizers. Bulky equipment limits testing to only protraction/retraction and elevation, and evaluates muscle groups rather than individual muscles.[31, 33] Isometric testing using a handheld dynamometer was chosen for this study in order to better isolate the scapular stabilizers. All testing positions and procedures were based off of grade 5 manual muscle testing procedures.[53, 64] Inter-tester and intra-tester reliability was conducted within the Neuromuscular Research lab and the ICCs and SEM for isometric strength testes are provided in Table 3. The chosen positions for isometric strength assessment of the upper, middle, and lower trapezius have been utilized in previous research and have demonstrated greater percent maximal voluntary isometric contraction (%MVIC) activation and muscle isolation.[33, 143] To assess the serratus anterior, the seated flexion method was chosen rather than the supine position. The supine position assesses the serratus anterior and the pectoralis minor through scapular protraction, while the seated position better isolates the serratus in its function of scapular UR. In addition, this position elicited the highest %MVIC when compare to other testing positions.[31, 33]

Table 3. Intra and Inter-tester Reliability and Standard Error of Measure for Musculoskeletal Characteristics of the Shoulder

	Intra-tester reliability	Intra-tester SEM	Inter-tester reliability	Inter-tester SEM
Serratus Anterior (%BW)	0.866	13	0.862	14
Upper Trapezius (%BW)	0.976	5	0.939	8
Middle Trapezius (%BW)	0.838	14	0.973	5
Lower Trapezius (%BW)	0.906	9	0.943	9

2.5.3 3-Dimensional scapular kinematics assessment

Several quantitative methods for evaluating scapular position have been conducted through clinical measures such as digital inclinometry and tape measures.[26, 74, 138, 144] However, these methods are constrained to only assessing scapular position in a single plane during static positioning which may differ compared to dynamic motion. Three-dimensional motion analysis has been used to evaluate constrained and functional movement in the upper and lower extremity in healthy and pathological populations.[10, 61, 62, 98, 99, 101, 112, 117, 118] Earlier research utilized electromagnetic systems that were validated through the use of bone pins.[62] This system provided the ability to evaluate scapular kinematics in all three planes during dynamic motion, and has provided useful data in regards to differences in scapular kinematics in different populations as well as scapular contribution to sport specific tasks. Some limitations to this methodology include metal interference, limited capture volume, and wires that may inhibit the subject’s natural movement. More recent research validated the use of a passive infrared video based motion analysis system to capture scapular kinematics during humeral elevation and depression in the planes of flexion and abduction. This method for evaluating scapular kinematics has been found to be valid and reliable compared to dynamic stereo X-ray.[11] Video based motion analysis is a favorable method for analyzing scapular kinematics because small markers placed on the shoulder and trunk are not likely to inhibit constrained or functional motions and a larger capture volume can be utilized based on the number of cameras available.

2.5.4 Electromyographic assessment

Electromyography (EMG) has been used to evaluate the electrical activity of living muscles, and serves to evaluate the status and function of the nerves and skeletal muscle fibers.[121] Surface and intramuscular electromyography have been utilized to evaluate muscular activity in healthy and pathological populations,[166] during sport specific tasks,[52, 68] and rehabilitation exercises[31, 33, 111, 128]. Variables that are often assessed in regards to shoulder function include muscular activation patterns during a movement, and intensity of activation based on maximal isometric contractions (%MVIC). Both of these variables are likely to provide useful information, specifically in regards to scapular kinematics, when comparing muscular function between a healthy population and a population with scapular dyskinesis. Evaluating %MVIC at specific time points during dynamic motion provides information as to the intensity (amplitude) and number of motor units (MU) being recruited by a specific muscle at that time point. While this is not a measure of strength, it can provide useful information as to how hard the muscle is working. Previous research has demonstrated that there are specific sequences of firing (on/off activation) in healthy populations during dynamic motion.[52, 68, 166] This may be of most importance when evaluating muscular function in regards to scapular kinematics and dyskinesis. Due to the coupling of the scapular stabilizer, dysfunction may be more related to altered firing patterns rather than decreased amplitude, though neither has been evaluated in a dyskinesis population.

3.0 METHODOLOGY

3.1 EXPERIMENTAL DESIGN

This study utilized an cross-sectional study design. This design evaluated the muscular characteristics associated with the presence of scapular dyskinesis compared to a normal group. Figure 1 illustrates the study design, subject recruitment, enrollment, and procedures.

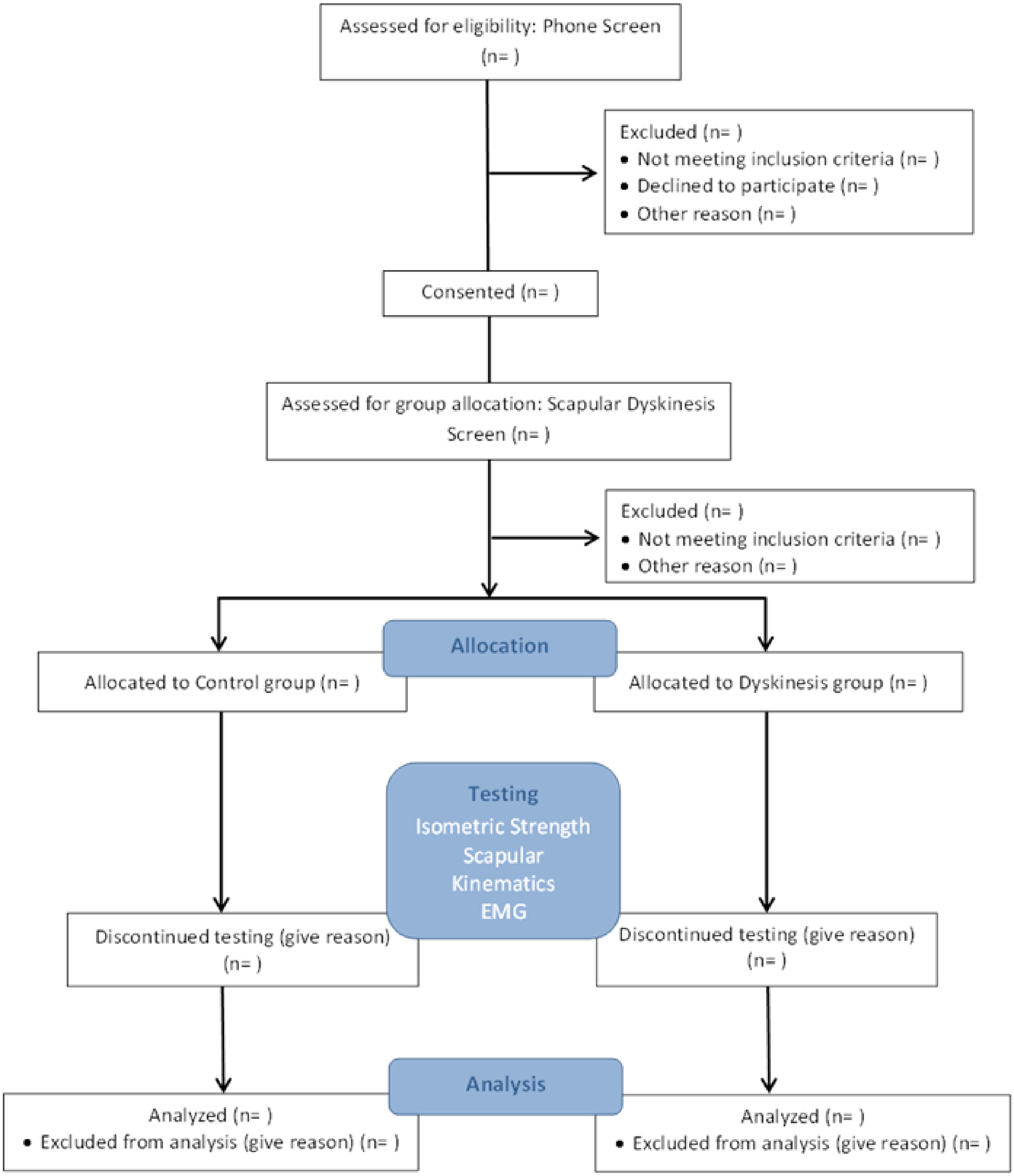

Figure 1. Consort diagram of study design

3.2 SUBJECT RECRUITMENT

The study was approved by the Institutional Review Board at the University of Pittsburgh prior to the implementation of all research procedures. Thirty-four overhead athletes were recruited from the communities surrounding the University of Pittsburgh. Study flyers and contact with sport health care clinicians facilitated the recruiting process, and interested participants contacted the primary investigator at the NMRL for phone screening.

3.3 SUBJECT CHARACTERISTICS

3.3.1 Inclusion Criteria

Individuals were eligible and included in this study if they were between the ages of 18-30, and regularly trained and competed in an overhead sport. An overhead athlete, for the purposes of this study was defined as an athlete who participated in regular practices and competition in a sport that required repetitive overhead motion (e.g.: swimming, volleyball, baseball, softball, tennis, water polo). In addition, eligible individuals were required to have self-rated shoulder pain less than 6/10 in their dominant shoulder, based on a VAS scale.

3.3.2 Exclusion Criteria

Individuals were deemed ineligible if they reported having self-rated shoulder pain greater than 6/10. Individuals were excluded if they report having a current upper body or upper extremity neurological injury or impairment; were unable to perform full active range of motion or maximal contractions of the scapular stabilizers; or reported an allergy to medical grade adhesives.

3.3.3 Group Classification

Individuals that meet the criteria for inclusion in the study and volunteered to participate were enrolled in the study and underwent a scapular dyskinesis screening to determine group classification. Two groups were needed for comparison: 1. Scapular dyskinesis group, and 2. Healthy control group. Specific definitions and procedures for the screening process are provided in section 3.6.1.

3.4 POWER ANALYSIS

To the author's knowledge, there were no previous studies examining scapular kinematics and muscular function in a population evaluated to have scapular dyskinesis compared to a normal group. Therefore, using GPower version 3.1.5 (Franz Faul, Universität Kiel, Germany) sample size calculator, thirty four subjects (seventeen per group) were needed for detectible differences between groups, using two-tailed t-tests with an effect size of 1.0, an α error probability of 0.05 and power set at 0.8. To account for 30% attrition, a total of forty six subjects may be recruited for enrollment into the study.

3.5 INSTRUMENTATION

3.5.1 Vicon Motion Analysis System

Scapular kinematics were collected using the Vicon Three-Dimensional (3D) Infrared Optical Capture System (Vicon, Centennial, CO). This system utilizes passive reflective markers which are placed on specific bony landmarks which reflect the infra-red light emitted by high speed infrared cameras. Ten high speed (250 Hz) cameras (Vicon, Centennial, CO) collected two dimensional coordinate data which was transferred to the Nexus software system where it was synchronized and combined to construct a 3D rigid body model to acquire joint position and orientation. Calibration was conducted based on the guidelines of the manufacturer using the wand method. Eight fixed cameras were mounted on the walls around the capture area and two were mounted on tripods and positioned and aimed at the shoulder behind the subject to ensure that each marker was continually in the line of sight of at least two cameras during performance of the tasks. Determination of position and angular data accuracy performed in the Neuromuscular Research Laboratory has yielded a room mean square error of 0.002m and 0.254° respectively.

3.5.2 Noraxon Telemyo DTS Electromyographic System

Muscular activation patterns were collected using wireless surface and indwelling electrodes and the Noraxon TeleMyo DTS telemetric electromyography (EMG) system (Noraxon USA Inc., Scottsdale, AZ). This system utilized up to sixteen light weight (< 14g) preamplified EMG sensor transmitter units with a 1st order high-pass filter set to 10Hz +/-10% cutoff and an input range of +/- 3.5mV. A belt receiver with a range of 10m, and a Noraxon 2400R G2 Analog Output Receiver that contains a 16 bit analog to digital conversion system. Communication with the computer system was achieved through wireless internet. A sampling frequency of 1500Hz was utilized to record activation of the scapular stabilizers.

3.5.3 Hand Held Dynamometer

A hand-held dynamometer (Lafayette Instrument Co., Lafayette, IN) was used to assess isometric muscle torque (Nm). For all measures peak force (kg) produced will be measured by the dynamometer to the nearest 0.1 kilogram.

3.6 TESTING PROCEDURES

3.6.1 Scapular Dyskinesis Screening

A previously validated and reliable method of screening for scapular dyskinesis was utilized for this study.[96, 149] Prior to group assignment individuals who meet the screening criteria were asked to perform five repetitions of bilateral active weighted shoulder flexion and abduction. Subjects weighing less than 150lbs used a three pound weight, while individuals weighing 150lbs or greater used a five pound weight. During the test the two examiners with clinical experience observed the scapular motion and rate the motion of the dominant shoulder according to Table 4. The final rating was used to establish the dyskinesis and normal groups. In order to establish clearly defined groups only subjects rated by both examiners to have obvious dyskinesis were placed in the dyskinesis group and only subjects rated by both examiners to have normal scapular motion were placed in the normal group.

Figure 2. Scapular dyskinesis screening in abduction and flexion

Table 4. Scapular Dyskinesis Screening

Operational Definitions

Normal scapulohumeral rhythm: The scapula is stable with minimal motion during the initial 30° to 60° of humerothoracic elevation, then smoothly and continuously rotates upward during elevation and smoothly and continuously rotates downward during humeral lowering. No evidence of winging is present.

Scapular dyskinesis: Either or both of the following motion abnormalities may be present.

Dysrhythmia: The scapula demonstrates premature or excessive elevation or protraction, non-smooth or stuttering motion during arm elevation or lowering, or rapid downward rotation during arm lowering.

Winging: The medial border and/or inferior angle of the scapula are posteriorly displaced away from the posterior thorax.

Rating Scale

a) *Normal Motion:* no evidence of abnormality in either plane of motion
b) *Subtle abnormality:* mild or questionable evidence of abnormality, not consistently present
c) *Obvious abnormality:* striking, clearly apparent abnormality, evident on at least three/five trials (dysrhythmias or winging of 1 in or greater displacement of scapula from thorax)

Final Rating

Normal: both test motions are rated as normal or one motion is rated as subtle
Subtle abnormality: both flexion and abduction are rated as subtle
Obvious abnormality: Either motion is rated as having obvious abnormality

3.6.2 Strength Assessment of the Scapular Stabilizers

A handheld dynamometer (HHD) (Lafayette, IN.) was used for all isometric strength testing. Testing position for the subjects and examiner were based off manual muscle testing procedures as outlined by Hislop and Montgomery[53] unless referenced otherwise. For all of the testing procedures subjects were asked to exert as much force as possible against an unmoving resistance (make test) for a duration of five seconds. A practice trial was conducted at 50% effort to ensure proper performance of the test. A total of three measured trials were performed on the dominant side. There was a thirty second rest period between trials to offset fatigue. Inter-tester and intra-tester reliability for the following tests is provided in Table 3.

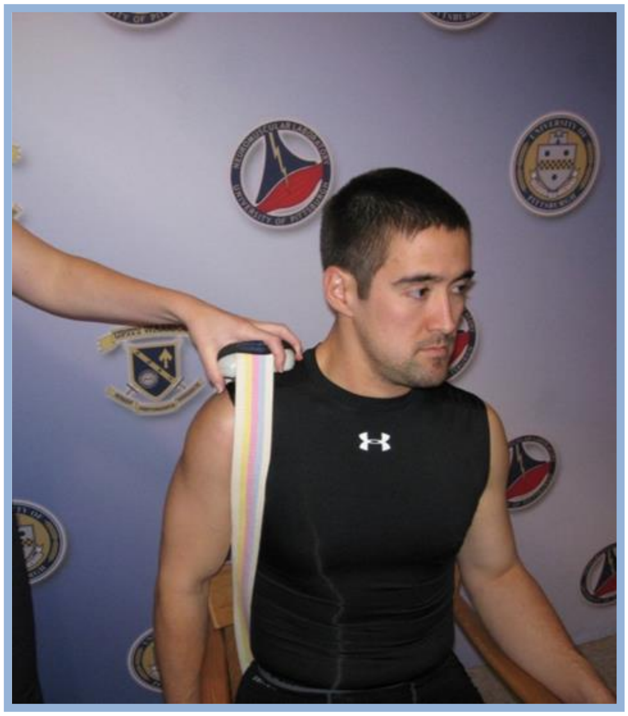

Figure 3. Measurement of isometric strength of the upper trapezius muscle

Upper Trapezius strength was measured with the subject short sitting in a chair with their hands relaxed in their lap and face turned slightly away from the side being tested. Due to the strength of this muscle, a therapy belt was utilized to provide resistance for this task. It was attached to the HHD and anchored to the chair. The examiner stood behind and above the subject with HHD placed on the acromion process. The subjects were instructed to produce an upward force with the shoulder into the HHD and belt, as if attempting to raise the shoulder towards the ear.

Figure 4. Isometric strength assessment of the middle trapezius

Middle Trapezius strength was measured using previously established manual muscle testing procedures.[32, 64] The subjects were asked to lie prone on a treatment table with the head in neutral and the non-test arm placed under the forehead for comfort. The test arm was at 90° abduction with the elbow fully extended and the thumb pointing up towards the ceiling. The examiner stood on the test side, slightly inferior to the shoulder. The HHD was placed on the radial styloid process slightly posterior to the most lateral aspect and the other hand was placed on the scapula to provide stabilization. The subjects were instructed to produce an upward force.

Figure 5. Isometric strength assessment of the lower trapezius

Lower trapezius strength was measured using previously established manual muscle testing procedures.[32, 64] The subjects were asked to lie prone on a treatment table with the arm over the head in 135° of abduction and the elbow extended with the thumb pointing up towards the ceiling. The examiner was standing on the test side. The HHD was placed on the radial styloid process directly posterior to the most lateral aspect and the other hand was placed on the scapula to provide stabilization. The subjects were instructed to produce an upward force.

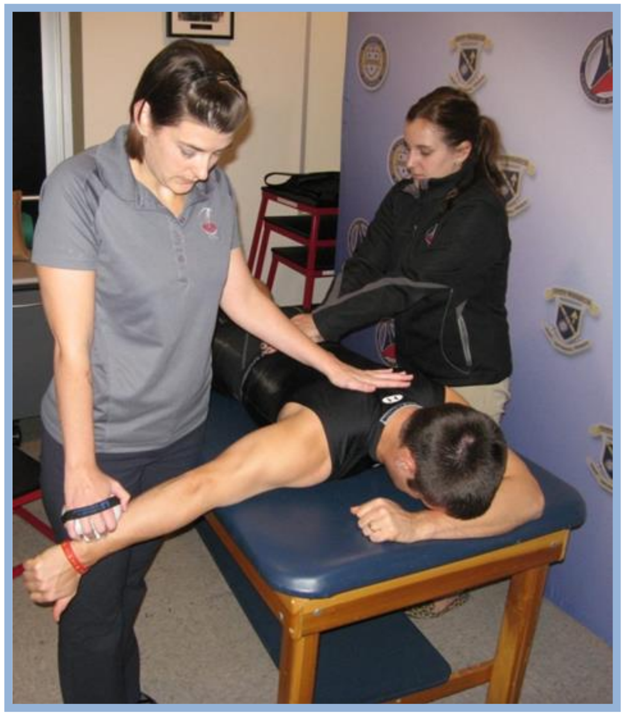

Figure 6. Isometric strength assessment of the rhomboids

Rhomboids strength was measured using previously established manual muscle testing procedures.[64, 143] Subjects laid prone on a treatment table with the head facing the table with their forehead on the forearm of the side not being tested. The test arm was in 90° abduction with the elbow extended and the thumb pointing down towards the floor. The examiner stood on the test side, slightly inferior to the shoulder. The HHD as placed above the ulnar styloid process, directly posterior to the most lateral aspect. The examiners' opposite hand was placed on the scapula for stabilization. The subjects were instructed to produce an upward force.

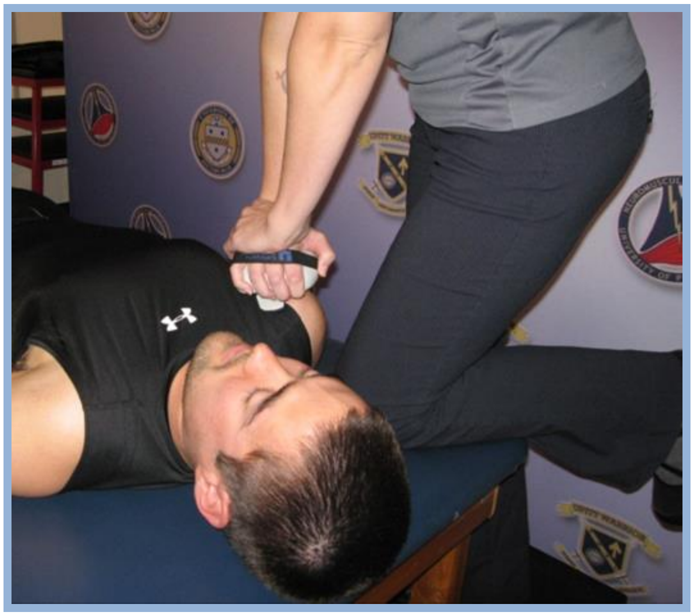

Figure 7. Measurement of isometric strength of the pectoralis minor muscle

Pectoralis Minor strength was measured using previously established manual muscle testing procedures.[64] Subjects laid supine on the treatment table with their arms resting at their side. The examiner stood opposite the test side, with the HHD placed on the anterior shoulder over the coracoid process. The subjects were asked to produce and upward force.

3.6.3 Electromyographic Assessment of the Scapular Stabilizers

To assess muscle activation patterns of the scapular stabilizers surface and indwelling EMG was utilized. After subjects completed the screening and isometric strength testing they were prepped for EMG analysis. The skin over muscles where indwelling electrodes were inserted was prepared using clean procedures of shaving and cleaning the area with an alcohol swab and iodine. Indwelling electrodes were used for the following muscles: Rhomboid major, levator scapulae, and pectoralis minor. All electrode insertion sites were determined based on the guidelines of Delagi et al[121]. Electrode insertion was performed using Noraxon guidelines and previously established methods.[76, 121] Two pre-manufactured, disposable non-paired 25 gauge 50 mm hook-wire electrodes (Nicolet, VIASYS) were inserted into each muscle at the insertion sites described below. The muscle belly for the rhomboid major was identified with the subject lying prone with the arm internally rotated with the hand resting on the small of the back. The electrodes were inserted midway between the root of the spine and inferior angle of the scapula just medial to the vertebral border through the middle trapezius; proper placement was confirmed by lifting the hand off the small of the back. The muscle belly for the levator scapulae was identified with the subject lying prone. The electrodes were inserted two fingerbreadths superior and one fingerbreadth medial to the superior-medial angle of the scapula through the upper trapezius; proper placement was confirmed by performance of scapular elevation. The muscle belly of the pectoralis minor was identified with the subject lying supine. The electrodes were inserted in the mid-clavicular line to the anterior surface of the third rib and will be withdrawn slightly; proper placement was confirmed by performance of scapular depression.[121]

For muscles being assessed through surface EMG the skin over the muscles was prepared by shaving, abrading and wiping the area with an isopropyl alcohol swab to minimize skin-electrode impedance. Surface electrodes were utilized for the following muscles: serratus anterior, upper trapezius, middle trapezius, and lower trapezius. All surface electrode placement sites were determined based on the guidelines of Cram et al.[18] Two 20mm oval self-adhesive, bipolar

Ag/Ag-Cl surface electrodes (AMBU Blue Sensor N; AMBU, Glen Burnie, MD) were placed over the marked muscle belly sites. The electrodes were placed in series with the muscle line of function with an inter-electrode distance of 2cm. The muscle belly of the upper trapezius was identified with the subject short seated, in order to better assess the actions of the upper trapezius associated with scapular motion the electrodes were placed along the ridge of the shoulder, lateral to one half the distance between the cervical spine at C7 and the acromion; proper placement was confirmed through the performance of shoulder elevation. The muscle belly of the middle trapezius was identified with the subject short seated and the electrodes were placed medially at the level of the root of the spine of the scapula. Proper placement was confirmed through the performance of scapular external rotation and shoulder abduction. The muscle belly of the lower trapezius was identified by having the subject retract and depress the scapula with the arm flexed at 90° and the electrodes were placed on an oblique angle (55°), 5cm inferior to the scapular spine medial to the medial border of the scapula. Proper placement was confirmed through abduction of the arm and external rotation of the scapula. The muscle belly of the serratus anterior was identified by having the subject flex their arm against resistance, and palpation of the contraction was felt anterior to the border of the latissimus dorsi at the level of the inferior angle of the scapula. The electrodes were placed horizontally below the axillary area at the level of the inferior angle of the scapula; proper placement was confirmed by forward flexion of the arm and protraction of the shoulder.

The wireless EMG transmitters was connected to the electrodes and secured to the skin with double-sided disc tape in an optimal location so that the lead wires connecting to the electrodes will be properly positioned. The transmitter leads and electrodes were secured with strips of Cover-Roll® Stretch Adhesive Bandage in order to minimize motion artifact.

Prior to the beginning of testing a five second quiet file was collected with the subject sitting in a relaxed/resting position which will be used to establish a baseline in which to determine muscle on/off activation patterns.[68] Maximal voluntary isometric contractions (MVIC) for each muscle were also collected prior to testing to allow for normalization of the EMG data during the performance of arm elevation and depression at specific time points. To collect the MVIC for each muscle the subject was positioned in the previously described positions used for verification of electrode placement. In each position the subject was asked to exert a maximal force against an unmoving resistance for five seconds.

3.6.4 Biomechanical Testing

Scapular kinematics during humeral elevation in the planes of flexion and abduction was calculated based on the three-dimensional coordinate data of retro-reflective markers placed on the subject's torso, upper extremities, scapula, and anthropometric measurements of the individual subject. Retro-reflective markers will be placed on the following landmarks: spinous process of the 7th cervical vertebra (C7), T10, sternal notch, xyphoid process, radial styloid, ulnar styloid, medial and lateral epicondyle, acromioclavicular joint, posterior corner of the acromion, medial border of the scapula at the level of the root of the spine of the scapula, inferior angle of the scapula, and a three marker triad on the shelf of the acromion, bilaterally. The three-dimensional coordinate data was collected with Vicon 3D Infrared Optical Capture System utilizing eight high-speed optical cameras sampling at 250 Hz.[10]

Figure 8. Marker placement of assessment of scapular kinematics

The scapular kinematic assessment included loaded raising and lowering the arm at a paced controlled speed (30 beats per minute) in the directions of flexion and abduction. Subjects weighing less than 150lbs were given three pound weights, while individuals weighing 150lbs or greater were given five pound weights to hold during the tasks. Subjects were asked to stand in a comfortable standing posture, and to perform five continuous repetitions of humeral elevation to their maximum range of motion in tempo with the beat of the metronome and depression back down to the starting point, a beat occurred at the bottom and the top of the arc of motion. The subjects were allowed to practice until they were comfortable with the tempo and task then one trial of five continues repetitions was collected for each direction. Scapular kinematic data was averaged across the three middle repetitions. Variables assessed included scapular upward/downward rotation, internal rotation/ external rotation, and anterior/posterior tilt at 30°, 60°, 90° and 120° of humeral elevation and depression. These variables represent standard critical points for scapular motion throughout humeral elevation and depression, and allowed for assessment of scapular kinematics between the dyskinesis and control groups.

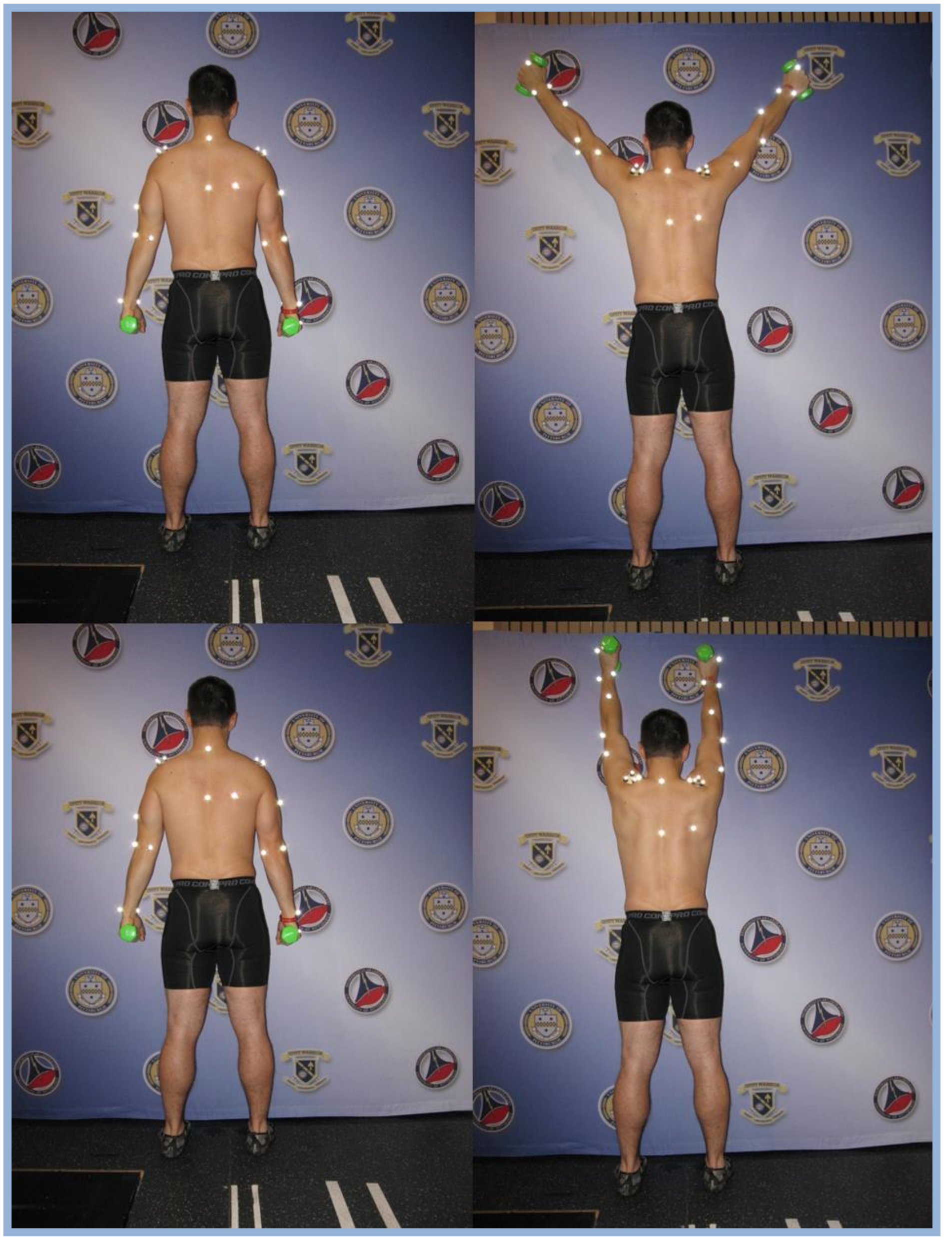

Figure 9. Starting and ending position for humeral elevation in abduction and flexion

3.7 DATA REDUCTION

3.7.1 Scapular Stabilizer Strength

Average peak force (kg) for all muscles was obtained and normalized to bodyweight (%BW = (average (kg)/ bodyweight (kg))*100).

3.7.2 Scapular Stabilizer Electromyography

Data reduction for indwelling electromyography was conducted according the recommendations of the International Society of Electrophysiology and Kinesiology (ISEK).[106] Within the sensor a common mode rejection ratio of 100dB was utilized. The analog signal was converted to a digital signal using the analog-to-digital board, and underwent full wave rectification. Because a 1st order high-pass filter set at 10Hz was performed within each sensor, only low-pass filters were applied for surface EMG. Surface EMG signals will be filtered using a 500 Hz low-pass Butterworth filter. Indwelling EMG signals produce a higher frequency spectrum and can detect single motor unit activity; therefore indwelling signals were filtered using a 750 Hz low-pass filter.[106, 124] The rectified signal of the MVIC was averaged and used to report the average percent of maximum voluntary isometric contraction (%MVIC) of each muscle during specific arcs of motion (30-60°, 60-90, 90-120°) across humeral elevation and depression trials. The rectified signal of the quiet trial was also normalized to the baseline signal. Each muscle was considered active when it reached and sustained amplitude of 5 times the baseline signal for at least 25ms. When the amplitude of a muscle dropped below the onset threshold it was considered to be off.[68] On/off activation patterns for each muscle were collected during humeral elevation and humeral depression.

3.7.3 Scapular Kinematics

Data reduction for scapular kinematic variables will be conducted according to the recommendations of the International Shoulder Group.[61, 154, 169] The 3D positions of the retro-reflective markers will be reconstructed in the global coordinate system. The position of the humeral head will be estimated based on the anthropometric data using the Scapular Plug-in Gait Model (Vicon, Oxford, UK) and the 3D coordinates of the markers will be exported through the Vicon Nexus software into a text file. A custom Matlab program (Mathworks, Natick, MA) will be used to access the 3D coordinate data and identify the peaks and valleys of humeral elevation/depression across the trial to create an excel output. Within Matlab data will be filtered using a fourth order zero-lag low-pass Butterworth filter with a cutoff frequency set at 5 Hz, as determined with power spectrum analysis. Euler angle decomposition will be used to determine the scapular and humeral orientation with respect to the thorax.[154, 169] Orientation of the scapula will be determined as rotation about the y-axis of the scapula (internal rotation/external rotation), rotation about the z-axis of the scapula (upward/downward rotation), and rotation about the x-axis of the scapula (anterior/posterior tilting).[61, 154, 169] The humeral orientation will be determined as rotation about the y-axis of the humerus (plane of elevation, rotation about the z-axis (elevation), and rotation about the y –axis (axial rotation).[154, 169]

3.8 STATISTICAL ANALYSIS

Data will be first assessed for normality with an alpha level set at 0.05 *a priori*. Based on the findings of the normality tests, descriptive data will be reported as means ± standard deviation (SD) or as median and interquartile range if normality was violated. Where normality assumptions are achieved independent t-tests for mean differences in kinematics, %MVICs, on/off sequencing, and strength between groups will be used. If data violates the normality assumption Mann-Whitney U tests will be used, with a significance level set *a priori* at alpha = 0.05. The statistical analysis for this study is addressing established hypotheses and in order to prevent an inflation of type II error bonferroni corrections will not be applied.

4.0 RESULTS

The primary purpose of this study was to determine if differences were present in scapular kinematics, muscular activation patterns, and strength between overhead athletes with normal scapular motion compared to overhead athletes with scapular dyskinesis.

4.1 SUBJECTS

4.1.1 Demographic Data

The subject recruitment process, the flow of participation, and subject enrollment are provided in Figure 10. A total of 61 overhead athletes expressed interest in participating, of which 58 met the initial eligibility criteria. Forty-four overhead athletes enrolled in the study and underwent the scapular dyskinesis screening. Ten subjects were excluded based on the scapular dyskinesis screening due to evaluator disagreement. A total of 34 subjects (Normal group = 17, Dyskinesis group = 17) meeting all eligibility criteria participated and completed all testing procedures.

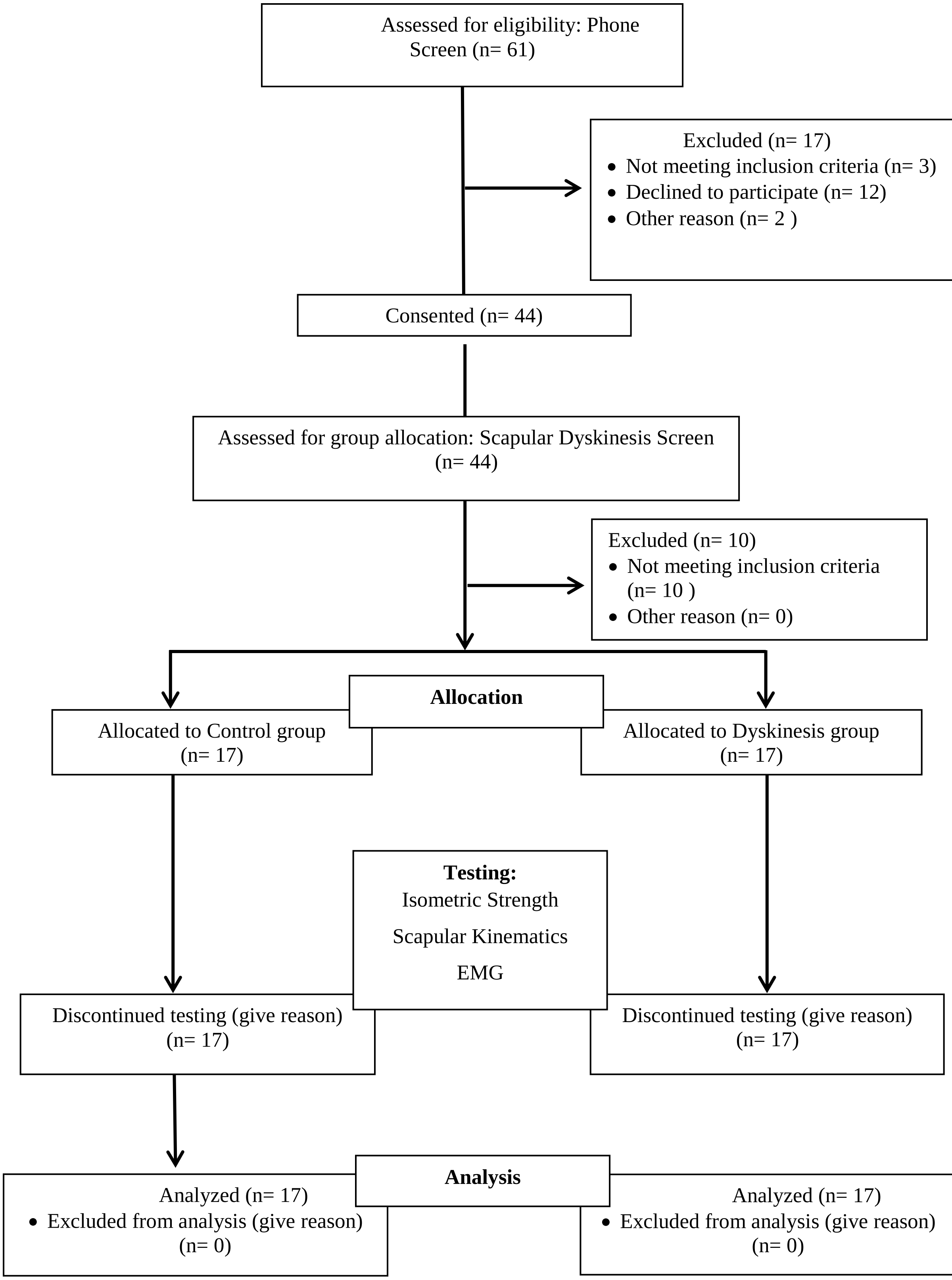

Figure 10. Consort Diagram

Subject demographics are presented in Table 5 and a breakdown of gender and sport for each group is provided in Figure 11. There were no statistically significant differences between groups in either gender distribution or age.

Table 5. Normal and Dyskinesis Group Demographics

	Normal					**Dyskinesis**				
	Mean	±	St.Dev	Min	Max	Mean	±	St.Dev	Min	Max
Age (yrs)	21.7	±	2.9	18.0	27.0	20.7	±	1.7	18.0	24.0
Height (mm)	1709.3	±	66.4	1596.0	1851.0	1786.4	±	81.2	1690.0	1940.0
Weight (kg)	70.2	±	9.5	53.9	83.9	76.1	±	11.7	55.4	95.9

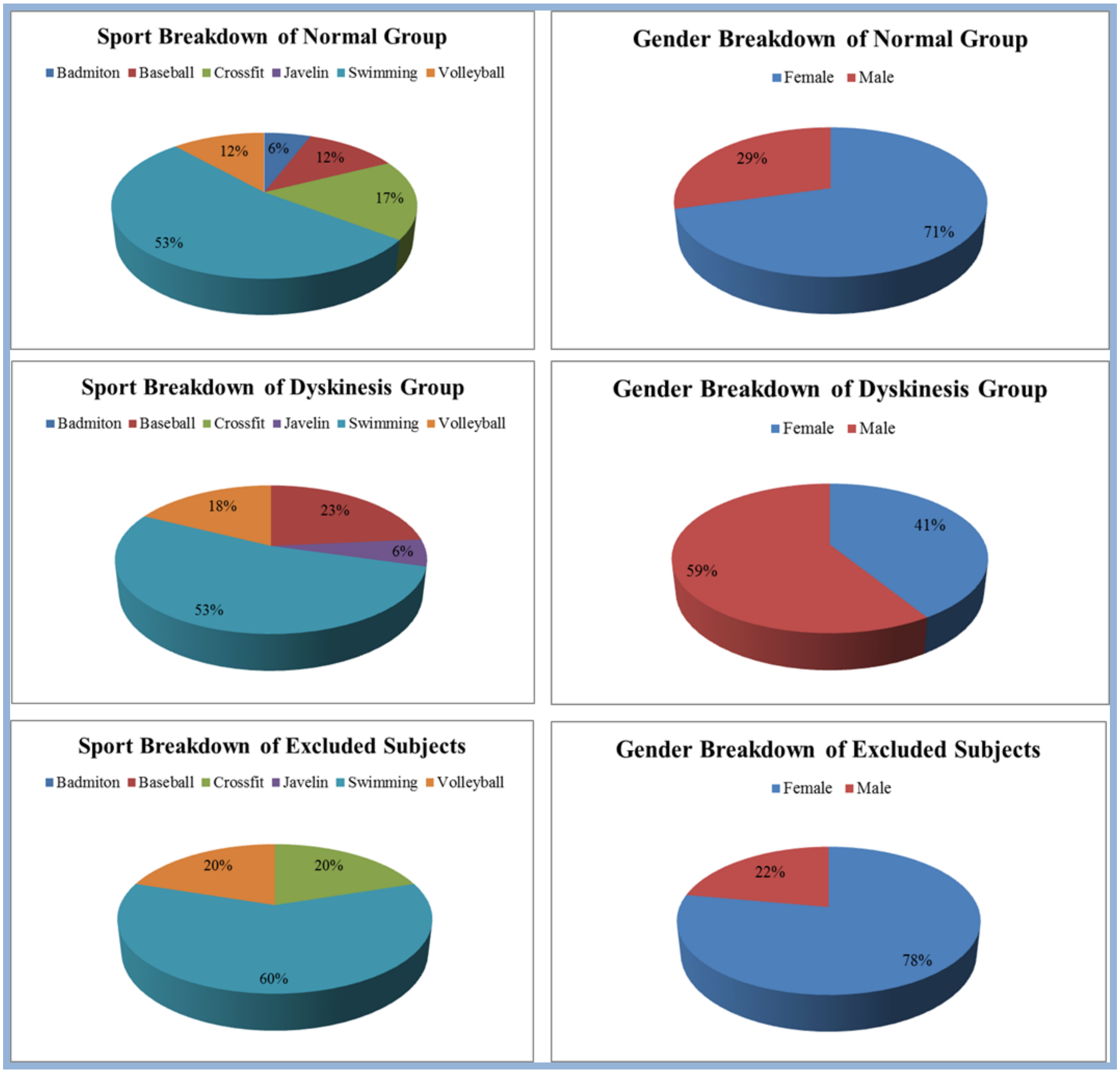

Figure 11. Group Demographics for Sport and Gender

4.1.2 Injury History and Shoulder Pain

Subjects were asked to self-report any injury history to the dominant shoulder/upper arm. Within the normal group, 11% (2/17) of subjects reported a history of shoulder complex injury, while

24% of the subjects in the dyskinesis group reported a history of shoulder complex injury. Similar findings were present between groups for self-reported pain based on a VAS. Forty-seven percent of subjects within the normal group reported the presence of shoulder pain, while 59% of the subjects reported the presence of pain in the dyskinesis group. Groups were also similar in the reported severity of shoulder pain with a minimum of 0 and a max of 4 in both groups. A breakdown of reported pain is presented in Figure 12.

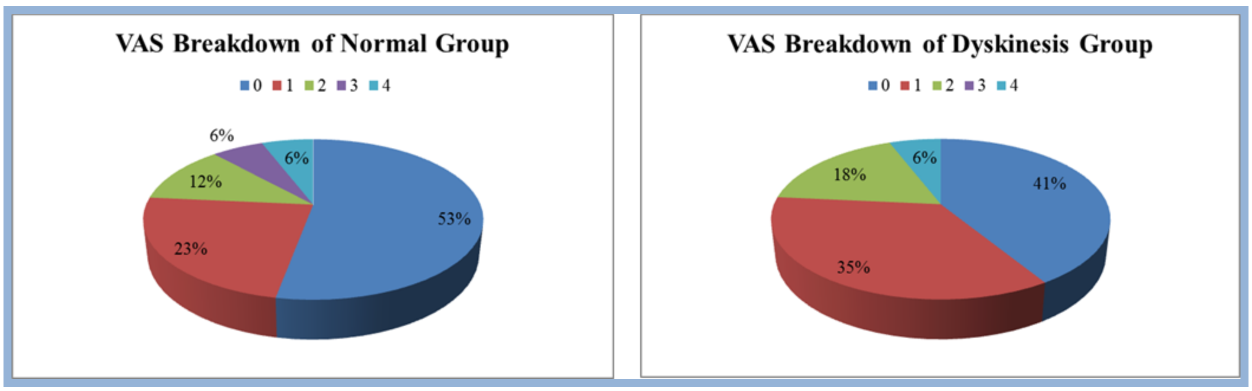

Figure 12. Reported pain within Normal and Dyskinesis Groups

4.1.3 Scapular Dyskinesis Screening

Forty-four subjects underwent the scapular dyskinesis screening; ten subjects were excluded from further participation due to evaluator disagreement as to the severity of dyskinesis present. Seventeen subjects were allocated to the dyskinesis group, of the subjects classified with a final score of Obvious Abnormality, 88% demonstrated inferior angle prominence either in isolation (35%) or conjunction with medial border prominence (47%) or dysrhythmia (5%). Fifty-eight percent demonstrated medial border prominence either in isolation (12%) or in conjunction with inferior angle prominence (47%).

4.1.3.1 Scapular Dyskinesis Screening Reliability Intra-tester and inter-tester reliability was assessed for agreement using a weighted κ (linear weighting) based on 3 possible ratings from the flexion and abduction test movements: normal, subtle or obvious. Strong and statistically significant intra-tester reliability was present for evaluation of dyskinesis in both planes as well as the final score which was used for group allocation and eligibility for testing procedures (Table 6). Moderate and statistically significant inter-tester reliability was present for evaluation of dyskinesis in both planes as well as the final score (Table 6).

Table 6. Scapular Dyskinesis Screening Reliability

	Intra-Tester		**Inter-Tester**	
	Weighted Kappa (κ)	Significance	Weighted Kappa (κ)	Significance
Flexion Score	0.726	<0.001	0.544	<0.001
Abduction Score	0.733	<0.001	0.661	<0.001
Final Score	0.725	<0.001	0.558	<0.001

4.2 BIOMECHANICAL CHARACTERISTICS BETWEEN GROUPS

It was hypothesized that individuals with obvious dyskinesis would demonstrate decreased scapular upward rotation, increased anterior tilt and increased internal rotation compared to the normal group during humeral elevation and depression. All biomechanical variables were assessed for and achieved the assumption for normality, therefore independent t-tests were used to assess for mean differences in scapular kinematics at 30°, 60°, 90°, and 120° of humeral elevation and depression in the sagittal and coronal planes.

4.2.1 Biomechanical Characteristics during Humeral Elevation and Depression in the Sagittal Plane

During humeral elevation in the sagittal plane (flexion) both groups demonstrated similar scapular kinematics: increasing internal rotation from 30° -90°, and decreased protraction at 120° of humeral elevation; increasing upward rotation from 30° - 120° (Figure 13). There was a statistically significant difference in scapular UR at 30° of humeral elevation and depression, with the normal group demonstrating significantly greater UR compared to the dyskinesis group (Table 7).

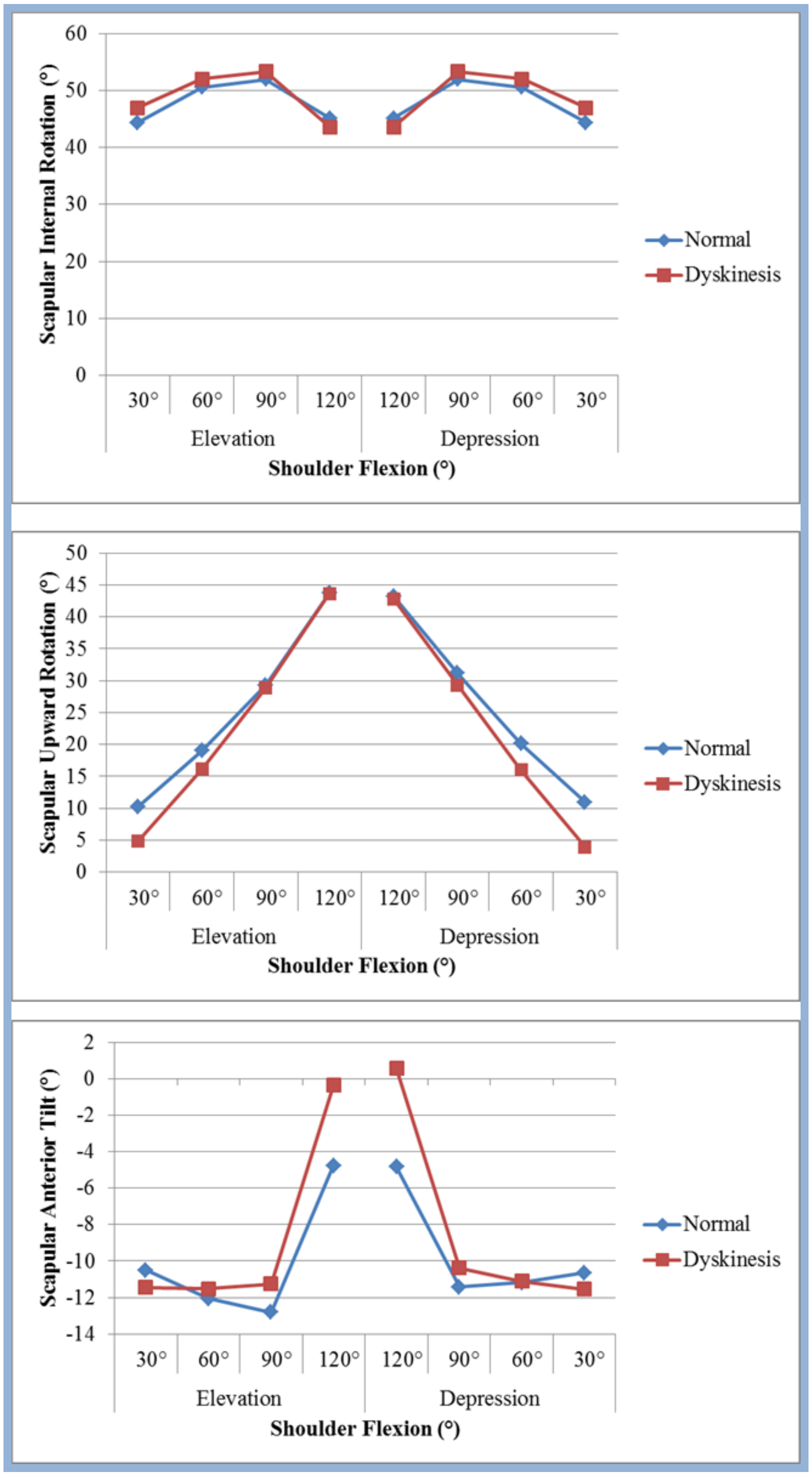

Figure 13. Mean scapular kinematics expressed in degrees at 30°, 60°, 90°, and 120° of humeral elevation and depression in the sagittal plane (flexion). Positive directions are defined as scapular internal rotation, upward rotation and posterior tilt.

Table 7. Scapular Kinematics during Humeral Flexion

	Normal			Dyskinesis			Independent T-Tests		
	Mean	±	St.Dev	Mean	±	St.Dev	Significance	95% Confidence Interval Lower	Upper
Humeral Elevation									
Internal Rotation(+) /External Rotation (-)									
30°	44	±	7	47	±	4	.191	-6.450	1.343
60°	51	±	7	52	±	4	.480	-5.545	2.657
90°	52	±	8	53	±	8	.592	-6.428	3.728
120°	45	±	11	44	±	16	.742	-8.151	11.329
Upward (+) /Downward (-) Rotation									
30°*	10	±	6	5	±	6	.012	1.246	9.476
60°	19	±	5	16	±	7	.192	-1.532	7.343
90°	29	±	6	29	±	6	.882	-4.965	5.753
120°	44	±	11	44	±	13	.987	-8.304	8.442
Anterior (-) /Posterior (+) Tilt									
30°	-11	±	4	-11	±	6	.590	-2.578	4.459
60°	-12	±	5	-12	±	8	.807	-4.957	3.888
90°	-13	±	7	-11	±	11	.605	-7.759	4.608
120°	-5	±	12	0	±	17	.395	-14.829	6.038
Humeral Depression									
Internal Rotation(+) /External Rotation (-)									
120°	45	±	11	44	±	16	.548	-7.196	13.307
90°	52	±	8	53	±	6	.741	-6.844	4.918
60°	51	±	7	52	±	4	.332	-6.173	2.172
30°	44	±	7	47	±	4	.134	-6.932	0.966
Upward (+) /Downward (-) Rotation									
120°	43	±	11	43	±	14	.927	-8.461	9.263
90°	31	±	7	29	±	9	.524	-3.942	7.592
60°	20	±	5	16	±	8	.065	-.281	8.591
30°*	11	±	5	4	±	8	**.004**	2.383	11.664
Anterior (-) /Posterior (+) Tilt									
120°	-5	±	12	1	±	18	.320	-16.256	5.471
90°	-11	±	7	-10	±	11	.743	-7.439	5.368
60°	-11	±	5	-11	±	7	.980	-4.359	4.250
30°	-11	±	4	-12	±	6	.614	-2.754	4.592

*indicates a significant difference between Normal and Dyskinesis groups at the level of $\alpha = 0.05$

4.2.2 Biomechanical Characteristics during Humeral Elevation and Depression in the Coronal Plane

During humeral elevation in the coronal plane (abduction) both groups demonstrated similar scapular kinematics with increasing upward rotation from 30° - 120°; and decreasing anterior tilt from 30° - 120° (Figure 14). However, while both groups had a similar amount of internal rotation at 30° of humeral elevation, each group demonstrated a different movement pattern about the vertical axis. As the arm was elevated the normal group demonstrated an increase in internal rotation while the dyskinesis group demonstrated a decrease in internal rotation. However, no statistically significant differences in scapular kinematics were present between groups during humeral elevation in the coronal plane (Table 8).

During humeral depression in the coronal plane different movement patterns were again present between groups. As the arm was lowered the dyskinesis group demonstrated an increase in internal rotation while the normal group demonstrated a decrease in internal rotation. Both groups completed the depression cycle with a similar amount of internal rotation at 30° of humeral depression. However, no statistically significant differences in scapular kinematics were present between groups during humeral depression in the coronal plane (Table 8).

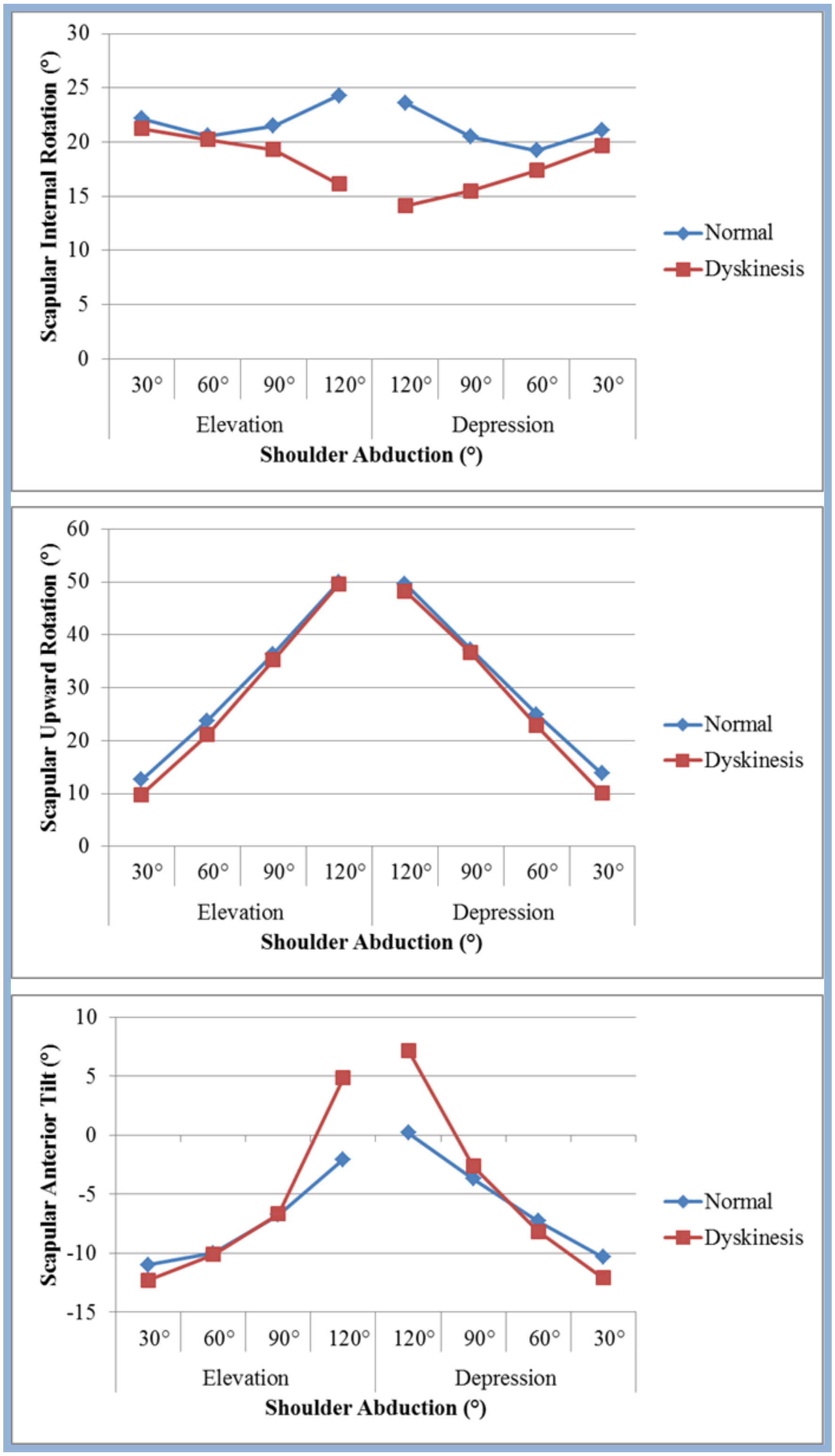

Figure 14. Mean scapular kinematics expressed in degrees at 30°, 60°, 90°, and 120° of humeral elevation and depression in the coronal plane (abduction). Positive directions are defined as scapular internal rotation, upward rotation and posterior tilt.

Table 8. Scapular Kinematics during Humeral Abduction

	Normal			Dyskinesis			Independent T-Tests		
	Mean	±	St.Dev	Mean	±	St.Dev	Significance	95% Confidence Interval Lower	Upper
Humeral Elevation									
Internal Rotation(+) /External Rotation (-)									
30°	22	±	7	21	±	8	.721	-4.386	6.271
60°	21	±	7	20	±	8	.903	-4.938	5.570
90°	22	±	10	19	±	9	.502	-4.370	8.736
120°	24	±	12	16	±	18	.132	-2.574	18.856
Upward (+) /Downward (-) Rotation									
30°	13	±	6	10	±	7	.204	-1.600	7.198
60°	24	±	5	21	±	6	.196	-1.442	6.751
90°	36	±	6	35	±	8	.662	-4.002	6.217
120°	50	±	10	50	±	13	.923	-7.862	8.655
Anterior (-) /Posterior (+) Tilt									
30°	-11	±	5	-12	±	4	.407	-1.860	4.475
60°	-10	±	5	-10	±	6	.952	-3.750	3.979
90°	-7	±	7	-7	±	8	.976	-5.254	5.100
120°	-2	±	12	5	±	16	.165	-16.833	3.008
Humeral Depression									
Internal Rotation(+) /External Rotation (-)									
120°	24	±	14	14	±	19	.102	-2.010	21.091
90°	20	±	10	15	±	10	.156	-2.007	11.971
60°	19	±	8	17	±	8	.492	-3.561	7.251
30°	21	±	8	20	±	8	.589	-3.963	6.859
Upward (+) /Downward (-) Rotation									
120°	50	±	10	48	±	15	.751	-7.318	21.091
90°	37	±	6	37	±	10	.836	-5.234	6.428
60°	25	±	5	23	±	6	.289	-1.942	6.302
30°	14	±	6	10	±	6	.061	-.185	7.791
Anterior (-) /Posterior (+) Tilt									
120°	0	±	13	7	±	16	.165	-16.970	3.025
90°	-4	±	7	-3	±	8	.688	-6.443	4.302
60°	-7	±	6	-8	±	7	.687	-3.630	5.442
30°	-10	±	6	-12	±	5	.347	-1.997	5.517

*indicates a significant difference between Normal and Dyskinesis groups at the level of $\alpha = 0.05$

4.3 ELECTROMYOGRAPHIC ASSESSEMENT OF THE SCAPULAR STABILIZERS BEWTEEN GROUPS

It was hypothesized that individuals with obvious dyskinesis would demonstrate altered muscular firing patterns compared to the normal group. The dyskinesis group was hypothesized to demonstrate delayed/decreased activation of the serratus anterior and/or earlier/increased activation of the rhomboids or pectoralis minor which could contribute to decreased upward rotation and increased anterior tilt, and delayed/decreased activation of the middle trapezius or rhomboids and/or earlier/increased activation of the pectoralis minor or serratus anterior which could contribute to increased internal rotation. All EMG variables were assessed for normality, the majority of the variables violated this assumption and for those variables Mann-Whitney U tests were used, for variables that achieved the assumption of normality independent t-tests were used for group comparisons. The appropriate statistical test was used to assess for differences between groups for the point of initial activation and final de-activation for each muscle which are both reported as a percentage of the elevation or depression cycle (between 30°-120° of humeral elevation). Initial activation was defined as the point in which the amplitude reaches and sustains 5 times the normalized quiet trial (baseline signal). Statistical analysis was also used to assess for differences in the average %MVIC for each muscle at 30-60°, 60-90°, and 90-120° of humeral elevation and depression in the sagittal and coronal planes.

4.3.1 Muscular Activation Patterns during Humeral Elevation and Depression in the Sagittal Plane

During humeral elevation in the sagittal plane (flexion), the point of de-activation of the pectoralis minor was statistically significant different between groups ($p = 0.020$) (Figure 15). During the elevation cycle the normal group demonstrated significantly earlier de-activation, at 92% of the elevation cycle, compared to the dyskinesis group which was still demonstrating pectoralis minor activity at the completion of elevation cycle. There was also a statistically significant difference between groups in the average %MVIC of the pectoralis minor from 90°-120° of humeral elevation in the sagittal plane ($p = 0.034$) (Table 9). The dyskinesis group demonstrated a significantly greater average %MVIC compared to the normal group from 90-120°.

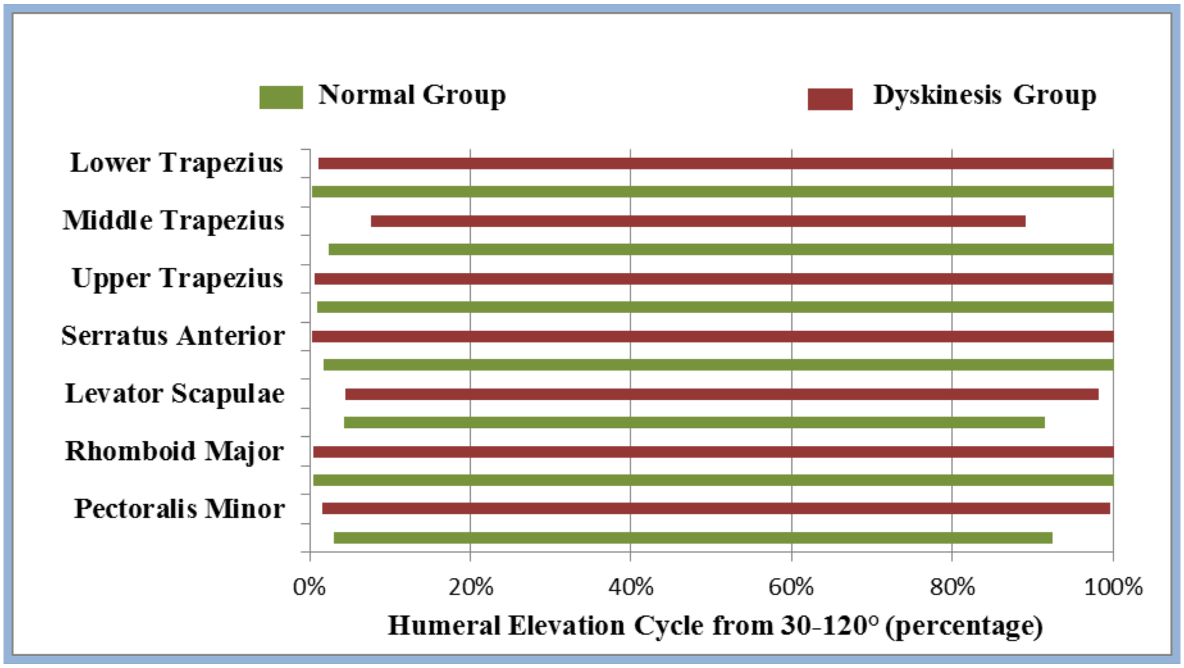

Figure 15. Muscular Activation Sequencing During Humeral Elevation in the Sagittal Plane

Table 9. Muscular Activation during Elevation in the Sagittal Plane

	Normal			Dyskinesis			Independent Mann Whitney U Test
	Mean	±	St.Dev	Mean	±	St.Dev	Significance
Humeral Elevation							
30-60° (Average %MVIC)							
Pectoralis Minor	34%	±	41%	89%	±	110%	0.057
Rhomboid Major	39%	±	29%	31%	±	31%	0.290
Levator Scapulae	29%	±	22%	43%	±	64%	0.786
Serratus Anterior	56%	±	64%	58%	±	48%	0.708
Upper Trapezius	68%	±	35%	76%	±	84%	0.518
Middle Trapezius	15%	±	7%	32%	±	48%	0.413
Lower Trapezius	43%	±	37%	54%	±	54%	0.760
60-90° (Average %MVIC)							
Pectoralis Minor	38%	±	52%	86%	±	111%	0.530
Rhomboid Major	42%	±	27%	33%	±	31%	0.170
Levator Scapulae	33%	±	25%	51%	±	66%	0.708
Serratus Anterior	60%	±	50%	62%	±	36%	0.540
Upper Trapezius	79%	±	38%	85%	±	93%	0.413
Middle Trapezius	16%	±	7%	36%	±	54%	0.375
Lower Trapezius	49%	±	40%	58%	±	53%	0.812
90-120° (Average %MVIC)							
Pectoralis Minor*	38%	±	55%	98%	±	132%	0.038
Rhomboid Major	47%	±	33%	34%	±	33%	0.193
Levator Scapulae	35%	±	31%	51%	±	69%	0.838
Serratus Anterior	60%	±	29%	63%	±	24%	0.433
Upper Trapezius	83%	±	45%	89%	±	100%	0.394
Middle Trapezius	17%	±	7%	37%	±	52%	0.375
Lower Trapezius	55%	±	44%	61%	±	56%	0.946

*indicates a significant difference between Normal and Dyskinesis groups at the level of $\alpha = 0.05$

During humeral depression in the sagittal plane (flexion), there were no statistically significant differences in the point of muscular activation/de-activation between groups (Figure 16). There was, however, a statistically significant difference between groups in the average %MVIC of the rhomboid major at each arc of motion (Table 10). The dyskinesis group demonstrated significantly less % MVIC compared to the normal group at 120-90°, 90-60°, and 60-30°.

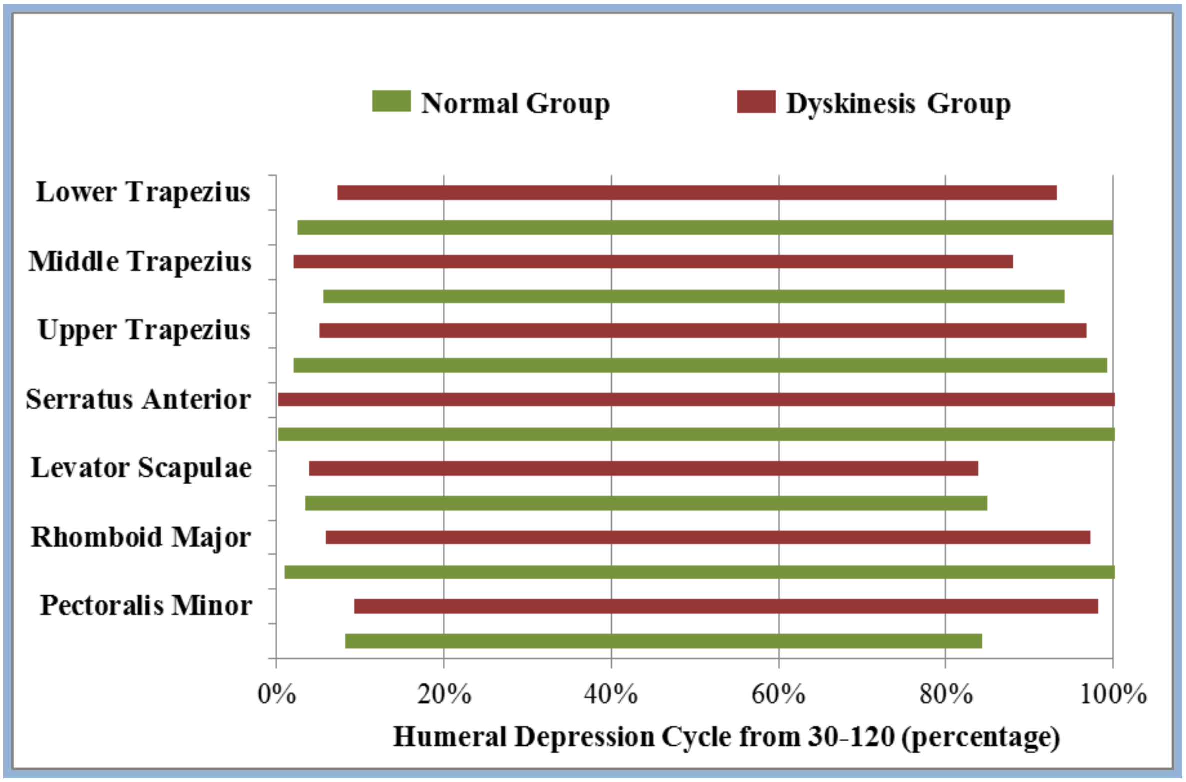

Figure 16. Muscular Activation Sequencing During Humeral Depression in the Sagittal Plane

Table 10. Muscular Activation during Humeral Depression in the Sagittal Plane

	Normal			Dyskinesis			Independent Mann Whitney U Test
	Mean	±	St.Dev	Mean	±	St.Dev	Significance
Humeral Depression							
120-90° (Average %MVIC)							
Pectoralis Minor	19%	±	27%	48%	±	70%	0.375
Rhomboid Major*	30%	±	28%	14%	±	14%	0.034
Levator Scapulae	19%	±	20%	19%	±	19%	0.760
Serratus Anterior	48%	±	47%	41%	±	18%	0.812
Upper Trapezius	70%	±	61%	50%	±	48%	0.231
Middle Trapezius	12%	±	8%	11%	±	7%	0.892
Lower Trapezius	36%	±	24%	27%	±	24%	0.182
90-60° (Average %MVIC)							
Pectoralis Minor	24%	±	34%	51%	±	65%	0.182
Rhomboid Major*	31%	±	23%	14%	±	14%	0.011
Levator Scapulae	18%	±	20%	21%	±	23%	0.734
Serratus Anterior	46%	±	40%	41%	±	21%	0.812
Upper Trapezius	64%	±	54%	49%	±	47%	0.357
Middle Trapezius	11%	±	6%	12%	±	7%	0.919
Lower Trapezius	36%	±	20%	29%	±	31%	0.092
60-30° (Average %MVIC)							
Pectoralis Minor	29%	±	42%	66%	±	87%	0.131
Rhomboid Major*	31%	±	22%	15%	±	16%	0.012
Levator Scapulae	20%	±	20%	24%	±	28%	0.838
Serratus Anterior	42%	±	29%	39%	±	16%	0.518
Upper Trapezius	61%	±	53%	51%	±	45%	0.563
Middle Trapezius	11%	±	5%	13%	±	9%	0.540
Lower Trapezius	37%	±	21%	29%	±	31%	0.073

*indicates a significant difference between Normal and Dyskinesis groups at the level of $\alpha = 0.05$

4.3.2 Muscular Activation during Humeral Elevation and Depression in the Coronal Plane

During humeral elevation in the coronal plane (abduction), the point of activation for the middle trapezius was statistically different between groups ($p = 0.016$) (Figure 17). During the elevation cycle the dyskinesis group demonstrated significantly later activation of the middle trapezius at 0.48% ± 0.86% of the elevation cycle, compared to the normal group which demonstrated activation at 0.47% ± 2% of the elevation cycle. There was also a statistically significant difference between groups in the average %MVIC of the upper trapezius at 30°-60° of humeral elevation in the coronal plane ($p = 0.045$) (Table 11). The dyskinesis group demonstrated a significantly less average %MVIC compared to the normal group from 30-60°.

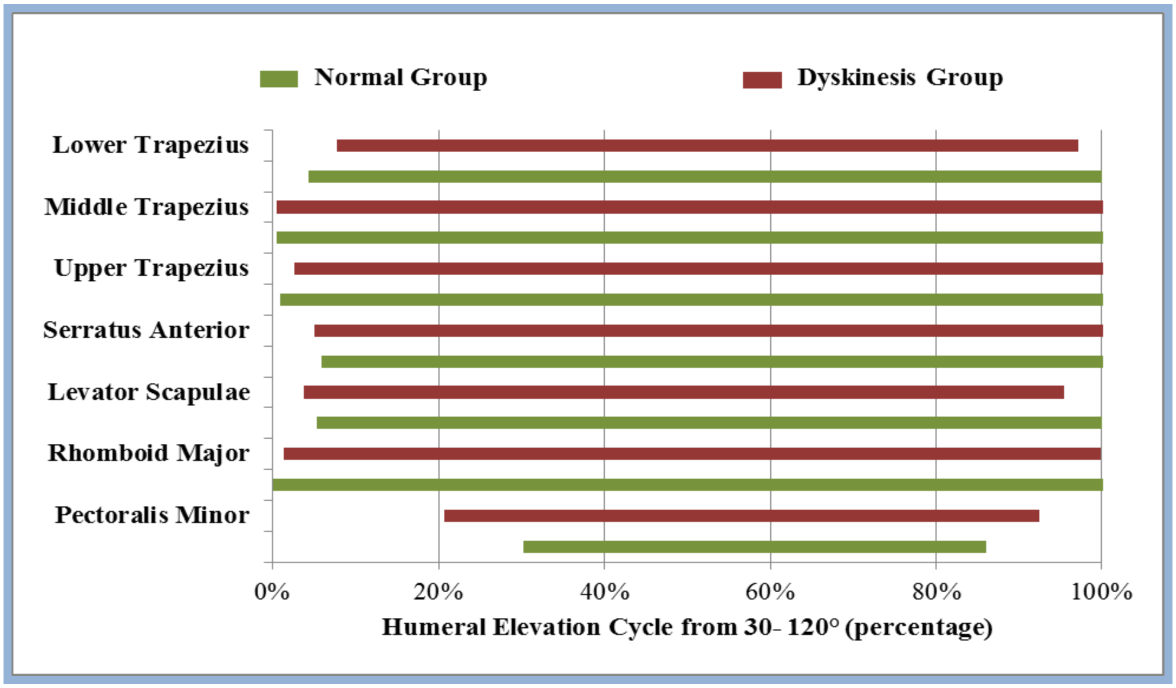

Figure 17. Muscular Activation Sequencing During Humeral Elevation in the Coronal Plane

Table 11. Muscular Activation during Humeral Elevation in the Coronal Plane

	Normal			Dyskinesis			Independent Mann Whitney U Test
	Mean	±	St.Dev	Mean	±	St.Dev	Significance
Humeral Elevation							
30-60° (Average %MVIC)							
Pectoralis Minor	5%	±	6%	6%	±	7%	0.563
Rhomboid Major	24%	±	18%	20%	±	15%	0.610
Levator Scapulae	76%	±	34%	61%	±	39%	0.106
Serratus Anterior	36%	±	64%	32%	±	53%	0.286
Upper Trapezius *	65%	±	43%	56%	±	68%	0.045
Middle Trapezius	34%	±	26%	32%	±	19%	0.865
Lower Trapezius	17%	±	9%	20%	±	23%	0.683
60-90° (Average %MVIC)							
Pectoralis Minor	7%	±	9%	10%	±	15%	0.563
Rhomboid Major	36%	±	21%	28%	±	19%	0.290
Levator Scapulae	100%	±	40%	95%	±	73%	0.218
Serratus Anterior	48%	±	52%	55%	±	60%	0.708
Upper Trapezius	109%	±	56%	97%	±	110%	0.092
Middle Trapezius	50%	±	29%	47%	±	23%	0.927†
Lower Trapezius	31%	±	20%	26%	±	23%	0.322
90-120° (Average %MVIC)							
Pectoralis Minor	9%	±	8%	15%	±	19%	0.474
Rhomboid Major	52%	±	33%	42%	±	33%	0.274
Levator Scapulae	106%	±	46%	112%	±	89%	0.518
Serratus Anterior	69%	±	68%	67%	±	43%	0.586
Upper Trapezius	142%	±	78%	119%	±	113%	0.182
Middle Trapezius	51%	±	21%	62%	±	28%	0.185†
Lower Trapezius	48%	±	31%	37%	±	26%	0.193

*indicates a significant difference between Normal and Dyskinesis groups at the level of $\alpha = 0.05$

† indicates that based on an achieved assumption of normality a parametric test (Independent T-test) was used

During humeral depression in the coronal plane, the point of activation of the serratus anterior was statistically different between groups ($p = 0.031$) (Figure 18). During the depression cycle, from 120°-30° the normal group demonstrated earlier de-activation at 99% ± 2% of the cycle, where the dyskinesis group remained active through the completion of the cycle (100% ±

0.02%). There was also a statistically significant difference between groups in the average %MVIC of the rhomboid major at 90-60° (p = 0.031) (Table 12). The dyskinesis group demonstrated significantly less % MVIC compared to the normal group at 90-60°.

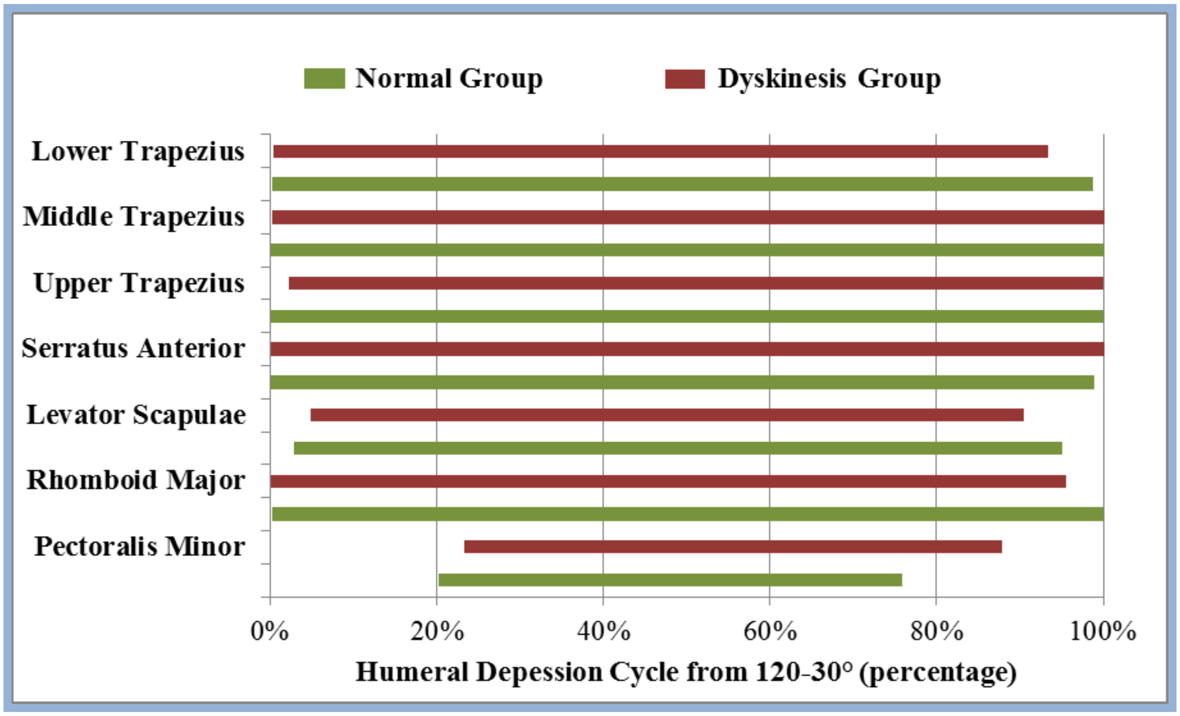

Figure 18. Muscular Activation Sequencing During Humeral Depression in the Coronal Plane

Table 12. Muscular Activation during Humeral Depression in the Coronal Plane

	Normal			Dyskinesis			Independent Mann Whitney U Test
	Mean	±	St.Dev	Mean	±	St.Dev	Significance
Humeral Depression							
120-90° (Average %MVIC)							
Pectoralis Minor	7%	±	9%	8%	±	12%	0.563
Rhomboid Major	60%	±	41%	40%	±	26%	0.068†
Levator Scapulae	78%	±	40%	57%	±	37%	0.122
Serratus Anterior	49%	±	52%	48%	±	23%	0.290
Upper Trapezius	108%	±	78%	74%	±	67%	0.150
Middle Trapezius	43%	±	24%	53%	±	34%	0.518
Lower Trapezius	59%	±	57%	39%	±	25%	0.518
90-60° (Average %MVIC)							
Pectoralis Minor	9%	±	16%	9%	±	9%	0.339
Rhomboid Major*	49%	±	34%	29%	±	19%	0.031†
Levator Scapulae	85%	±	43%	65%	±	44%	0.085
Serratus Anterior	38%	±	33%	37%	±	18%	0.274
Upper Trapezius	101%	±	70%	67%	±	64%	0.160
Middle Trapezius	42%	±	19%	49%	±	23%	0.357
Lower Trapezius	44%	±	34%	28%	±	16%	0.218
60-30° (Average %MVIC)							
Pectoralis Minor	8%	±	10%	22%	±	52%	0.474
Rhomboid Major	37%	±	26%	25%	±	17%	0.231
Levator Scapulae	84%	±	55%	76%	±	60%	0.375
Serratus Anterior	24%	±	13%	35%	±	21%	0.106
Upper Trapezius	85%	±	63%	67%	±	66%	0.357
Middle Trapezius	41%	±	21%	45%	±	21%	0.786
Lower Trapezius	29%	±	21%	24%	±	13%	0.610

*indicates a significant difference between Normal and Dyskinesis groups at the level of $\alpha = 0.05$

† indicates that based on the assumption of normality a parametric test (Independent T-test) was used

4.4 SCAPULAR STABILIZER STRENGTH BETWEEN GROUPS

It was hypothesized that individual with obvious dyskinesis would demonstrate decreased isometric strength in the muscles controlling scapular upward rotation (lower trapezius, serratus anterior), posterior tilt (lower trapezius, serratus anterior) and external rotation (middle trapezius, rhomboids) compared to the normal group. All strength variables were assessed for normality, the majority of the variables achieved the assumption of normality and for those variables independent t-tests were used. The variables that violated the assumption of normality were assessed using Mann-Whitney U tests. The appropriate statistical test was used to assess for differences in isometric strength (%BW) of the scapular stabilizers between groups. However, the assessment of isometric strength of the scapular stabilizers did not identify any significant differences in strength between groups (Table 13).

Table 13. Isometric Scapular Stabilizer Strength

	Normal			**Dyskinesis**			**Shaprio-Wilk Test for Normality**		**Independent T-Tests**		
	Mean	±	St.Dev	Mean	±	St.Dev	Normal Group	Dyskinesis Group	Significance	95% Confidence Interval Lower	Upper
Pectoralis Minor	34	±	6	37	±	9	0.079	0.998	0.161	-9.523	1.646
Rhomboid Major	10	±	3	10	±	2	0.326	0.392	0.683	-1.576	2.368
Serratus Anterior	13	±	3	14	±	3	0.214	0.953	0.477	-3.115	1.490
Upper Trapezius	49	±	18	51	±	18	0.085	0.459	0.738	-14.401	10.312
Middle Trapezius	8	±	2	7	±	2	0.030	0.494	0.786§	-	-
Lower Trapezius	8	±	2	7	±	1	0.334	0.746	0.418	-.787	1.849

§ indicates a rejection of the null hypothesis that the population is normally distributed at the level of $p = 0.05$ and a non-parametric test (Mann-Whitney U test) was used

5.0 DISCUSSION

The development of shoulder pathology is a constant concern in the overhead athlete. The identification of scapular dyskinesis in the presence of shoulder pathologies has given rise to intervention strategies which focus on restoring normal scapular position and motion. However these interventions have been limited in their successful restoration of normal scapular kinematics. The current study provided insight regarding the specific kinematic alterations, muscular coupling patterns, and isometric strength associated with the presence of scapular dyskinesis in overhead athletes. These findings shed light on muscular deficiencies and loss of optimal force couple control of scapular motion. Clinicians will be able to utilize this information to target muscular deficiencies and re-establish coordinated muscular control of scapular position and dynamic scapular motion, providing a more thorough rehabilitation of the shoulder complex when scapular dyskinesis is identified. The purpose of this dissertation was to examine the association of scapular dyskinesis with scapular kinematic patterns and muscular characteristics in overhead athletes. It was hypothesized that individuals clinically screened to have obvious dyskinesis would demonstrate: 1) altered scapular kinematics such as decreased scapular upward rotation, increased anterior tilt and increased internal rotation during humeral elevation and depression; 2) altered muscular activation patterns such as delayed/decreased activation of the serratus anterior and/or earlier/increased activation of the rhomboids or pectoralis minor which could contribute to decreased upward rotation and increased anterior tilt, and delayed/decreased activation of the middle trapezius or rhomboids and/or earlier/increased activation of the pectoralis minor or serratus anterior which could contribute to increased internal rotation; 3) altered isometric strength such as decreased isometric strength in the muscles controlling scapular upward rotation (lower trapezius, serratus anterior), posterior tilt (lower trapezius, serratus anterior) and external rotation (middle trapezius, rhomboids) compared to the normal group. Our hypotheses were partially supported, as there were some statistically significant differences between groups in scapular kinematics and muscular activation patterns. Group characteristics, independent and dependent variables, research hypotheses, limitations and future directions are discussed in the following sections.

5.1 SUBJECT CHARACTERISTICS

Male and female overhead athletes were recruited for participation in the current study. An overhead athlete was defined as an individual who participated in regular practices and competition in a sport that required repetitive overhead motion. The intention of this definition was to include a variety of athletes that utilize repetitive overhead movement. The sample within both the obvious dyskinesis and normal groups achieved a good representation of a variety of overhead athletes within both genders.

5.2 DYSKINESIS SCREENING

A Scapular Dyskinesis Screening Test was used for the evaluation and allocation of research subjects to either the normal or obvious dyskinesis group. The presence and severity of scapular dyskinesis is difficult to assess and is reliant on subjective measures. This screening method was used because it has been shown to have moderate inter-rater reliability compared to other qualitative screening methods.[149] In order to minimize potential bias, two evaluators with clinical experience performed the screening. A subject was allotted to a group if both evaluators agreed on the final score of normal or obvious dyskinesis. For the final score the evaluators demonstrated strong intra-tester reliability ($\kappa = 0.725$, $p = <0.001$), and the primary investigator demonstrated good inter-rater reliability ($\kappa = 0.558$, $p = <0.001$).[123]

5.3 SCAPULAR KINEMATICS

Scapular kinematics at 30°, 60°, 90°, and 120° of humeral elevation and depression in the sagittal and coronal planes demonstrated a characteristic pattern for scapular motion and were similar to those reported in other studies (Table 14),[61, 62, 81, 85, 100, 112, 149, 156] including several which utilized similar tasks and screening methods.[81, 149] Tate et al.[149] and Lopes et al.[81] both conducted studies which evaluated and grouped overhead athletes into normal and obvious dyskinesis groups using the same Dyskinesis Screening Test that was used in the current study. The scapular kinematics in the normal group of both studies were consistent with our findings. Tate et al. found that the obvious dyskinesis group demonstrated significantly decreased upward rotation at rest, 30°, and

60° of humeral elevation in the sagittal plane which was consistent with our findings. During abduction they found that the obvious dyskinesis group demonstrated significantly less upward rotation at rest. Tate et al. also observed greater posterior tilt at rest in the obvious dyskinesis group. We also observed greater posterior tilt in the obvious dyskinesis group as well but only 120° of humeral elevation and depression. Lopes et al.[81] using the Dyskinesis Screening Test found that the obvious dyskinesis group demonstrated significantly greater internal rotation compared to the normal group during shoulder flexion. These findings are different compared to ours, however the sample utilized was a general population with a large age range, and all subjects in both groups were also diagnosed to have subacromial impingement syndrome. Therefore, the presence of pathology may have contributed to the differences in scapular dyskinesis found. Huang et al.[57] evaluated a general population between the ages of 18-50yrs and compared scapular kinematics of a group diagnosed to have type I or II scapular dyskinesis while performing humeral elevation in the scapular plane compared to healthy controls. They found that the dyskinesis groups (type I and type II) demonstrated greater scapular internal rotation during humeral depression and the type 1 group also demonstrated less posterior tilt compared to the normal group. We hypothesized we would see a decrease in posterior tilt in the dyskinesis group but no differences were found. The different findings between studies may be attributed to the fact that Huang et al.[57] evaluated dyskinesis based on specific types. Those with inferior angle prominence were not combined with other types of dyskinesis as they were in the current study.

Table 14. Comparison of Scapular Kinematic Among Previous Studies

Author	**Ludewig et al, 1996**	**Karduna et al, 2000**	**Mclure et al. 2001**	**Myers et al, 2002**	**Varnell et al, 2009**	**Tate et al, 2009**	**Lopes et al, 2015**	**Varnell et al, current investigation**
Age	18-40	27-37	27-37	21.58 ± 1.77	50-79	20.7 ± 2.6	46.4 ± 10.9	18-27
Population	General, healthy	General, healthy	General, healthy	Throwing Athletes	General, healthy	Overhead Athletes (healthy)	General, healthy	Overhead Athletes (healthy)
Modality	Surface Electro-magnetic Tracking System	Surface & bone based Electro-magnetic Tracking System	Surface & bone based Electro-magnetic Tracking System	Surface based Electro-magnetic Tracking System	Surface Active Optical Tracking System	Surface based Electro-magnetic Tracking System	Surface based Electro-magnetic Tracking System	Surface Infrared Optical Capture System
Kinematics during Humeral Elevation	Scaption	Scaption	Sagittal	Scaption	Scaption	Sagittal / Coronal	Sagittal	Sagittal / Coronal
Resting				*30° Reported*		*30° Reported*		*30° Reported*
PT	-8°*	2°*	5°*	-11°	2°	-6°* / -2°*	-11°*	-11° / -11°
UR	2°*	18°*	18°*	9°	9°	0°* / 4°*	0°*	10° / 13°
IR	33°*	35°*	35°*	37°	27	34* / 23°*	35*	44° / 22°
60°	*Not reported*							
PT	-	8°*	8°*	-10°	7°	-4°* / -1°*	-10°*	-12° / -10°
UR	-	26°*	26°*	19°	12°	10°* / 16°*	18°*	19° / 24°
IR	-	35°*	35°*	41°	37	38* / 23°*	37*	51° / 21°
90°								
PT	-2°*	10°*	10°*	-9°	15°	-3°* / -1°*	-11°*	-13° / -7°
UR	21°*	37°*	37°*	27°	21°	25°* / 29°*	35°*	29° / 36°
IR	28°*	33°*	34°*	46°	37	40* / 24°*	40*	52° / 22°
120°	*140° reported*							
PT	7°*	14°*	16°*	0.1°	25°	-2°* / 2°*	-8°*	-5° / -2°
UR	36°*	58°*	50°*	32°	36°	40°* / 40°*	54°*	44° / 50°
IR	20°*	30°*	29°*	48°*	34	38* / 25°*	39*	45° / 24°

* Corresponds to values extracted from graphs

5.4 MUSCULAR ACTIVATION PATTERNS

Evaluating activation patterns of the scapular stabilizers at specific time points during dynamic motion provides information as to the intensity (amplitude) and sequencing of muscular activation for each muscle. Analysis of electromyography (EMG) does not assess muscles strength, but it does provide insight about the attempt to produce muscular force, and can be used to evaluate altered muscular function in individuals with scapular dyskinesis. Due to the coupling of the scapular stabilizers, dysfunction may be related to altered amplitude of activation or firing patterns and has only recently been evaluated in a dyskinesis population.

We found similar trends in muscular activation and amplitude compared to other research studies.[57, 81, 166] Lopes et al.[81] evaluated muscular activity during humeral flexion in a general population and compared a group with obvious dyskinesis to a group with normal scapular motion. They found their dyskinesis group had significantly higher upper trapezius activity from 30°-60° of humeral elevation. We found our dyskinesis group also demonstrated an average increase in activation of the upper trapezius (8%) from 30°-60° of humeral elevation compared to the normal group during humeral elevation in the sagittal plane. However, in the plane of abduction we found that the dyskinesis group demonstrated significantly lower activation of the upper trapezius from 30°-60° of humeral elevation compared to the normal group. This may be due to the differences in plane of motion evaluation (flexion vs abduction). Decreased activation of the lower trapezius and serratus anterior was also found by Huang et al.[57] who evaluated a general population between the ages of 18-50yrs and compared scapular kinematics and muscular activity of a group diagnosed to have type I or II scapular dyskinesis while performing humeral elevation in the scapular plane compared to healthy controls. They found that those with type II dyskinesis had significantly higher upper trapezius activity above 120° humeral depression. Subjects with type I and II also demonstrated decreased activation of the lower trapezius and serratus anterior.

We were also interested in evaluating sequencing of activation and deactivation of the scapular stabilizers during humeral motion. Previous research has demonstrated that there are specific sequences of firing (on/off activation) in healthy populations during dynamic motion.[52, 68, 166] Due to the coupling of the scapular stabilizers, the presence of dyskinesis may be related to altered firing patterns and not just amplitude of activation. We did find some similarities to a previous study looking at activation sequencing. Wickham et al.[166] evaluated muscular activation during humeral abduction in a general population of healthy adults. Muscle activation was visually assessed and they determined that all muscles were active prior to 30° of humeral elevation and remained active through 30° of humeral depression. Sequencing of activation was similar to our study with early activation of the muscles controlling scapular external rotation (middle trapezius and rhomboids) and elevation/upward rotation (upper trapezius), and with the pectoralis minor being the last muscle to activate and one of the first to de-activate. There were some differences in specific order of activation and duration of activation. The study conducted by Wickham et al.[166] demonstrated much earlier onset of activation (prior to initiation of movement). This is likely due to a difference in the definition of onset/offset between the two studies.

5.5 ISOMETRIC STRENGTH

Isometric strength of each of the scapular stabilizers demonstrated similar values compared to another studies conducted within our lab (Table 15). Previously, we have used the same methods to evaluate isometric strength in healthy recreationally active individuals as well as throwing athletes. Subjects in the previous study were not evaluated for the presence of scapular dyskinesis, but were healthy and injury free at the time of testing. No other studies, outside those conducted in our lab, were found for comparison that evaluated isometric strength of the scapular stabilizers in a population evaluated to have scapular dyskinesis. Rather, previous research has looked at the relationship between altered scapular position and the presence of decreased strength of the rotator cuff musculature,[107, 142] and extrinsic shoulder musculature.[141, 150] If differences are present in isometric strength of the scapular stabilizers relative to dyskinesis, clinicians and research investigators will be able to use isometric strength assessments for determining rehabilitative exercises for intervention and restoration of strength of the scapular stabilizers.[51, 143]

Table 15. Isometric Strength from Previous Studies in the Neuromuscular Research Laboratory.

	Throwing Athletes (Baseball & Softball)			Recreationally Active		
	Mean	±	St.Dev	Mean	±	St.Dev
Age (yrs)	19.5	±	1.1	24.9	±	3.5
Height (cm)	175.8	±	11.1	172.7	±	9.5
Weight (kg)	78.5	±	14.1	74.5	±	17.9
Isometric Strength (%BW)						
Pectoralis Minor	-	±	-	39	±	8
Rhomboid Major	10	±	3	11	±	4
Serratus Anterior	11	±	2	14	±	4
Upper Trapezius	47	±	15	60	±	19
Middle Trapezius	8	±	2	10	±	2
Lower Trapezius	8	±	2	9	±	2

5.6 COMPARISON OF BIOMECHANICAL AND MUSCULOSKELETAL CHARACTERISTICS BETWEEN GROUPS

5.6.1 Scapular Kinematics

Scapular kinematics were measured to evaluate if a group of overhead athletes visually identified to have obvious scapular dyskinesis demonstrated altered scapular position compared to a normal group. Through visual assessment the dyskinesis group was identified to have obvious dyskinesis either during flexion, abduction, or both. It was observed by the evaluators that inferior angle prominence and medial border prominence were the most often identified alterations. Based on this visual identification of inferior angle prominence in most cases, it was expected that the biomechanical variables would show a decrease in scapular upward rotation, an increase in scapular anterior tilt and an increase in scapular internal rotation particularly toward the end of humeral depression (60°, 30°) where the alterations were most obvious visually. However these hypotheses were only partially supported. A decrease in scapular upward rotation was present between groups at 30° of humeral elevation and depression in the sagittal plane. A decrease in upward rotation has been identified to contribute to narrowing of the subacromial space; therefore even minor changes could be clinically meaningful. Large effect sizes for scapular upward rotation at 60° humeral elevation (d = 0.5) and depression (d = 0.7) were found with post hoc testing using G*Power 3.1.6 (Cohen's d).[12, 38] Had a larger sample been tested and adequate power been achieved scapular upward rotation may have also been significantly different at 60° of humeral elevation and depression as well. The dyskinesis group demonstrated less scapular upward rotation below 90° but demonstrated similar values at 90° and 120°. This is different to what is usually seen in a population with pathologies such as SAIS.[45, 67, 145] A narrowing of the subacromial space due to decreased upward rotation is a risk factor for injury in the overhead athlete who is performing repetitive overhead motion. These findings may also suggest that when evaluating for dyskinesis the clinician should also be mindful of resting scapular position and motion below 90°.

It was also hypothesized that the dyskinesis group would demonstrate increased scapular internal rotation. No statistically significant differences were found for scapular internal rotation in either plane or at any point in elevation or depression. Though not statistically significant, the dyskinesis group demonstrated what may be a clinically significant increase in scapular internal rotation (3°) at 30° of humeral elevation and depression in the sagittal plane. Again, based on large effects sizes during flexion for scapular internal rotation at 30° humeral elevation (d = 0.5) and depression (d = 0.5) had a larger sample been tested and adequate power been achieved scapular internal rotation may have also been significantly different at 30° of humeral elevation and depression. During humeral elevation in the coronal plane we found both groups started with similar scapular internal rotation. As the arm was elevated the normal group demonstrated an increase in scapular internal rotation while the dyskinesis group demonstrated a decrease in scapular internal rotation. The same pattern was present during depression. We found the normal group had increased scapular internal rotation during humeral elevation which was similar to the findings from other studies.[81, 112, 149, 156] Huang et al. evaluated a dyskinesis group performing humeral elevation in the coronal plane found that scapular internal rotation decreased in both the control and dyskinesis groups.[57] The plane of humeral elevation seems to have a large effect on both the absolute values of scapular internal rotation and potentially the direction of scapular motion, independently. When evaluating an athlete for the presence of scapular dyskinesis the clinician should keep in mind what plane of humeral motion is more functionally relevant for that specific athlete, as the alteration in scapular internal rotation that contributes to dyskinesis may be different depending on the plane of humeral motion.

The hypothesis that the dyskinesis group would demonstrate increased anterior tilt was also rejected due to lack of statistical significance in either plane or at any point in elevation or depression. Visually, with the identification of inferior angle prominence in the majority of subjects with dyskinesis, we anticipated that we would see the greatest difference between groups in anterior tilt. The effect size of this variable was small (0.0-0.2) from 30°-90° of humeral elevation/depression in the sagittal plane, and no clinically meaningful differences were observed. Given the small amplitude of movement in this plane there were clinically meaningful differences between groups at 120° elevation and depression in both the sagittal and coronal planes. The dyskinesis group did not demonstrate increased anterior tilt during flexion as hypothesized, rather at 120° the dyskinesis group was in decreased anterior tilt during elevation and in posterior tilt during depression compared to the normal group. Similar findings, though not statistically significant were found by Tate et al.[149] and Lopes et al.[81] Tate et al.[149] also used overhead athletes and attributed the lack of difference potentially to measurement error due to increased muscle bulk of overhead athletes which could limit the ability to detect scapular tilting.

Inferior angle prominence was identified visually in the majority of subjects scored to have obvious scapular dyskinesis. The presence of inferior angle prominence may not just be attributed to increased scapular anterior tilt. Rather, it may be the combination of small alterations of scapular position across multiple planes. Each individual plane demonstrated slight differences compared to the normal group: decreased upward rotation, increased internal rotation and variable posterior tilt which individually may or may not have been statistically significant, but perhaps the culmination of subtle changes in each plane combine to present a visually obvious alteration in scapular position. If the dyskinesis group was broken down by type of dyskinesis there may have been a statistically significant difference compared to the control group. As the groups were established in the current study, it appears that independent of type of dyskinesis present, upward rotation and potentially scapular internal rotation contribute to the presence of obvious scapular dyskinesis as defined by McClure et al[96].

5.6.2 Muscular Activation Patterns

Muscular activation patterns were measured to evaluate if a group of overhead athletes visually identified to have obvious scapular dyskinesis demonstrated altered amplitude of activation and different activation sequencing compared to a normal group. We expected that a decrease in activation of the serratus anterior and the rhomboid major and an increase in activation of the pectoralis minor would be found particularly toward the end of humeral depression (60°-30°) where identification of inferior angle prominence was most obvious visually. These hypotheses were only partially supported.

A significant decrease in average rhomboid major activation was present in the dyskinesis group throughout humeral depression in the sagittal plane. The dyskinesis group also demonstrated decreased rhomboid major activation in the coronal plane, again, most noticeably during depression. Though not statistically significant in the coronal plane, the dyskinesis group had on average 12%-20% less activation compared to the normal group. It was hypothesized that a decrease in rhomboid major activation would contribute to altered scapular motion, specifically increased scapular internal rotation. These findings coincide with our kinematic data during humeral depression in the coronal plane which showed that scapular internal rotation increased during humeral depression as the amplitude of the rhomboid major decreased. Only one other study was found evaluating the amplitude of activation of the rhomboid major.[166] They only evaluated a normal population performing humeral elevation and depression in the coronal plane. The amplitude of activation of the rhomboid major was consistent with the finding of the normal group in the current study. No studies have been found which evaluated the activation of the rhomboid major in a group with scapular dyskinesis for comparison. Increased scapular internal rotation has been noted to be a component of scapular winging,[110] has been demonstrated in patients with SAIS.[84, 165] The clinician should keep rhomboid function in mind if scapular winging is identified during clinical evaluation. If identified early, intervention could prevent the development of shoulder pathologies such as SAIS.

A significant increase in average pectoralis minor activation was present in the dyskinesis group at 90°-120° of humeral elevation in the sagittal plane. The dyskinesis group also demonstrated 55% greater activation at 30°-60° and 48% greater activation at 60°-90° of humeral elevation in the sagittal plane compared to the normal group. Though not statistically significant these may be clinically meaningful differences as the pectoralis minor on average demonstrated over two times the amplitude of the normal group. It is not surprising that the pectoralis minor was highly active during flexion, as it would assist in achieving additional scapular internal rotation needed compared to scaption or abduction. While the normal group showed moderate activity (19%-38% average activation) of the pectoralis minor throughout elevation and depression in the sagittal plane, the dyskinesis group demonstrated very high activity (48%-98% average activation) throughout elevation and depression. This increase in activation supports the theory that muscular imbalance contributes to altered scapular positioning. Wickham et al.[166] also evaluated the amplitude of activation of the pectoralis minor during humeral elevation and depression in the coronal plane in a normal population and found only a small average activation through humeral elevation and depression, which were consistent with our findings. During humeral abduction less activity of the pectoralis minor is needed as the scapula is naturally in a more retracted position and scapular posterior tilt or internal rotation are not as challenged in this plane of motion. The difference in activation between the sagittal and coronal planes suggests that the plane of humeral motion does have an impact on muscular activations. Therefore, depending on what muscles are affected/involved, scapular dyskinesis be may be more apparent in one plane versus another. We often graded scapular dyskinesis to be more severe in the sagittal plane compared to the coronal plane. During humeral motion in the sagittal plane a greater imbalance in muscular activation was demonstrated between muscles contributing to internal/external rotation: increased activation of the pectoralis minor and decreased activation of the rhomboid major, as was hypothesized. This imbalance was not as apparent during humeral motion in the coronal plane likely due to the retracted position of the scapula in the coronal plane. Since, only one other study that was found evaluating activation of the pectoralis minor, further evaluation of all scapular muscles in regards to both normal and altered scapular motion in needed.

We hypothesized that a decrease in serratus anterior activation would be present in the dyskinesis group. We did not find any significant differences in average serratus anterior activation at any portion of humeral elevation or depression in either plane. The amplitude of activation throughout abduction in the normal group was consistent with previous research.[57, 166] Lopes et al.[81] evaluated serratus anterior activation and did not find any difference between groups. Huang et al.[57] did find that a group with type I and II dyskinesis demonstrated significantly less serratus anterior activation during humeral depression. They evaluated and categorized dyskinesis groups based on Kiblers' method[74] whereas the current study and the one conducted by Lopes et al.[81] used the more general categorization suggested by McClure et al.[96] Therefore the difference in findings may indicate that an observed decrease in activation of the serratus anterior may be more indicative to a specific alteration such as medial border prominence combined with inferior angle prominence, and a general categorization of obvious dyskinesis is not specific enough evaluate the involvement of the certain muscles including the serratus anterior.

There were also no significant differences in average middle trapezius activation at any portion of humeral elevation or depression in either plane. During humeral elevation in flexion the amplitude of activation of the middle trapezius was over two times that of the normal group which may be clinically meaningful. An increase in activation of the middle trapezius in the dyskinesis group could be compensatory in an attempt to counteract the increased amplitude of the pectoralis minor which was demonstrating its highest average activation during elevation in this plane. In addition, the rhomboid major which would be an agonist to the middle trapezius for decreasing scapular internal rotation was demonstrating decreased activation, potentially putting more reliance on activation of the middle trapezius. Previous research has not identified this deficiency in co-activation and agonist/antagonist imbalance because no research has been found evaluating the rhomboid major and pectoralis minor with regard to the presence of scapular dyskinesis.

5.6.3 Isometric Strength

Isometric strength of the scapular stabilizers was measured to evaluate if overhead athletes visually identified to have obvious scapular dyskinesis demonstrated strength differences compared to a normal group. None of our hypotheses regarding strength differences between groups were supported in the current study. We expected to find a decrease in isometric strength in the serratus anterior, rhomboid major, lower and middle trapezius in the dyskinesis group compared to the normal group. Across all muscles hypothesized to be different only a maximum difference of 1%BW (approximately 0.73kg) was observed between groups, indicating no clinically meaningful difference was present. The lack of any differences in strength between groups may be an indication that strength is not the issue but muscular activation and coordination may be the primary contributing factors to the presence of scapular dyskinesis. Isometric strength testing may not a sensitive method for quantifying or evaluating muscular involvement in individuals with scapular dyskinesis. This may be due to the fact that isometric strength assessment is conducted with the shoulder in stabilized position for many of the tests, in order to minimize compensatory activation of other musculature. If the muscles do not have to control scapular position in the isometric testing position the presence of dyskinesis may not be a confounding factor in the ability to maximally contract a muscle. To further investigate if muscular weakness contributes to the presence of scapular dyskinesis, isokinetic testing such as the shrug or protraction/retraction tests may provide more insight as to whether muscular strength contributes to the presence of scapular dyskinesis.

5.7 LIMITATIONS

Alterations in muscular and kinematic characteristics may be specific to the type of dyskinesis (winging, inferior angle prominence, dysrhythmia) present. We evaluated a general categorization for scapular dyskinesis compared to a normal group. This general categorization for scapular dyskinesis has been shown to be more reliable and has been validated, despite this, a general categorization may not be sensitive enough to evaluate or differentiate between the muscular contributions or biomechanical characteristics associated with specific types of scapular dyskinesis. In order to establish more definitive groups, only athletes evaluated to have a final score of obvious dyskinesis were used and compared to a normal group. As the scapular dyskinesis screening works, both planes of motion were scored individually and combined for a final score. Using this screening method a subject with a final score of obvious scapular dyskinesis could have been scored to have subtle dyskinesis or normal motion in one plane and obvious dyskinesis in another. Because both planes were evaluated based on the final score, the inclusion of subtle or normal motion for some subjects in the obvious dyskinesis group may have confounded the findings and are a limitation to using this general scapular dyskinesis screening test. Despite this, a clinician may identify that scapular dyskinesis is only present or more severe in one plane of motion and still warrant intervention. A general categorization also acknowledges that multiple alterations are often observed together when performing a screening test. Therefore, the use of this general screening test provides clinicians with relevant data to guide treatment of a more ambiguous classification of dyskinesis.

Sample size for the current study was calculated based on the assumption of a large effect size based on scapular upward rotation. We did meet the effect size and achieved adequate power for upward rotation at 30° of humeral depression in the sagittal plane. Our findings do provide meaningful insight that is consistent with larger studies that have been conducted.

5.8 STUDY SIGNIFICANCE

The current study provided insight regarding the certain kinematic alterations and difference in muscular activation in overhead athletes with obvious scapular dyskinesis. Specifically, these findings shed light on altered muscular activation specifically with the pectoralis minor and the rhomboid major and their contributions to scapular dyskinesis. Both these muscles have been under-investigated likely due to the invasive nature of evaluating electromyographic activity. Our findings support the use of interventions targeting activation of the scapular retractors and improving muscular balance of the anterior and posterior scapulothoracic complex. We found differences in scapular kinematics and muscular activation compared to studies that evaluated individuals with scapular dyskinesis and shoulder pathology. This may suggest that musculoskeletal characteristics which contribute to presence of scapular dyskinesis may differ from the characteristics that are seen in the presence of pathology. Therefore, when clinicians evaluate the shoulder and scapula-thoracic complex and identify the presence of obvious scapular dyskinesis, they can more specifically target muscular deficiencies and re-establish coordinated muscular control of scapular position and dynamic scapular motion.

5.9 FUTURE DIRECTIONS

Previous research has demonstrated the importance of sensorimotor control and functional joint stability of the shoulder,[131, 132] and has addressed the importance of restoring functional joint stability through rehabilitation strategies for treatment of shoulder pathologies.[80, 114, 131, 132] The scapula serves as the foundation of shoulder motion; therefore these same concepts should be explored in a population with scapular dyskinesis. Future research should evaluate if neuromuscular deficits of the shoulder are present in a population with scapular dyskinesis. This would aid in identifying a relationship between dyskinesis and the potential development of capsuloligamentous injury. Furthermore, future research should evaluate methods for regaining neuromuscular control of the scapular stabilizers in order to correct altered scapular motion. Several investigators have evaluated muscular activation during rehabilitative exercise in order to reduce pain and treat pathologies of the shoulder,[21, 73, 111, 153] and a single study was found that evaluated muscular activation relative to the presence of scapular dyskinesis.[22] Investigators should continue to evaluate if an intervention which focuses on improving selective and coordinated activation of the rhomboid major and upper trapezius while minimizing the activity of the pectoralis minor over a training period in a group with scapular dyskinesis can re-establish normal scapular motion.

The findings from the current study provided additional insight to the biomechanical and musculoskeletal characteristics that contribute to the presence of obvious scapular dyskinesis. Categorizing an individual to have obvious scapular dyskinesis may not possess the sensitivity to fully identify the musculoskeletal alterations contributing to the presence of obvious scapular dyskinesis. Future research should also aim to evaluate kinematics and muscular activation in specific types of scapular dyskinesis in order to ascertain what unique characteristics contribute to each type of dyskinesis compared to a general categorization. This may allow clinicians to more specifically target muscular deficiencies and re-establish coordinated muscular control of scapular position and dynamic scapular motion, providing a more thorough rehabilitation of the scapulothoracic complex.

5.10 CONCLUSIONS

Scapular dyskinesis is prevalent in the overhead athletic population. We identified clinically meaningful differences in scapular kinematics and muscular activation in overhead athletes with obvious scapular dyskinesis. Specifically, athletes with obvious scapular dyskinesis on average demonstrated decreased scapular upward rotation, decreased activation of the upper trapezius and rhomboid major, and increased activation of the pectoralis minor. Therefore, when clinicians clinically screen for and identify the presence of obvious scapular dyskinesis, rehabilitation strategies should aim to increase activation of the of the scapular upward and external rotators while addressing potential hyper-tonicity of the pectoralis minor in order to re-establish coordinated muscular control of scapular position and dynamic scapular motion.

APPENDIX A

QUESTIONNAIRES AND SCREENING TOOLS

A.1 Injury History Questionnaire

IRB#:
Title: The evaluation of scapular kinematics and muscular characteristics of the scapular stabilizers in overhead athletes presenting with scapular dyskinesis compared to healthy controls

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Subject ID: ____________________ Date of Survey: ____________________

☐ No history of dominant shoulder injury

Date of Injury (mm/yyyy): ____________________ Injury # ____________________

Provide a brief description of how the injury occurred:

Sport
- ☐ Baseball
- ☐ Softball
- ☐ Volleyball
- ☐ Tennis
- ☐ Swimming
- ☐ Water polo
- ☐ Other: ________________

When did your injury occur?
- ☐ Practice
- ☐ Competition
- ☐ Other

Location of Injury
- ☐ Right
- ☐ Left

Stage
- ☐ Acute
  - ☐ First Time
  - ☐ Recurrent
- ☐ Chronic (pain > 6 months)
- ☐ Overuse

Cause of injury
- ☐ Direct contact w/player
- ☐ Direct contact w/ball
- ☐ Direct contact w/base
- ☐ Fall/stumble - same level
- ☐ Slip/twist/turn (no fall)
- ☐ Throwing
- ☐ Landing
- ☐ Jumping
- ☐ Unknown
- ☐ Other

Time Missed / Restricted Activity

Restricted _______ days / wks / yrs

Missed _________ days / wks / yrs

Injured body region
- ☐ Glenohumeral Joint
- ☐ Upper arm
- ☐ Clavicle/Scapula

Injury type
- ☐ Arthritis
- ☐ Avulsion fracture
- ☐ Bursitis
- ☐ Capsulitis
- ☐ Dislocation
- ☐ Fracture
- ☐ Impingement
- ☐ Inflammation
- ☐ Infection
- ☐ Laceration
- ☐ Nerve injury
- ☐ Open wound
- ☐ Periostitis
- ☐ Rupture (ligamen, Grade 3)
- ☐ Sprain (Grade 1, 2)
- ☐ Strain
- ☐ Stress fracture
- ☐ Subluxation
- ☐ Tendonitis
- ☐ Other

Surgery
- ☐ No
- ☐ Yes

Notes

A.1.2. Scapular Dyskinesis Screening

Scapular Dyskinesis Screening

Operational Definitions

Normal scapulohumeral rhythm: The scapula is stable with minimal motion during the initial 30° to 60° of humerothoracic elevation, then smoothly and continuously rotates upward during elevation and smoothly and continuously rotates downward during humeral lowering. No evidence of winging is present.

Scapular dyskinesis: Either or both of the following motion abnormalities may be present.

Dysrhythmia: The scapula demonstrates premature or excessive elevation or protraction, non-smooth or stuttering motion during arm elevation or lowering, or rapid downward rotation during arm lowering.

Winging: The medial border and/or inferior angle of the scapula are posteriorly displaced away from the posterior thorax.

Single Plane Rating Scale

Normal Motion: no evidence of abnormality in either plane of motion

Subtle abnormality: mild or questionable evidence of abnormality, not consistently present

Obvious abnormality: striking, clearly apparent abnormality, evident on at least 3/5 trials (dysrhythmias or winging of 1 in or greater displacement of scapula from thorax)

Single Plane Flexion Rating			**Single Plane Abduction Rating**		
☐ Normal	☐ Subtle Dyskinesis	☐ Obvious Dyskinesis	☐ Normal	☐ Subtle Dyskinesis	☐ Obvious Dyskinesis
Identify primary type of dyskinesis present for selected rating in each plane					
	☐ Dysrhythmia ☐ Medial border ☐ Inferior Angle			☐ Dysrhythmia ☐ Medial border ☐ Inferior Angle	

Final Rating Scale

Normal: both test motions are rated as normal or 1 motion is rated as subtle

Subtle abnormality: both flexion and abduction are rated as subtle

Obvious abnormality: Either motion is rated as having obvious abnormality

Final Rating		
☐ Normal Motion	☐ Subtle Abnormality	☐ Obvious Abnormality

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