Comparison of 3D Shoulder Kinematics, Thoracic Posture and Shoulder Strength between Asymptomatic Elderly and Young Population

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Abstract

The elderly population are at risk of having shoulder pain and dysfunction. One possible contributor to shoulder impairment is abnormal scapulothoracic and glenohumeral motion. Comparing the elderly and young age groups based on changes in kinematics and thoracic posture during completion of day-to-day functional tasks is not well understood. The purpose of this study was to compare three-dimensional shoulder kinematics, thoracic posture and shoulder strength between asymptomatic elderly and young individuals. Subjects included 50 asymptomatic right dominant, gender and BMI matched individuals equally divided into young (20 to 40 years) and elderly (above 65 years) groups. A 3D electromagnetic motion capture system was used to record scapulothoracic and glenohumeral angular positions during scapular plane abduction, forward reach, reaching the back, reaching the wallet and touching the head tasks. Kinematics were computed at 25%, 50%, 75% and 100% of the humeral angular motions. A 3D CT based reconstructed anatomical model was animated based on group mean motion data to compute the minimum linear distance from rotator cuff footprints to potential impinging structures. Thoracic posture in static and dynamic conditions was measured for flexion-extension. Isometric shoulder strength was measured in four directions with a portable dynamometer and strength ratios were computed.

Significant kinematic differences between groups were present for humerothoracic elevation range of motion, scapular internal rotation during scapular plane abduction, scapular upward rotation during forward reach, glenohumeral external rotation during forward reach, scapular internal rotation during reaching the back,

scapular posterior tilt during reaching the back and scapular internal rotation during reaching the wallet. The mean differences between groups were less than 8° with the exception of glenohumeral external rotation (<19°) during the forward reach task. Overall, relative to the number of comparisons, few group differences existed for the tested conditions and those that were different had small magnitude. It was believed that these differences represent natural consequences of aging even in the absence of shoulder pain or dysfunction.

Minimum linear distance was reduced in the elderly for forward reach and reaching the wallet tasks. It was believed, however, that position was the issue during reaching the wallet task since both groups had submillimeter minimum distances for that task. Significant dynamic thoracic flexion-extension differences between groups existed for reaching the back and reaching the wallet tasks. However, the magnitudes of the differences between groups were less than 2°, so it was thought that these differences were not clinically meaningful. Significant reduction in shoulder strength for the elderly group was evident in flexion, abduction, external rotation and internal rotation directions, but strength ratios were similar for both the groups.

Based on the findings it was assumed that forward reach and possibly reaching the wallet tasks may benefit from further investigation due to the possibility of higher potential for rotator cuff compression in the elderly group. Maintaining strength ratios may be protective for developing rotator cuff disease. Modification of the forward reaching and reaching the wallet tasks may be considered while planning shoulder intervention strategies for the elderly.

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CHAPTER I

INTRODUCTION

I. Background and Clinical Significance

Chronic pain leads to disability in the geriatric population (Leveille et al., 2009) and results in muscle weakness with reduced functional abilities (Eggermont et al., 2009; Lamb et al., 2000; Leveille et al., 2007). The second most common cause of musculoskeletal pain is shoulder joint pathology (Picavet & Schouten, 2003). Rotator cuff (RC) disease is the commonest cause of shoulder pain (Chard et al., 1991; van der Windt et al., 1995; Vecchio et al., 1995a; Wofford et al., 2005). Jette & Davis (1991) reported that shoulder pain ranks second after low back pain, in the number of patients visiting physical therapy clinics. Prevalence of shoulder pain in patients visiting physician clinics ranged from 31% to 48% (Pope et al., 1997). In fact the quality of life is affected in patients with shoulder problems (MacDermid et al., 2004). According to Meislin et al. (2005) the economic burden to treat shoulder joint problems in the United States was about $7 billion in 2000.

RC disease is the most common pathology causing shoulder pain and disability (Chakravarty & Webley, 1990; MacDermid et al., 2004). In a systematic review it was reported that in the year 2002 about 4.5 million patients visited physician offices due to RC pathology and 40,000 patients were operated on to repair the soft tissue with the average cost of $14,000 per surgical approach (Oh et al., 2007). Studies have stated that 29% to 70% of all shoulder problems are due to RC pathology (Chard et al., 1994; van der Windt et al., 1995; Vecchio et al., 1995b). Prevalence of RC tears increases with age, especially in the population over 40 years and affects over 50% of individuals with shoulder disease above the age of 60 years (Milgrom et al., 1995; Sher et al., 1995). The cost of care for shoulder injuries could rise exponentially due to increases in the elderly population suffering from RC disease (Gomoll et al., 2004). There is evidence of similar short and long term RC disease outcomes with conservative treatment when compared to surgical measures (Brox et al., 1999; Haahr & Andersen, 2006). Other studies commented that irrespective of treatment choices, about one- third of the patients do not have successful outcomes and continue to suffer from pain and disability (Brox et al., 1993; Brox et al., 1999).

Factors causing RC tendon pathology can be classified as extrinsic and intrinsic. Extrinsic factors are believed to reduce SA space and compress the RC tendons. These factors include changes in shoulder joint kinematics, postural anomalies, shoulder joint muscular deficits, and different acromial or humeral anatomy. Extrinsic compression which is mechanical in nature is further divided in two categories: subacromial and internal impingement. Subacromial impingement syndrome as termed by Neer (1983) occurs when RC tendons are compressed by the coracoacromial (CA) arch structures which include the undersurface of the acromion and the CA ligament (Neer, 1972). Internal impingement occurs with the arm in abduction and external rotation where the articular side RC tendons get compressed between the postero-superior glenoid rim and the humeral head (Davidson et al., 1995; Edelson & Teitz, 2000; Paley et al., 2000; Heyworth & Williams, 2009). Sometimes internal impingement also occurs between the anterior glenoid margin and humeral head by the side of the lesser tuberosity with slight arm abduction and internal rotation (Edelson & Teitz, 2000). On the other hand, an intrinsic mechanism of RC degeneration is caused by changes in physiology such as reduced vascularity (Biberthaler et al., 2003; Rudzki et al., 2008), tendon degradation (Sher et al., 1995; Tempelhof et al., 1999), changes in tendon biology (Kumagai et al., 1994) and altered mechanical properties (Bey et al., 2002), all occurring within the tendon complex . Rotator cuff disease is progressive in nature (Neer, 1983) which makes the elderly population vulnerable to shoulder issues and identifying the causative factors is critical in devising proper exercise strategies to reduce pain and debility.

II. Shoulder Pain, RC Disease and Aging

Aging is a potential covariate in rotator cuff disease since prevalence of RC tears increases with age (Iannotti et al., 1991; Milgrom et al., 1995; Sher et al., 1995). Neer (1983) thought that age is an important factor while describing subacromial impingement. A prospective study by Yamaguchi et al. (2001) gave evidence of the progressive nature of RC disease where more than 50% of the initially asymptomatic rotator cuff tear patient cohort developed pain and disability in less than four years. Shoulder pain may develop due to compression of the supraspinatus tendon, biceps tendon, and greater tuberosity against the CA arch structures (Burns & Whipple, 1993). Aging has been shown to decrease tendon elasticity and reduce tensile loading collagen alignment of the tendons (Woo et al., 2000). There is evidence of histological changes in the RC tendons that include calcification and fibrovascular proliferation in the elderly population even without shoulder symptoms (Kumagai et al., 1994). Riley et al. (1994a) found that there is reduced number of total glycosaminoglycan and proteoglycan content within the supraspinatus tendon. There is reduction in collagen content and increase in the irregularly arranged or weaker type III collagen fibers found in the tendons with aging (Kumagai et al., 1994). Other researchers believe that collagen changes in the supraspinatus tendon may be due to inferior healing after repeated microtrauma of the tendon (Bank et al., 1999; Riley et al., 1994a). It is not known if aging in itself is a causative factor for RC tendinopathies or if repeated microtrauma to the tendons, which are already weakened due to intrinsic changes with age, make them more vulnerable to injuries.

III. Shoulder Kinematics

It is believed that scapular mobility is a key component of normal shoulder function and 3D scapulothoracic motion affects humeral mobility (McQuade et al., 1995). Scapular motion on the thorax constitutes approximately 1/3 of the total motion during arm elevation, with the rest being humeral motion (Braman et al., 2009). The normal shoulder biomechanics allows the humeral head to remain centered on the glenoid during raising of the arm (Fung et al., 2001; Kibler, 1998; McQuade et al., 1995). To avoid the RC tendons being impinged by CA arch structures, the acromion tilts up or posteriorly during arm elevation (Kibler, 1998). Scapular maltracking leading to improper postioning during glenohumeral elevation will increase the risk of impingement of the RC tendons under the CA arch (McQuade et al., 1995). Alterations in the 3D scapular kinematics in subjects with subacromial impingement have included reduction in scapular upward rotation (Endo et al., 2001; Ludewig & Cook, 2000) and posterior tilt (Endo et al., 2001; Ludewig & Cook, 2000; Lukaseiwicz et al., 1999). Ludewig & Cook (2000) theorized that decreased upward rotation and posterior tilt contributes to reduction in the subacromial (SA) space leading to subacromial impingement syndrome. Atalar et al. (2009) using multislice computed tomography images taken during abduction at 60°, 90° and 120°, found that restricting upward rotation and posterior tilt using a custom brace led to reduction in the acromiohumeral distance at 90° abduction.It is also noted that increased subacromial space is attributed to increases in scapular upward rotation and posterior tilt (McClure et al., 2006). Different rehabilitation measures have been undertaken to treat patients with impingement syndrome such as scapular taping (Selkowitz et al., 2007), retraining of thoracic posture to improve scapular posterior tilt (Kendall et al., 1993), and stretching and strengthening (Ludewig & Borstad, 2003).

There is literature suggesting intrinsic changes result in RC tissue degeneration which might occur with aging (Iannotti et al., 1991; Milgrom et al., 1995; Tempelhof et al., 1999). It is believed to be critical to have optimum shoulder joint kinematics, subacromial space, thoracic posture and shoulder strength to prevent RC tendon degeneration (Solem- Bertoft et al., 1993; Kebaetse et al., 1999; Lukasiewicz et al., 1999; Ludewig & Cook, 2000; Endo et al., 2001; Borich et al., 2006; McClure et al., 2006; Cools et al., 2007; Gumina et al., 2008). It may be that these factors interact in the elderly population to result in increased incidence of shoulder dysfunction.

Shoulder joint kinematics plays an important role in the normal biomechanics of the scapulothoracic and glenohumeral joint. Unfortunately prevalence of shoulder joint pain is quite high and it affects the quality of life of an individual. RC pathology is common in the elderly population and is progressive in nature leading to functional loss and disability. There is evidence of shoulder kinematic differences between the elderly with pain- free shoulders and the general adult population (Rundquist et al., 2011). But to my knowledge there are no studies to date that have looked into the unique shoulder biomechanical characteristics comparing the healthy elderly population and healthy young group during completion of day-to-day functional tasks.

Numerous studies have described that reduction in subacromial space as measured by the acromiohumeral distance (AHD) may be associated with RC disease. These studies quantified the linear measurement between the acromion and humerus based on MRI scans, ultrasonography or radiographs in the adult population. The average AHD in an adult healthy population varies between 7 mm and 14 mm with the arm at the side (Azzoni & Cabitza, 2004; Weiner & Macnab, 1970). The range will probably be less in adults with RC pathologies and may be further compromised in the elderly group both healthy (probably due to thinning of the cuff) and with painful shoulders. An extensive literature search was unable to find any experiments quantifying AHD and minimum linear distance of RC footprints to the CA arch in the healthy aging population when compared to healthy young population during performance of functional motions.

Thoracic posture is an important contributor to normal shoulder mechanics. Increased thoracic kyphosis (Kebaetse, 1999) may lead to greater anterior scapular position which might create reduced AHD and/ or reduced RC footprint to CA arch distance. In healthy adults with arm elevation thoracic extension occurs (Crawford & Jull, 1993; Edmondston et al., 2012), but due to aging there may be decreased thoracic extension or relative increase in flexion/ kyphosis (Crawford & Jull, 1993; Culham & Peat, 1993). I believe that thoracic extension range of motion will be less in the healthy elderly group when compared to the healthy younger group. I was not able to find any studies that quantified this assumption in the elderly population during activities of daily living.

Shoulder strength is critical for normal kinematics since the muscles support the humeral head in the glenoid cavity. The muscles impart both static and dynamic stability. The coordinated muscular action produces an overall 2:1 scapulohumeral rhythm (Braman et al., 2009; Inman et al., 1944) beyond the setting phase of first 30° during arm elevation. Aging can cause atrophy of the muscles that might ultimately result in muscular weakness (Lexell et al., 1988; Frontera et al., 2000). Weak muscles may not be able to fully control the arthrokinematic motion between the humeral head and scapula which might lead to RC diseases. Till date there is no literature available that studied isometric shoulder strength in the healthy elderly population when compared to healthy young subjects.

IV. Overall Research Question

Are there shoulder biomechanical changes present in healthy older persons as compared to healthy younger persons during performance of functional tasks?

V. Aims and Hypotheses

A. Kinematic Factors—

I. *Shoulder joint motion:*

Aim 1. To quantify any 3D angular kinematic changes in scapulothoracic or glenohumeral motion during active arm elevation that distinguishes the two age groups.

- ***Hypotheses—***

H.1.a. The older subject group will have no change in humerothoracic range of elevation motion during active elevation for scapular plane abduction motion when compared to the younger group.

H.1.b. The older subject group will have reduced scapular internal rotation during active elevation for scapular plane abduction, reaching forward and touching head motions when compared to the younger group.

H.1.c. The older subject group will have no change in scapular upward rotation and posterior tilt during active elevation for all motions when compared to the younger group.

H.1.d. The older subject group will have reduced humeral external rotation during active elevation for all motions when compared to the younger group.

II. *Rotator cuff tendon proximity:*

Aim 2. To quantify any 3D angular kinematic changes between the older asymptomatic and younger asymptomatic groups that alters the minimum rotator cuff tendon footprint to coracoacromial arch and glenoid linear distances during active arm elevation.

- ***Hypotheses—***

H.2.a. The older subject group will have no change in the minimum linear distances from the cuff footprints to the coracoacromial arch during active elevation for positions tested compared to the younger group.

III. *Postural Effects:*

Aim 3. To quantify thoracic postural changes during static and dynamic conditions that distinguishes the two groups.

- ***Hypothesis—***

H.3.a. The older group will have significantly more thoracic kyphosis when compared to the younger group during static neutral relaxed standing with the arms hanging by the side.

H.3.b. The older group will have significantly less thoracic extension when compared to the younger group during active elevation for all motions.

B. Strength —

Aim 4. To quantify any changes in shoulder strength that distinguishes the two groups.

- ***Hypothesis—***

H.4.a. Older subjects with asymptomatic shoulders will demonstrate significantly reduced isometric shoulder flexion, abduction, internal and external rotation normalized torque with the arm by the side when compared to the younger group.

H.4.b. Older subjects with asymptomatic shoulders will demonstrate significantly increased flexion to abduction and internal to external rotation strength ratios when compared to the younger group.

Hypotheses were based on previous literature in some cases that supported an expectation of group differences and in other cases where no group differences were expected, the hypotheses were based on clinically meaningful interpretations. In conclusion, it is believed that if differences do exist between the two asymptomatic groups then the elderly population with reduced scapulothoracic and glenohumeral motion, reduced subacromial space, more flexed posture and reduced shoulder joint muscle strength are prone to shoulder joint ailments and dysfunction leading to diminished quality of life and increased social burden. On the contrary if there are no differences between the two asymptomatic groups then the elderly volunteers are being protected from shoulder injuries through activities of daily living, inherent compensatory techniques, diet and most importantly exercise or physical fitness. In addition, if differences do not exist between groups, it identifies that these biomechanical changes are not a natural consequence of aging.

VI. Definition of Terms

1. Anterolateral shoulder pain— Shoulder pain on the anterior, lateral or superior aspect of the glenohumeral joint.

2. Geriatric population— Individuals 65 years old and over (http://www.census.gov/population/www/pop-profile/elderpop.html; Novak, 1997)

3. Rotator cuff footprint— The tendon insertion area of subscapularis, supraspinatus, and infraspinatus on the humeral head (lesser tuberosity and greater tuberosity, respectively) that will be identified from 3D bone modeling using CT scan images.

4. Minimum linear distance— The minimum distance from any point on the footprint to any point on the undersurface of the coracoacromial arch structure during arm elevation motion.

CHAPTER II

REVIEW OF LITERATURE

I. Introduction

The shoulder joint is made of three bones which include the humerus, scapula and clavicle. This dynamic joint complex is comprised of three different joints which are the glenohumeral (GH), acromioclavicular (AC) and sternoclavicular (SC) joints. The necessary balance between mobility and stability gives the shoulder joint its unique characteristic features. Scapular motion is dependent on SC and AC joint mobility, which is an important factor for normal GH range of motion (ROM) during arm elevation. Inman et al. (1944) discussed the importance of coordinated scapular mobility on normal GH motion. This symbiosis was suggested by McClure et al. (2001) as scapular motion abnormalities such as reduced scapular external rotation may create increased stress on GH external rotation which could lead to various GH joint pathologies. The classic scapulohumeral rhythm of 2:1 described by Inman et al. (1944) is possible due to the fact that scapula is floating on the thorax and is connected to the axial skeleton by the clavicle only through the acromioclavicular (AC) joint.This anatomical relationship makes us believe the importance of AC joint mechanics (scapulothoracic motion) in the normal shoulder joint motion.

Inman et al. (1944) described scapulohumeral rhythm based on the different phases of arm elevation. The first 30 degrees of shoulder elevation, which is known as the setting phase, is achieved primarily through glenohumeral motion and in this phase scapulothoracic movement is small and inconsequential. After the first 30 degrees of shoulder elevation, glenohumeral and scapulothoracic motion is simultaneous. The important function of the scapulohumeral rhythm is to attain full range of shoulder motion and also to keep the humeral head centered in the glenoid fossa. It is said that in every 15 degrees of shoulder abduction there is 10 degrees of glenohumeral and 5 degrees of scapulothoracic motion beyond the first 30 degrees of abduction which is known as the setting phase. In a complete GH abduction of 180 degrees there are 120 degrees of glenohumeral and 60 degrees of scapulothoracic motion. Some variability exists as the scapulothoracic and glenohumeral motions do not have a linear relationship. The 2:1 ratio describes a reasonable interpretation of the overall ROM during a scapulohumeral rhythm. It is thought that any disturbance in the 2:1 classical scapulohumeral rhythm can cause abnormal glenohumeral muscle mechanics (Ludewig & Cook, 2000; Lin et al., 2005) due to changes in the length-tension relationship of the pectoralis minor muscle (Borstad & Ludewig, 2005) and also increases risk of impingement of rotator cuff tendons between the humerus and the undersurface of the CA arch (Ludewig & Cook, 2000). Normal scapulohumeral rhythm between 60° and 120° of GH elevation is critical to prevent the possibility of shoulder impingement (Flatow et al, 1994; Brossmanm et al., 1996).

The optimum function of the shoulder joint is possible due to the coordinated action of glenohumeral, scapulothoracic, sternoclavicular and thoracohumeral muscles. Glenohumeral muscles which include the rotator cuff (RC), deltoid and teres major are an important area of concern as dysfunction of any of these muscles may lead to various shoulder joint pathologies. In fact shoulder joint problems may also lead to dysfunction of the above said muscle group. The RC, which is thought to be injured during shoulder impingement (Soslowsky et al., 2002), is made of four muscles which include the subscapularis, supraspinatus, infraspinatus and teres minor. These muscles give the shoulder both stability and the dynamic component necessary to function optimally. The RC muscles originate from the scapula and are inserted near the humeral head. They stabilize the humeral head within the shallow glenoid fossa of the scapula. Favard et al. (2007) believe that the RC has two important roles to play: stability of the GH joint and external rotation motion of the humerus. The RC pulls the humeral head into the glenoid cavity thus centering it and prevents superior migration during arm elevation by the pull of the deltoid during arm elevation (Halder et al., 2001; Favard et al., 2007). The RC tendons pass under the coracoacromial arch before they attach to the humerus. As a result of this structural abnormality, the RC tendons are predisposed to subacromial impingement which can progress to the development of rotator cuff tears (Zuckerman et al., 1992).

The most common cause of shoulder joint pain, which range from 44- 65% of all shoulder pathologies in individuals who visited physician offices, is due to subacromial impingement (van der Windt et. al., 1995, 1996; Vecchio et. al., 1995a;). A study on shoulder joint pathology in the geriatric population by Chard & Hazleman (1987) found that symptomatic shoulder disorders were very common. They found that 21% of the subjects suffered from mild to moderate shoulder pain with movement and resisted motion of the arm. A community study by Chakravarty and Webley (1990) on 100 elderly individuals concluded that 34% of them suffered from shoulder pain. Vecchio et al. (1995b) in their three year community survey study found that 67% of 80 elderly patients were suffering from increased or no change in chronic shoulder pain and functional impairment status. It is common knowledge amongst the healthcare practitioners that shoulder pain and dysfunction may be due to the aging process (Chard et al., 1991; Chakravarty and Webley, 1990). Based on past literature and clinical experience my belief is that shoulder pain is prevalent in the elderly population which may lead to reduced functional independence and increased societal burden.

II. Incidence and Prevalence of Shoulder pain

Shoulder pain is one of the most prevalent complaints of musculoskeletal pain (Picavet & Schouten, 2003). It is the second most common type of musculoskeletal pain with a point prevalence of 20.9% (Picavet & Schouten, 2003). The authors mailed questionnaires to 3718 individuals and 3664 responded to the survey. The subject age range was 25 years and older in which 33.1% of the sample size were above 65 years. Males and females were equally distributed at nearly 50% throughout the age range. The point prevalence for males above 65 years was 13.2% and that of women in the same age group was 23.1%. They also found that 55% of the sample size had a recurrence of shoulder and neck pain. Women of all ages had higher odds of 1.8 in having shoulder and neck pain when compared to males of all age groups.

In another study by Pope et al. (1997), 51% of the population under study in the age group of 18 to 75 years complained of some form of shoulder pain. The authors sent out questionnaires to 500 randomly selected patients from the general practice register and 312 responded to the survey. The subjects were aged between18 to 75 years, with males comprising 45% and females 55%. Pope et al. (1997) did a follow- up interview on 232 individuals of the responder group. The point prevalence of shoulder pain only was 32%. Based on the survey and interview it was reported by the authors that the shoulder pain prevalence ranged from 32% to 51%.

In a different study by Hasvold & Johnsen (1993) it was reported that 20% of the adult population suffered from shoulder symptoms at any point of time. A self-administered postal questionnaire was sent to 29,026 individuals in the age range of 20-56 years. 17,650 (about 48% males and nearly 52% females) responded to the survey. Prevalence for shoulder or neck pain was 26.9% males and 36.3% females in the age group of 50- 56 years. The rates were lower in 40- 49 years (17% for males and 30.9% for females) and 30- 39 years age range (13.1% for males and 21.5% for females). The trend of increasing prevalence shows a rise in shoulder or neck pain complaints with age.

Allander (1974) found that shoulder pain complaints seem to have an increasing annual incidence rate with the highest of 2.5% for males and 2.2% for females in the 42-46 year age group. The population under study was 4195 subjects in the age range of 31-74 years. The study was completed in two phases. In the first phase questionnaires were mailed to a population of 15,268 and then a representative sample of 4195 individuals were chosen to be clinically examined. According to the author, males had a higher prevalence of shoulder pain than females in older age groups with 27% in males compared to 20% in females in 56- 60 year olds and 21% males versus 16% females in 70-74 year olds.

Jette & Davis (1991) completed a survey of 321 physical therapy outpatient practices in the United States. The therapist ranked upper extremity soft tissue conditions as the second highest percentage (11.2% and 10.7% for hospital and private practices respectively) and the most frequent painful complaint after back injury based on a mailed questionnaire to therapists. van der Windt et al. (1995) in their study included 18 general practitioners who collected data from 392 patients and concluded that the annual incidence rate of shoulder complaints was 14.7 per 1000 with 12.8 and 6.7 per 1000 in the age group of 65- 74 and above 75 years respectively. Females had a higher incidence rate than males (11.1 to 8.4 per 1000 per year). It was also noted that subacromial syndrome had the highest incident rate (5.0 per 1000 per year) of all shoulder pathologies that were evaluated.

Based on these studies we can conclude that shoulder pain has a high prevalence ranging from 20% to as high as 51% in some cases. The annual incidence rate varies from about 1.47% to more than 2%. Shoulder pain has been shown to affect both genders equally. There is enough evidence to show that shoulder pain is a disabling factor in the elderly population based on the high incidence and prevalence rates. It is logical to say that shoulder pain will affect performance of functional activities in the elderly population. But most of the above discussed studies used surveys and questionnaires to collect data with the exception of one study which used an interview method. There are a lot of confounding factors affecting the data collected through secondary methods such as surveys and questionnaires. As a result, interpretations of these studies are limited. It is not possible to conclude if the elderly population is predisposed to shoulder pain based on the assumption that there is increase in shoulder pain with age.

III. Vascularity of Rotator Cuff Tendon and Impact in Shoulder Pathology

Abnormal vascular mechanics have been theorized to be a causative factor in shoulder joint pathology. The common site for rotator cuff tears adjacent to the supraspinatus tendon insertion on the greater tuberosity of the humeral head is thought to be a high risk location where there is a deficient vascular supply (Moseley & Goldie, 1963; Rothman & Park, 1965). I wish to discuss the mechanism of action of this critical factor that may lead to the development of various shoulder problems especially impingement and/or RC tears.

In a histologic cadaveric study by Rathbun & Macnab (1970), they visualized the microvascular structure within the rotator cuff (RC) soft tissue. Using micropaque injection technique the authors introduced the dye through the internal mammary and vertebral arteries. The shoulder was then frozen and each of the four RC tendons with the bony insertion was dissected. Antero- posterior and lateral view of each section were radiographed and then visualized. The authors observed in the X- ray slides that there is a constant zone of avascularity at the point of supraspinatus insertion. The scientists believe that the less vascularity is due to the longitudinal direction of the blood vessels which is then subjected to tension and compression. The other reason for avascularity may be due to the wringing effect of the supraspinatus tendon by the continuous pressure of head of humerus. This phenomenon can be described as squeezing out the blood supply from the supraspinatus insertion area on the greater tuberosity by the humeral head during adduction of the arm probably due to sustained stretching of the tendon leading to reduction in the tendon cross section area thereby pumping the blood outside. During forced lateral rotation of the shoulder the researchers found that there is a zone of relative avasularity in the subscapularis tendon near the insertion area. Rathbun & Macnab also found evidence of tendinitis, calcification and rupture of the tendon areas in the critical zones. They conclude from their study that the degeneration of the tendon is due to reduced blood supply as it was restricted only within the avascular zone. But there may be other pathomechanics involved in tendon degeneration and vascular issues may not be the only predisposing factor of RC disease.

Orthogonal polarization spectral imaging, a relatively new noninvasive technique to evaluate microcirculation, was used by Biberthaler and colleagues (2003) during shoulder arthroscopic procedures. They had 11 patients (8 men and 3 women) with a mean age of 56±9 years (all subjects over 40 years) presenting with clinical signs of degenerative rotator cuff disease. The authors found that the mean functional capillary density in the area near rotator cuff lesions was significantly reduced when compared to unaffected control areas in the same subject with intact supraspinatus tendon in the insertion region. But the mean capillary diameter did not differ between the lesion and control groups. The authors had significant evidence of reduced number of vessels in the degenerative site when compared to that of the control areas.

In vivo dynamic evaluation of intact asymptomatic rotator cuff (supraspinatus tendon) using contrast- enhanced ultrasound was studied by Rudzki et al. (2008). They had 31 patients (10 men and 21 women) with a mean age of 41.5 years (22- 65 years). Each subject underwent a baseline scan and a post exercise protocol scan. The tendon was divided into four areas based on medial or lateral and superior or inferior. The articular medial portion of the tendon in both the scans had evidence of reduced blood flow when compared to the other three areas. The researchers found that all the four areas had significantly increased blood flow after exercise when compared to baseline. The study gave evidence of reduced blood flow in the 40 years and older group when compared with patients less than 40 years. Similar conclusion was drawn from the post exercise scans between the two age groups. . The authors believe that reduced vascularity may lead to RC tears.

Laser doppler flowmetry is a noninvasive, real time continuous measurement technique of blood flow which was used in the experiment during shoulder arthroscopic surgery by Levy and colleagues (2008). They recruited 56 subjects (35 men and 21 women) with a mean age of 49.6 years (20- 75 years) and divided them into three groups of impingement, cuff tear and instability, or normal with 32, 14 and 10 subjects respectively. The RC supraspinatus tendon was divided into six distinct areas. Even though there was significant difference in blood flow between the groups, the authors noticed that there was no hypoperfusion in the critical or high risk zone as there was no change in flux or blood flow in the normal or control group. There was a lower perfusion in the impingement group when compared to normal and cuff tear groups. Increase in blood flow was seen at the edges of the tear in the cuff lesion group which was believed due to repair and healing processes. The anterolateral and posterolateral areas of the tendon had significantly less perfusion when compared to the other four areas. The authors believe that reduced blood supply may be an effect rather than a causative factor for RC disease.

All the studies give evidence of reduced vascularity of RC tendons after impingement. Studies also show reduced blood flow (Rudzki et al., 2008) and capillary density (Biberthaler et al., 2003) with aging. Rathbun & Macnab (1970) support the fact that reduction in blood flow is due to certain arm positions like adduction and neutral rotation or forced lateral rotation. In fact Levy et al. (2008) mentioned that certain areas are more prone to tears due to hypovascularity than other sites in the RC tendon. But use of cadavers in the study (Rathbun & Macnab, 1970) limits the direct application of their results in the dynamic state. Also there is conflicting evidence of hypoperfusion in critical locations of supraspinatus tendon as seen in studies by Rathbun & Macnab (1970) and Rudzki et al. (2008) but Levy et al. (2008) mentions that it fails to demonstrate any such area in normal cuffs. Unfortunately use of different measurement techniques, definition of subject groups, location and type of lesion, and lack of in vivo application limits the conclusive evidence that can be drawn for these experiments. As a result we are unable to conclude if reduced vascularity in RC tendons is a cause or effect of RC pathology.

IV. Effect of Rotator Cuff Tendon Properties in Shoulder Pathology

Tendon normally functions as a distributor of muscular tensile loads to move and give stability to the joint. It maintains normal function and helps to prevent injury of a joint. Tendons are essentially made of fibroblasts which contains collagen, proteoglycan, elastin and water (Woo et al., 2000). Microtrauma that builds up over time due to repeated motion leads to tendon overuse injury (Hess et al., 1989). Content of the tendon matrix changes with age and there is an increase in collagen content and reduction in glycosaminoglycan content (Ippolito et al., 1980). As a result the collagen bundle becomes stiffer and less elastic (Carlstedt, 1987). Degeneration also causes disruption in fiber organization and decreased cellular components (Chard et al., 1994). The changes in these aged tendons do not give them enough room to adapt and can be damaged further with exercise (Smith et al., 1999).

Fourier transform infrared spectroscopy was used by Chaudhury et al. (2011) to detect any alterations of the chemical components within the tendon matrix in RC tendon tears when compared to intact RC tendon. Specimens from 91 patients with mean age of 65.7 years (45- 89 years) undergoing tendon repair surgeries were collected. Age and gender matched subjects were also included in the study. It was seen in the study that there is a greater reduction in collagen I and II as the tear size increases than that of collagen III. Elastin protein was also found to increase from small to massive tears but there was no change in elastin concentration between partial tears and normal cuff tendons. There were also changes in the lipid and proteoglycan content in partial and small tears only. Damage to the structure and organization of collagen including reduced structural integrity of proteoglycans was seen with increasing tear size. The authors do state that they were still uncertain if these biological alterations cause RC tear or arise because of the tears. But it is believed that some amount of matrix changes is brought about by the biological modification such as healing and progression of tears. The biological change and/ or mechanical trauma cause the collagen ultra- structure to lose its integrity causing the tendons to weaken and make them prone to rupture. The cycle progresses and disrupts the structure and organization of the collagen- proteoglycan complex in the tendon matrix. Change in the structural component of the tendon results in reduced tensile strength and increase in the tear size.

Riley et al. (1994a) measured glycosaminoglycans (GAGs) in 84 cadaver shoulders with no history of tendon pathology and also collected RC tendon biopsies of 53 separate shoulders after surgical repair of the cuff. The age range for the two groups (cadavers and symptomatic patients) was 11- 95 years and 38- 80 years respectively. The extracted GAGs were analyzed through electrophoresis and assayed by dyes. The study found that there was a significant decrease in total GAGs content, chondroitin sulphate and dermatan sulphate in the supraspinatus tendon with age by quantifying the concentration of each chemical in both the groups and then correlating them with age. In chronic tendinitis of the supraspinatus tendon there was a significant rise in hyaluronan, chondroitin sulphate and dermatan sulphate concentration. The authors believe that the increase in GAGs with chronic tendinitis is probably due to new proteoglycan synthesis as a result of an inflammatory response. Reduction in the cellularity in normal tendons is thought to be due to decreased cellular activity with age. It was also thought that reduced blood supply to the critical zone of the tendon may cause reduced cellular activity. As a result the tendons become weak and progresses to a tear.

Organization and composition of tendon might predispose it to injury due to the changes in biochemical properties such as collagen and GAGs. There is evidence of structural and molecular changes within the tendon matrix with repeated injury or aging, but the causation of RC tears is still not known.

V. Normal 3D Kinematics

This section aims to discuss normal 3- dimensional (3D) motion of the scapulothoracic and glenohumeral joints. To date there are no studies published specifically on the geriatric population to analyze normal 3D kinematics. However, to my understanding the shoulder motion sequence in this population will be similar to the normal adult population. There are many studies that have evaluated normal shoulder motion using different systems such as electromagnetic trackers with surface sensors (McQuade & Smidt, 1998; Karduna et al., 2000; Ludewig & Cook, 2002; Borstad & Ludewig, 2002; McClure et al., 2004; Mell et al., 2005, Ebaugh et al., 2006; McClure et al., 2006, Lin et al., 2005; Laudner et al., 2006; Fayad et al., 2008), bone fixed sensors (McClure et al., 2001; Braman et al, 2009; Ludewig et al., 2009; Ludewig et al., 2010; Phadke et al., 2011), opto- electronic reflective markers (Hebert et al., 2002; Senk & Chez, 2006; Bonnefoy- Mazure et al., 2010) or biplanar fluoroscopy (Bey et al., 2007; Bey et al., 2008; Bey et al., 2011; Giphart et al., 2012). There are also differences in analysis of motion data based on Euler/ Cardan sequences (Ludewig et al., 2009; Ludewig et al., 2011) or Helical axis/ Projection angle (Koh et al., 1998) approaches. The discussion will include studies which describe the different parameters and variables involved in the measurement and analysis of 3D shoulder kinematics.

Studies related to normal kinematics have investigated the scapulothoracic (McClure et al., 2001; Braman et al., 2009; Ludewig et al., 2009) and glenohumeral joints (Ebaugh et al., 2006; Bey et al., 2008; Braman et al., 2009; Ludewig et al., 2009). Scapulothoracic motion is essentially a combination of both sternoclavicular and acromioclavicular joint motions (McClure et al., 2001; Ludewig et al., 2009). Quantifying clavicular motion is complex because of the anatomical structure of the bone. The clavicular motion includes protraction- retraction, elevation- depression and posterior- anterior rotation (Ludewig et al., 2009). The three scapular motions with arm elevation have been defined based on the anatomical axes of the scapula. Upward/ downward motion occurs about an axis perpendicular to the plane of the scapula, internal/ external rotation about an approximately vertical axis and anterior/ posterior tipping or tilting about an axis approximately parallel to the scapular spine (Karduna et al., 2000). Similarly with arm elevation the clavicle rotates posteriorly though the long or lateral axis of the bone, elevates approximately about the vertical or anterior axis and retracts approximately about the horizontal or superior axis (Ludewig et al., 2009). As for the humerus there are two motion sequences— humerothoracic and glenohumeral. Humerothoracic motions include plane of elevation about the superior axis, angular elevation along an anteriorly directed axis and internal- external rotation along the humeral long axis which goes through the shaft of humerus. Glenohumeral joint motion has humeral elevation about an anteriorly directed axis, plane of elevation through the scapular plane (about 40° anterior to the coronal plane) and internal- external rotation through the humeral shaft about the superior axis (Ludewig et al., 2009).

Ludewig et al. (1996) studied 3- dimensional (3D) scapular motion sequences with arm elevation. They had a population of 25 subjects including 11 men and 14 women with no symptoms of shoulder pain or pathology and an age range of 18 to 40 years. The subjects were supported and stabilized, and then a cuff with a pendulum potentiometer was attached to the arm. The arm elevation, which was scapular plane abduction, was performed statically at humerothoracic elevation angles of 0° (rest), 90° and 140°. These positions were selected so that they encompass the functional range of arm elevation motion. The authors mention that this plane of motion is a close approximation of unconstrained functional elevation motion. The study reported that the scapula undergoes progressive upward rotation of 2° to 36°, anterior to posterior tilting from -8° to 7° and external or decrease in internal rotation from 33° to 20° with increase in humeral elevation from 0° to 140°. The authors believe that a coincident or parallel increase in upward rotation with humeral elevation is necessary to continue the length-tension relationship of the deltoid which might affect the power produced and the range of elevation achieved. This study was one of the earlier analyses on 3D kinematics of the scapula and sheds light on the importance of 3D measurements, but is limited by the static nature of the study and the few angles that were analyzed.

A study by McQuade & Smidt (1998) investigated the scapulohumeral rhythm in asymptomatic shoulders during scapular plane abduction in three loading conditions. The study included 25 adult males in an age group of 18 to 45 years. The three loading conditions were passive, free active and application of maximal resistance through cable and pulley system attached to an isokinetic dynamometer on the arm while elevating. It was a dynamic repeated motion series with three sensors attached to different body segments like anterior thorax (sternum), acromion, and a cuff attached to the arm. The authors also used radiographs to measure linear distances from bony landmarks to each sensor at different arm elevation positions to check error rate due to sensor skin slip and found that the scapular sensor was within 4.2 mm and that of humeral sensor was within 3.1 mm from their anatomical landmarks respectively. Based on the r^2 value of 0.94 the X- ray angular value has high correlation with electromagnetic system collected angular values. They concluded that scapular upward rotation on the thorax has a non- linear motion with humeral elevation. The authors believe that the plane of elevation may be an important variable to find out a relationship between humeral elevation and scapular rotation motion, but in this study the factor was not significant owing to the fact that there were nearly no deviations in the plane of elevation as a vertical sliding board was placed along the scapular plane to prevent any digression. McQuade & Smidt (1998) commented that there is reduced scapulohumeral rhythm that ranged from 7.9:1 to 2.9:1 in unloaded condition to 3.1:1 and 4.3:1 in light loaded condition and 1.9:1 to 4.5:1 in the maximal resistance condition with increase in loading phase. The authors measured humerothoracic and scapulothoracic motion in contrast to the classical study by Inman et al. (1944) where they measured glenohumeral and scapulothoracic motion. The 2:1 ratio by Inman et al. (1944) is based on the glenohumeral data and McQuade & Smidt (1988) had 3:1 ratio for humerothoracic motion. The higher ratio (3:1) in this study resulted in higher values for different loading conditions. It is also believed that in the unloaded condition there is more humeral motion than scapular motion leading to ratios higher than 2:1. With maximal loading scapular motion was probably more than normal to assist humeral elevation by increasing the muscular force. The elevation motion was performed in the scapular plane and not in pure flexion or abduction plane so the ratio will be different from the classical scapulohumeral rhythm of 2:1. With the 3D approach the authors could measure the scapular upward rotation and humeral elevation independently. They conclude that scapulohumeral rhythm is an important component that should be observed in shoulder dysfunction. I believe it is an important variable that should be looked into while observing changes in shoulder kinematics. But the changes in scapulohumeral rhythm may be sequelae to some other pathomechanics within the shoulder joint that is causing the changes in the rhythm. This study failed to find out if muscular changes like fatigue or imbalance lead to alterations in the scapulohumeral rhythm or is it vice- versa.

Direct measurement technique of scapular motion in healthy subjects was studied by McClure et al. (2001). The authors used bone pins that were inserted into the scapula with an electromagnetic sensor attached to the bone pins. Two other surface sensors were placed on the Thoracic spine and humerus respectively. The humeral sensor was placed on a thermoplastic cuff then strapped on the distal humerus just above the epicondyles. Eight healthy subjects (3 women and 5 men) without any shoulder problems with an age range of 27 to 37 years were recruited for the study. The subjects were all right hand dominant but the left shoulder was tested in all subjects except one. The authors used the

Polhemus Fastrak electromagnetic tracking device to analyze the kinematics of the shoulder joint. Three different active movements including scapular plane abduction, flexion and long axis humeral rotation in 90 degrees humeral abduction were performed. The subjects stood in an erect posture and data was collected for scapular and clavicular motion. Scapular plane abduction was done by elevating the humerus through a plane that was at 40° to the frontal plane with elbow extended and thumb pointing superiorly. Flexion motion was performed by raising the humerus through the sagittal plane and internal/ external rotation was done in the frontal plane with shoulder elevated to 90° and elbow flexed to 90°. Clavicular motion was not determined directly as no sensor was attached to it. The researchers extrapolated clavicular protraction and elevation data from thoracic and scapular sensors by calculating the information from sternal notch and acromioclavicular joint locations. They analyzed the collected data based on five degree increments of humerothoracic motion and then averaged across three trials for each subject.

The authors reported scapular upward rotation of 50°, posterior tilting of 30° and external rotation of 24° with arm elevation in the scapular plane. They also concluded that the clavicle elevates by 10° and retracts by 21° with scapular plane abduction. Results showed that scapular upward rotation and both clavicular motions assume a linear relationship with humeral elevation and also during lowering when a linear and third order polynomial curve fit was done on all the three humeral motion sequences. On the other hand there was a nonlinear relationship with scapular posterior tilting and scapular external rotation. They believe that posterior tilting of scapula is an important motion sequence probably to prevent the humeral head from compressing the RC tendons causing repeated friction injury from the undersurface of the acromion or coracoacromial arch as in subacromial impingement. They also found out that there were similar scapular motion sequences, which were evidenced in scapular plane abduction, in internal/ external rotation of the arm in 90° abduction position in the coronal plane and also in sagittal plane flexion. They were not able to measure clavicular long axis rotation as no sensors were placed on the bone. The other two motions were calculated from thoracic and scapular sensors. This study did draw important conclusions and validated the data when compared to other studies but the sample size was small and tested the nondominant arm where there might be unknown biomechanical differences when compared to the dominant arm that might play a role in altering the normal shoulder joint kinematics. A 3D clavicular study by Ludewig et al. (2004) included 39 subjects with 30 in the asymptomatic group and age ranging from 20 to 44 years, 47% and 44% of each group, respectively were female. Due to the limited number of studies available on SC and AC joint motion, this study tries to determine the reliability of surface sensors in tracking clavicular motion with arm elevation. They used the electromagnetic motion capture system with placement of sensors on the thorax, clavicle and humerus. The results of the study are that with arm elevation there is progressive clavicular elevation of about 10° in all the three motion sequences like humeral flexion, scapular plane abduction and humeral abduction. There is also an increase in posterior long axis rotation of about 15° in the three motion sequences. Increased clavicular retraction (approximately 5°) is present in humeral abduction and scapular abduction motion. Arm dominance was not addressed in the study. Subjects older than 50 years were not included in the study. There is also a disproportionate sample size in the two groups. Also McClure et al. (2001) found clavicular retraction to be 21° though clavicular elevation angles have similar numbers between the studies.

In a recent study, Ludewig et al. (2009) used 3D motion to compare between concentric and eccentric action of the arm in three separate elevation planes. The study included 12 subjects (five women and seven men) without any shoulder abnormality and an age range of 22 to 41 years. The nondominant arm was tested in 10 subjects. The authors used three transcortical bone pins attached to the scapula, clavicle and humerus to which electromagnetic sensors were fixed. The authors calculated angle values of SC, AC, scapulothoracic and GH joints. They calculated at 0°, 15° and thereafter in 5° increments with a maximum of 120°. SC joint motion was described as protraction-retraction about the superior axis, elevation-depression about the anterior axis, and anterior-posterior rotation about the lateral axis. Similarly AC joint and scapulothoracic joint motion were defined using the same terms, internal-external rotation about the superior axis, upward-downward rotation about the axis perpendicular to the plane of the scapula, and anterior-posterior tilting about the lateral axis. The GH motion was described as humeral elevation about the initially anterior axis, the plane of elevation (in front of or behind the scapular plane) about the initially lateral axis, and internal-external axial rotation about the initially superior axis. The authors reported that with humeral elevation there is increase in clavicular elevation (from 11° to 17°), retraction (from 23° to 39°) and long axis posterior rotation (from 0° to 31°). Scapular motion changes with arm elevation are an increase in upward rotation (from 11° to 50°) and posterior tilting (from -13° to 8°) with a decrease in internal rotation (from 37° to 35°). They also identified that AC joint motion,due to the movement of scapula relative to clavicle, demonstrated scapular internal rotation increased from 57° to 65°, upward rotation increased from 5° to 16° and posterior tilting also increased from -4° to 15° with arm elevation. There is increased external rotation from 10° to 51° in the GH motion with humeral elevation. The few limitations in this study are small sample size and only nondominant shoulder joints were tested.

VI. Altered 3D Kinematics

To understand the kinematic changes that may occur with RC disease, knowledge of altered kinematics compared to that of the normal is essential. Analyzing abnormal kinematics of the shoulder joint may give us information about the pathomechanics of scapular, clavicular and humeral motion that might be a predisposing factor to RC disease or shoulder impingement. There is evidence to show that kinematic abnormalities may lead to RC compression due to either the humeral head translating superiorly (Deutsch et al., 1996) or the acromion moving inferiorly which is same as increased scapular anterior tilt (Lukasiewicz et al., 1999; Ludewig & Cook, 2000). Other potential causative factors for RC pathology can range from soft tissue restriction, or altered muscular activity and postural changes that can influence the shoulder complex to move differently from the normal sequence (Lin et al., 2006; Ludewig & Cook, 2000; Kebaetse et al., 1999). It is also important to have an in depth knowledge in abnormal kinematics while doing assessment, surgery and implementing exercise protocols for improving the health aspect of the quality of life.

Lukaseiwicz et al. (1999) compared scapular motion between healthy and impingement subjects. An electromechanical method based on multiple potentiometers linked in a static digitizer was used to analyze 20 asymptomatic subjects with a mean age of 34 years and 17 impingement cases with mean age of 46 years. The study had 8 men and 12 women in the asymptomatic group and 12 men and 5 women in the impingement group. The asymptomatic group had 15 subjects with right hand dominance and 5 with left hand dominance. The impingement group had all subjects who were right hand dominant. The subjects with impingement had to have three of the six criteria to be included in the experimental or impingement group. The six tests were Neer sign, Hawkins sign, Pain with active arm elevation in the scapular abduction plane, pain on palpation of the RC tendons, history of C5- C6 dermatome pain and pain on performing resisted isometric abduction. If the subjects had any one of the three factors (current neck pain, shoulder instability and AC joint pain) then they were excluded from the study. The exclusion criteria were current cervical spine symptoms, Sulcus sign or Apprehension sign for test of shoulder instability and AC joint pain. Static measurements at three positions were taken with the arm by the side, arm parallel to the floor (90°) and maximum elevation. Orientation of the scapula was explained by three different angular positions like posterior tilting angle, upward rotation angle and internal rotation angle. The authors defined the position of the scapula as medio-lateral position which is the horizontal distance from C7 to centroid of the three digitized scapular anatomical landmarks and supero-inferior position which is the vertical distance between C7 and centroid of the three digitized scapular anatomical landmarks. They made sure that the subject's trunk was stabilized by strapping it to the chair. The arm elevation was kept consistent by keeping the forearm in neutral or in mid-prone, elbow in extension, and the thumb pointing up or superiorly. The subject was also instructed to keep the palm facing forward. Each subject had to do two trials in each position the data of which was then averaged. The study reported decrease in posterior tilt at the horizontal (14°) and maximum elevation (25°) position within the impingement group when compared to 22° and 35° in the two positions for the asymptomatic group. They also found an increase in scapular superior translation of 7 cm and 5 cm respectively in the symptomatic group, which can be described as clavicular elevation since scapular motion is a combination of SC and AC joint action (Dvir and Berne, 1978). It is important to say that the authors did not find any statistically significant differences for scapular upward rotation, internal rotation and medio-lateral position. They believe that the relative anterior tilted position of the scapula might be a predisposing factor for impingement but it is not known if this position causes impingement or vice-versa. It is believed by the authors (Lukaseiwicz et al. 1999) that the reduced posterior tilting may be due to pectoralis minor tightness or loss of scapular mobility. Static positions were compared which may not represent the actual dynamic events of the arm elevation. Data was analyzed based on projection angle descriptions which are prone to miscalculations due to projection errors (de Groot, 1999). The starting position assumed a rest posture with a slightly abducted arm which means starting point of subjects will be variable and the data should have been normalized to give accurate angular values.

One of the studies on abnormal kinematics that involved a large sample size from a specific population was done by Ludewig & Cook in 2000. They used similar electromagnetic devices on 52 male construction workers with an age range of 20 to 71 years and divided them in two equal groups of impingement and nonimpingement categories. Three sensors were attached on the thorax, acromion and humerus respectively. The humeral elevation was consistent since the researchers used a flat surface to guide the motion in the scapular plane. Five repetitions of each motion that included unloaded condition and with loads of 5 and 10 pounds respectively were measured and data collected for further analysis. They also collected data of the scapular position at rest or arm by the side. Angular values during scapular plane arm abduction resulted in a scapular upward rotation of 20° to 45° and a relatively less anterior tilted or more posterior tilted scapular position of -20° to -10° when compared to subjects with shoulder impingement. The authors also reported that they did find decreased upward rotation (4.1°) in the impingement group with both loading conditions at 60 degrees but did not find significant differences at 90 and 120 degrees. Similarly they found significant difference at 120 degrees in both loading conditions for increased anterior tipping or relative reduction in posterior tipping of 5.8° when compared to the control group. There was increased scapular medial rotation or internal rotation (5.2° and 4.4°) of the scapula in both loading conditions during the abduction motion but this difference in motion was not seen in the unloaded condition. This investigation used surface sensors which are prone to errors due to skin slip issues.

These authors (Ludewig & Cook, 2000) completed simultaneous EMG analysis and concluded that the upper trapezius activity was greater for all conditions and phases in the symptomatic group. Increased lower trapezius activity was also found in ranges of 60 degrees and above. There was a 9% reduction in serratus anterior activity within the impingement group.

Endo et al. (2001) used static antero-posterior radiographic images to evaluate scapular rotation in shoulder impingement syndrome. Twenty seven patients with unilateral chronic impingement in the age range of 41 to 73 years were included in the study. They compared the involved with the uninvolved side at 0, 45 and 90 degrees of arm abduction. They used a novel mathematical technique for calculating angles from uniplanar radiographs. The authors also introduced a new reference line to measure scapular rotation which they define as the scapular spine line. This line is defined as the line joining Trigonum Spinae (TS) and posterior point of the AC joint on the acromion. Endo et al. (2001) concluded that there was presence of a significant difference in the impingement side at 90° abduction where the scapular upward rotation is 40.7°± 8.7° which is less than the contralateral healthy shoulder of 44.3°± 7.2°. The posterior tilt was also found to be significantly less (-1.75° and 11°) at 0° and 90° of abduction. The scientists used projection angle methods on planar radiographs that are prone to projection angle error which gets even more accentuated since the scapula is sitting on the thorax in a plane which is at about 35°- 40° anterior to the coronal plane which the AP radiographs do not consider during the imaging procedure.

Another study by Hebert et al. (2002) investigated scapular mechanics in an impingement group when compared to a healthy group. The study enrolled 51 subjects in the age of 30 to 60 years and 41 of them suffered from shoulder impingement syndrome. The study population involved 21 men and 20 women. There were 29 subjects with impingement on the dominant side. They used a 3D analysis system to collect scapular data. They tried to quantify 3D scapular orientation at specific shoulder positions relative to resting position which was 0° arm abduction. The 3D scapular attitude was calculated using Cardan sequences at specific static positions. They measured the 3D scapular attitudes and their contribution to the total scapular motion during two movements. The authors collected data at rest and in static positions of 70, 90 and 110 degrees in both flexion and abduction. Their main findings were anterior tilting (49% of total scapular ROM) of the scapula during flexion between 90°- 110°and external rotation (41.5% of total scapular ROM) during abduction in the similar range. They did not find any significant differences in the 3D scapular attitude between the two sides. Similarly there was no difference in external rotation (mean difference of 1.4°) of the scapula and the impingement side showed less anterior tilting. The anterior tilting values of scapula at 70°, 90° and 110° for impingement group were 9.5°, 14.1° and 20° respectively when compared to controls with 11.5°, 17.7° and 25.4° respectively. Their finding of no significant difference may lie in the fact that even the asymptomatic shoulder of the opposite has similar anatomical and morphological characteristics like the impingement affected shoulder. This limitation could have been offset by introducing a separate control group of asymptomatic or healthy individuals. They used a different coordinate system Zx'y" to describe the scapulothoracic motion and not the ISB standard of Yx'z" (Wu et al., 2005). Also the axes orientation used in this study is different than the ISB standard (Wu et al., 2005) of x- forward, y- upward and z- lateral. As a result of which the values are difficult to interpret clinically. Another limitation of the study is that the authors assumed 0° arm elevation to be arm resting by the side of the subject which may not be true due presence of soft tissue between the arm and the trunk.

A study by McClure et al. (2006) compared 3D scapular kinematics, shoulder ROM, muscular force, and posture in subjects with and without shoulder impingement syndrome. They included 90 subjects between ages of 24 to 74 years and divided in two equal groups by matching them based on age, sex and hand dominance. The study population had 21 females and 24 males in each group. There were 38 right and 7 left hand dominant subjects in each group. Data was collected using Polhemus Fastrak electromagnetic tracking system for the scapula and clavicle during two motions of flexion (sagittal plane) and scaption, which is scapular plane abduction. At higher angular position of 120° there was increase in scapular posterior tilt (-1.5° in flexion and 7.5° in scaption) and clavicular retraction (-30° in flexion and -33.5° in scaption) in the impingement group when compared to controls. At 90° there is an increase in upward rotation (43° in flexion and 38° in scaption) in the impingement group. Scapular upward rotation is significantly higher during flexion in the impingement group (42° and 58°) than the controls (38° and 52°) at both 90° and 120°. Upward rotation is only significant at 90° of scaption for the impingement group (38°) when compared to controls (35°). Scapular posterior tilt is significantly higher in the impingement group (7.5°) when compared to controls (4°) during scaption motion. The authors believe that these changes in the motion sequences when compared to other literature may be due to compensatory motions used by the patients to reduce pain and dysfunction due to impingement. They also found that there was an increase in clavicular elevation (12.5° at 90° of flexion and 18° at 120° of flexion) during humerothoracic flexion motion in the impingement group which was similar to previous studies (Lukasiewicz 1999; Lin 2006; Laudner 2006). They also found significantly reduced ROM while doing active internal and external rotation at 90° abduction of 50.1° and 90.9° respectively when compared to controls of 70° and 111.9° respectively. Similar reduction in shoulder ROM of 144.6° was seen during active flexion when compared to controls of 163.5°. There was less force production in the impingement group when compared to the controls for internal rotation, external rotation and scaption positions of 11.6 kg, 9.6 kg and 5.6 kg respectively when compared to 14 kg, 12.4 kg and 8.6 kg respectively.

VII. Subacromial (SA) Space

The SA space is formed by the inferior surface of the acromion on the supero-posterior aspect, coracoacromial (CA) ligament on the superior side, coracoid process on the supero- anterior surface and the superior part of the humeral head defining the inferior surface. This space contains the four RC tendons, subacromial bursa and the long head of biceps. It is postulated that the RC tendons get compressed by the anterior acromion and

CA ligament during arm elevation due to narrowing of the SA space (Neer, 1972). The extrinsic mechanism of RC pathology where there is a mechanical compression of the RC tendons is termed as subacromial impingement by Neer (1972). A different type of RC disease known as internal impingement is based on the extrinsic mechanism seen in athletes prone to repeated overhead shoulder injuries. It has been theorized that the articular region of the RC tendons gets squeezed between the humeral head and posterior part of the glenoid rim (Kvitne & Jobe, 1993; Jobe, 1995; Kibler, 1998).

Quantification of SA space has evolved with the advancement of technology. SA space has been measured as 2- dimensional (Petersson & Redlund-Johnell, 1984; Solem-Bertoft et al., 1993) and 3- dimensional (Pappas et al., 2006; Bey et al., 2007) linear distances between the two closest points on acromion and humeral head respectively. It has also been calculated based on supraspinatus outlet area (Zuckerman et al., 1992). Different instruments used to measure the SA space were radiographs (Petersson & Redlund-Johnell, 1984; Nove-Josserand et al., 2005; Saupe et al., 2006), stereophotogammetry (Flatow et al., 1994), ultrasonography (Azzoni & Cabitza, 2004; Desmeules, 2004; Cholewinski, 2008), MRI (Graichen et al., 1999; Hebert et al., 2003; Saupe et al., 2006), and biplanar fluoroscopy combined with CT data (Bey et al., 2007). Werner et al. (2006) measured pressure changes within the SA space with humeral motion.

One of the earliest and probably the only study that measures SA space in terms of subacromial outlet area was by Zuckerman et al. (1992). The authors directly measured 140 cadaveric shoulders (39 male and 31 female) with an average age of approximately 57 years for males and about 68 years for females, divided into intact RC (112 shoulders) and complete RC tear (28 shoulders) groups. A triangular area marked by four anatomic locations including glenoid center, posterolateral acromion, anterolateral acromion, and anterolateral tip of coracoid described the SA space. Overall incidence rate for full RC tears was 20% and 29% in the case of subject population over 60 years. They found significant difference for the distance between the humeral head and acromion which was nearly 5 millimeter (mm) for the RC tear group and 6.5 mm for the intact RC group. The researchers found significant difference in the available CA arch area or supraspinatus outlet area which was smaller by 22.5% in the RC tear (336 mm^2) group when compared to intact RC (434 mm^2) group. They also concluded that the acromion of the RC tear (6.8 mm) group had more anterior projection than the intact (10.6 mm) group. Zuckerman et al. (1992) believed that impingement is directly correlated with reduction in the supraspinatus outlet space which might be an important etiologic factor for RC tears. This study had a large sample size which was age and sex matched. Unfortunately 2D static analysis was done and cadavers were used. Information from dynamic data is lost leading to possible error in calculating the space.

A MRI study by Solem- Bertoft et al. (1993) on four normal subjects (2 male and 2 female) was done to evaluate changes in SA space while doing internal/ external rotation of the scapula. Images were taken from two separate positions that included retraction and protraction with sandbag weighing 5% of subject bodyweight attached to the wrist to mimic gravitational pull in the standing position. The subacromial space in the sagittal plane was found to reduce from retraction (8.5 to 13.2 mm) to protraction (6.6

to 9.6 mm). Evidence of alteration in the subacromial width in the coronal plane was minimal from retraction (7.3 to 10.0 mm) to protraction (7.0 to 9.5 mm). The acromial angle on the other hand reduced as the scapula moved from retraction (3.0° to 21.5°) to protraction (2.0° to 14.5°). Based on the data it seems like protraction leads to narrowing of the SA space that might be a contributing factor towards the occurrence of impingement.

The study did try to quantify 2D linear distance of SA space from MR image which gives better precision and accuracy than radiographic technique. The result of this study correlates with the fact that thoracic spine kyphosis leads to protraction of the scapula (Kebaetse et al., 1999; Wang et al., 1999) that might reduce SA space (Gumina et al., 2008) which is a common postural alteration with aging. Major limitation of this study is sample size of four with which it is near impossible to generalize the result. Also subject age, hand dominance, strength of MRI used was not mentioned in the study which might affect the outcome.

Analysis of SA space on specific motion sequences was performed by Graichen et al. (1999). They employed a new technique to measure SA space during arm abduction by placing the subject within an open MR imaging system. The open MR minimizes space constraints and aids in performingtests in multiple positions. This study included 10 healthy (4 females and 6 males) and 10 patients with impingement (5 females and 5 males). The age range was 23 to 35 years for the healthy group and 39 to 64 years for the impingement group. The healthy subjects were 30° supine lying on the 1.5T scanner table with the arm fixed in the scapular plane at three different arm abduction positions of 60°, 90°, 120° with a customized positioning system. Both healthy and affected shoulder of the patients were scanned at 30° and 90° of abduction in the relaxed phase and at 90° abduction with a 10N weight attached to the distal humerus forcing the shoulder abductors to contract isometrically. Acromiohumeral distance (AHD) in healthy subjects with no muscular activity was 6.7 mm at 60°, 5.4 mm at 90° and 3.6 mm at 120° of abduction.

It was noted by the authors that the significant difference in reduction of SA space from 90° to 120° was probably due to the greater tuberosity moving towards the acromion at higher abduction angles. The minimal AHD vector at 60° and 90° were seen to pass through the supraspinatus muscle but not at 120° where the supraspinatus insertion has already crossed the AHD vector which then lies laterally to the muscle. SA space remained nearly the same at all the three abduction angles (4.7 mm, 4.1 mm and 4.8 mm respectively) with isometric muscle contraction. But on comparing with the relaxed phase at different angular elevation it was found that there is a reduction of AHD by 32% at 60°, no change at 90° and increased AHD by 44% at 120° of abduction. On comparing the sides of the impingement group who were in the early stage of the disease it was noted that the AHD reduced significantly to 1.4 mm at 90° abduction with muscle activation when compared to the healthy shoulder (4.4 mm), at 90° abduction for diseased shoulder (3.8 mm) without muscle contraction and at 30° abduction for the diseased shoulder (6.5 mm) but with no muscle activation. SA space in subjects with full thickness RC tears was found to be significantly reduced at both arm positions and in both phases of muscular activation.

This study correlated with other studies using MRI (Hebert et al., 2003; Saupe et al., 2006) that there is a reduction of AHD in patients with RC disease. AHD during active arm elevation positions was smaller in subjects with RC tendinopathy compared to healthy shoulders (Allmann et al., 1997; Hebert et al., 2003). Use of 3D image reconstruction eliminated the projection error but calculated linear distance of SA space which is essentially a 3D quantity or volume thereby losing potential vital information. The subjects were not age matched so correlation between the two groups can be a source of error. The muscle activation pattern was done at only 90° abduction and protocol was not same for both the groups. Even with some important limitations we can still conclude from this study that similar to Bey et al. (2007), AHD starts to decrease with increasing humeral elevation.

Cholewinski and colleagues (2008) used ultrasonography (US) to measure AHD. They calculated the distance between the infero- lateral acromion edge and the apex of the greater tuberosity of the humerus (AGT) using 6 and 8 MHz ultrasound. The study enrolled 57 patients with unilateral subacromial impingement syndrome (SIS) with an average age of 56 years (34- 83 years). The right shoulder of 32 patients was affected with SIS and 36 patients dominant arm had SIS. Inclusion criteria were current shoulder pain, pain more than six months, movement restriction and a positive Neer test, a positive Hawkins-Kennedy test and also a painfree Neer test done after lidocaine was injected within the SA space. Exclusion criteria included patients less than 30 years old, bilateral SIS, or other shoulder disorders like instability, arthritis, cervical radiculopathy, brachialgia and adhesive capsulitis. The control group included 36 (14 men and 22 women) healthy volunteers with no history of shoulder injury or trauma. The mean age was 57 years with a range of 38- 79 years. US of both shoulders were done for both groups using five views like transverse, longitudinal and three auxiliary views. The imaging was also done to classify status of RC muscles as five different types and also to measure the thickness of RC tendon. The AGT distance was measured from the longitudinal view with the arm by the side and in neutral rotation.

The average AGT distance in the control group was calculated to be 22.7 mm (18.3- 29.4 mm). No difference was found in the AGT distance on comparing the dominant to non- dominant limb. AGT distance of the affected shoulder in the study group was 19.4 mm (11.2- 31.2 mm) and that of non- affected shoulder in the study group was 22.2 mm (16.4- 34.2 mm). The authors believe that AGT distance of more than 2.1 mm when compared to opposite non- affected shoulder and a RC thickness of more than 1.1 mm might be due to RC disease.

This study tried to quantify SA space based on US measurement which is a 2D method and will result in error of estimating the distance accurately. Only static analysis was done in one position which will not provide any dynamic information. Some of the subjects did undergo conservative treatment which might change the biomechanics of the shoulder complex. The study had wide range of sample and a large size which would present representative results.

Biplanar fluoroscopy was used by Bey et al. (2007) to measure 3D in vivo SA space width during arm elevation. This was one of the earliest studies measuring 3D linear distance of SA space during real time shoulder motion sequence. The study involved 11 subjects including 9 male and 2 female with the average age of 63.2 years. Patients with partial tears, multi- tendon tears, labral and GH pathology were excluded from the study. All subjects underwent RC tendon repair and acromioplasty after full thickness supraspinatus tear and unsuccessful conservative treatment. Subjects were tested at least 12- 16 weeks post- surgery. All members had no history of injury or trauma on the contralateral shoulder. Subjects had their arm elevated from 0° adduction or arm by the side to about 120° elevation in the frontal plane. A three pound weight was held in hand during the elevation motion. Both shoulders were tested and three trials performed for each shoulder with a three minute rest between trials to prevent fatigue. The author in a previous study validated this technique with a linear accuracy of 0.4 mm and an angular of 0.5°. Subject specific CT shoulder bone models were combined with the biplane X-ray images to quantify the SA space width.

The SA width decreased from 7.4 mm to 2.3 mm for repaired shoulder and from 7.1 mm to 1.2 mm for the contralateral shoulder. This shows a significantly reduced width with increase in elevation angles. At glenohumeral elevation of 27.7° to 36.1° the minimum AHD passed through the supraspinatus footprint area. Though the minimum reduction in AHD occurred at 60° glenohumeral abduction in both shoulders, during this phase the supraspinatus tendon insertion has already passed beneath the under surface of the acromion. This space of 1 to 2 mm is due to the proximity of greater tuberosity to the acromion. There was an average distance of 0.5 mm reduction, which was statistically significant, in the SA space width for the contralateral shoulder when compared to the operated shoulder.

This study gave information regarding SA space measurement in an in vivo scenario. I believe using a 3D technique the authors quantified the minimum linear distance but to get accurate RC tendon proximity to undersurface of the CA arch we will need more information on the RC footprint and measure the distance. The study included subjects who had undergone RC repair that might change the kinematics of the shoulder joint. Small sample size and no control group were used and contralateral unaffected shoulder was used which might be already predisposed to RC disease. The results do show a relationship with Graichen et al. (1999) that the AHD decreases with increasing humeral elevation. In accordance with Flatow et al. (1994) and Graichen et al. (1999) this study also concludes that the subacromial space is reduced maximally at 90° arm abduction as the greater tuberosity comes closest to the acromion leading to minimal bone to bone distance. Also the supraspinatus tendon insertion has passed safely under the acromial inferior surface above 90° of arm elevation, but the footprint may still get compressed against the posterior glenoid rim and the humeral head at elevation angles more than 90° (Flatow et al., 1994; Brossmann et al., 1996).

VIII. Shoulder Kinematics in the Elderly Population during Performance of Functional Tasks

The proposed study will look into the kinematics of shoulder joint motions during ADLs. Basic functional tasks which are easy for young adults such as combing, scratching the back or grabbing an object from a kitchen shelf becomes tough to complete for the elderly population. 3D kinematic research in the elderly population during performance of ADLs is limited.

A recent study by Rundquist et al. (2011) recruited 52 asymptomatic subjects in two groups younger (18 to 35 years) and older (above 50 years). They used 3D electromagnetic motion capture system to collect shoulder kinematic data during activities of daily living. Four different activities with three repetitions of each motion were performed by the subjects which included overhead reach, brushing hair, feeding and washing contralateral axilla. The older population presented with significantly less glenohumeral (GH) external rotation (ER), more posterior tilt, significantly less scapular internal rotation (IR) and reduced upward rotation (UR) during brushing hair when compared to the younger group. Similarly, during forward reaching task the older subjects had significantly reduced GH ER, less posterior tilt, significantly less scapular IR and less UR. Kinematic changes for feeding task were similar to overhead reach. Washing contralateral axilla the older group demonstrated significantly more GH IR, more posterior tilt, significantly reduced protraction and increased upward rotation.

		GH Rotation (Degrees)	**Scapular Tilt (Degrees)**	**Scapular ER/ IR (Degrees)**	**Scapular UR (Degrees)**
Brushing Hair	Older	-56.4*	2.4	31.7*	28.1
	Younger	-69.7*	1.6	38.3*	33.7
Overhead Reach	Older	-38.0*	3.5	39.9*	23.8
	Younger	-49.8*	4.9	55.9*	24.7
Feeding	Older	-22.2*	8.9	34.2*	6.9*
	Younger	-38.5*	10.0	42.8*	14.9*
Washing Axilla	Older	16.2*	7.6	46.0*	15.5
	Younger	3.2*	9.1	53.7*	14.4

* Denotes significance at $p<0.05$. Bold text defines tasks of interest for the current study

Thoracic posture alterations affect kinematic measurements of the shoulder joint especially when testing for functional tasks. The biggest limitation of this study is not measuring thoracic posture which influences both scapulothoracic and glenohumeral angular values. No information is present if the individuals were matched for gender and BMI. Effect of confounders will reduce the reliability of the study if the groups are not matched.

Another study by Aizawa et al. (2010) included 20 healthy individuals with 10 subjects for each gender. Age range was between 18 and 34 years and BMI between 17 and 27 kg/m^2. Thoracohumeral data was collected with a Fastrak Polhemus surface motion tracking system. Researchers defined coordinates systems according to current ISB standards. Scapula kinematics were not evaluated, only humerothoracic (HT) rotation was computed other than elbow and wrist motions. Functional tasks related to personal hygiene and food habits that include the motions of interest to this study- combing hair and touching back, of the total 16 motion patterns. Four repetitions of each task at comfortable speed were completed by the subject population. During touching the back task, it was found that there was a mean HT internal rotation of 150° and a mean external rotation of 57° during combing hair action.

	HT Rotation Mean (SD)
Touching Back (positive value is IR)	150° (29)
Combing Hair (negative value is ER)	-57° (18)

The researchers examined the kinematic patterns for HT motion only but failed to evaluate scapulothoracic or glenohumeral motions. Understanding humeral axial rotation is best defined in terms of GH joint motion as the humerus is rotating on the glenoid or scapula which is also moving on the thorax. Therefore, the study failed to provide accurate description of GH rotation during the different conditions as scapula is not a rigid body with trunk but has three separate motions with respect to the trunk. The sample size is small and the age range does not match with the current study criteria.

Sheikhzadeh et al. (2008) studied 3D kinematics of the scapular and shoulder on eight healthy individuals (six males and two females) in the age of 25 to 40 years. Polhemus surface motion tracking device was used to compute the 3D kinematics of the scapulothoracic and glenohumeral motions based on the current ISB standards. Each motion was recorded three times. Subjects simulated three functional tasks by touching different areas of the body with the index finger. Combing hair task was the only action that was common to this study. During touching the top of the head motion that mimics combing hair action there was an average of 105° elevation of arm relative to trunk, 28° of scapular UR, 4° of anterior tilt, 38° of internal rotation and 50° of GH external rotation.

	Scapular UR	**Scapular Tilt**	**Scapular ER/ IR**	**GH Rotation**	**HT Elevation**
Combing Hair (Mean and SD)	-28° (4)	-4° (4)	38° (7)	-50° (10)	-105° (9)

Tasks were completed bilaterally by all subjects, even though one joint was tested. Argument shared by the authors was that simultaneous bilateral arm motion would reduce compensatory trunk motions. It might be true but is not a normal phenomenon as we do not use both shoulder joints simultaneously to complete ADLs such as combing hair. It is true that variability will increase but will give us a more normative data without any external influences. The sample size is quite small which makes it difficult to translate any findings from this study.

IX. Thoracic Posture

It is thought that poor posture can give rise to shoulder complaints that may lead to dysfunction and pain. The belief is that optimal skeletal posture is required for proper muscular length- tension relationship to occur. Changes in thoracic posture, changes the motion sequence of the scapula (Kebaetse et al., 1999). Thoracic posture has a major role in scapular movement pattern (Kebaetse et al., 1999; Culham & Peat, 1993) which in turn might affect activation pattern of shoulder stabilizers and mobilizers. It seems that the body which can be thought as a link segment modeling system functions optimally when all factors are working in rhythm. Unfortunately with increase in age, changes in spinal curvature (Kebaetse et al., 1999) and degradation of muscle fiber characteristics (Grounds, 2002) occur. Kebaetse et al. (1999) found that force production reduced when the arm was horizontally placed. In fact the scapula had a more elevated position in this posture as a result of which scapula translated more superiorly with abduction. Scapular internal rotation was also attributed to slouched posture and with arm abduction the scapula tilted posteriorly. Reduced ROM of arm abduction was attributed to this kyphotic posture since the thoracic spine must extend completely so that the shoulder can elevate maximally in all directions. With age there was an increase in the angulation of thoracic slope resulting in reduced abduction motion. The result of altered scapular kinematics causes decrease in muscle force generation. Kebaetse et al. (1999) concluded that due to scapular superior translation the upper trapezius, deltoid, and supraspinatus were not able to generate maximal force as they were in a shortened position causing disruption in the length- tension relationship. Reduction in force production at 90° is a major concern for younger generation as many activities related to work and games occur in this region. The scapula had reduced upward rotation and posterior tilt in the kyphotic posture with a slight increase in internal rotation. The reduction in shoulder abduction range can be due to decreased posterior tilt and less upward rotation of the scapula which is probably due to the slouched posture. The limitation is that the authors did not measure any subjects in the elderly population so actual phenomenon may be different.

Finley & Lee (2003) studied healthy shoulders in the young adult age group and collected scapular kinematic data from erect and slouched posture. They found that in the slouched posture there is increased scapular upward rotation and anterior tilt including internal rotation of the humerus. Their finding on increased thoracic kyphosis leading to increased anterior tilt of scapula was similar to Culham & Peat (1993). Increased thoracic kyphosis caused greater internal rotation, upward rotation and anterior tilting of the scapula which was similar to Kebaetse et al. (1999) findings.

Endo et al. (2004) studied a healthy group of individuals in a broad age range from 16 to 73 years. They believe that reduction in internal rotation, posterior tilt and upward rotation angles is due to accentuated thoracic curvature and altered scapular kinematics. They had similar values of posterior tilt to that of Culham & Peat (1993).

Narrowing of acromiohumeral distance is caused by abduction of the arm and reduced scapular rotations in the sagittal and coronal plane. Reduced scapular rotation may be due to muscular weakness around the shoulder joint but this was not quantified by the authors. The authors believe that changes in scapular kinematics may lead to increased exposure of older people to shoulder impingement.

Wang et al. (1999) found that thoracic kyphosis stretches posterior scapular stabilizers which with time gets weaker as a result of which a crossed syndrome appears where the pectoralis muscle shortens leading to imbalance in force generation exaggerating the thoracic curvature and changing the scapular resting position. They had significant gains in force production for both scapular rotation components including horizontal abduction. At 90° of active arm elevation the scapula had less upward rotation, less superior translation and more internal rotation which was similar to the study by Finley & Lee (2003). The findings suggest that reduced scapular upward rotation may lead to impingement pathology due to the greater tuberosity and acromion pinching the soft tissues in between. According to the authors rotator cuff strengthening and cuff tendon gliding may improve glenohumeral motion. On the contrary, Finley & Lee (2003) found that there was reduced superior translation of the scapula meaning that stabilization of scapula on the thorax is an important component of glenohumeral motion. The study by Wang et al. (1999) also discussed about reduced scapular elevation muscle force and changes in scapular kinematics in kyphotic posture.

I believe that these studies describe a great deal on the thoracic component and its relation to changes in glenohumeral and scapulothoracic mechanics. All the studies included subjects in the younger age category with the exception of Endo et al. (2004) who had a broad age range that included elderly individuals. It is important to understand that alterations in scapular like reduced upward rotation and posterior tilt including superior translation may be related to thoracic curvature and resting position of the scapula.

X. Shoulder Muscle Strength

A study by Evans (2010) concluded that with aging strength loss leads to sarcopenia of the muscle, where there is a decrease in skeletal muscle mass. More fat is deposited and quality of muscle deteriorates (Marcus et al., 2010). Muscular strength loss may be due to reduction in the number of fibers or cells in a muscle and/ or decrease in size or fiber number of individual muscle (Evans, 2010). One study has shown that there is a greater decline of Type II than Type I fibers (Lexell, 1995). It is believed that reduced shoulder strength lead to reduced force production, poor static and dynamic shoulder stability leads to RC pathology or biomechanical changes. Wang et al. (1999) thought that poor shoulder posture may lead to muscular imbalance that might contribute to the shoulder dysfunction and pain. Doherty (2003) noted that there was age related strength reduction from 20- 40% throughout the aging process. It is thought that losses in strength can be overcome by strength training. The authors reported to have similar maximal isometric strength and muscle cross section area when the elderly group was compared to young controls (Doherty, 2003).

Gaur et al. (2007) did a comparative study of shoulder muscle strength measured with surface EMG on young adults and older individuals separated in two groups. They measured the potential gradient of maximum voluntary contraction on four muscles namely middle deltoid, posterior deltoid, supraspinatus and infraspinatus. Four activities were performed in sequence including push, pull, elevation and throw. No significant difference was found in the push, pull phase between and within the two groups. During elevation both the groups had higher middle deltoid activation than the rest three muscles. In the throwing phase all the muscles showed maximal activation with infraspinatus the most active muscle but in the young only supraspinatus muscle were active. It was elucidated by the authors that all four muscles had higher maximal voluntary contraction. Greater activity was seen in posterior deltoid and infraspinatus during elevation. The reason for more activation might be due to the fact that older individuals need more effort to perform these activities. Increase in activity at high force levels can be due to variability of motor unit discharge rate. Gaur et al. (2007) believed that older individuals exhibit reduced force control and may have slower neuro-muscular contractile properties as a result of which greater proportion of motor unit recruitment may occur during an activity in order to compensate for decrease in muscle strength that occurs with age. Stabilizer muscles like supraspinatus and infraspinatus have greater activation and that of the mobilizer muscles like middle deltoid and posterior deltoid also have greater activation in older individuals during high effort activities. During pushing and throwing the primary stabilizer muscle infraspinatus was more active but during pulling and elevation, mobilizer muscles were more active in older individuals. The authors conclude that aging alters activation pattern of shoulder girdle muscles during dynamic activities.

Ludewig et al. (1996) studied EMG responses of upper and lower trapezius, serratus anterior and levator scapulae at three positions of humeral elevation. With the increase in arm elevation there was progressively more upward rotation, posterior tilting and external rotation. The authors believed that optimal serratus anterior action was an important component for all the three scapular rotations. The authors believed that rehabilitation should consider scapular muscle strengthening and proper biomechanics of the scapular motions.

It is evident that scapular stabilizers and mobilizers play an important role in scapulohumeral rhythm and in prevention of impingement. There is not much data on muscular activation patterns in the elderly population. I believe soft tissue (shoulder musculature) and bony structure (thoracic spine) play equally important role in the prevention and maintenance of shoulder girdle health. If one structure is compromised then the other will be affected which would lead to pain and dysfunction of the shoulder joint.

XI. Conclusion

Based on the discussion in this chapter including the extensive literature search done, it can be assumed that there is a paucity of data related to the elderly population especially when describing 3D kinematics in performance of functional tasks during activities of daily living. The fundamental challenge of compartmentalizing biomechanical issues do not help achieve evidence based practice in rehabilitation science. For example, treatment of shoulder pain includes not only strengthening of specific muscle groups but also correction of posture and also improvement in joint mechanics. Studying 3D kinematics separate from strength or posture in vastly different demographics may not give the expected results or help promote efficacy in rehabilitation. The current study would like to look into the global aspect of shoulder joint health that will not only include 3D kinematics but also add SA space distance measurement, thoracic posture and shoulder joint muscle strength. Evaluation of these variables during performance of functional tasks will allow rehabilitation professionals make sound clinical judgments in the elderly patients with or without shoulder issues. It is hoped that the results drawn from this study will give the audience a broad knowledge on factors that might be associated to either causation of shoulder dysfunction or improve techniques of rehabilitation from preventive and/ or treatment perspectives.

CHAPTER III

METHODS

I. Subject population

Subjects were divided into two groups: young and elderly with each group having 25 individuals. The young group had subjects in the age range of 20-40 years and the elderly group consisted of subjects above 65 years of age. The elderly study population had more female subjects probably due to increased lifespan in women than men. This disparity was evidenced in a study by Chard & Hazelman (1987) in which there were 61.9% females to 38.1% males over the age of 74 years. To minimize potential confounding factors affecting the subjects, recruited individuals were group matched for gender, body mass index and hand dominance. Group matching was done by initially recruiting subjects in the elderly group. Based on the demographics of the elderly group, subjects were then included in the young category to retain overall group similarity.

a. Inclusion Criteria— Asymptomatic elderly group for the dominant arm

1. Age above 65 years (Novak, 1997)
2. No history of shoulder joint pain lasting greater than 1 week in the past 10 years
3. No current shoulder joint pain or tenderness
4. GH joint muscle strength for flexion, extension, abduction, internal rotation and external rotation as measured by Medical Research Council (MRC) scale of > 3 which is subject able to lift arm full ROM against gravity without any resistance
5. Pain-free age adjusted humero-thoracic elevation range of motion of at least 120° at the shoulder joint as measured goniometrically during scapular plane abduction

6. Pain-free range of motion for shoulder internal/external rotation in 90° abduction at least 75% of the opposite extremity

b. Inclusion Criteria— Asymptomatic Young group for the dominant arm

1. Age between 20- 40 years— Union between the head and the shaft usually occurs at approx. 18 years of age (Rockwood Jr. et al., 2009) and normalized constant score reduces after 40 years age in both genders (Katolik, 2005).
2. No history of shoulder joint pain lasting greater than 1 week in the past 10 years
3. No current shoulder joint pain or tenderness
4. GH joint muscle strength for flexion, extension, abduction, internal rotation and external rotation as measured by Medical Research Council (MRC) scale of > 3 which is subject able to lift arm full ROM against gravity without any resistance
5. Pain- free age adjusted humerothoracic elevation range of motion of at least 140° at the shoulder joint as measured goniometrically during scapular plane abduction
6. Pain-free range of motion for shoulder internal/external rotation in 90° abduction at least 75% of the opposite extremity

c. Exclusion Criteria— Both groups for the dominant arm

1. History of any surgery on the shoulder joint based on patient report

2. History of fracture of clavicle, scapula or humerus from patient reports
3. Presence or history of dislocation/ instabilities of the AC, SC or glenohumeral (GH) joint based on patient history and instability tests such as anterior and posterior load and shift tests (Magee, 2008) for anterior and posterior shoulder instabilities respectively and sulcus sign (Magee, 2008) for inferior instability of the GH joint
4. Gross GH and AC joint arthritic changes during clinical exam as evidenced from reduced ROM of shoulder elevation (less than 120°) in the scapular plane, internal/ external rotation (less than 75% of the opposite extremity)
5. Inability to perform activities of daily living
6. Production of shoulder pain with active/ passive cervical spine motion
7. Radicular symptoms (C4, C5, C6, and C7 dermatomal distribution) of the upper extremities suggestive of peripheral nerve involvement
8. Neurological disorder such as traumatic brain injury, stroke, peripheral nerve injury or compression affecting the tested upper limb, myasthenia gravis, spinal cord injury, or motor neuron disorders
9. Congenital anomalies and systemic illness affecting the musculoskeletal system such as rheumatoid arthritis, or ankylosing spondylitis
10. Skin infection in areas where surface sensors or tape would be applied.
11. Known severe tape allergy
12. Currently receiving any medical or therapeutic treatment for neck, shoulder or upper extremity

II. Subject recruitment and IRB

a. Recruitment—

The subjects were recruited from the University of Minnesota community and clinics, and the local metropolitan community. Recruitment of subjects was done with the use of flyers and postings around the campus and also through word-of-mouth.

b. Institutional Review Board and Informed Consent—

The experimental protocol was submitted to the University of Minnesota Institutional Review Board Human Subjects Committee and approved as a minimal risk study. An informed consent form (Appendix 1) explaining the risks and benefits of participating in the study was signed by all subjects.

III. Sample Size Calculation

The first 20 subjects' (10 in each group) data were used to confirm the necessary power and sample size. Shoulder kinematic studies involving adults less than 65, 25 subjects per group (two groups with and without shoulder impingement) were able to detect a between group difference of 5° at above 80% power (Ludewig & Cook 2000). A 5° difference in group means was found by Zuckerman et al. (1992) for the acromial tilt angle (33.5° for intact and 28.5° for RC tear groups) that distinguished these groups. Using an average standard deviation of 8˚ from the four scapular upward rotation angles and four scapular tilt angles (25%, 50%, 75% and 100%) based on the first 20 subjects (10 in each group), the effect size was calculated to be 0.75 to determine a group difference of 6° or more. At an α level of 0.05 and 80% power we needed 25 subjects to detect a significant difference between the two groups. The use of scapular upward rotation and tilt standard deviation to calculate power of the study was based on the fact that in a recent study by Rundquist et al. (2011) the two motions were consistently different between groups for most of the conditions tested; therefore it is believed that upward rotation and tilting are important motion components in the completion of different ADL tasks in the elderly population.

IV. Risks

There was minimal risk for the subjects in this study. The experimental setup at the Musculoskeletal Biomechanics Research Lab did not use any techniques that the subjects are not exposed to in their regular activities of daily living.

V. Physical Screening

The physical examination was performed in the University of Minnesota, Minnesota Rehabilitation Biomechanics Laboratory by a physical therapist as follows:

a. Subject Medical History and Questionnaires—

- Subject Information Form (Appendix 2) — Contact information and demographics
- Subject Questionnaire Form (Appendix 3) — History of pain, type, and symptoms
- Clinical Examination Form (Appendix 4) — Range of motion, strength and special tests

- Disabilities of the Arm, Shoulder and Hand (DASH) (Appendix 5)

b. Clinical Examination— Tested for both shoulders and for both groups

- Active ROM tests for cervical spine and shoulder joint: Shoulder joint motion was goniometrically quantified for flexion, abduction, scapular plane abduction, internal and external rotation. Visual assessment for cervical spine motion including flexion, extension, bilateral rotations and side-bending was also completed.
- Shoulder Instability Tests:

  Anterior tested by Load and Shift Test (Magee, 2008)

  Posterior tested by Load and Shift Test (Magee, 2008)

  Inferior tested by Sulcus test (Magee, 2008)
- Cervical spine clearance tests to determine any cervical reproduction of shoulder symptoms

  Quadrant tests (Magee, 2008)

  Compression/ distraction tests (Magee, 2008)
- Impingement tests for the shoulder joint—

  Hawkins- Kennedy (Hawkins & Kennedy, 1980)

  Neer (Neer, 1972; 1983)

  Jobe (Jobe & Bradley, 1989; Jobe & Pink, 1993)
- Other tests

Painful arc of motion (Kessel & Watson, 1977): To check for GH pain between 45°-60° to 120° and AC joint pain at end range of arm abduction

- External rotation resistance test with arm by the side (Michener et al., 2009; Park et al., 2005): To assess subacromial impingement by comparing bilateral shoulders for pain and weakness

VI. Data collection

a. Instrumentation—

(i) DASH Questionnaires:

DASH has an excellent reliability (average ICC of 0.90) with a high content and group validity including a good internal consistency with calculated Cronbach's alpha to be more than 0.90 (Roy et al., 2009).

(ii) Strength Testing:

The same physical therapist performed data collection for all subjects in the study for reliability purposes. Shoulder strength was measured with a portable hand- held dynamometer by Lafayette Manual Muscle Testing System Model 01165 (Lafayette Instrument Evaluation, Lafayette IN). Strength was quantified keeping the arm by the side with the subject in sitting and isometrically checking shoulder strength by using a break test method (Bohannon, 1997) directed towards flexion, abduction, external rotation and internal rotation. The distance from the center of the dynamometer sensor to the joint axis of rotation was quantified for each strength measure to calculate the torque in each direction. The distance from the dynamometer center placed on the distal arm to the lesser tuberosity was measured for flexion and the distance from the dynamometer center placed on the distal arm to the greater tuberosity for abduction. The distance from the dynamometer center placed proximal to the ulnar and radial styloids to the lateral epicondyle was measured for external rotation and the distance from the dynamometer center placed proximal to the ulnar and radial styloids to the medial epicondyle for internal rotation. Torque (N-m) was then normalized to body weight (Kg). Individual normalized torque (Nm/Kg) and the ratios for flexion to abduction and internal to external rotation were used to compare the two groups.

(iii) Kinematic Analysis:

Kinematic data was collected using the Flock of Birds (Ascension Technology Corporation, Burlington, VT) 3D electromagnetic motion capture system. This electromagnetic motion tracking system allows simultaneous collection of position and orientation information from up to 7 sensors. Reported RMS accuracy is 0.5° for orientation and 0.18 cm for position within a hemispherical range with 76.2 cm radius forward from the transmitter. The Minibird 800 sensors had dimensions of 18mm x 5mm x 5mm and contained 3 electromagnetic coils orthogonal to each other. The sensor data were collected at a sampling rate of 100 Hz per sensor. One of the sensors was attached to a stylus (digitizer) with known offsets to digitize anatomical landmarks for building the joint coordinate systems.

MotionMonitor software (Innovative Sports Training, Chicago, IL) was used to extract kinematic data. It provided real- time animation and graphic display of the motion and later allowed exporting data using various kinematic descriptors of rotation matrices and Euler angle sequences.

b. Subject set- up and Procedures—

The subjects were initially screened through a phone interview where they had to complete a phone screen form and later a clinical exam by a physical therapist to check if they could be included in the study. An informed consent was signed by all subjects that explained the risks and benefits to their participation in the study. The clinical examination screening form and information regarding medical history and any past diagnostic reports on shoulder pathology were collected. Exposure scores on job or occupation with shoulder work activities and sports with overhead shoulder activities were also documented. The DASH questionnaire was then explained and completed by all subjects.

(i) Strength testing procedure:

During shoulder strength testing the subject was seated for all the four motions. The examiner palpated both the epicondyles and placed the subject's arm in the anatomical position with the shoulder in neutral and the medio-lateral epicondylar line in the coronal plane. The dynamometer was placed just above the epicondyles on the anterior aspect of the distal arm to measure flexion, and the lateral aspect of the distal arm to measure abduction, keeping the elbow extended. The dynamometer was placed proximal to the ulnar and radial styloids on the dorsal side of the hand keeping the forearm in mid-prone position and with the elbow 90° flexed to measure external rotation (Figure 1) and again proximal to the ulnar and radial styloids on the palmar side of the hand for internal rotation. Two repetitions in each direction were collected and later averaged to get the mean strength values. Before the actual measurements were collected, one submaximal practice trial was performed in each direction.

(ii) Kinematic procedure:

Female subjects were asked to dress in a loose sleeveless tee such as a sports bra and for males no shirt was worn to allow direct placement of the three electromagnetic sensors over areas of interest to be tested. The three mini- bird sensors (Figure 2, Figure 3 and Figure 8) were attached to three different segments respectively. The first sensor was attached with double-sided adhesive tape to the sternum (just beneath the sternal notch), the second on the flat superior surface of the acromion process, and the third on a thermoplastic cuff secured to the distal humerus (just proximal to the epicondyles). The subject was then asked to stand in an anatomical neutral posture for palpation of the anatomical landmarks (Wu et al. 2005) and digitized (using the sensor setup sequence in MotionMonitor) by placing the digitizer on the anatomical landmarks of the body segments (Figure 2 and Figure 3) to create a subject specific scaled skeletal model (Figure 4 and Figure 5). These landmarks were based on the ISB standards developed by Wu et al. (2005). Landmarks for the thorax were the xiphoid process, T8, the suprasternal notch and C7. The scapular landmarks were posterior root of spine, inferior angle, and posterolateral acromion. For the humerus, landmarks were the lateral epicondyle and medial epicondyle. The digitization process defined the local anatomical coordinate system for each body segment according to International Society of Biomechanics standards (Wu et al. 2005). To calculate the humeral head center, the arm was moved in different directions along the body planes keeping the proximal shoulder joint as stable as possible. Nineteen different sets of humeral head rotation data were collected and the centroid was averaged to determine the axis of rotation in accordance to the rotation method (An et al., 1991) for correctly defining the GH rotation center. The root mean square error (variation in the estimate of the joint center) was required to be less than 1 cm to proceed with data collection.

A standing with arms relaxed by the side posture was collected to check baseline data for the shoulder joint positions (Figure 6 and Figure 7). The MotionMonitor creates an axis system for each body segment (thorax, scapula and humerus) using the ISB protocol as described below (Wu et al., 2005).

The subjects were asked to perform three repetitions each for all the active shoulder motions including four functional tasks and scapular plane abduction. Kinematic data were collected for simulated functional tasks that are typically performed as activities of daily living. These functional motions included (1) Functional reach: Forward reach such as mimicking grabbing an object from a kitchen shelf, (2) Touching the head: Reaching the top of the head as done during hair combing, (3) Reaching back: Reaching up behind the back as done when scratching the back, and (4) Reaching wallet: Reaching for wallet in the back trouser pocket. (5) A planar motion in the form of scapular plane abduction, which was defined as an angle between 35°- 40° anterior to the coronal plane (Giphart et al., 2013; Ludewig et al., 2009; Teece et al., 2008; McClure et al., 2001), was also collected. The elevation motion was controlled by a wooden board acting as a guide for arm elevation and lowering. After assessing reliability, the average of the three trials was used in the data analysis. Prior trials of the same motion were completed by the subjects to help them get adapted and be prepared to complete the motion correctly and accurately.

Instructions to complete the functional tasks:

(1) Forward reach (Figure 8) — Please grab the water bottle as you would do while grabbing an object from your kitchen shelf. Try to ignore all the wires and cables and complete the motion as normally as possible. Let us try doing the movement twice before we collect data. Once you are ready my associate will give the go ahead signal and you will have to complete the motion three times. Please pause for a second after you grab the water bottle and again pause for a second when your arm is by the side. Continue doing the motion for three repetitions.

(2) Touch the head (Figure 9) — Please touch the top of your head as you would do while combing your hair. Try to ignore all the wires and cables and complete the motion as normally as possible. Let us try doing the movement twice before we collect data. Once you are ready my associate will give the go ahead signal and you will have to complete the motion three times. Please pause for a second after you touch the top of your head and again pause for a second when your arm is by the side. Continue doing the motion for three repetitions.

(3) Reaching back (Figure 10) — Please slide the back of your hand with the thumb pointing upwards over the spine as high as possible, without creating any discomfort in your shoulder, arm or neck. Try doing this motion without bending your body in any direction. Try to reach the top as smoothly as possible and do not jerk when you reach the

top. Again try to ignore all the wires and cables and complete the motion as normally as possible. Let us try completing the motion twice before we collect data. Once you are ready my associate will give the go ahead signal and you will have to complete the motion three times. Do pause for a second when your thumb reaches the highest possible level on the spine and again pause for a second after you bring your arm by the side. Continue doing the motion for three repetitions.

(4) Reaching wallet (Figure 11) — Please place the hand on your back pocket as you would do while reaching for your wallet. Again try to ignore all the wires and cables and complete the motion as normally as possible. Let us try doing the movement twice before we collect data. Once you are ready my associate will give the go ahead signal and you will have to complete the motion three times. Please pause for a second after you place your hand on the back pocket and again pause for a second after you bring your arm by the side. Continue doing the motion for three repetitions.

(5) Scapular Plane Abduction (Figure 12) — Please slide the palm of your hand over the board and lift it as high as possible. Kindly remember that the starting position of your arm is by the side of the body and then the board will guide you. If you are able to lift your arm higher then you can slide your arm off the board. Pause for a second at the highest point and again pause for a second when your arm is by the side. The examiner counted 3 seconds during arm elevation and 3 seconds for lowering. Kindly continue doing the motion for three repetitions.

Additionally, to quantify static thoracic posture, this study used a similar protocol performed by Kebaetse et al. (1999) where they digitized superior (2 inches above) and inferior points (2 inches below) of each of the two vertebrae (T2 and T11) in the thoracic spine. Instead of using the 2 inches supero- inferior points, the researcher used 1^{st} and 3^{rd} thoracic spinous processes for the superior vector and 10^{th} and 12^{th} thoracic spinous processes for the inferior vector. During the thoracic landmark data collection the subject was standing in a static neutral relaxed posture. The 2D angle (removing any medial/lateral component) formed by the two vectors created from the pre- defined four points is the thoracic angle (Figure 13). Increase in the thoracic angle refers to flexion and reduction in the angular value is extension. Extracting the flexion-extension trunk angle involves a two-step process. Firstly, a conversion of the thoracic point relative to the trunk anatomical coordinate system from the trunk sensor was required. This computation was done by using the formula (Zatsiorsky, 1998) which is expressed as:

$P_{AT}=T_{AS}*P_{ST}$

P_{AT}: Thoracic point relative to trunk anatomical coordinate system

T_{AS}: Transformation matrix of trunk sensor relative to trunk anatomical coordinate system

P_{ST}: Thoracic point relative to trunk sensor

The second step involves use of T1, T3, T10 and T12 converted thoracic points (P_{AT}) to create the two vectors and then compute the flexion- extension 2D angle between the two vectors in y and x axes. Use of z coordinate was eliminated as there was very minimal medio- lateral shift of the thoracic spinous processes. The resultant angle was then subtracted from 180° to get the thoracic flexion- extension angular value.

c. Data reduction—

(i) Kinematic Analysis:

The setup of the coordinate systems for different body segments were initially built relative to the global or transmitter frame of reference and then the local axis systems was expressed with respect to the other local axis systems (usually the proximal part). Euler- Cardan angle sequences were used since they provided clinically interpretable values. Angle descriptions for the joints were based on the segment orientation and rotation. This study used ISB recommended sequences which were described as follows: x as anterior positive, y as superior positive and z as right lateral positive. To prevent any gimbal lock or singularity at 0-20 degrees and 160-180 degrees of elevation for the second rotation in Euler angles and at 70-110 degrees for the second rotation in Cardan sequences, the study used ISB recommended shoulder sequences of Cardan Yx'z" for scapula to thorax (scapulothoracic), and Euler Yx'y" for humerus to thorax (humerothoracic). A different sequence, Cardan Xz'y" (Phadke et al., 2011) was used for the glenohumeral joint (humerus to scapula). This rotation sequence eliminates the chances of gimbal lock or singularity positions when arm is by the side (0°- 20°) and at complete elevation (160°- 180°). The dependent variables tested for all five conditions (four functional tasks and one scapular plane abduction) were scapular UR, scapular tilt, scapular ER/ IR and GH axial rotation (Table 1).

All functional tasks dependent variables such as three scapular rotations and one glenohumeral axial rotation were converted to percentiles of 25%, 50%, 75% and 100%

of humero-thoracic elevation. Maximum humero-horacic elevation angle was made equivalent to 100%. Scapular plane of abduction analysis was fixed to a maximum of 120˚ of humero-thoracic elevation. The dependent variables were collected at 30˚, 60˚, 90˚ and 120˚ of humero-thoracic elevation for scapular plane of abduction.

Dynamic thoracic posture was analyzed for all functional tasks to quantify the thoracic flexion-extension angular change from initial to final humero-thoracic elevation position. The formula (Zatsiorsky, 1998) applied to compute this angular change is expresses as:

$T_{12}= [T_{G1}]^{-1}*[T_{G2}]$

T_{12}: Transformation matrix of final position relative to initial position

T_{G1}: Transformation matrix of initial position relative to global

T_{G2}: Transformation matrix of final position relative to global

To extract the angular value the researcher used Zxy rotation sequence where Z is flexion- extension, x is side bending and y is axial rotation.

(ii) CT Bone Reconstruction:

From an existing data set, a single subject computed tomography (CT) scan was used based on average demographics such as age, gender, BMI, and arm dominance. The CT images were segmented in Mimics version 16 (Materialise, Leuven, Belgium) software. The segmented structure created masks of the bone sections from which 3D objects were generated. These 3D objects are the bone models of the scapula, humeral head and the epicondyles (Figure 14).

(iii) CT Shoulder Joint Modeling:

The CA ligament was developed from 3D planes that were created in the Mimics software based on anatomic origin and insertion points (Edelson & Luchs, 1995) of the ligament in the acromion and coracoid process (Figure 14). The rotator cuff tendon insertions for subscapularis, supraspinatus and infraspinatus were then identified in Mimics software from the 3D humeral head bone model by anatomically identifying the footprints or insertion points on the humeral head and using 3D planes to slice the specific footprint area (Figure 15).

To simulate arm elevation in this reconstructed bone model the humeral head must be centered on the glenoid and this is done by an optimization approach. At least six points were then identified on the glenoid rim. A circle fit algorithm (http://www2.geog.ucl.ac.uk/~plewis/bpms/src/start/steve/ls3dcircle.m) using points on the glenoid rim calculates a circle center and circle plane. Next a sphere was fit manually in Mimics on the humeral head articular surface. The humeral head was split and the cut articular surface exported as point cloud. The point cloud data are imported into a customized sphere fit code (http://www2.geog.ucl.ac.uk/~plewis/bpms/src/start/steve/lssphere.m) that calculated the sphere center and sphere radius. The Matlab calculated sphere center of the humeral head was positioned at the glenoid center. The sphere radius and circle plane were then used to shift the humeral head laterally perpendicular to the circle plane at the distance of the radius. The CT image does not account for any presence of articular cartilage between the humeral head and glenoid. A 2 mm distance was subsequently added between the circle and sphere centers that would simulate cartilage thickness within the joint surfaces.

A customized Matlab (MathWorks, Natic, MA) program was used to calculate the, minimum linear distances of the RC footprints to any point on the undersurface of the CA arch at lower humero-thoracic angular elevation and to the glenoid at higher humero-thoracic angular elevation. The code inputs the three RC footprints, undersurface of the acromion, CA ligament and glenoid slices which are exported from Mimics as point clouds. The algorithm also uses coordinates from three scapular digitized points, the humeral epicondyles, and the Matlab calculated humeral center. Based on the three different glenohumeral rotations imported it calculates minimal distance between the three RC footprints to the glenoid, CA ligament and acromion respectively.

Glenohumeral position was modeled by rotating the humerus relative to the scapula based on the group mean positions at 25%, 50%, 75% and 100% of humero-thoracic elevation for the four functional tasks at positions which are statistically different between groups for 30˚, 60˚, 90˚ and 120˚ of humero-thoracic elevation for the scapular plane of abduction motion. The rotated humeral head stl and footprint data is then re-exported in Mimics to visualize the proximities of RC footprints to potential impinging structures and changes in the minimum linear distances between the two groups across different positions for different tasks with arm elevation.

(iv) Minimum Linear Distance:

Linear distances of the three rotator cuff tendon (subscapularis, supraspinatus and infraspinatus) footprints (insertion points on the humeral head) are measured relative to the CA ligament and acromion at lower humero-thoracic elevation angles and glenoid at higher angles for each modeled glenohumeral position. The customized minimum distance Matlab code will measure the linear distance of each point in the footprint to each point in the coracoacromial arch and glenoid at different humeral elevation positions.

VII. Overall Research Question

Are there shoulder biomechanical changes present in healthy older persons as compared to healthy younger persons during performance of functional tasks?

VIII. Aims and Hypotheses

A. Kinematic Factors—

I. Shoulder joint motion:

Aim 1. To quantify any 3D angular kinematic changes in scapulothoracic or glenohumeral motion during active arm elevation that distinguishes the two age groups.

- ***Hypotheses—***

H.1.a. The older subject group will have no change in humerothoracic range of elevation motion during active elevation for scapular plane abduction motion when compared to the younger group.

H.1.b.The older subject group will have reduced scapular internal rotation during active elevation for scapular plane abduction, reaching forward and touching head motions when compared to the younger group.

H.1.c.The older subject group will have no change in scapular upward rotation and posterior tilt during active elevation for all motions when compared to the younger group.

H.1.d. The older subject group will have reduced humeral external rotation during active elevation for all motions when compared to the younger group.

The above four hypotheses was tested using similar statistical analyses.

Statistic: Mixed model repeated measures 3- way ANOVA

Factors: Groups and Percentiles/Angles

Independent variables: Groups (young and elderly, between subjects factor) and percentiles for functional tasks (25%, 50%, 75%, 100% of humero- thoracic elevation; within subjects factor) and angles for scapular plane of abduction (30˚, 60˚, 90˚, 120˚ of humero-thoracic elevation; within subjects factor)

Dependent variables: Scapulothoracic internal/external, upward/downward, anterior/posterior tilt rotation sequences; and glenohumeral axial rotation.

Statistical Analyses:

Data was analyzed using Number Cruncher Statistical System 2007 (NCSS, LLC. Kaysville, Utah, USA) and [SAS/STAT] software, Version [9.3] (SAS Institute Inc., Cary, NC, USA). Preliminary statistics were completed prior to hypotheses testing. Preliminary statistics included were tests of trial effects, determination of reliability for the three trials, normality testing, descriptive statistics, homogeneity of variance testing, and covariate analyses. Hypotheses testing were different for different aims.

Preliminary statistics—

Repeated measures 3-way ANOVA between groups, phase and repetitions were completed to check for effect of trials. If no significant or presumed meaningful effect between trials was found, then the trials were averaged and the mean used for further testing. Reliability of each trial for each phase at each angular position was measured by doing a one-way ANOVA for groups. Using the between subject mean square (BMS) and within subject mean square (WMS) values, Intraclass Correlation Coefficients or ICCs and the Standard Error of the Measurement or SEMs were calculated. ICC value of 1 or -1 defines perfect agreement or in this case the trials are similar to each other and zero indicates no agreement. Increase in reliability between trials relate to lower SEM values, so SEM closer to zero indicates high reliability amongst trials. Reliability of three trials for each task and each dependent variable were determined using ICC (1, 1) = (BMS-WMS)/ (BMS+ (k-1) WMS) (Portney & Watkins, 2009). The SEM was determined to be the square root of the WMS (Fleiss, 1999). Data were checked for normality based on skewness (-1 to 1 is an acceptable range) (Portney & Watkins, 2009) and kurtosis (1.7 to 10 is an acceptable range) (Feldt, 1993). If normality was absent then appropriate transformations were considered specific to the type of abnormality. Non-parametric testing was used if data failed to attain normality criteria after attempted transformation. Descriptive analyses were completed to determine the mean, standard deviation and range. Circularity/sphericity was tested to check for homogeneity of variance.

Potential covariates considered were gender and body mass index (weight in kg/ square of height in meters). Correlations were computed between each dependent variable and the covariates. If the correlation coefficient was found to be statistically significant and had an ‘r’ value stronger than 0.50 (Portney & Watkins, 2009) then they were used in the analysis of covariance (ANCOVA) to check if they had any significant effect on the dependent variables. If there were no significant effects then the covariates were not retained for hypotheses testing.

Hypotheses testing—

A 3-way repeated measures ANOVA was used setting the α level at 0.05. Two groups (young and elderly) and four angular positions (25%, 50%, 75%, 100%) for the functional tasks or four angles for scapular plane abduction (30°, 60°, 90°, 120°) were used as between-subject and within-subject factors to determine the changes in 3D angular kinematics. A proc mixed model ANOVA was used to analyze dataset when covariates were retained. If an interaction of group existed then Tukey-Kramer multiple comparison two factor interaction tests were completed comparing the groups at each angular position. Hypotheses H.1.a, H.1.b, H.1.c. and H.1.d. were tested for main effect of groups and interactions between groups and angles and between groups and phases.

II. Rotator cuff tendon proximity:

Aim 2. To quantify any 3D angular kinematic changes between the older asymptomatic and younger asymptomatic groups that alters the minimum rotator cuff tendon footprint to coracoacromial arch and glenoid linear distances during active arm elevation.

- **Hypotheses—**

H.2. The older subject group will have no change in the minimum linear distances from the cuff footprints to the coracoacromial arch during active elevation for positions tested compared to the younger group.

Statistic: Descriptive statistics (mean and standard deviation) were computed.

Independent variables: Groups (Young and Elderly, between subjects factor) and angular positions for functional tasks (25%, 50%, 75%, 100% of humero-thoracic elevation; and angles for scapular plane of abduction (30˚, 60˚, 90˚, 120˚ of humero- thoracic elevation)

Dependent variable: Minimum linear distance

III. Postural Effects:

Aim 3. To quantify any thoracic postural changes during static and dynamic conditions that distinguishes the two groups.

- **Hypotheses—**

H.3.a. The older group will have significantly more thoracic kyphosis when compared to the younger group during static neutral relaxed standing with the arms hanging by the side.

H.3.b. The older group will have significantly less thoracic extension when compared to the younger group during active elevation for all motions.

Statistic: Unpaired Student's t- test was done for hypothesis H.3.a and mixed model repeated measures 2- way ANOVA was used for hypothesis H.3.b.

Independent variables: Groups (young and elderly) and phases (elevation and lowering)

Dependent variables: Thoracic flexion-extension ROM for static posture and dynamic postures that included the four functional tasks and scapular plane abduction.

Statistical Analyses:

Preliminary statistics were performed as discussed before. Unpaired Student's t-test was used to analyze static posture data comparing the two groups. Repeated measures 2-way ANOVA for H.3.b was tested as in Aim 1. Two groups (young and elderly) and two phases angular positions (elevation and lowering) for the functional tasks and scapular plane abduction were used as between-subject and within-subject factors to determine the changes in dynamic thoracic posture. Hypothesis H.3.b was tested for main effect of groups and interactions between groups and phases. If an interaction between groups existed then Tukey-Kramer multiple comparison two factor interaction tests were completed comparing the groups at each phase.

B. Strength —

Aim 4. To quantify any changes in shoulder strength that distinguishes the two groups.

- **Hypotheses—**

H.4.a. Older subjects with asymptomatic shoulders will demonstrate significantly reduced isometric shoulder flexion, abduction, internal and external rotation normalized torque with the arm by the side when compared to the younger group.

H.4.b. Older subjects with asymptomatic shoulders will demonstrate significantly increased flexion to abduction and internal to external rotation strength ratios when compared to the younger group.

Statistic: Mixed model repeated measures 2-way ANOVA for H.4.a and Unpaired Student's t- Test was performed for H.4.b.

Independent variables: Groups (young and elderly), direction of strength testing (flexion-abduction and ER-IR) for H.4.a and strength ratios (flexion- abduction and ER-IR) for H.4.b.

Dependent variables: Normalized torques in Nm/Kg and normalized torque ratios respectively for the two hypotheses.

Statistical Analyses:

Preliminary statistics was performed as discussed previously. Reliability (ICC and SEM) were measured based on two trials for each direction. Repeated measures 2-way ANOVA for H.4.a was tested as in Aim 1 using proc univariate in SAS. Two groups (young and elderly) and four directions (flexion, abduction, external rotation and internal rotation) for the four strength measures were used as between-subject and within-subject factors to determine the changes in normalized torque. Hypothesis H.4.a was tested for main effect of groups and interactions between groups and direction. If an interaction between groups existed then contrast statement for multiple comparison two factor interaction tests were completed comparing the groups at each direction. Unpaired Student's t-test was used for H.4.b to analyze normalized torque ratio data comparing the two groups.

TABLES

Table 1. Shoulder Motions

Describes dependent variables (italicized names indicate dependent variables tested for all conditions) with rotation axes and direction of motion.

Shoulder Motions	Rotations	Positive	Negative
Scapular Internal Rotation	*Y*	*Protraction or Internal Rotation*	*Retraction or External Rotation*
Scapular Upward Rotation	*x'*	*Medial or Downward Rotation*	*Lateral or Upward Rotation*
Scapular Tilt	*z''*	*Posterior Tilt*	*Anterior Tilt*
Humero Thoracic Plane	Y	Anterior to Coronal Plane	Posterior to Coronal Plane
Humero Thoracic Elevation	x'	Depression	Elevation
Humero Thoracic Rotation	y''	Internal Rotation	External Rotation
Glenohumeral Angle of Elevation	X	Depression	Elevation
Glenohumeral Plane of Elevation	z'	Anterior to Scapular Plane	Posterior to Scapular Plane
Glenohumeral Axial Rotation	*y''*	*Internal Rotation*	*External Rotation*

FIGURES

Figure 1. Subject sitting tall and erect with elbow flexed to 90˚ during isometric strength measure of shoulder external rotators. Note that the dynamometer is in the tester's hand.

Figure 2. Humeral sensor on distal humerus just above the epicondyles.

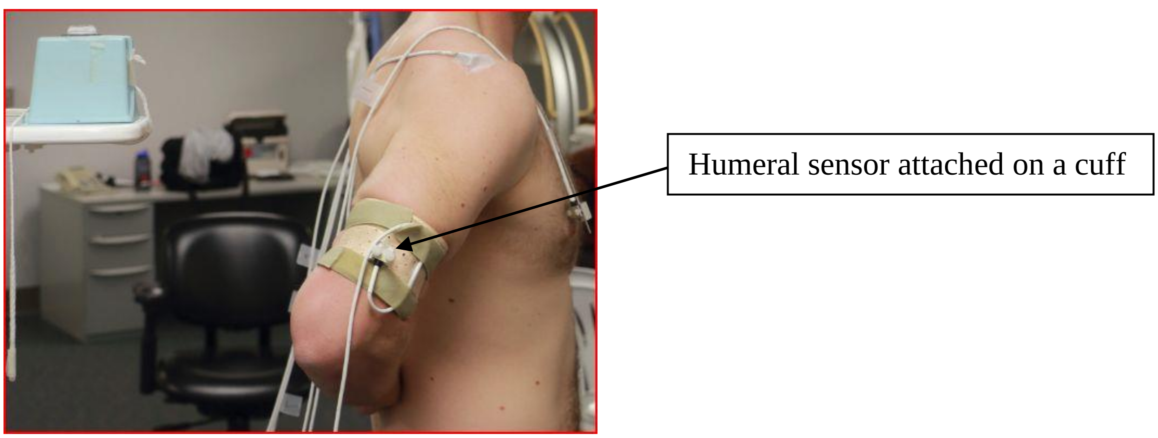


Figure 3. Tester digitizing posterolateral acromion with digitizer.

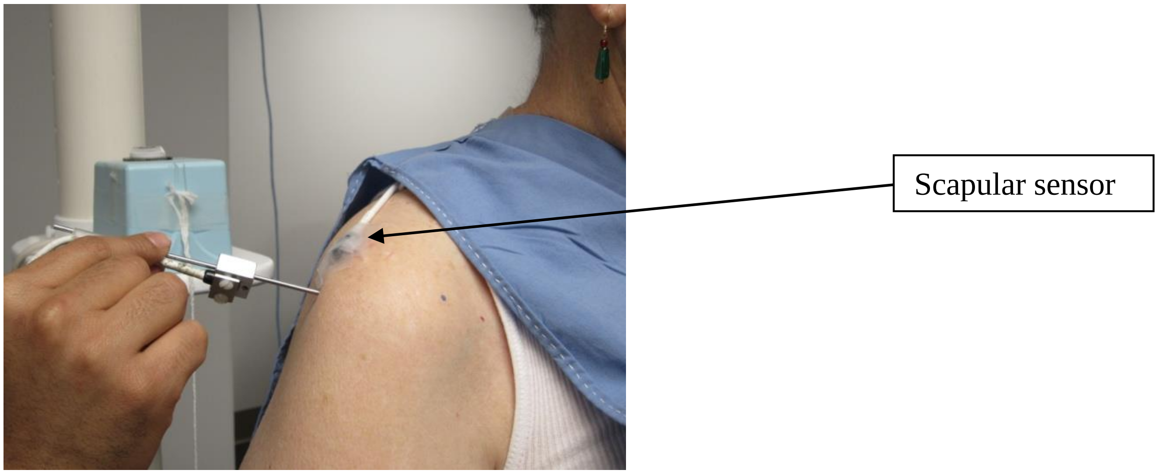


Figure 4. Anteroposterior view of MotionMonitor generated subject specific skeletal model with coordinate systems for each segment.

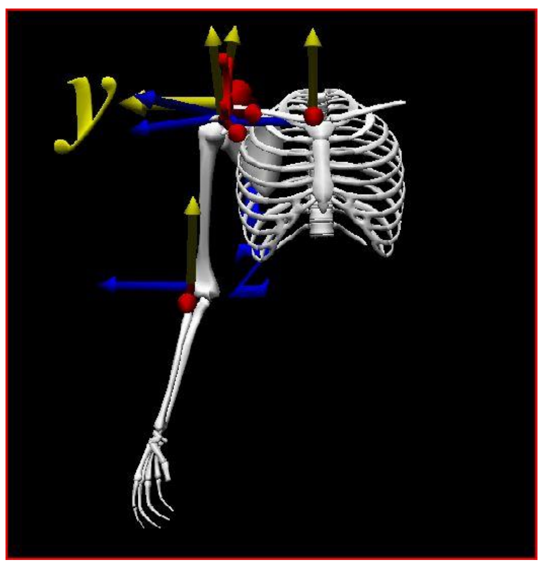


Figure 5. Oblique view of MotionMonitor generated subject specific skeletal model with coordinate systems for each segment.

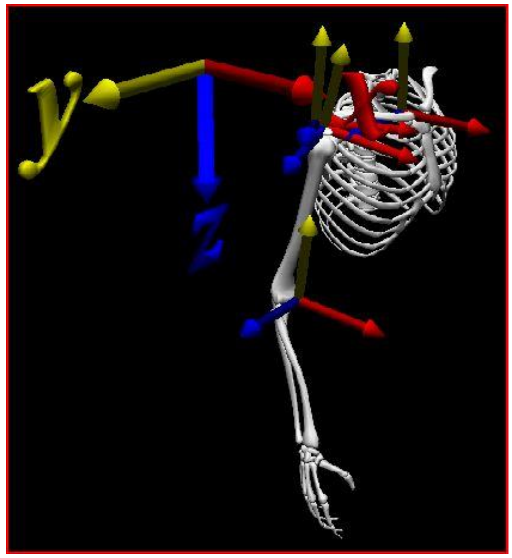


Figure 6. Mini- bird sensors attached to scapula and humerus. The subject is standing anterior to the electromagnetic transmitter, attached to the pole.

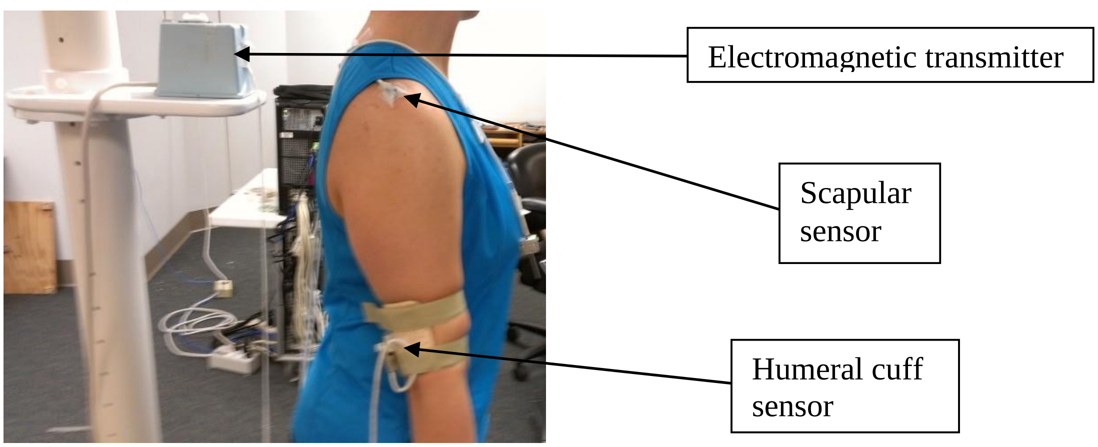


Figure 7. Mini- bird sensor attached to the thorax. Sensors not being used are hanging from the left shoulder.

Figure 8. Subject forward reaching to grab the water bottle, mimicking getting an object from kitchen shelf.

Figure 9. Subject touching the top of the head to mimic combing action.

Figure 10. Subject sliding thumb up the spine to mimic scratching the back action.

Figure 11. Subject placing hand on the gluteus to mimic grabbing the wallet from back trouser pocket.

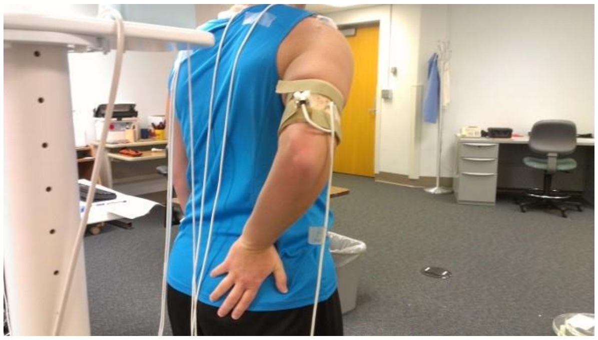


Figure 12. Subject sliding the palm on the board to complete scapular plane abduction motion.

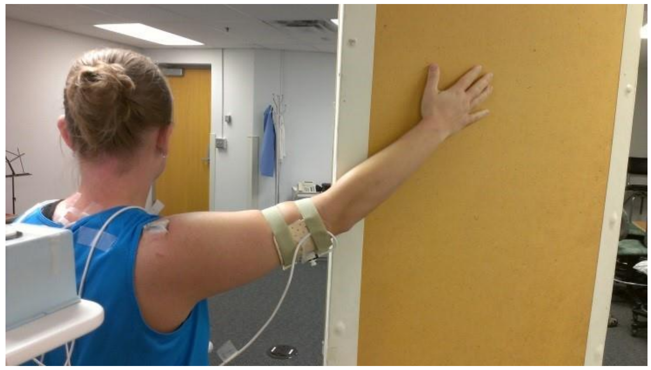
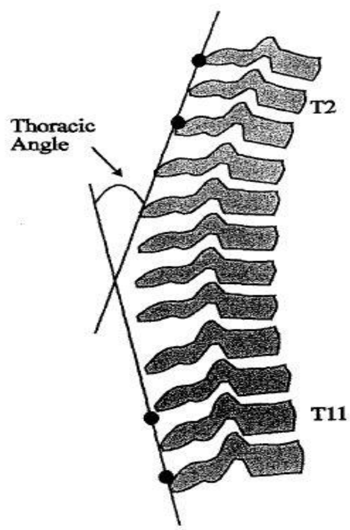


Figure 13. The four points were digitized at 2 inches above and below 2nd Thoracic (T2) and 11th Thoracic (T11) vertebrae. The angle formed between the two vectors calculated by connecting these points and then subtracting it from 180° is the thoracic angle.



Reprinted with permission from Kebaetse M, McClure P, Pratt NA. 1999. Thoracic position effect on shoulder range of motion, strength, and three-dimensional scapular kinematics. Arch Phys Med Rehabil. 80(8):945-950.

Figure 14. Mimics generated 3D model of right shoulder joint in neutral position.

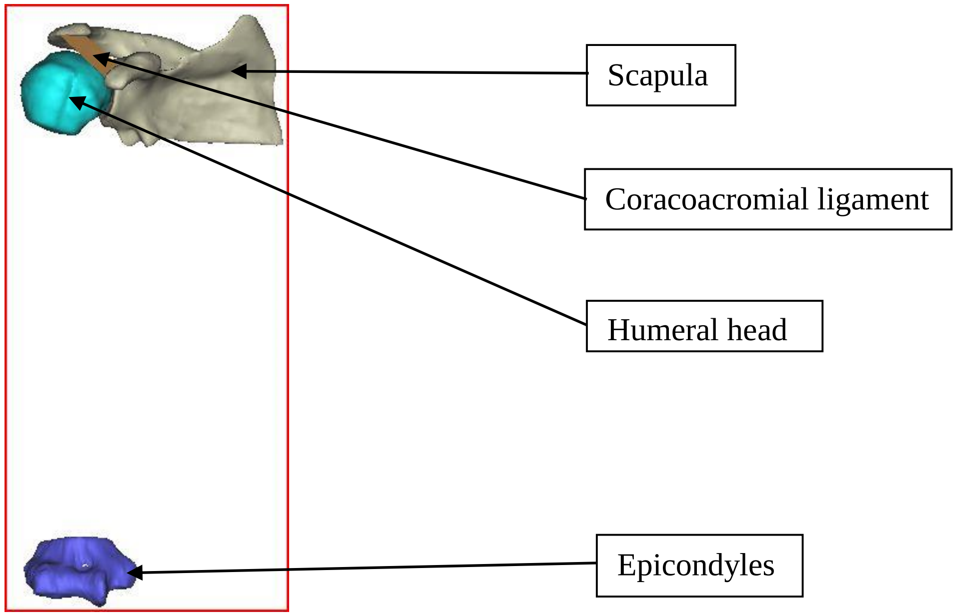
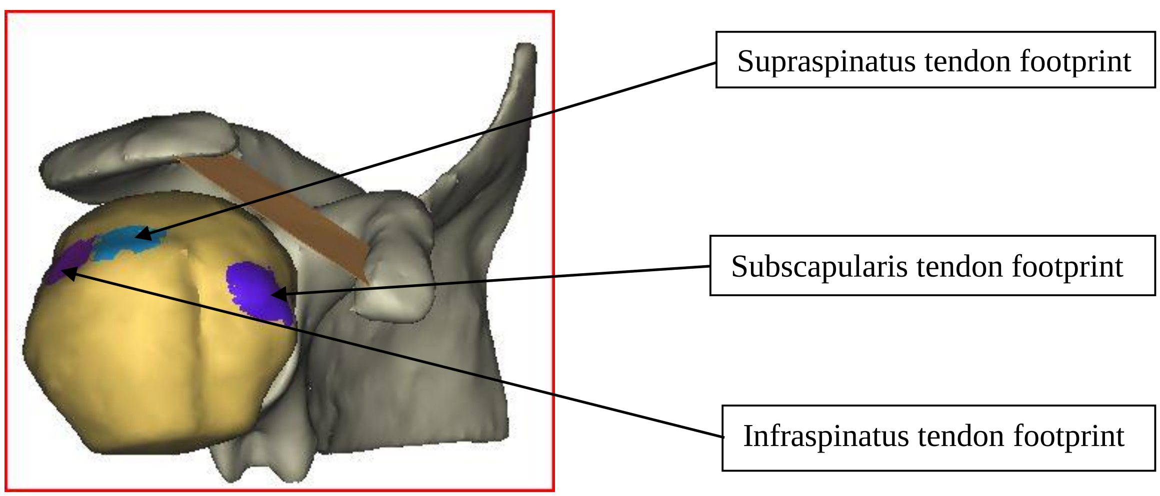


Figure 15. Mimics generated 3D model of three rotator cuff tendon footprints on the greater and lesser tuberosities at neutral humeral head position.



CHAPTER IV

RESULTS

I. Subjects

A total of 50 subjects, two groups with 25 each, were recruited for the study. Subjects in the elderly group had a mean age of 71 years and subjects in the younger group had a mean age of 27 years. Group demographics are provided in

Table 2. Gender was matched for both the groups with 16 females and nine males (Table 2). The Disabilities of the Arm, Shoulder and Hand (DASH) scores varied between zero and 20.83 for the elderly and between zero and 2.59 for the younger group. Three of the 25 elderly subjects had a DASH score of greater than 5 but were still believed to be asymptomatic with no reproduced pain or tenderness or loss in ROM. After removing 3 DASH questions seemingly unrelated to the shoulder (#2, 3, and 16), as well as answers clearly identified as other upper extremity issues, Appendix 6 (Table A6.1) describes in percentages the questions that were answered as mild or greater difficulty by the three elderly individuals. A DASH score above 5 was judged to be of possible interest as representing a score that might imply dysfunction based on the range of scores in the young healthy population. Five subjects had a DASH score of zero in the elderly group compared to twenty subjects with a zero score in the younger group. Mean DASH score for the elderly group was 3.55 and that of the younger group was 0.27. A t-Test between groups was found to be significantly different (Table 2). Exploratory analyses was performed by taking out the three subjects with higher DASH scores for the

conditions that had significant group differences with the kinematic variables (Appendix 6, Figure A6.1 and Figure A6.2).

Physical examination findings including cervical ROM (Appendix 6, Table A6.2), internal rotation ROM which was defined as thumb to thoracic spinous processes (Appendix 6, Figure A6.2), shoulder joint instability tests, shoulder joint impingement tests, painful arc, and external rotation resistance tests (Appendix 6, Table A6.3) did not give evidence of any shoulder issues. Subjects were also asked to provide descriptive recall history of work or sports performed with arm elevation in their lifetime (Appendix 6, Table A6.4). Arm elevated activities were defined as any work or sports involving shoulder flexion, abduction or a combination of both with arm elevation greater than 40°. History of overhead occupation and sports were considered to be of relevance if the individual had worked or played for at least one year and a minimum of two months per year.

Means for all shoulder joint ROM measured goniometrically were within the normal range (Boone & Azen, 1979; Gunal et al., 1996) for both the groups. The elderly group had less mean ROM when compared to the younger population by 5° to 10° for all directions (Table 3). There was a significant reduction in flexion, abduction, scapular plane abduction, and external rotation in the elderly group (Table 4).

Preliminary statistics were completed by each aim including:

1. Effects of trials
2. Reliability (ICC and SEM)
3. Descriptive analyses

4. Normality (skewness and kurtosis)
5. Effects of Covariates
6. Homogeneity of variance (Circularity/ Sphericity)

II. Shoulder joint motion: Kinematic factors

Aim 1. To quantify any 3D angular kinematic changes in scapulothoracic or glenohumeral motion during active arm elevation that distinguished the two age groups.

Preliminary Analyses:

There were significant effects of trial for the four functional tasks and scapular plane abduction. However, a total of 76 of the 80 conditions either had no interaction effect or negligible (<2°) interaction effect between trial and phase or main effect of repetition. Only 4 of the 80 condition combinations had significant interaction effects with pairwise follow-up differences between two trials (either trial 1 & 2 or trial 1 & 3) having a magnitude between 2˚ and 4˚. Nine conditions had main effects of trials only but with magnitudes less than 2°. Subsequently the three trials were averaged for each subject for descriptive statistics and hypothesis testing. Detailed presentation of trial effects is provided in Appendix 7, Table A7.1.

Reliability of the kinematic data included both groups at four angular positions and both phases during performance of the five tasks. ICC values for scapular plane abduction ranged between 0.91 and 0.99 and SEM values ranged from 0.8˚ to 3.2˚ (Appendix 8, Table A8.1). Forward reach ICCs ranged between 0.94 to 0.99 and SEMs from 0.8˚ to 3.6˚ (Appendix 8, Table A8.2). The ICC ranges for reaching the back were between 0.89 to 0.99 and SEMs between 0.6˚ to 4.1˚ (Appendix 8, Table A8.3). ICC values for reaching the wallet ranged between 0.94 to 0.99 and SEMs from 0.7˚ to 3.4˚ (Appendix 8, Table A8.4). ICCs for the touching head task were between 0.95 and 0.99 and SEMs were between 0.8˚ to 4.6˚ (Appendix 8, Table A8.5).

Descriptive analyses (mean and standard deviation) of each dependent variable for each task by group, angular position, and phase of motion (elevation and lowering) are presented in Appendix 9 (Table A9.1 to Table A9.5). General motion patterns for both the groups during the elevation phase of the scapular plane abduction and forward reach tasks were scapular upward rotation, scapular posterior tilt, scapular internal rotation and glenohumeral external rotation. Opposite motions occurred during the lowering phase for both the groups. The reaching the back motion for both groups caused the scapula to downwardly rotate, anteriorly tilt, internally rotate and the humerus to internally rotate relative to the scapula, with opposite motions during the return phase. During the elevation phase of the reaching the wallet task both the groups demonstrated scapular downward rotation, scapular anterior tilt, scapular external rotation and glenohumeral external rotation with opposite motions occurring during the lowering phase. The touching the head activity had similar patterns of motion in both the groups with scapular upward rotation, scapular posterior tilt, scapular internal rotation and glenohumeral external rotation occurring and opposite motions during the lowering phase.

The vast majority of skewness and kurtosis values for each condition/variable combination were within the recommended range. Due to minimal magnitude and low frequency of deviation from accepted range, transformations were not employed. Few values which were outside the range were marginal and not consistently so (Appendix 10, Table A10.1 to Table A10.5), as a result the data were considered to be normal.

Appendix 11 (Table A11.1 to Table A11.20) presents covariate (gender and BMI) correlation test results for both the groups in elevation and lowering phases during completion of the five tasks at the four angular positions. Due to minimal deviation from the accepted range and inconsistent effect on different angular positions, covariates were not included in the ANOVA model. After checking for each dependent variable separately, it was decided that gender would be tested in an ANCOVA model for scapular tilt for the reaching the back task because of higher correlations during the elevation phase in the younger group. Similarly, BMI was tested in an ANCOVA model for GH rotation because of higher correlations in the elderly group during the elevation phase of the forward reach task and the lowering phase of the reaching the wallet task. BMI was also tested in an ANCOVA model for scapular tilt because of higher correlations in the elderly group during the lowering phase of the touching the head task. After running the ANCOVA model for GH rotation, BMI was retained as a significant covariate for hypotheses testing of the forward reach task. For the remaining ANCOVA models tested, the respective covariates were not significant, so they were not retained. Homogeneity of variance was tested for dependent variables that were found to be significantly different for group, or interactions of group and phase or angular position. The only case where homogeneity of variance was rejected was for the dependent variable of glenohumeral rotation during the forward reaching task. Subsequently, an adjusted p- value was calculated using a Geisser-Greenhouse epsilon adjustment (Appendix 12, Table A12.1).

- ***Hypotheses—***

H.1.a. The older group will have no change in humerothoracic range of elevation motion during active elevation for scapular plane abduction motion when compared to the younger group.

Hypothesis Testing:

There was a significant group difference (df= 48, t= 3.06, p-value <0.004) for the humerothoracic kinematic data during maximum arm elevation while performing scapular plane abduction motion. The mean reduction in maximum humerothoracic elevation for the elderly group was 8° (Table 5). The finding does not support this hypothesis.

H.1.b.The older group will have reduced scapular internal rotation during active elevation for scapular plane abduction, forward reach and touching the head tasks when compared to the younger group.

Hypothesis Testing:

A 3-way interaction of group by phase by angle for scapular internal rotation (IR) was present during scapular plane abduction (Figure 16., Table 6). Follow ups between groups at each condition combination level resulted in significant differences at 75% and 100% of angular position during the elevation phase (Figure 16., Table 6). The elderly group had 7° more scapular IR than the younger group at both the angular positions during elevation respectively. The finding does not support this hypothesis.

There was no 3-way interaction of group by phase by angle during the forward reach task for scapular IR (Figure 17.a., Table 6). Group by angle interaction was significant during this task (Figure 17.a.b, Table 6). Follow ups did not result in significant differences between groups for comparisons of interest. The result does not support the hypothesis.

There was no 3-way interaction of group by phase by angle during the touching the head task for scapular IR (Figure 18., Table 6). Group by phase or group by angle interactions including main effect of groups were absent during of the touching the head task (Table 6). The result does not support the hypothesis.

No 3-way interaction of group by phase by angle was present during the reaching the back task for scapular IR (Figure 19.a., Table 6). Significant interaction effects were found between group and angle (Table 6) with significant group difference at 100% angular position only (Figure 19.a.b). The elderly group had increased scapular IR by 5° when compared to the young group.

A 3-way interaction of group by phase by angle was absent during the reaching the wallet task for scapular IR (Figure 20.a., Table 6). Interactions were found between group and angle (Table 6) with significant group differences occurring at 75% and 100% angular positions (Figure 20.a.b). The elderly group had more scapular IR when compared to the young group at these positions. Mean differences between groups were 6° and 7° respectively.

H.1.c.The older group will have no change in scapular upward rotation and posterior tilt during active elevation for all motions when compared to the younger group.

Hypothesis Testing:

Combinations of interest having significant difference between groups for scapular upward rotation was found in forward reaching task and for scapular tilt was found in reaching the back task only.

There was a presence of 3-way interaction for group by phase by angle during scapular plane abduction for scapular UR (Figure 21., Table 7). Follow ups between groups at each condition combination level did not result in any significant differences. The result (significant interaction but no significant follow-ups) neither supports nor disputes this hypothesis.

A 3-way interaction of group by phase by angle for scapular UR was absent for the forward reach task (Figure 22.a., Table 7). Group by phase interaction was significant in this combination (Table 7). Follow up analysis for this task resulted in significant group differences during the elevation phase only (Figure 22.a.b). The elderly group presented with less scapular UR when compared to the young group. Mean difference between groups during elevation phase was 5°. The finding does not support this hypothesis.

A 3-way interaction of group by phase by angle was found to be significant between the two groups for scapular UR during the reaching the back task (Figure 23., Table 7). Follow ups between groups at each condition combination level did not result in any significant differences. The result (significant interaction but no significant follow-ups) neither supports nor disputes this hypothesis.

There was a presence of 3-way interaction for group by phase by angle during the reaching the wallet task for scapular UR (Figure 24., Table 7). Follow ups between groups at each condition combination level did not result in any significant differences. The result (significant interaction but no significant follow-ups) neither supports nor disputes this hypothesis.

A 3-way interaction of group by phase by angle for scapular UR was absent during touching the head task (Figure 25.a., Table 7). Group by phase interaction was significant (Figure 25.a.b, Table 7). Follow up analysis for touching the head task did not show any significant difference between groups for either phase. The result (significant interaction but no significant follow-ups) neither supports nor disputes this hypothesis.

There was no 3-way interaction of group by phase by angle during scapular plane abduction for scapular tilt (Figure 26., Table 8). Group by phase or group by angle interactions including main effect of groups were absent for the task (Table 8). The results support this hypothesis.

A 3-way interaction of group by phase by angle was found for scapular tilt during the forward reach task (Figure 27., Table 8). Follow ups between groups at each condition combination level did not result in any significant differences (Table 8). The result (significant interaction but no significant follow-ups) neither supports nor disputes this hypothesis.

Three-way interaction of group by phase by angle for scapular tilt was absent for reaching the back task (Figure 28.a.). Group by angle interaction was present for scapular tilt (Figure 28.a.b.). Follow up statistics resulted in significant differences between groups at the 100% angular position only (Table 8). The elderly group had less scapular anterior tilt than the younger group. The mean difference between groups at 100% of the motion was 4°. The finding does not support the hypothesis.

There was no 3-way interaction of group by phase by angle during the reaching the wallet task for scapular tilt (Figure 29., Table 8). Group by phase or group by angle interactions including main effect of groups were absent for the tasks (Table 8). The results support this hypothesis.

A 3-way interaction of group by phase by angle was found for scapular tilt during the touching the head task (Figure 30., Table 8). Follow ups between groups at each condition combination level did not result in any significant differences (Table 8). The result (significant interaction but no significant follow-ups) neither supports nor disputes this hypothesis.

H.1.d. The older group will have reduced humeral external rotation during active elevation for all motions when compared to the younger group.

Hypothesis Testing:

A 3-way interaction of group by phase by angle for glenohumeral (GH) external rotation (ER) was absent during the forward reach task (Figure 31.a., Table 9). Group by angle interaction was present for GH rotation (Table 9). Follow up statistics resulted in significant differences between groups at 25% and 50% angular positions (Figure 31.a.b). The elderly group had relatively less GH ER compared to the younger group at both angular positions. Mean differences between groups at 25% and 50% angular positions were 19° and 13° respectively. The findings support this hypothesis.

There were no 3-way interactions of group by phase by angle during scapular plane abduction (Figure 32.), reaching the back (Figure 33.), reaching the wallet (Figure 34.) or touching the head (Figure 35.) tasks for GH ER (Table 9). Group by phase or group by angle interactions including main effect of groups were absent for the tasks (Table 9). The results do not support this hypothesis.

III. Rotator cuff tendon proximity

Aim 2. To quantify any 3D angular kinematic changes between the older asymptomatic and younger asymptomatic groups that alters the minimum rotator cuff tendon footprint to coracoacromial arch and glenoid linear distances during active arm elevation.

- ***Hypotheses—***

H.2.a. The older subject group will have no change in the minimum linear distances from the cuff footprints to the coracoacromial arch during active elevation when compared to the younger group for all motions where group difference were present in kinematics.

Hypothesis Testing:

Minimum linear distances between RC tendon footprints to any point on the undersurface of the CA arch were measured for 3D position combinations that had significant group differences during kinematic analyses. Lower angular humeral elevation positions were of interest with regard to potential subacromial impingement risk (RC tendon abrasion or compression against the acromion or CA ligament) and higher angular arm elevation positions were described to be a risk for causing internal impingement (RC tendon abrasion or compression against the glenoid). Linear minimal distance of less than 5mm from the RC tendon footprint to the potential impinging structures was of interest due to the intervening soft tissue thickness (Collinger et al., 2009, Roh et al., 2000; Matsuhashi et al., 2013).

Acromion and CA ligament

During the forward reach task, significant group differences were present for GH rotation at 25% and 50% angular positions. Groups were also different for scapular UR during the elevation phase. Minimum linear distance between the three RC tendons and potential impinging structures for the combination of interest varied from 2.2 mm to 22.2 mm for the elderly group and 2.8 mm to 26.9 mm in the young group (Table 10).

During the reaching the back task there was a significant group difference at the 100% angular position for the elevation phase for scapular tilt and scapular IR. At the 100% angular position the arm is fully adducted and internally rotated. The average humerothoracic elevation at the 100% angular position was 51° for the elderly group and 53° for the younger group, an elevation range where subacromial impingement is a potential concern. Minimum linear distance between the three RC tendons and potential impinging structures for the this position combination varied from 1.2 mm to 11.1 mm for the elderly group and 1.1 mm to 11.8 mm for the younger group (Table 11).

During the reaching the wallet task there was a significant group difference at the 100% angular position for the elevation phase for scapular IR. At the 100% angular position the arm is completely adducted. The average humerothoracic elevation at the 100% angular position was 58° for the elderly group and 53° for the young group. Minimum linear distances between the three RC tendons and potential impinging structures for this position combination varied from 0.3 mm to 21.5 mm for the elderly group and 0.6 mm to 23.1 mm in the younger group (Table 12).

Glenoid

During scapular plane abduction there was a significant group difference for the elevation phase at the 75% and 100% angular positions for scapular IR. Minimum linear distances between the RC tendons and potential impinging structure for this position combination varied from 3.7 mm to 4.4 mm for the elderly group and 3.6 mm to 4.2 mm in the younger group (Table 13).

IV. Thoracic Posture Analyses

Aim 3. To quantify thoracic postural changes during static and dynamic conditions that distinguishes the two groups.

- ***Hypotheses—***

H.3.a. The older group will have significantly more thoracic kyphosis when compared to the younger group during static neutral relaxed standing with the arms hanging by the side.

Preliminary Analyses:

Data for both groups were normal with a skewness of -0.05 and kurtosis of 2.38 for the elderly group. The younger group had a skewness of 0.75 and kurtosis of 5.57. There were no effects of covariates ($r<0.50$) on the static thoracic angle for the two groups (Appendix 13, Table A.13).

Hypothesis Testing:

Elderly subjects had a mean thoracic angle of 42.6° (SD= 18.76) and the younger group had a mean of 36.0° (SD= 14.94). Comparing the static posture between the two groups did not generate a significant difference (df= 48, t- score= 1.36, p- value= 0.18). The findings do not support this hypothesis.

H.3.b. The older group will have significantly less thoracic extension when compared to the younger group during active elevation for all motions.

Preliminary Analyses:

There were significant effects of trial for the four functional tasks and scapular plane abduction. However, the magnitude of these trial effects was less than 1˚ for 9 of the 15 total comparisons. Subsequently the three trials were averaged for each subject for all descriptive statistics and hypothesis testing. Detailed presentation of trial effects followed by a brief description of interactions and main effects for each condition is provided in Appendix 14 (Table A14). The ICC values for flexion-extension trunk motion during the elevation phase in the elderly group for all the five conditions ranged from 0.35 to 0.90 and the SEM ranged from 0.9° to 1.5° (Appendix 15, Table A15). The younger group ICCs ranged from 0.74 to 0.85 and SEMs ranged from 1.0° to 1.3° (Appendix 15, Table A15).

The flexion (negative value) and extension (positive value) mean and standard deviation values in the elderly group for all the five tasks ranged from -1.1° (2.1°) of flexion for the touching the head task to 4.5° (1.2°) of extension for the forward reach task (Appendix 16, Table A16.1 to Table A16.5). The flexion (negative value) and extension (positive value) mean and standard deviation values in the younger group for all the five tasks ranged between -1.4° (2.3°) of flexion for the touching the head task to 4.0° (2.6°) of extension for the forward reach task (Appendix 16, Table A16.1 to Table A16.5). Kurtosis values for both the groups during all the tasks including both phases were within acceptable ranges (Appendix 17, Table A17). In the elderly group the skewness values for all tasks including both phases were within the acceptable range (Appendix 17, Table A17). For the younger group, three of 10 combinations exceeded the acceptable range (<1.0) for skewness (Appendix 17, Table A17). Data were not transformed since only three of a total of 20 combinations (including both groups) were out of range and the values were only slightly higher than the acceptable limit.

No moderate or strong associations of BMI with the dependent variable of dynamic trunk motion were present. There were two conditions (scapular plane abduction and touching the head) where gender was correlated with thoracic flexion-extension angle with an r more than 0.5 (Appendix 18, Table A18.1 to Table A18.5). Only four of the 20 conditions had $r>0.5$, so the gender covariate was not added in the ANOVA model as the correlation between gender and the thoracic flexion-extension angle was not consistently strong (r>0.50) across tasks. Circularity/ sphericity was tested for dependent variables that were found to be significantly different. A repeated measures ANOVA was run to check for violation of this assumption. All outcome variables were found to accept homogeneity of variance.

Hypothesis Testing:

Mixed model repeated measures 2-way ANOVA testing during dynamic trunk flexion- extension motion resulted in significant differences between groups for two of the five tasks. There was group by phase interaction effect during reaching the back task and main effect of group during reaching the wallet task.

A significant interaction effect of group with phase was seen for the reaching the back task (df= 1, 48, F= 11.58, p- value= 0.001). Follow up analyses resulted in significant effects between groups for the elevation phase only (Figure 36., Table 14). The elderly group had 2° less thoracic extension during elevation. The result supports this hypothesis.

There was a significant main effect of group for the reaching the wallet task (df= 1, 48, F= 4.16, p- value= 0.05). (Figure 37., Table 14). The elderly group had 0.4° less thoracic extension when compared to the young group. The result supports the hypothesis.

There was no evidence of significant differences for trunk flexion-extension during scapular plane abduction, forward reach or touching the head tasks (Table 14). These findings do not support this hypothesis.

V. Shoulder Strength Measures

Aim 4. To quantify any changes in shoulder strength that distinguishes the two groups.

- ***Hypotheses—***

H.4.a. Older subjects with asymptomatic shoulders will demonstrate significantly reduced isometric shoulder flexion, abduction, internal and external rotation normalized torque with the arm by the side when compared to the younger group.

Preliminary Analyses:

Internal rotation torque was the only variable having a significant trial effect. Flexion, abduction and external rotation did not have any effect of trials. The magnitude of the difference between trials for internal rotation was 0.01 Nm/Kg. The magnitude was very small with a percent error of 1.4% between trials, so it is believed that there were no meaningful effect of trials and the two trials were averaged for subsequent analyses. ICC and SEM values for all variables are provided in Appendix 19, Table A19. The ICC values for both groups and four torque measures ranged from 0.93 to 0.98 and SEM was between 0.01 Nm/Kg to 0.05 Nm/Kg. The mean and standard deviation of normalized torque for the elderly group in the four directions were between 0.27 Nm/Kg (0.07) and 0.66 Nm/Kg (0.13) (Appendix 20, Table A20). The mean and standard deviation of normalized torque for the young group in the four directions were between 0.36 Nm/Kg (0.09) and 0.85 Nm/Kg (0.17) (Appendix 20, Table A20). Kurtosis values for all test conditions were within acceptable ranges for both groups. One (ER torque) of the four skewness values was outside the accepted range (1.66) but by a small magnitude (0.66).

As only one of the 8 test conditions had a skewness value slightly higher than the standard range (Appendix 21, Table A21), the data were not transformed.

Gender was consistently associated with normalized torque with r>0.5 for five of eight test conditions (Appendix 22, Table A22). Three of the total eight test conditions demonstrated association between BMI and normalized torque with r>0.5 (Appendix 22, Table A22). Gender was included in the model for ANOVA testing, since more than 50% of the combinations had r>0.50. BMI was not considered for further analysis as less than 50% of the combinations had r>0.50. Circularity/sphericity was assessed for the two dependent variables. A repeated measures ANOVA was run to check for violation of this assumption without adding the covariates in the model. All outcome measures were found to accept homogeneity of variance.

Hypothesis Testing:

Using a proc mixed model in SAS, there was a significant main effect of groups (df= 1, 47, F= 35.33, p- value= <0.0001) in the flexion-abduction normalized torque data. (Figure 38., Table 15). The elderly group had less flexion and abduction strength by 0.13 Nm/Kg when compared to the young subjects. The result supports this hypothesis.

ER-IR normalized torque had a significant group by direction interaction effect (df= 1, 48, F= 4.54, p- value= 0.04). Follow up analyses resulted in significant differences between groups for both the ER and IR directions (Figure 39., Table 15). The elderly group had less ER (0.08 Nm/Kg) and IR (0.13 Nm/Kg) strength when compared to the young subjects. The result supports the hypothesis.

H.4.b. Older subjects with asymptomatic shoulders will demonstrate significantly increased flexion to abduction and internal to external rotation strength ratios when compared to the younger group.

Preliminary Analyses:

Means and standard deviations torque ratios for the two groups are provided in Appendix 23, Table A23. Skewness and kurtosis values for all test conditions were within acceptable range (Appendix 24, Table A24). The two potential covariates (gender and BMI) did not have associations with $r > 0.5$ for either group or ratio direction (Appendix 25, Table A25).

Hypothesis Testing:

Two sample unpaired t-tests were completed for normalized flexion- abduction and ER-IR ratios. The normalized flexion-abduction torque ratio was not significantly different between groups (df= 48, t= 0.73, p- value= 0.47). The normalized ER-IR torque ratio was not significantly different between groups (df= 48, t= -0.07, p- value= 0.95). Neither torque ratio supports the hypothesis as group differences were absent.

TABLES

Table 2. Demographics

Demographics of subject characteristics, shoulder functional status and statistical comparisons between the two groups.

	Elderly (n=25): Mean or n (SE or %)	**Younger (n=25): Mean or n (SE or %)**	**p-value**
Age (years)	70.88 (0.77)	27.16 (0.92)	0.00*
Males	9 (36%)	9 (36%)	-
Females	16 (64%)	16 (64%)	-
Height (cm)	169.16 (0.72)	171.30 (0.68)	0.39
Weight (kgs)	76.66 (6.51)	76.36 (5.87)	0.94
BMI (kg/sq m)	26.78 (0.96)	26.06 (0.79)	0.56
DASH Score	3.55 (0.87)	0.27 (0.13)	0.0005*

*Significantly different between the two groups

Table 3. Shoulder ROM

Right shoulder joint goniometric range of motion by group.

Right Shoulder Joint	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**	**Range**
Elderly Flexion	161°	10°	144°	180°	36°
Young Flexion	169°	7°	152°	179°	27°
Elderly Abduction	165°	8°	146°	180°	34°
Young Abduction	175°	6°	158°	182°	24°
Elderly Sab[a]	157°	8°	136°	180°	44°
Young Sab[a]	165°	7°	153°	179°	26°
Elderly ER[b]	80°	7°	67°	94°	27°
Young ER[b]	89°	6°	74°	95°	21°
Elderly IR[c]	60°	9°	41°	72°	31°
Young IR[c]	65°	11°	48°	92°	44°

[a]Sab= Scapular plane abduction, [b]ER= External rotation, [c]IR= Internal rotation

Table 4. T-test of Shoulder ROM

T-tests between groups for each direction of range of motion (ROM).

Right Shoulder Joint Motion	df	t-score	p-value
Flexion	48	-3.46	0.00*
Abduction	48	-4.96	0.00*
Sab[a]	48	-3.65	0.00*
ER[b]	48	-4.58	0.00*
IR[c]	48	-1.71	0.09

*Significantly different between the two groups at p<0.05
[a]Sab= Scapular plane abduction, [b]ER= External rotation, [c]IR= Internal rotation

Table 5. Humerothoracic ROM

T-tests for humerothoracic (HT) range of arm elevation motion between the two groups during scapular plane abduction.

Scapular Plane Abduction	Elderly Mean Elevation	Younger Mean Elevation	df	t-score	p-value
HT Elevation	134.0°	142.3°	48	3.06	0.004

Table 6. Scapular IR ANOVA

Mixed model repeated measure 3-way ANOVA table during all conditions for scapular internal rotation.

Condition	Factor	df	F- ratio	p level
Scapular Plane Abduction	Group X Phase X Angle	3,144	10.08	<0.01*
	Group X Angle	3,144	0.62	0.61
	Group X Phase	1,48	6.88	0.01*
	Group	1,48	3.45	0.07
Forward Reach	Group X Phase X Angle	3,144	0.64	0.59
	Group X Angle[#]	3,144 (1.2, 57.6)	6.12	<0.01* (0.01*)
	Group X Phase	1,48	0.39	0.54
	Group	1,48	1.69	0.20
Reaching Back	Group X Phase X Angle	3,144	0.00	1.00
	Group X Angle[#]	3,144 (1.14, 54.72)	5.24	<0.01* (0.02*)

	Group X Phase	1,48	0.68	0.41
	Group	1,48	2.73	0.11
Reaching Wallet	Group X Phase X Angle	3,144	0.71	0.55
	Group X Angle[#]	3,144 (1.13, 54.00)	9.90	<0.01* (<0.01*)
	Group X Phase	1,48	1.70	0.20
	Group	1,48	3.60	0.06
Touching Head	Group X Phase X Angle	3,144	0.52	0.67
	Group X Angle	3,144	0.88	0.05
	Group X Phase	1,48	3.92	0.45
	Group	1,48	3.52	0.07

* Indicates statistical significance at $p < 0.05$
[#] Indicates violation of homogeneity of variance so adjusted p value was used

Table 7. Scapular UR ANOVA

Mixed model repeated measure 3-way ANOVA table during all conditions for scapular upward rotation.

Condition	Factor	df	F- ratio	p level
Scapular Plane Abduction	Group X Phase X Angle	3,144	3.21	0.02*
	Group X Angle	3,144	0.29	0.83
	Group X Phase	1,48	4.02	0.051
	Group	1,48	0.67	0.42
Forward Reach	Group X Phase X Angle	3,144	2.03	0.11
	Group X Angle	3,144	0.52	0.67
	Group X Phase	1,48	6.08	0.02*
	Group	1,48	3.01	0.09
Reaching Back	Group X Phase X Angle	3,144	2.85	0.04*
	Group X Angle[#]	3,144 (1.17, 56.16)	6.07	<0.01* (0.01*)
	Group X Phase	1,48	2.60	0.11
	Group	1,48	0.06	0.81
Reaching Wallet	Group X Phase X Angle	3,144	5.23	<0.01*
	Group X Angle	3,144	1.34	0.26
	Group X Phase	1,48	2.37	0.13
	Group	1,48	0.00	0.98

Touching Head	Group X Phase X Angle	3,144	2.14	0.10
	Group X Angle	3,144	0.86	0.47
	Group X Phase	1,48	4.93	0.03*
	Group	1,48	0.44	0.51

* Indicates statistical significance at $p < 0.05$

# Indicates violation of homogeneity of variance so adjusted df with adjusted p level was used

Table 8. Scapular Tilt ANOVA

Mixed model repeated measure 3-way ANOVA table during all conditions for scapular tilt.

Condition	Factor	df	F- ratio	p level
Scapular Plane Abduction	Group X Phase X Angle	3,144	0.83	0.48
	Group X Angle	3,144	2.36	0.05
	Group X Phase	1,48	3.92	0.07
	Group	1,48	0.03	0.86
Forward Reach	Group X Phase X Angle	3,144	6.34	<0.01*
	Group X Angle	3,144	0.09	0.97
	Group X Phase	1,48	16.69	<0.01*
	Group	1,48	0.71	0.40
Reaching Back	Group X Phase X Angle	3,144	0.32	0.81
	Group X Angle#	3,144 (1.11, 53.28)	7.53	<0.01* (0.01*)
	Group X Phase	1,48	0.36	0.55
	Group	1,48	1.33	0.25
Reaching Wallet	Group X Phase X Angle	3,144	0.16	0.92
	Group X Angle	3,144	2.56	0.06
	Group X Phase	1,48	0.12	0.73
	Group	1,48	0.10	0.76
Touching Head	Group X Phase X Angle	3,144	4.53	<0.01*
	Group X Angle	3,144	0.47	0.70
	Group X Phase	1,48	22.54	<0.01*
	Group	1,48	0.65	0.42

* Indicates statistical significance at $p < 0.05$

# Indicates violation of homogeneity of variance so adjusted df with adjusted p level was used

Table 9. GH Rotation ANOVA

Mixed model repeated measure 3-way ANOVA table during all conditions for glenohumeral rotation.

Condition	Factor	df	F- ratio	p level
Scapular Plane Abduction	Group X Phase X Angle	3,144	1.77	0.16
	Group X Angle	3,144	0.93	0.43
	Group X Phase	1,48	1.09	0.30
	Group	1,48	1.36	0.25
Forward Reach	Group X Phase X Angle	3,144	2.31	0.08
	Group X Angle[#]	3,144 (1, 144)	22.86	<0.01* (<0.01*)
	Group X Phase	1,48	0.03	0.86
	Group	1,48	6.37	0.02*
Reaching Back	Group X Phase X Angle	3,144	0.59	0.62
	Group X Angle	3,144	0.03	0.99
	Group X Phase	1,48	0.13	0.72
	Group	1,48	0.51	0.48
Reaching Wallet	Group X Phase X Angle	3,144	1.42	0.24
	Group X Angle	3,144	1.81	0.15
	Group X Phase	1,48	0.97	0.33
	Group	1,48	1.09	0.30
Touching Head	Group X Phase X Angle	3,144	2.65	0.05
	Group X Angle	3,144	1.90	0.13
	Group X Phase	1,48	3.48	0.07
	Group	1,48	1.69	0.20

* Indicates statistical significance at $p < 0.05$
[#] Indicates violation of homogeneity of variance so adjusted df with adjusted p level was used

Table 10. Minimum Linear Distance for Forward Reach Task

Minimum linear distance between the rotator cuff footprints and the potential impinging structures for the two groups at the 25% angular position during the elevation phase of the forward reach task.

Linear Distance	Elderly (mm)	Young (mm)
SST[a]- Acromion	**2.8**	**4.3**

SST[a] – CA Ligament	**3.7**	5.9
IST[b]- Acromion	**2.3**	**2.8**
IST[b] – CA Ligament	9.9	8.0
Sub[c] – Acromion	22.2	26.9
Sub[c]– CA Ligament	10.9	16.7

[a]SST= Supraspinatus, [b]IST= Infraspinatus, [c]Sub= Subscapularis
Bolded values indicate structures at potential risk of being impinged.

Table 11. Minimum Linear Distance for Reaching the Back Task

Minimum linear distance between the rotator cuff footprints and the potential impinging structures for the two groups at 100% angular position during elevation phase of reaching the back task.

Linear Distance	Elderly (mm)	Young (mm)
SST[a]- Acromion	**2.0**	**2.2**
SST[a] – CA Ligament	**1.2**	**1.1**
IST[b]- Acromion	**3.1**	**3.0**
IST[b] – CA Ligament	10.7	10.5
Sub[c] – Acromion	11.1	11.8
Sub[c]– CA Ligament	**1.8**	**1.7**

[a]SST= Supraspinatus, [b]IST= Infraspinatus, [c]Sub= Subscapularis
Bolded values indicate structures at potential risk of being impinged.

Table 12. Minimum Linear Distance for Reaching the Wallet Task

Minimum linear distance between the rotator cuff footprints and the potential impinging structures for the two groups at 100% angular position during elevation phase of reaching wallet task.

Linear Distance	Elderly (mm)	Young (mm)
SST[a]- Acromion	**2.3**	**3.7**
SST[a] – CA Ligament	6.8	7.9
IST[b]- Acromion	7.6	8.9
IST[b] – CA Ligament	21.5	23.1
Sub[c] – Acromion	6.3	8.5
Sub[c]– CA Ligament	**0.3**	**0.6**

[a]SST= Supraspinatus, [b]IST= Infraspinatus, [c]Sub= Subscapularis
Bolded values indicate structures at potential risk of being impinged.

Table 13. Minimum Linear Distance for Scapular Plane Abduction

Minimum linear distance between the rotator cuff footprints and the potential impinging structures for the two groups at 100% angular position during elevation phase of scapular plane abduction.

Linear Distance	Elderly (mm)	Young (mm)
SST[a]- Glenoid	**3.7**	**3.6**
IST[b]- Glenoid	**4.4**	**4.2**

[a]SST= Supraspinatus, [b]IST= Infraspinatus
Bolded values indicate structures at potential risk of being impinged.

Table 14. Trunk Flexion-Extension ANOVA

Mixed model repeated measure 2-way ANOVA table represents the main effect of group and interaction effect between group and phase for trunk flexion-extension during the four tasks and one motion.

Flexion-Extension Trunk Motion	Factor	df	F-ratio	p level
Scapula Plane Abduction	Group Group X Phase	1,48 1,48	2.85 0.40	0.10 0.53
Forward Reach	Group Group X Phase	1,48 1,48	0.35 0.36	0.56 0.55
Reaching Back	Group Group X Phase	1,48 1,48	1.00 11.58	0.32 <0.01*
Reaching Wallet	Group Group X Phase	1,48 1,48	4.16 1.07	0.05* 0.31
Touching Head	Group Group X Phase	1,48 1,48	0.11 0.48	0.74 0.49

* Indicates statistical significance at $p < 0.05$

Table 15. Shoulder Strength ANOVA

Mixed model repeated measure 2-way ANOVA table represents each direction, describing the interaction effect between group by direction and main effect of group.

Dependent Variable	Factor	df	F- ratio	p level
Flexion-Abduction	Group Direction Group X Direction	1,47 1,48 1,48	35.33 41.47 2.38	<0.01* <0.01* 0.13

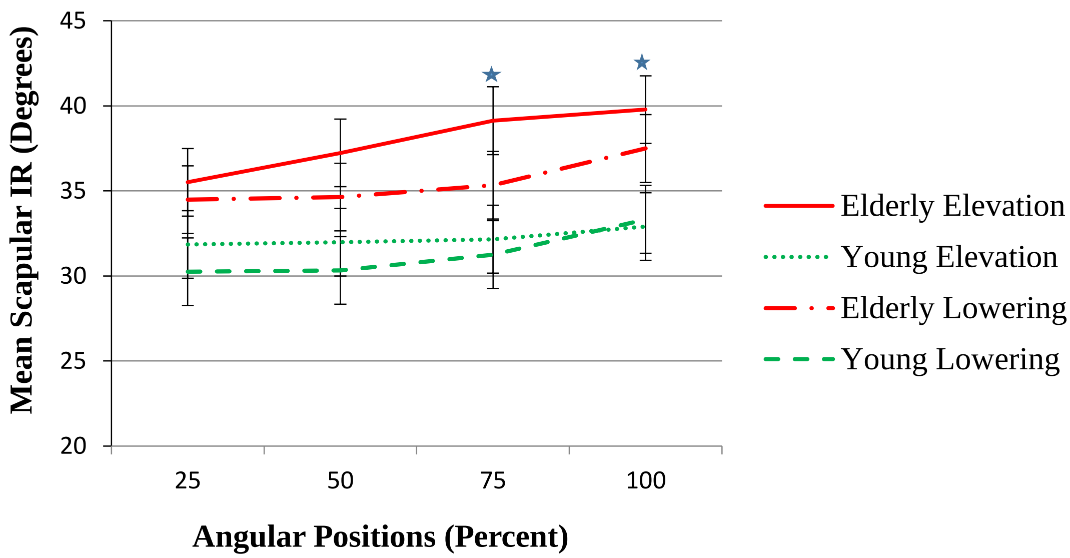
ER[a]-IR[b]	Group	1,47	26.21	<0.01*
	Direction	1,48	136.43	<0.01*
	Group X Direction	1,48	4.54	0.04*

* Indicates statistical significance at $p < 0.05$

[a]ER: External rotation, [b]IR: Internal rotation

FIGURES

Figure 16. Plot of group by phase by angle interaction effect between the two groups for scapular internal rotation (IR) during scapular plane abduction with standard error bars.



★ Indicates significant difference between groups at 75% and 100% angular positions during elevation phase

Figure 17.a. Plot of the two groups' average values and standard errors for scapular internal rotation (IR) during the forward reach task.

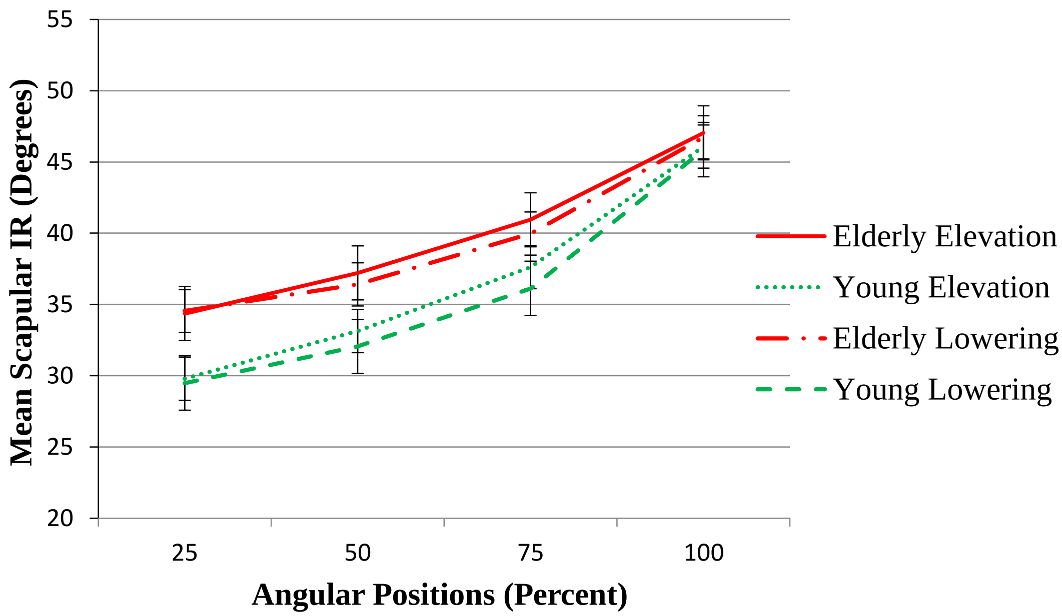


Figure 17.b. Group by angle interaction effect between the two groups for scapular internal rotation (IR) during the forward reach task with standard error bars.

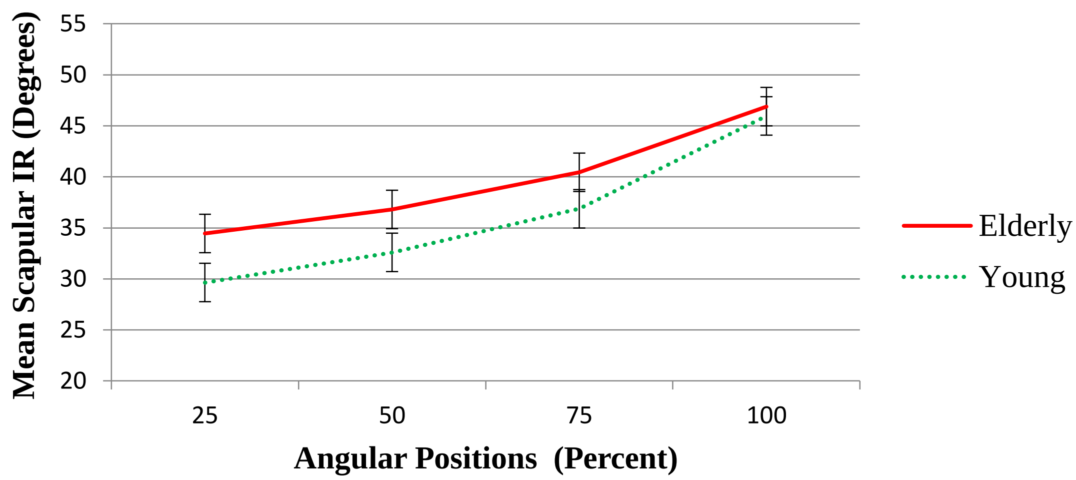


Figure 18. Plot between the two groups for scapular internal rotation (IR) during touching the head task with standard error bars.

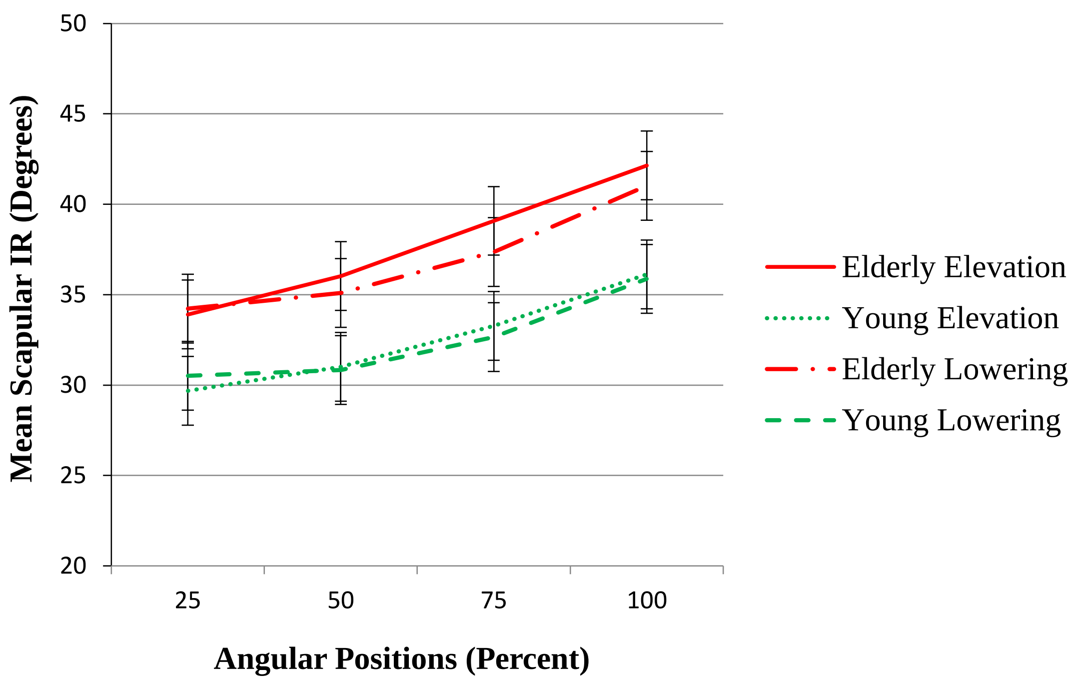


Figure 19.a. Plot between the two groups for scapular internal rotation (IR) during reaching back task with standard error bars.

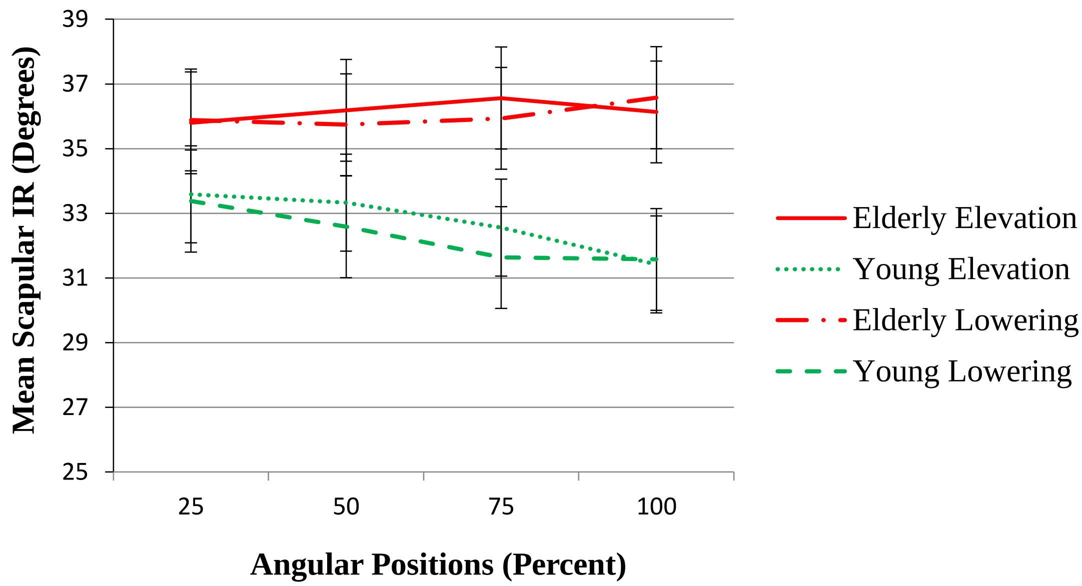
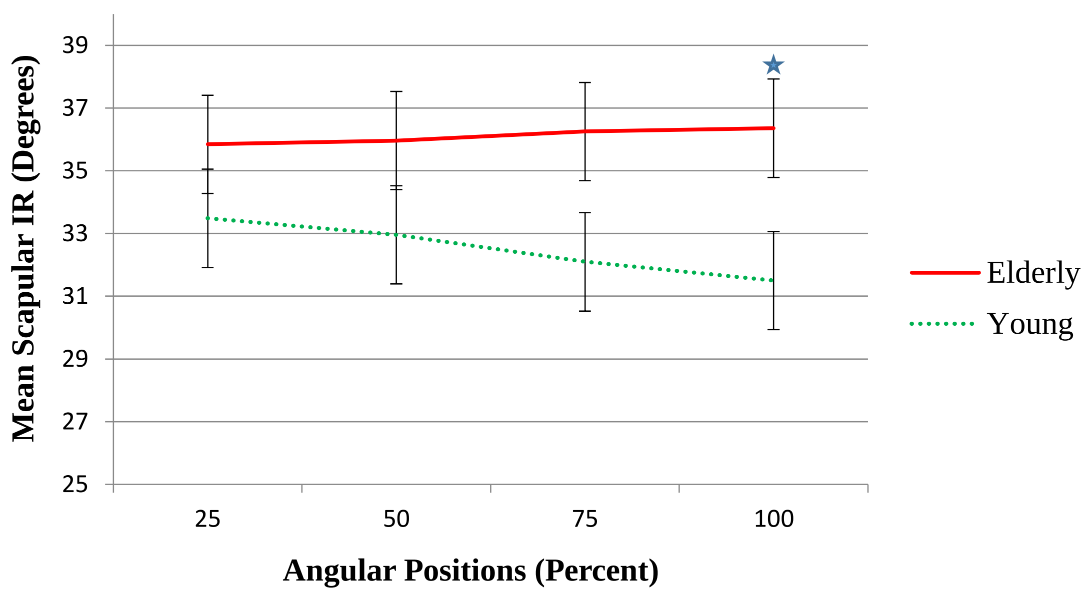


Figure 19.b. Group by angle interaction effect between the two groups for scapular internal rotation (IR) during the reaching the back task with standard error bars.



★ Indicates significant difference between groups at 100% angular position

Figure 20.a. Plot between the two groups for scapular internal rotation (IR) during reaching wallet task with standard error bars.

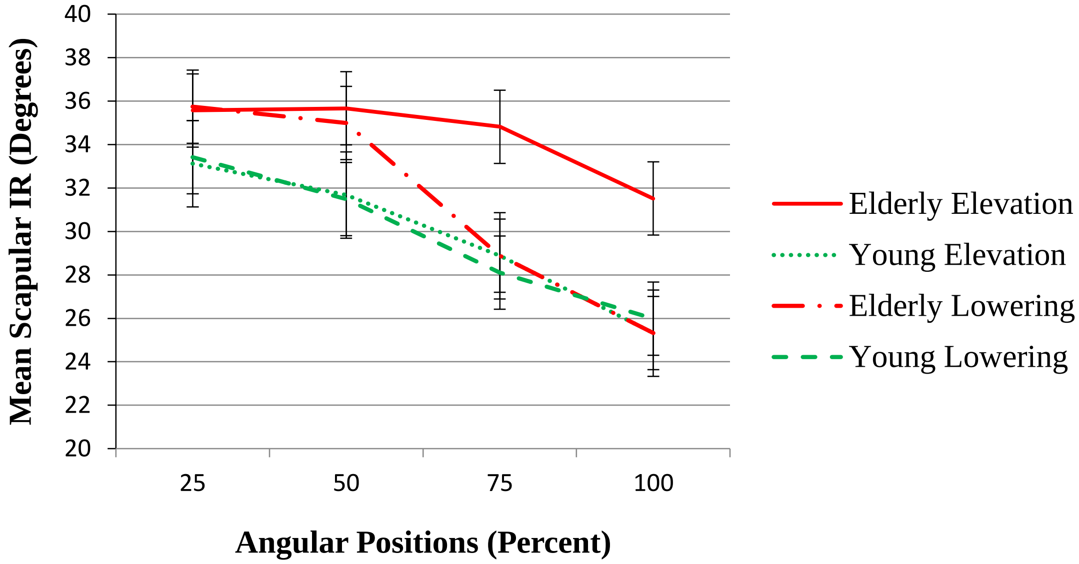
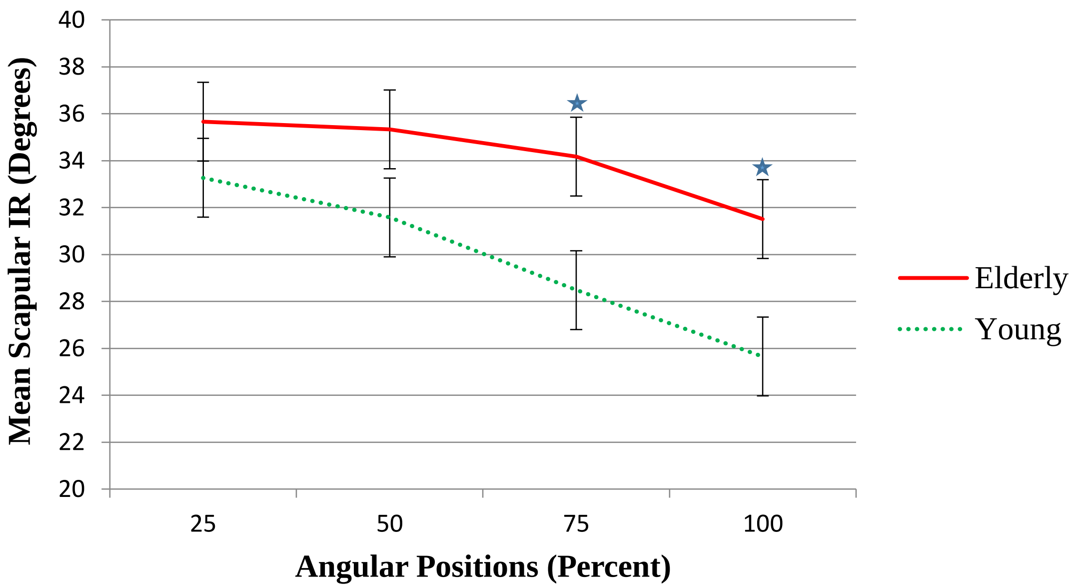


Figure 20.b. Significant group by angle interaction effect between the two groups for scapular internal rotation (IR) during reaching wallet task with standard error bars.



★ Indicates significant difference between groups at 75% and 100% angular positions

Figure 21. Plot between the two groups for scapular upward rotation (UR) during scapular plane abduction with standard error bars.

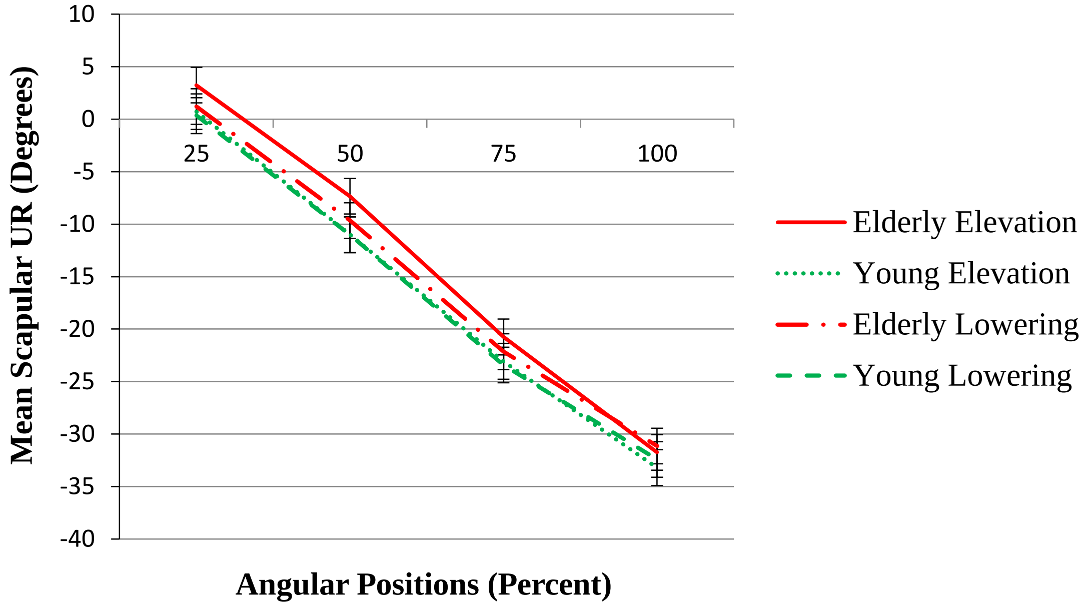


Figure 22.a. Plot between the two groups for scapular upward rotation (UR) during forward reach task with standard error bars.

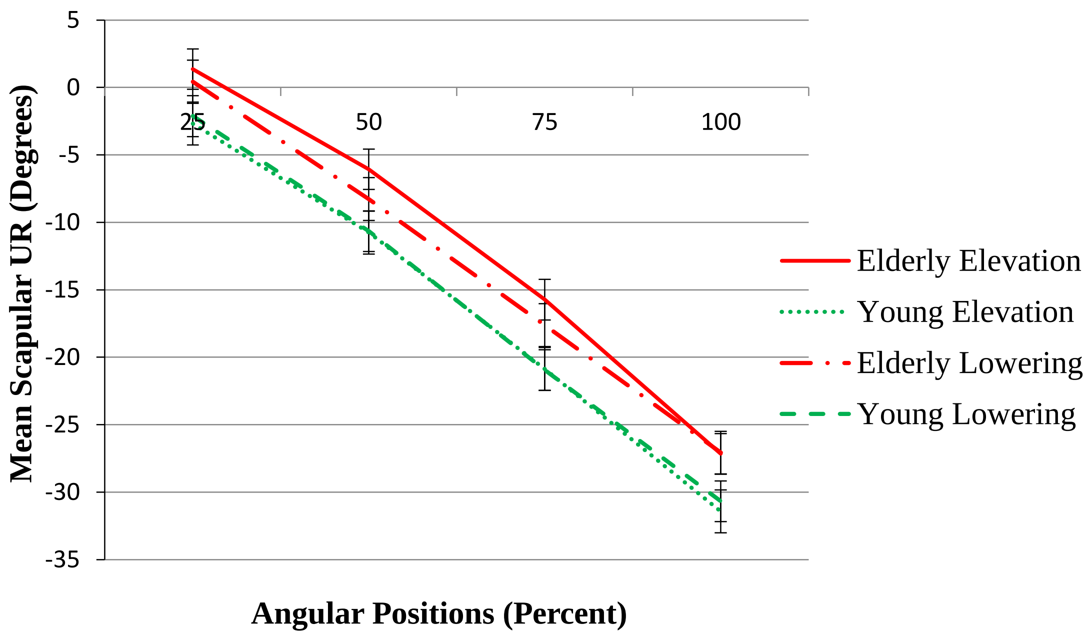
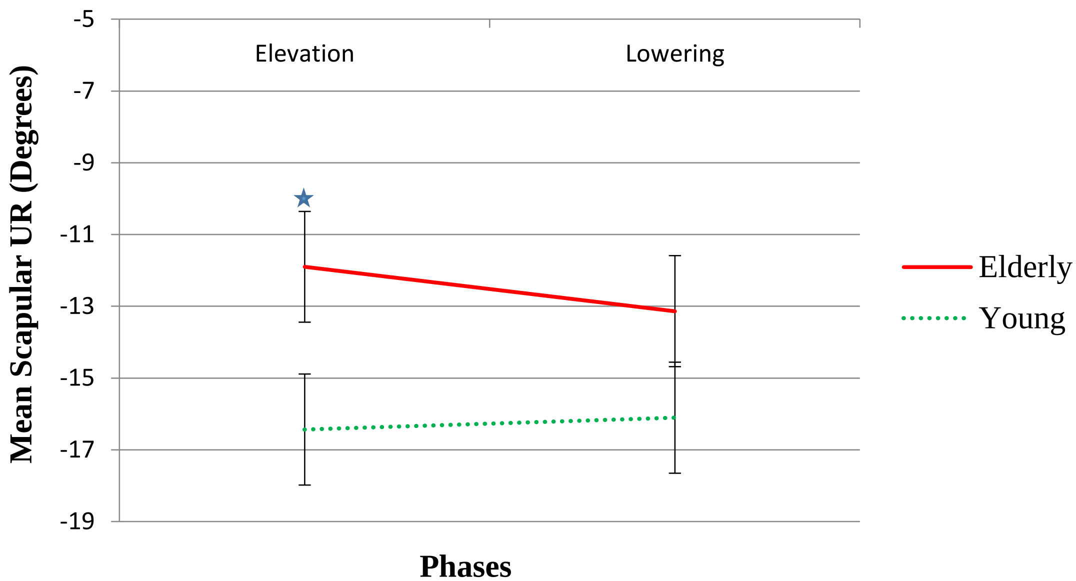


Figure 22.b. Group by phase interaction effect between the two groups for scapular upward rotation (UR) during forward reach task with standard error bars.



★ Indicates significant difference between groups during elevation phase

Figure 23. Plot between the two groups for scapular upward rotation (UR) during reaching the back task at with standard error bars.

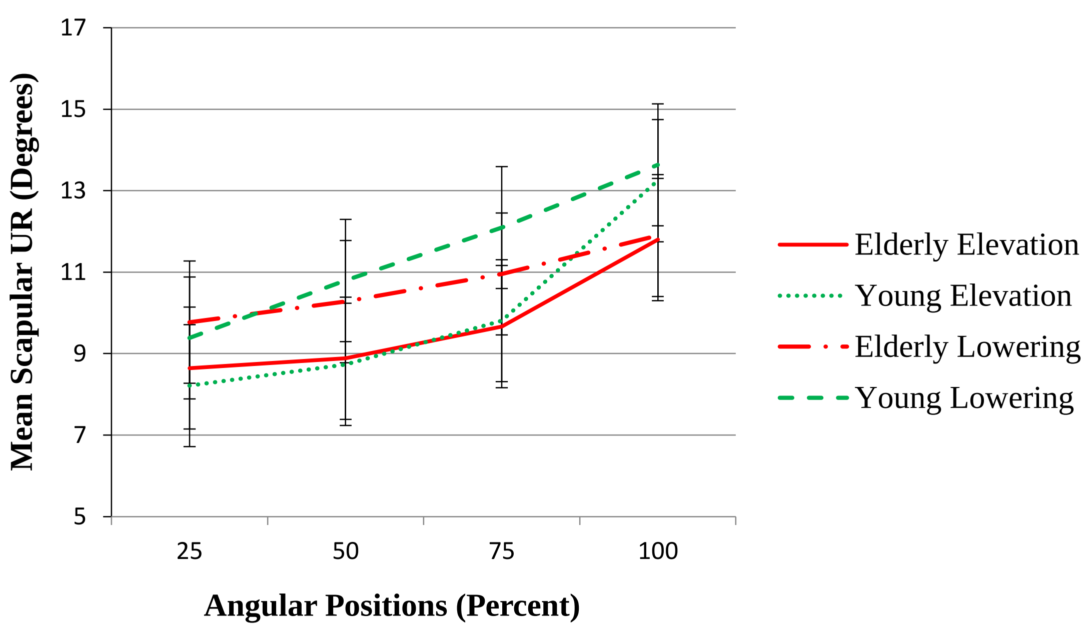


Figure 24. Plot between the two groups for scapular upward rotation (UR) during reaching wallet task with standard error bars.

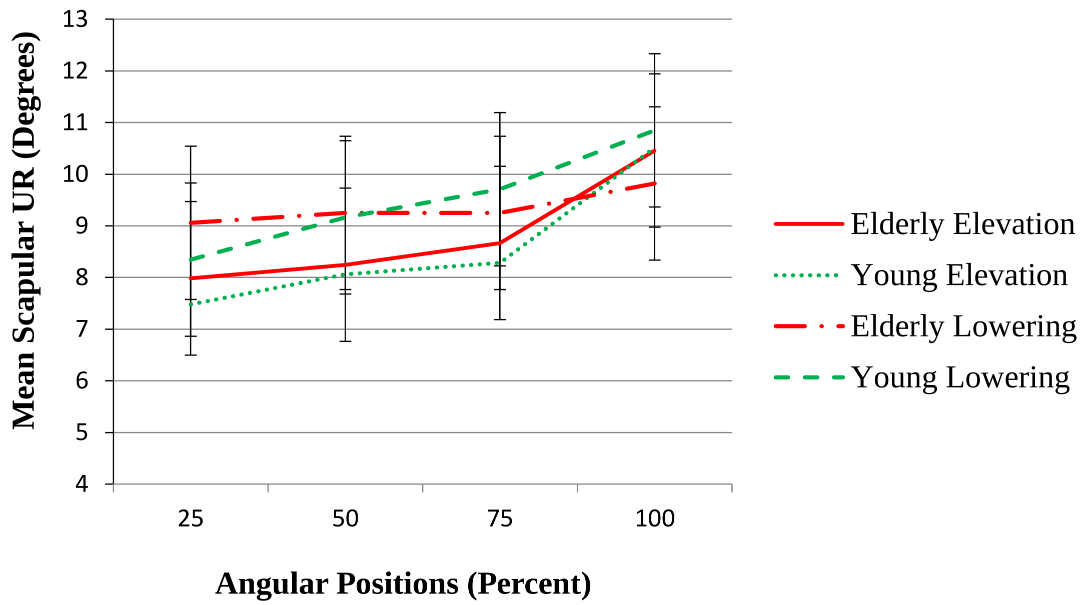


Figure 25.a. Plot between the two groups for scapular upward rotation (UR) during touching the head task with standard error bars.

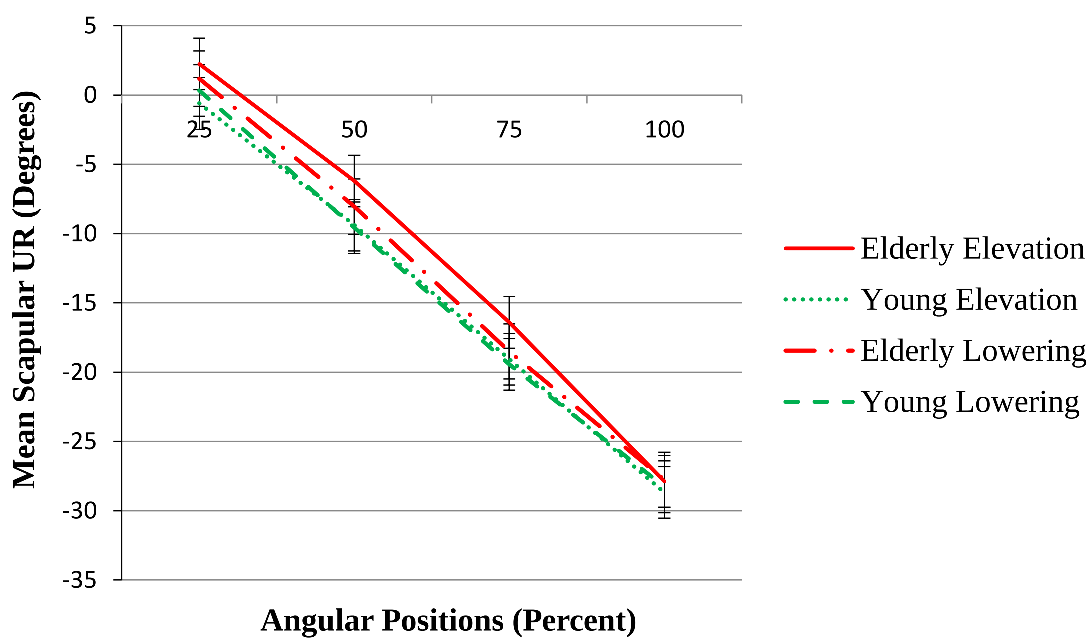


Figure 25.b. Group by phase interaction effect between the two groups for scapular upward rotation (UR) during touching the head task with standard error bars.

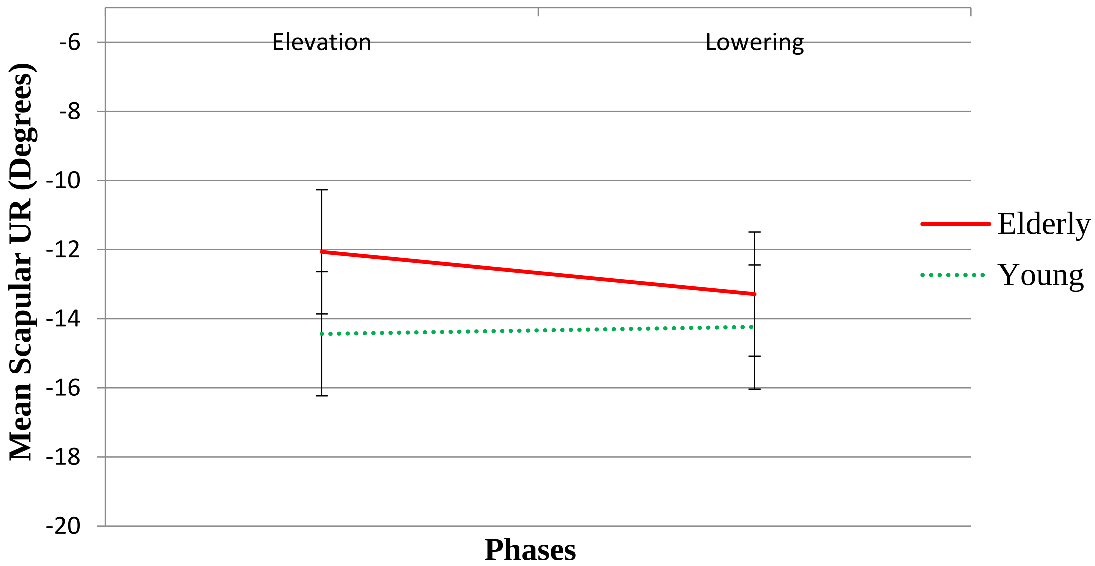


Figure 26. Plot of group by phase by angle interaction effect between the two groups for scapular tilt during scapular plane abduction task with standard error bars.

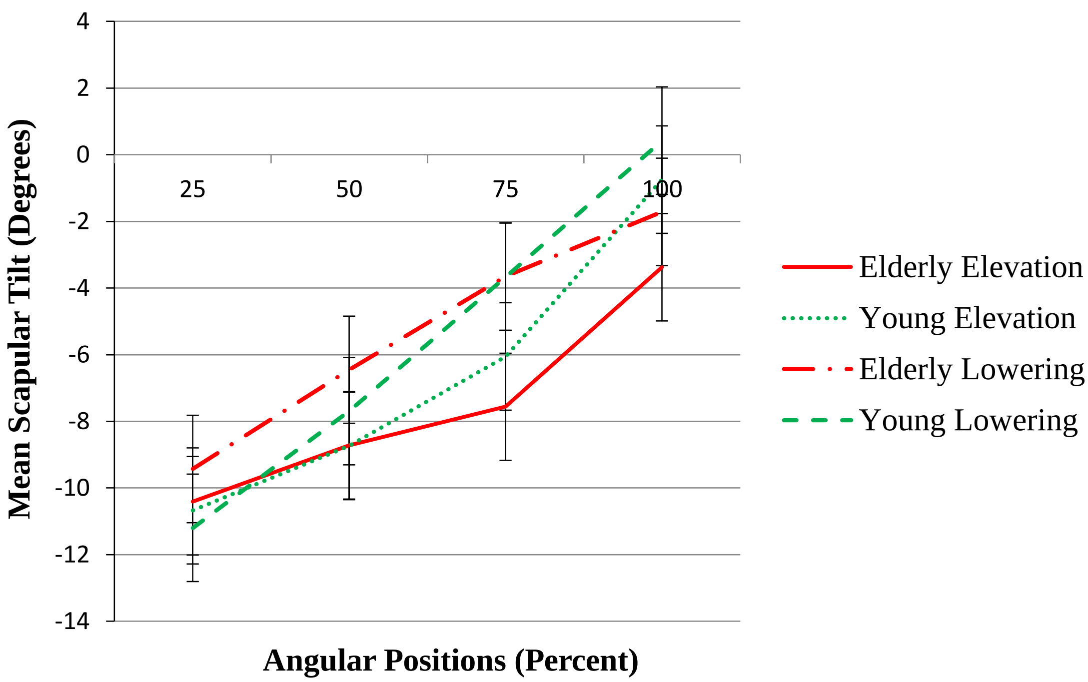


Figure 27. Plot of group by phase by angle interaction effect between the two groups for scapular tilt during forward reach task with standard error bars.

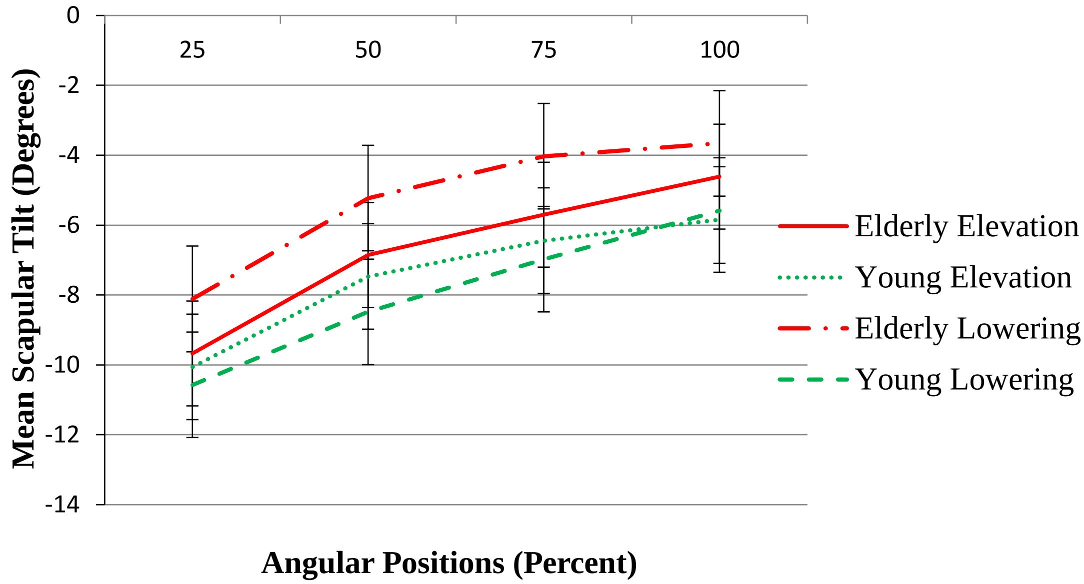


Figure 28.a. Plot between the two groups for scapular tilt during reaching the back task with standard error bars.

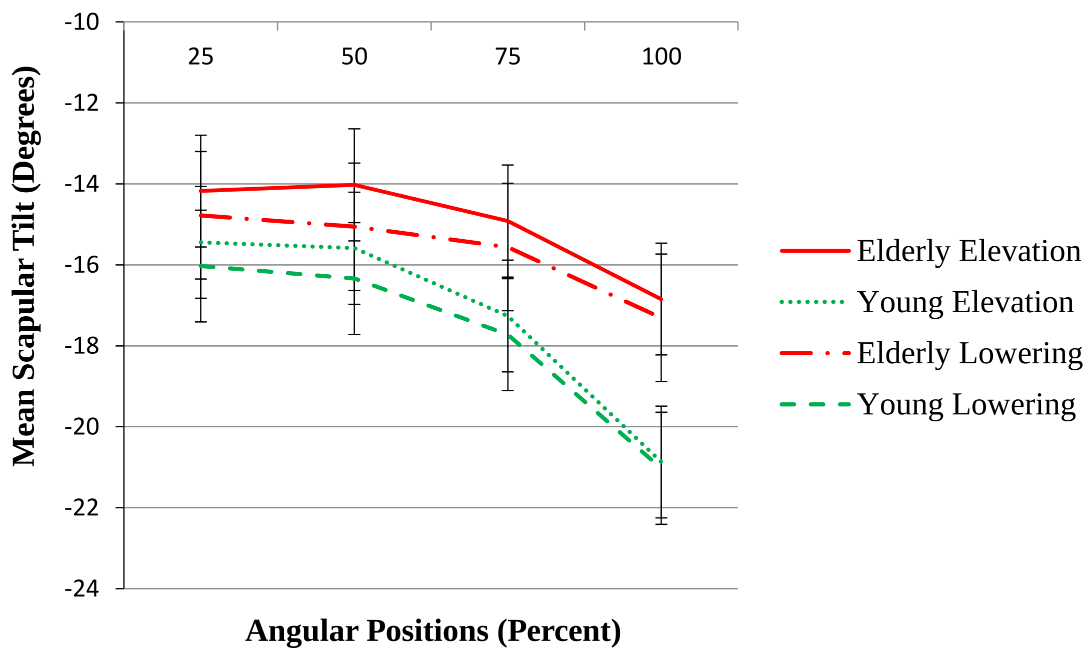
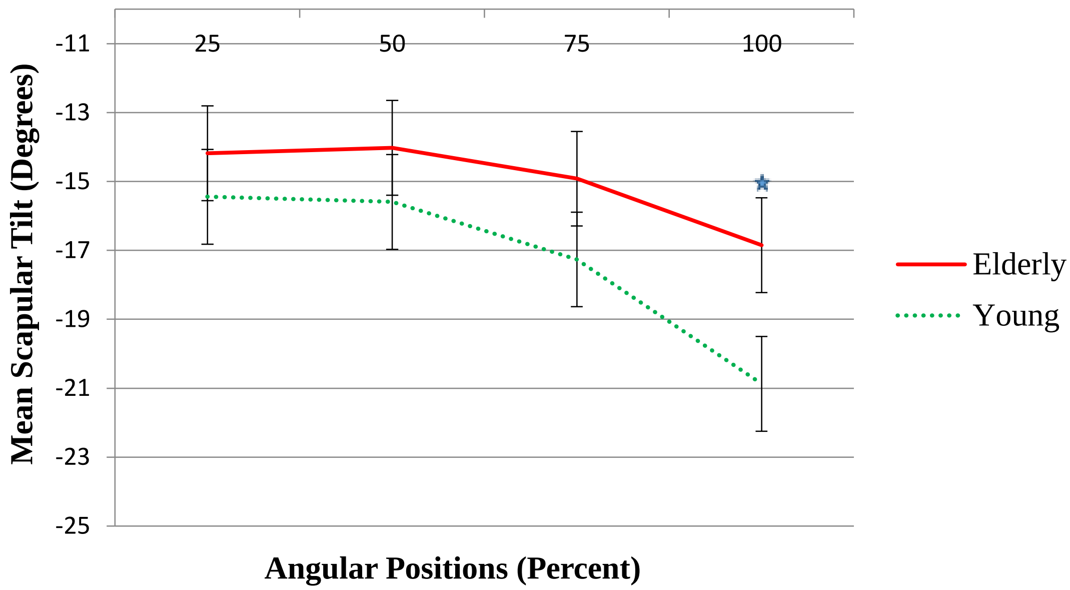


Figure 28.b. Group by angle interaction effect between the two groups for scapular tilt during reaching the back task with standard error bars.



★ Indicates significant difference between groups at 100% angular position

Figure 29. Plot between the two groups for scapular tilt during reaching wallet task with standard error bars.

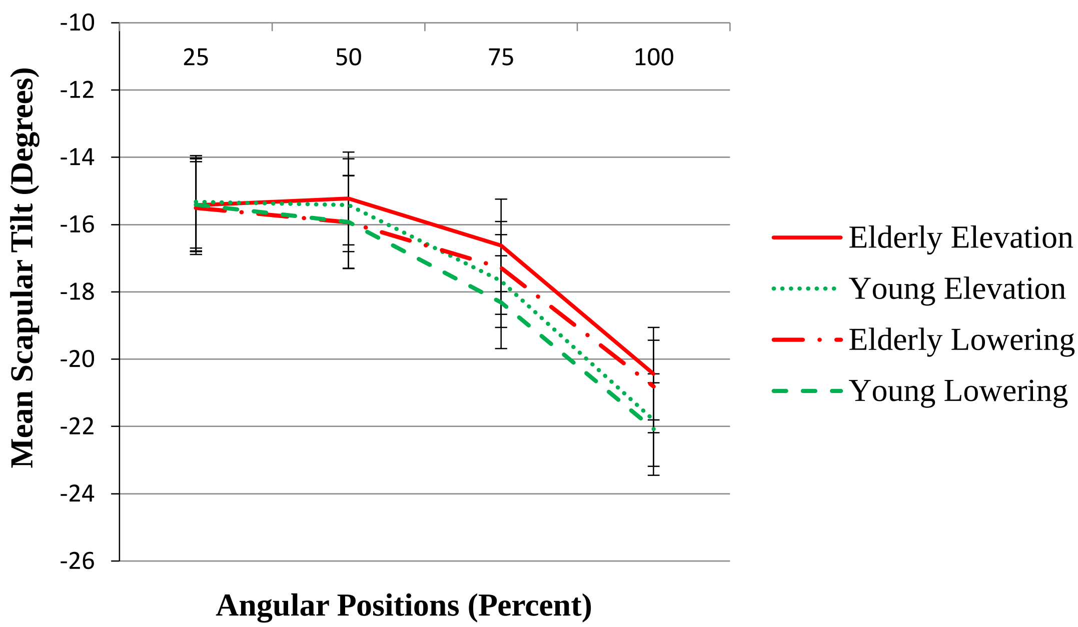


Figure 30. Plot between the two groups for scapular tilt during touching the head task with standard error bars.

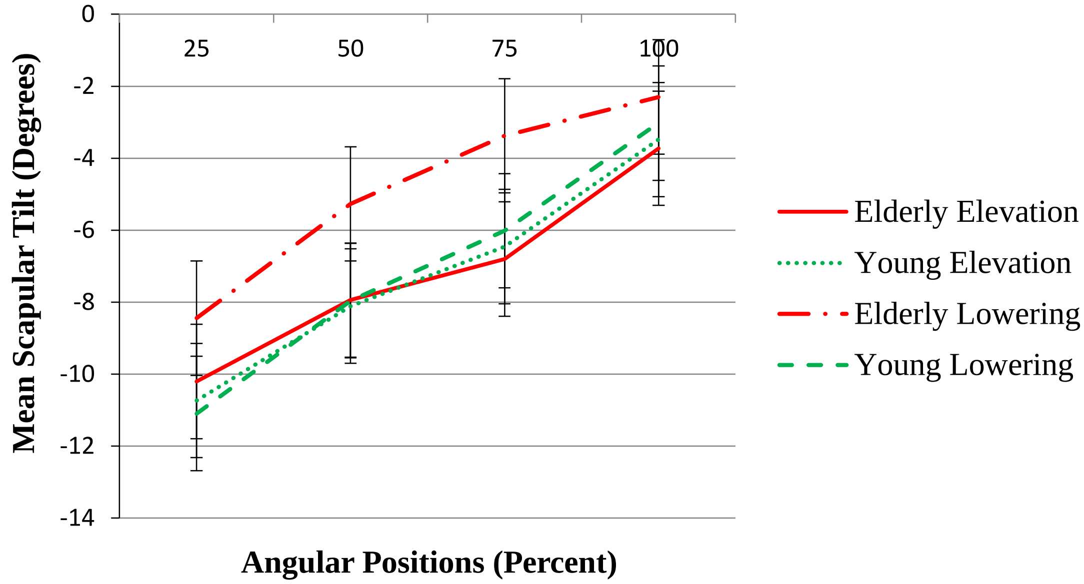


Figure 31.a. Plot between the two groups for glenohumeral (GH) rotation during forward reach task with standard error bars.

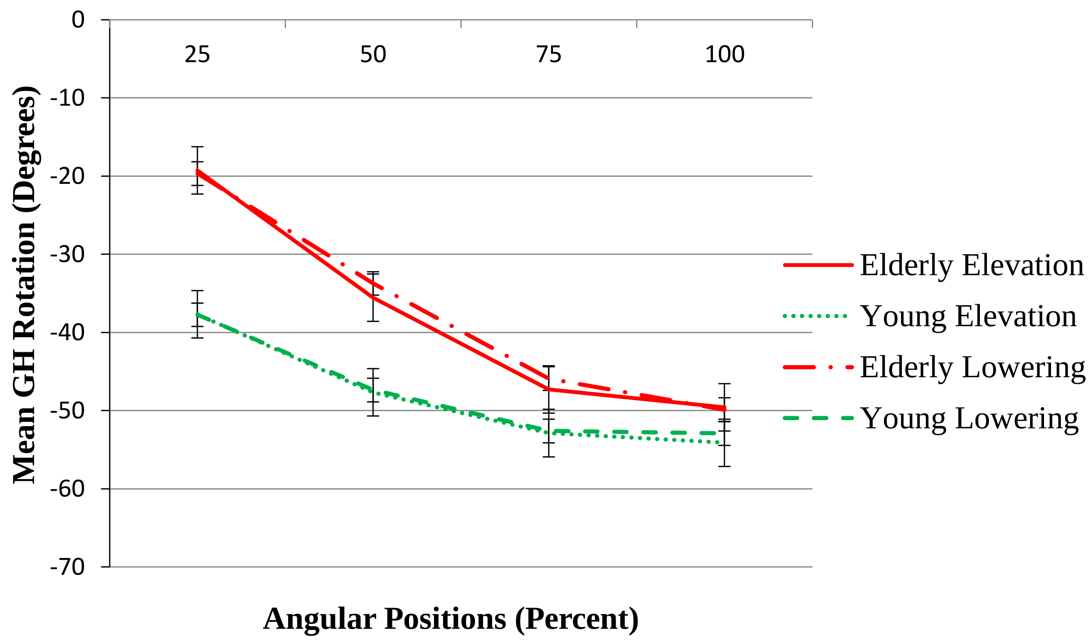
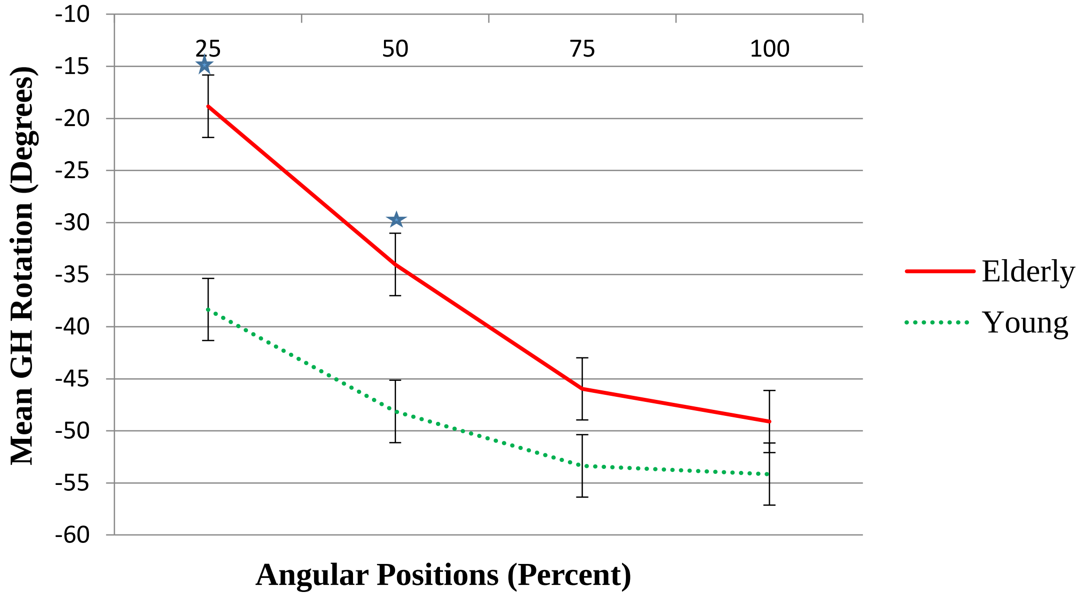


Figure 31.b. Group by angle interaction effect between the two groups for glenohumeral (GH) rotation during forward reach task with standard error bars.



★ Indicates significant difference between groups at 25% and 50% angular positions

Figure 32. Plot between the two groups for glenohumeral (GH) rotation during scapular plane abduction task with standard error bars.

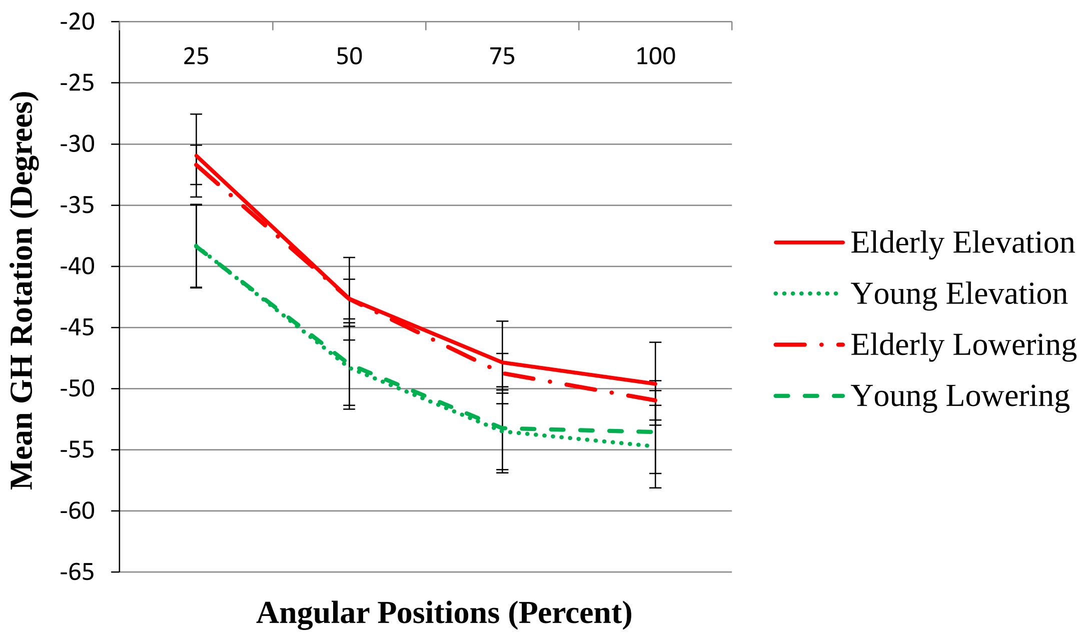


Figure 33. Plot between the two groups for glenohumeral (GH) rotation during reaching the back task with standard error bars.

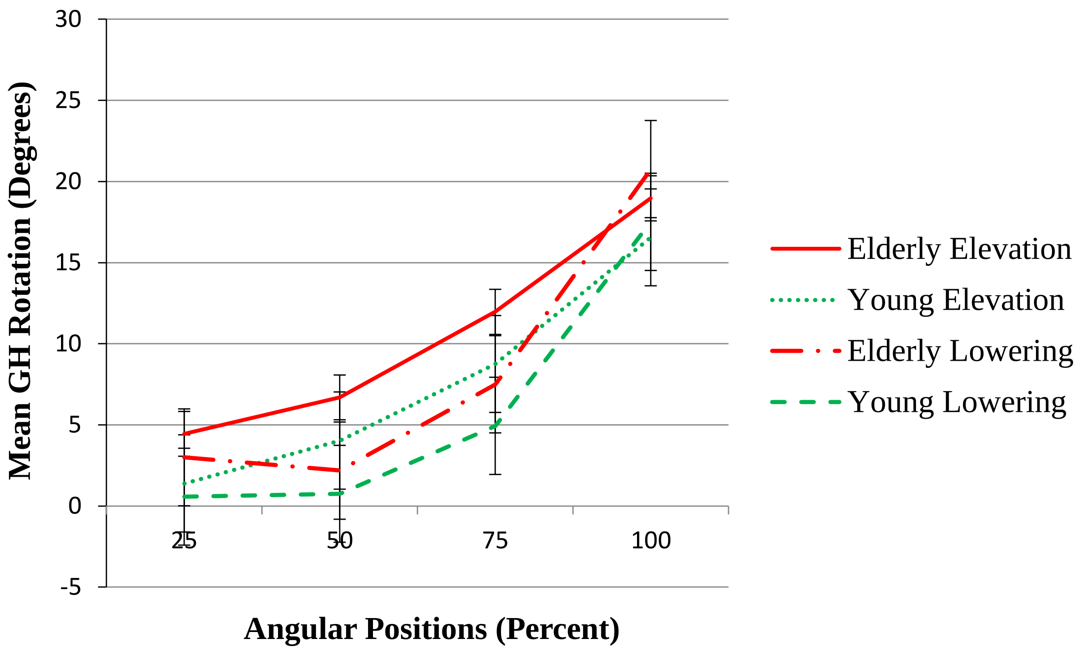


Figure 34. Plot between the two groups for glenohumeral (GH) rotation during reaching wallet task with standard error bars.

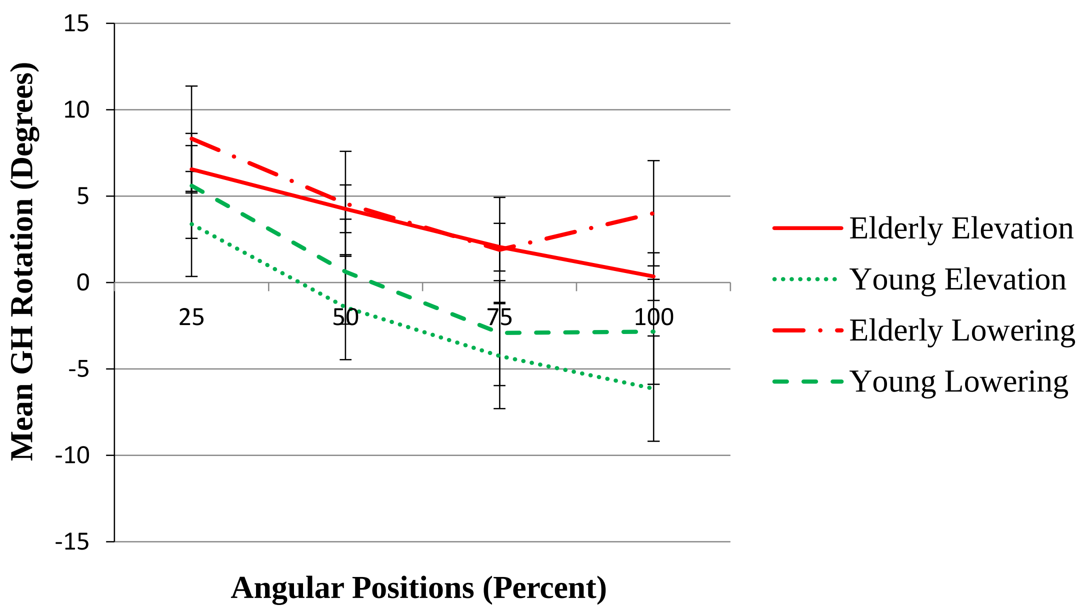


Figure 35. Plot between the two groups for glenohumeral (GH) rotation during touching the head task with standard error bars.

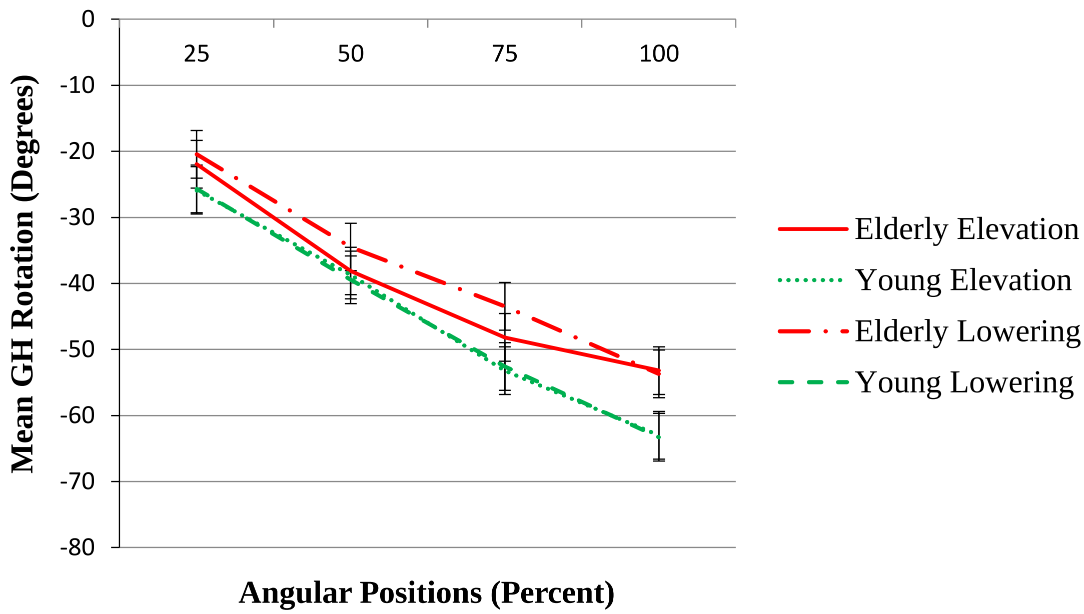
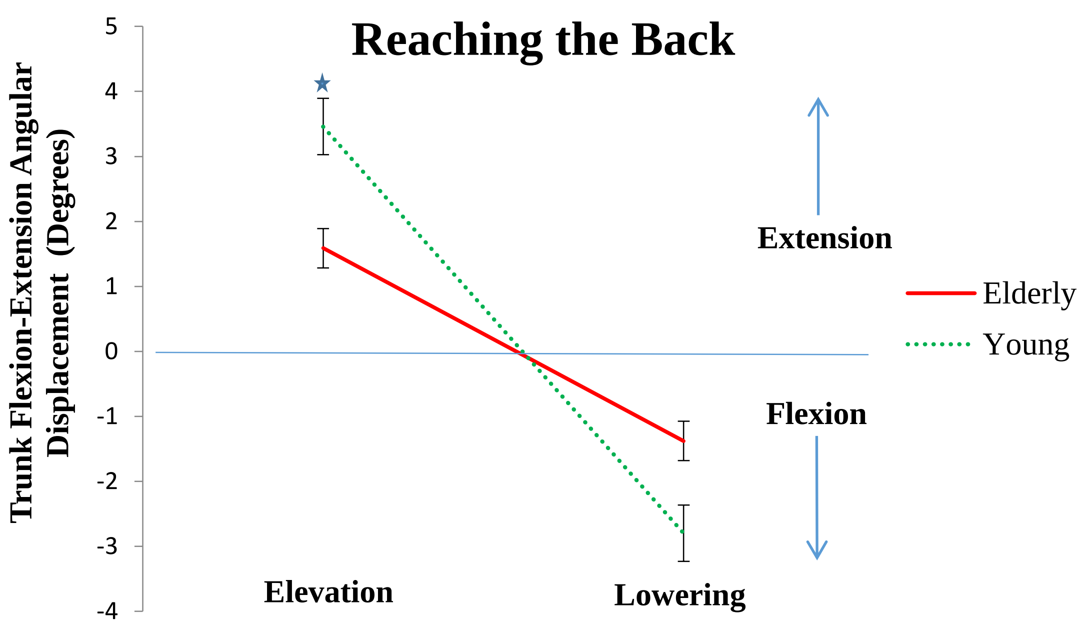
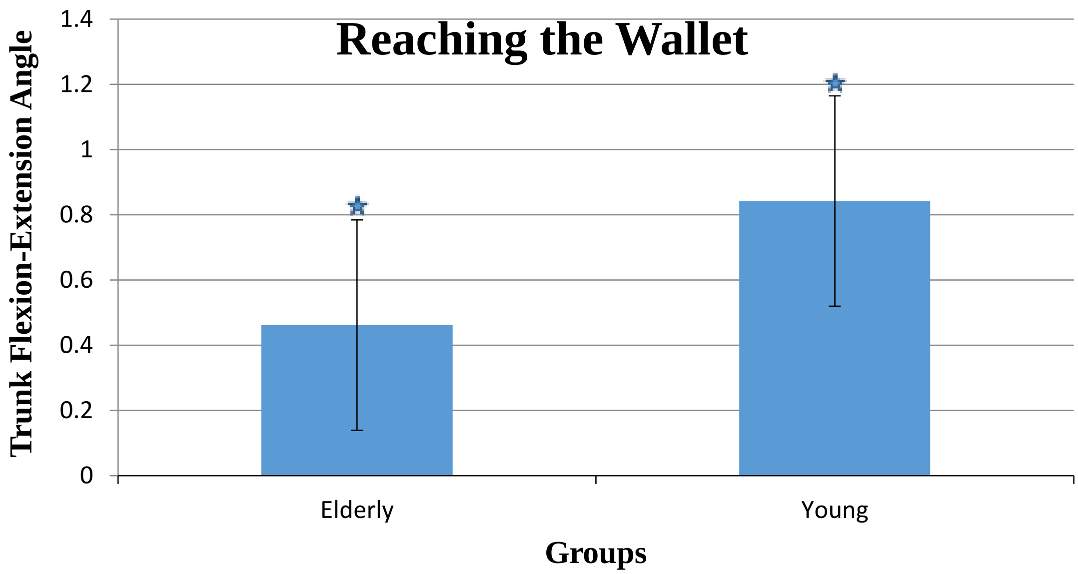


Figure 36. Group with phase interaction plot between the two groups for trunk flexion-extension during reaching the back task with standard error bars.



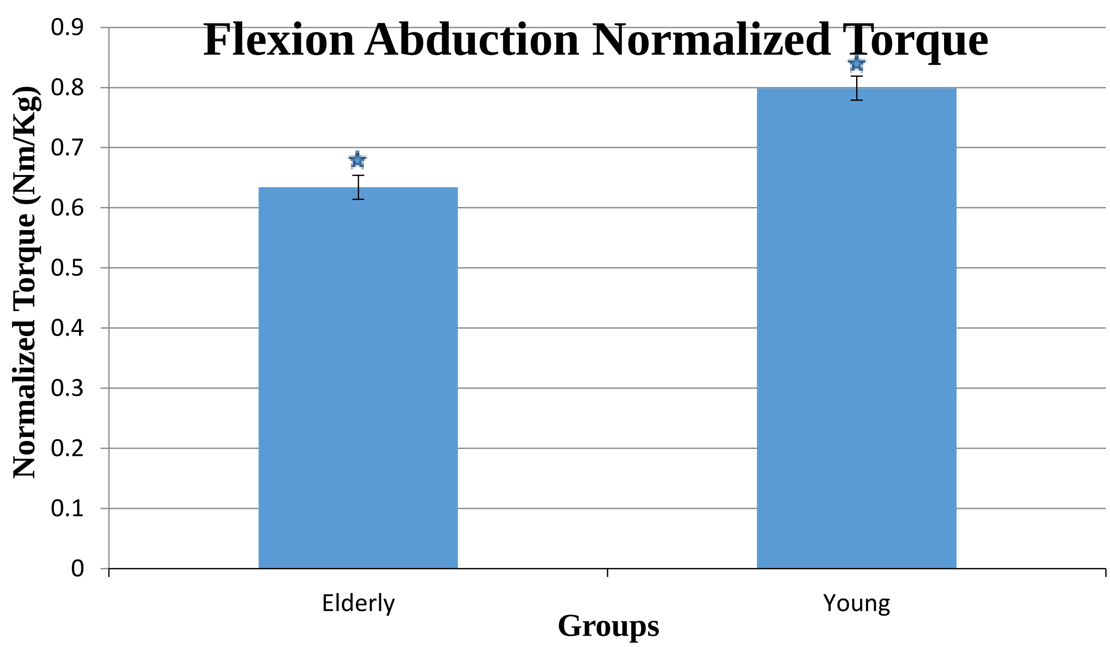
★ Indicates significant difference between groups during elevation phase

Figure 37. Group main effect plot between the two groups for trunk flexion-extension during reaching wallet task with standard error bars.



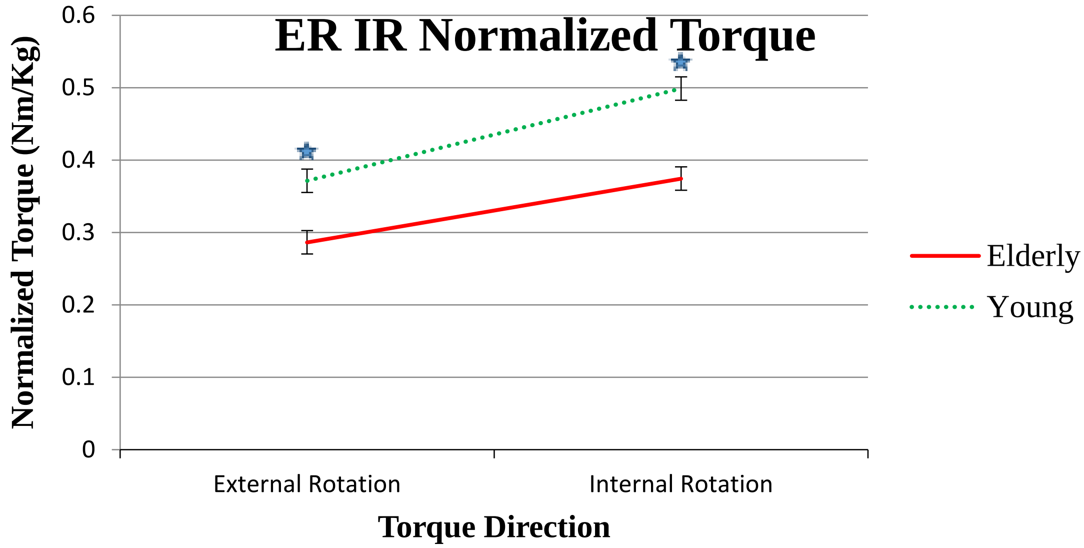
★ Indicates significant difference between groups for both phases

Figure 38. Group main effect plot between the two groups for flexion-abduction normalized torque with standard error bars.



★ Indicates significant difference between groups for both torque directions

Figure 39. Group by direction interaction plot between the two groups for external rotation-internal rotation normalized torque with standard error bars.



★ Indicates significant difference between groups for both directions

CHAPTER V

DISCUSSION AND CONCLUSION

I. Summary and Interpretation of Significant Findings

Goniometric motion for the elderly group was significantly reduced by 5 to 10 degrees for flexion, abduction, scapular plane abduction and external rotation. The elderly group had significantly higher DASH scores (3.28), and significantly reduced (8°) humerothoracic range of elevation motion. Scapular plane abduction motion demonstrated significantly increased scapular internal rotation at 75% (7°) and 100% (7°) angular positions during the elevation phase for the elderly group. The elderly group had increased scapular internal rotation (5°) at the 100% angular position during the reaching the back task. Similarly, during the reaching the wallet task the elderly group had increased scapular internal rotation at 75% (6°) and 100% (7°) angular positions. Scapular upward rotation was found to be reduced (5°) in the elderly group during the elevation phase for the forward reach task. Scapula posterior tilt was increased (4°) in the elderly group at the 100% angular position during performance of the reaching the back task. Glenohumeral external rotation was reduced in the elderly group at 25% (19°) and 50% (13°) angular positions during the forward reach task. The mean DASH scores for the elderly group were 3.55 compared to the young with 0.27. The score for the elderly being 3.3% worse than the young group. The age-adjusted Constant score (Katolik et al., 2005) for the elderly was 86.5 and that of the young was 91.5 (higher score is improved function), with the elderly being 5% worse than the young group. Based on both questionnaires it was evident that there was a consistent significant but small reduction in shoulder function as seen in the DASH score and Constant score in the asymptomatic elderly population when compared to the young.

The range of motion and DASH findings will be subsequently discussed. Of primary interest, however, were the kinematic differences between groups during the various movement tasks. Of relevance is how the magnitude and direction of these differences relate to rotator cuff tendon insertion proximity to potential impinging anatomical structures, and if the kinematic differences present in the asymptomatic elderly group might create any increased risk for mechanical compression of the rotator cuff. In addition, given the presence of differences between groups, determining potential causative mechanisms (thoracic posture or muscle strength imbalances) are also of potential interest.

To better understand the relation between movement dysfunction and potential compression of the rotator cuff tendons under the coracoacromial arch or relative to the glenoid during shoulder joint motion, quantification of distance between these structures was used. Minimum linear distance between rotator cuff tendon insertions and potential impinging structures has been calculated previously by Gold et al., 2007 and Pappas at al., 2006. These studies were limited by static arm position measurements (Gold et al., 2007) and commonly used impingement tests (Pappas at al., 2006). The current study used similar technique to measure the minimum linear distance during dynamic motions, at positions where kinematic differences between groups existed. Collinger et al. (2009), Matsuhashi et al., (2013) and Roh et al. (2000) determined the thickness of the supraspinatus tendon to be between 4.2 and 4.9 mm. As such, a subacromial distance of less than 5 mm. was believed to potentially increase risk of impingement of the cuff as the CA arch can compress the tendon.

In this current investigation, the elderly group may be more at risk for rotator cuff compression during the forward reach task as the minimal linear distance was reduced by 25% for the supraspinatus to acromion, 33% for supraspinatus to CA ligament, and 33% for infraspinatus to acromion distances when compared to the young subjects (Table 10).

During the reaching the wallet task, the elderly group might be at more risk of developing subacromial impingement as the distance was reduced by 38% for supraspinatus to acromion and by 50% for subscapularis to CA ligament compared to the young group (Table 12).However, for this comparison, it should be noted that the values for the young subjects were already extremely low, such that the position may generally create compression risk regardless of age group. It is also possible that the RC tendons are being impinged by the coracoid during the performance of the task, but this mechanism of impingement called coracoid impingement was not studied in the current project.

In contrast, despite significant angular differences between groups for reaching the back and scapular plane abduction tasks, the calculated minimal distances (Table 11 and Table 13) were similar between groups. Subsequently, it is believed that there is no likely increased risk of subacromial or internal impingement for the elderly subjects during these tasks. It is unknown, however, if there are other risks for development of shoulder pain related to these kinematic changes in the elderly.

Based on the kinematic and minimum linear distance findings it seems that the elderly group potentially has increased risk of impingement during the forward reach task. Scapular upward rotation and glenohumeral external rotation are thought to be clinically significant contributors as they are reduced (5° and 13° to 19° respectively) during the forward reach task. The glenohumeral external rotation is reduced by a large magnitude, and this motion was also reduced in the goniometric measure of shoulder external rotation but not internal rotation. It may be useful to further investigate if maintaining or improving glenohumeral external rotation in the elderly during forward reaching has potential to reduce risk of impingement and development of shoulder pain with aging. Interestingly, the elderly group appears to have the ability to externally rotate during elevation similarly to the young group, as noted by no difference in external rotation between groups during scapular plane abduction or touching the head tasks. This suggests that the identified differences in forward reaching might be amenable to movement training.

Glenohumeral plane was not originally included in the analyses to find group differences for glenohumeral external rotation during the forward reach task. As a result, the significant group difference may be due to the effect of glenohumeral plane alterations on glenohumeral external rotation. Subsequently, statistical analyses were conducted to determine if glenohumeral plane of elevation was different between groups during forward reaching task and significant differences in plane of elevation were identified. As a result, minimum linear distances were computed for glenohumeral external rotation "controlling" the glenohumeral plane during forward reach task at 25%

angular position for raising and lowering phases (Appendix 26, Table A26.1 and Table A26.2). The resultant analyses did show that when glenohumeral plane was consistent between the two groups, the group differences in minimal linear distance were reduced.

In addition to the significant kinematic differences found between groups, potential group differences which were not statistically significant were evident in certain conditions for certain variables. Consistent patterns of disparity in sample magnitude between groups were seen in scapular IR during forward reach and touching the head tasks, with the elderly group tending toward increased IR. Similar reductions in the elderly group were noted in GH axial rotation during scapular plane abduction, touching the head and reaching the wallet tasks. Presence of increased thoracic kyphosis was noted in the elderly group when compared to the young even though the difference in magnitude was minimal and not statistically significant. It is possible that these differences currently not statistically significant may be indicators of gradual progression to potentially detrimental biomechanics that could impact shoulder joint function later in life. It should be noted that the average age of the subjects investigated could still be considered “young” old (Novak, 1997). The researcher is not aware of any factor that may contribute to shoulder problems in the study population. These differences between groups both significant and non-significant may be a natural consequence of aging even in the absence of shoulder pain.

The common diagnostic label of shoulder impingement syndrome is somewhat misleading as the pathology encompasses a multitude of shoulder soft tissue problems. Impingement associated with movement dysfunction and presumed cuff compression is usually termed as mechanical impingement. It is still unknown if movement anomalies cause or contribute to the mechanical impingement pathology, or if they result from it. This type of impingement is also classified as subacromial, usually occurring at lower arm elevation angles where RC tendons are impinged under the CA arch. Internal or posterior mechanical impingeent is believed occur at higher arm elevation angles where the RC tendons are impinged by the glenoid. Coracoid mechanical impingement is believed to occur where the subscapularis tendon is compressed by the coracoid process. In the current project subacromial and internal mechanical “impingement” due to movement dysfunction were studied in terms of reduction in minimum linear distance between potential impinging structures. While this potential mechanism for development of shoulder pain from the natural kinematic consequences of aging was investigated, it should be noted that there are other potential mechanisms of development of shoulder pain with aging that were not investigated in this study.

Based on past literature, the kinematic differences between groups might be expected to relate to changes in thoracic posture (Culham & Peat, 1993; Kebaetse et al., 1999). Changes in increased thoracic kyphosis can lead to increased scapular internal rotation (Culham & Peat, 1993; Kebaetse et al., 1999), reduced scapular posterior tilt (Culham & Peat, 1993; Kebaetse et al., 1999) and/or reduced scapular upward rotation (Kebaetse et al., 1999). As a result altered thoracic posture affects scapular kinematics which may lead to reduced shoulder ROM, shoulder dysfunction, and shoulder muscle weakness. While the elderly group had 2° and 0.4° reduced thoracic extension as compared to the young subjects during the reaching the back and reaching the wallet tasks respectively, the magnitude of these differences is so small as to be unlikely of clinical significance. The kinematic differences were also not related to imbalances in strength ratios, as no differences in these ratios were found between groups, despite the elderly group presenting with reduced normalized torque for all comparisons. Based on these findings it can be proposed that thoracic postural differences are not necessarily a natural consequence of aging in the study population. It is also evident that aging will lead to reduced muscle strength (Larsson et al., 1979; Murray et al., 1985; Young et al., 1985) but maintaining or improving overall muscle strength ratios may be a factor in preventing the elderly from having shoulder pain.

A presence of significant group difference for goniometric measurements of shoulder ROM and electromagnetic measures of elevation ROM indicated that there was a reduction in ROM for all directions in the elderly group except for glenohumeral internal rotation. Barnes et al. (2001) indicated similar findings of shoulder ROM changes in their study. The study included 280 healthy subjects equally divided in seven decades (four to 70 years) of life. Goniometrically measured active ROM was collected in six different directions. They used linear regression to predict changes in ROM with age. The study concluded that there was a reduction in forward elevation (flexion), abduction and external rotation with age but shoulder internal rotation range increased with aging. The current study agrees with the results of Barnes et al. for all motions with the exception of glenohumeral internal rotation where there was no change between the groups. The current study findings of reduction in shoulder ROM with aging are not unexpected as were seen in previous literature (Barnes et al., 2001; Macedo et al., 2009;

Medeiros et al., 2013). While it is believed a decrease in ROM might negatively affect function of a joint, the magnitude of reduction between groups was less than 10° for all motions. Functional tasks rarely reach end range of motion to be completed (Aizawa et al., 2010; Magermans et al., 2005; Sheikhzadeh et al., 2008), so these group differences may be of little consequence in relation to ADLs. For clinicians it is important to remember that reduction in ROM that affects completion of functional tasks is more important to treat than ROM reductions that will not affect performance of ADLs.

The DASH score was statistically significant ($t = 5.7$, $df = 45$, $p < 0.01$) even after removing the three subjects with relatively higher scores (>5.0). The mean difference between groups for the DASH score was 2.05. This suggests that there are some minor reductions in function in elderly subjects, even when asymptomatic.

II. Comparison of Findings to Other Studies

The current standard of quantifying shoulder joint kinematics was established by the International Society of Biomechanics (Wu et al., 2005). When comparing to other studies it is important to recognize many different kinematic procedures have been used to quantify shoulder motion such as X- rays (Dvir & Berme, 1978; Freedman & Munro, 1966; Poppen & Walker, 1976), linkage digitizers (Ludewig et al., 1996), 3D electromagnetic surface tracking devices (McQuade et al., 1998; McClure et al., 2001), globographic systems (Doorenbosch et al., 2003), optical systems using cameras and markers (Bourne et al., 2007; van Andel et al., 2008) and 3D electromagnetic sensors attached to bone pins (Braman et al., 2009; Ludewig et al., 2009). Further, scientists have used different coordinate systems and Euler angle sequences (Senk & Chez, 2006; Ludewig et al., 2010; Phadke et al., 2011) to understand shoulder kinematics either more clinically or accurately. Scientists use a variety of methods to collect data and the techniques need to be considered when comparing results and drawing conclusions. Literature on shoulder kinematics during simulated functional tasks or activities of daily living are limited in number (Aizawa et al., 2010; Magermans et al., 2005; Rundquist et al., 2011; Sheikhzadeh et al., 2008). These studies use different methodologies of data collection and interpretation which makes it difficult to compare between studies.

The present study used the current ISB standards of describing thorax, scapula and humeral coordinate systems (Wu et al., 2005) with the exception of glenohumeral rotation where a Cardan sequence (X,z',y") was used (Phadke et al., 2009). The current study and other kinematic studies for functional tasks (Aizawa et al., 2010; Bourne et al., 2007; Magermans et al., 2005; Rundquist et al., 2011; Sheikhzadeh et al., 2008; van Andel et al., 2008) all used the current standard for scapular motion descriptions, but much past work used the posterior acromioclavicular joint rather than the posterolateral acromion. A study by Ludewig et al. (2010) compared the two scapular landmarks (posterior AC and posterolateral acromion) based on old and new ISB scapular coordinate systems and described differences in scapular rotation values during scapular plane abduction. They concluded that the current standard (posterolateral acromion) had reduced scapular internal rotation and upward rotation values throughout the motion as compared to the original standard. Increased posterior tilt at maximum elevation was also noted with the current standard. The magnitudes of differences between the two standards were biggest at maximum humerothoracic elevation angles, which were on an average 6° to 12° for each rotation at 120° of elevation.

Motions in kinematic studies are usually described in phases with small increments in position. The angular positions normally used are 30°, 60°, 90° and 120° of humerothoracic elevation (Camci et al., 2013; Ebaugh et al., 2005; Karduna et al., 2001; Ludewig et al. 2010, McClure et al., 2006; Phadke et al., 2011). Alternate angular positions of 40°, 60°, 80°, 100° and 120° are also used sometimes (Borstad & Ludewig, 2002; Ludewig et al., 2009). These angular positions represent full ROM of humeral elevation. There are minimal functional implications at more than 120° humerothoracic elevation and also greater error in surface sensor tracking due to increased skin slip. To normalize the ROM for all individuals in this study, complete elevation and lowering tasks were assumed to be 100% of the total motion and four phases of 25% each were described across this range. This was done for all tasks except scapular plane abduction, where 100% was defined at 120 degrees, thus not including data where very large skin motion artifacts occur.

1. Scapular internal rotation

Scapular axial rotation during arm elevation has been an inconsistent measure in past studies since there is evidence of both internal (Camci et al., 2013; Ludewig et al., 2009) and external rotation (Ebaugh et al., 2005; Matsuki et al., 2011; McClure et al., 2001) described in the healthy population. During the elevation phase of scapular plane abduction there was a consistent pattern of scapular internal rotation for both the groups in the current study. Motion description was consistent with Camci et al., 2013 and Ludewig et al., 2009. The present study has a mean scapular IR of 38° in the elderly group and 33° in the young group from 30° to 120° of humerothoracic elevation. The values of the current study agree with previously published works (McClure et al., 2001; Ebaugh et al., 2005; Ludewig et al., 2009; Matsuki et al., 2011). A mean of 38° scapular IR was calculated by Ludewig et al. (2009). Similarly, Camci et al. (2013) noted a mean of 37°. Both studies included a young population. Studies by Ebaugh et al. (2005) and McClure et al. (2001) ranged between 43° and 33° respectively. Differences in motion patterns and scapular IR values may be attributed to different subject age ranges, use of dominant/ nondominant shoulders, methodology (such as use of AC joint instead of PLA for building the scapular coordinate system) and interpretation approaches.

In past work, there were significant group differences across the range for scapular internal rotation during the forward reach task (Rundquist et al., 2011). The elderly group had reduced scapular internal rotation by 16° compared to the young population. The current study did not find any significant group difference and the group mean differences varied between 1° to 4° for the four angular positions.

The current study also disagrees with Rundquist et al. (2011) for internal rotation during touching the head task. Rundquist et al. had a significant group difference with reduced internal rotation in the elderly group by 7° across the range. The present study failed to find any significant group difference and the mean difference varied between 4° to 6° for the four angular positions.

2. Scapular upward rotation

Group differences for scapular upward rotation during scapular plane abduction were absent in the present study. The findings suggest that the elderly group had similar motion patterns and magnitude of upward rotation when compared to the young group for this task. The group means at the 25% angular position varied between 1° to 3° and at 100% humerothoracic elevation the mean was 32° for both groups during scapular plane abduction. Endo et al. (2004) collected radiographs for fixed coronal plane abduction motion at two angular positions in 44 healthy subjects with age range between 16-73 years. At 0° abduction the scapular upward rotation varied between 2° to 22° between subjects, compared to 27° to 55° between subjects at 90° abduction. The authors found a significant correlation (r= -0.41) between age and upward rotation at 90° but this was not seen at 0°. Their finding suggests that scapular upward rotation for a fixed angular position reduces with age. The current study had a scapular upward rotation group mean of 20° in the elderly group and 23° in the young group at the comparable 75% angular position, with no significant difference.

The current study presented with reduced scapular upward rotation during the forward reach task for the elderly group which disagrees with the results of Rundquist et al., 2011. Statistically significant group difference was present in the current study, but Rundquist et al. failed to find any difference. Rundquist et al. reported 24° upward rotation across the range for the older group and 25° for the young. The current study reports 1° to 27° variation across the four angular positions in the older group and 3° to 31° in the young group for the similar task.

3. Scapular posterior tilt

Significant differences between groups were seen during the reaching the back task for scapular posterior tilt. The elderly group mean varied between 14° to 17° across the range and that of the young population between 15° to 21°. No significant group differences were present in the current study for posterior tilt during scapular plane abduction motion. At 25% humerothoracic elevation the scapular anterior tilt for the elderly group was 10° and that of the young group was 11°. At 100% humerothoracic elevation the scapular anterior tilt for the elderly group was 3° and that of the young group was 1°. Scapular tilt data collected at 0° humerothoracic elevation for elderly individuals above 50 years by Endo et al. (2004) ranged between 14° to -14° during coronal plane abduction. At 90° humerothoracic elevation the tilt ranged between 0° to 17° for subjects older than 50 years with significant correlation (r= -0.44) between age and scapular tilting. The current study presented with scapular anterior tilt at the 75% angular position during scapular plane abduction. The magnitude of tilt in this position was 8° in the elderly group and 6° in the young subjects, with no significant difference.

The forward reach task did not result in significant group differences in the current study with anterior tilt ranging between 5° to 10° in the elderly group and 6° to 10° in the young. Similarly, Rundquist et al. (2011) failed to find significant group differences and presented with 4° of tilt for the older group across the range and 5° for the young group.

The touching the head task also did not result in any significant group differences in the current study. Anterior tilt values varied between 4° to 10° for the elderly group and 3° to 11° for the young group. Similarly no significant group differences were present in the tilt data collected by Rundquist et al. (2011). Rundquist et al. had 2° of tilt across the range for both the groups.

4. Glenohumeral external rotation

The present study had a significant group difference for glenohumeral external rotation during the forward reach task. External rotation varied from 19° to 49° in the elderly group across the angular positions and between 38° to 55° for the young. Similarly, Rundquist et al., 2011 also found significant group differences during performance of the forward reach task. Rundquist et al. reported values of 38° in the elderly and 50° in the young group across the range of motion. The current study agrees with Rundquist et al. (2011) as both studies presented with significant group differences and also the magnitude of glenohumeral external rotation is similar for both the studies.

The touching the head task did not result in a significant group difference in the current study with glenohumeral external rotation ranging between 22° to 53° in the elderly group and 26° to 63° in the young across 100% humerothoracic elevation. The current study disagrees with Rundquist et al. (2011) as they found a significant group difference with the elderly having 38° and the young 50° of external rotation across the range.

The Rundquist et al. (2011) study differs from the current study with respect to many methodological issues. The authors used a fixed reaching height (177 cm.) for all subjects for the reaching task. Individuals having different height may reach for the object differently. If differences in height exist between elderly and young groups, this may lead to a difference in magnitude of arm motions for the reaching task which is related to height rather than reaching kinematics. Rundquist et al. did not match subjects on height, weight, BMI or arm dominance. BMI in the elderly may be more than the young which may create group differences due to BMI rather than age (Gupta et al., 2013). Skin motion artifact is also likely higher in subjects with higher BMI (Hamming et al., 2012; Karduna et al., 2001). Arm dominance was not explained in the Rundquist et al. study. It may be possible that number of right sided shoulders tested in the young was different than the elderly and this difference in side might create kinematic alterations that may lead to group differences unrelated to aging. Angular values were averaged across the range which may not elucidate the magnitude of change at specific positions that may be important to understand shoulder pain and dysfunction due to rotator cuff dysfunction. Interactions of age and angle or phase of arm elevation could not be detected in the Rundquist et al. study. The current study eliminates these limitations by normalizing the reaching height, matching subjects for BMI and arm dominance, having no history of shoulder joint pain for more than one week in the past 10 years and using four angular positions to describe the motion pattern. Multiple confounders present in the study (Rundquist et al., 2011) makes it difficult to interpret their results accurately.

The Endo et al. (2004) study differs from the current study in aspects ranging from subject inclusion criteria, techniques of data collection and interpretation of results. The authors collected static radiographs at 0° and 90° of coronal plane abduction. Endo et al. found that age was able to explain only 16% of the scapular upward rotation variance at 90° arm abduction. The regression equation was not provided by the authors which made it impossible to calculate the potential magnitude of difference between age groups. Also, some other variables such as gender, which was not matched in the study, may have influenced the correlation of age and scapular motion. The number of males was greater and the mean age was less compared to the female demographics. Data for arm dominance and history of shoulder pain were not provided in the study. Scapular tilt was measured indirectly from AP radiographs using customized mathematical formulas by the authors. The 2D measures of scapular tilt were prone to projection errors. The current study eliminates these limitations by matching subjects for gender and arm dominance, having no history of shoulder joint pain for more than one week in the past 10 years and using a 3D electromagnetic system to collect position data at four angular positions that describes the motion. Multiple confounders present in the study (Endo et al., 2004) makes it difficult to interpret their results accurately.

III. Static and Dynamic Posture

Static posture was computed based on the methods described in the Kebaetse et al., 1999 study. Angular values represent thoracic flexion-extension acute angle. Static thoracic posture was not significantly different between groups. The thoracic flexion value for the elderly group was 36° and that of the young group was 43°. Kebaetse et al., 1999 calculated trunk angle for erect and slouched posture. The mean thoracic angle for erect posture in the sitting position was found to be 26°. Compared to the current study, Kebaetse et al. found reduced thoracic flexion possibly due to collection of data in the sitting position and posture was forced to be erect. The current study had subjects in a relaxed standing posture. Kamitani et al., 2013 concluded that in elderly individuals within a general population the median thoracic angle was about 43°. A somewhat higher value in thoracic flexion compared to the current study may be due to inclusion of symptomatic subjects in the general population. Culham & Peat (1993) measured thoracic posture in young healthy women and calculated the average angular value to be about 30° with the vertical. The lower thoracic flexion angle may be due to differences in inclusion criteria and measurement of the thoracic angle.

Dynamic posture was calculated for all the five conditions as change in the angular value from initial to final position of the trunk sensor during arm elevation. Thoracic extension was reduced in the elderly group for reaching the back and reaching the wallet tasks. The magnitude was small (2° and 0.4° respectively), such that it was not believed to be clinically meaningful. Reduction in thoracic extension for the two reaching tasks in the elderly group may be due to a decrease in shoulder internal rotation end range as evidenced during subject assessment. The young group were able to touch higher levels of thoracic spinous processes with the right thumb when compared to the elderly group. In fact only one of the 25 elderly subjects were able to touch thoracic spinous process higher than T6 compared to 10 subjects in the young group. This reduction in range of motion may relate to a reduction in associated thoracic extension.

IV. Shoulder Muscle Isometric Strength

The elderly group presented with decreased shoulder strength in all the four directions. Flexion normalized torque in the elderly was 56.5% compared to 70.1%. Abduction normalized torque in the elderly was 65.7% compared to 85.1% in the young. External rotation normalized torque was 27.3% in the elderly and 35.8% in the young. Internal rotation normalized torque in the elderly was 36.1% and 48.5% in the young group. Bohannon, 1997 quantified shoulder abduction normalized force to be 25.6% in the elderly and 32.3% in the young. The author measured shoulder external rotation normalized force in the elderly to be 18.9% and 25.2% for the young. The current study agrees with Bohannon with regard to the young group in both studies having higher strength values than the elderly group. Also, abduction strength was more than the external rotation strength in both the studies. The normalized values cannot be directly compared between studies as the current study used normalized torque and the Bohannon study used normalized force.

There were no differences between groups in the current study for the shoulder strength ratios. The flexion to abduction ratio was 0.86 for the elderly and 0.82 for the young. ER to IR ratios for the elderly were 0.76 and 0.74 for the young. Hughes et al. (1999) calculated normalized torque of ER to IR to be 0.79 for the healthy elderly and 0.66 for the healthy young with the arm at 30° external rotation and abducted to 90°.

They found an ER to IR strength ratio of 0.58 (with no group difference) with the arm at 0° internal rotation and abducted to 15°. This position is close to the position of strength measured in the current study. The current study presented with different magnitude of strength ratios to that of Hughes et al. The authors calculated strength ratios with the arm at 15° abduction and 0° internal rotation whereas, the current study had the subject's arm by the side with elbow flexed to 90° and forearm in mid-prone position. Possible difference in values for ER to IR may be due to type of instrument used and method of measuring strength data such as position of arm during data collection.

The data of Hughes et al. (1999) supports the argument that maintaining shoulder strength ratios may help in preventing shoulder pain. The authors reported that the subjects were asymptomatic and had no history of shoulder disorders similar to the inclusion criteria of the current study. The elderly presented with a higher ER/IR strength ratio (0.79) compared to the young (0.66) which might relate to the fact that the elderly group is still asymptomatic by better sustaining ER strength. Maintaining ER strength is believed better to protecting the shoulder joint from RC compression. External rotation during arm elevation will rotate the greater tuberosity from underneath the CA arch and minimize the RC tendons from being compressed beneath the coracoacromial arch. It is believed that glenohumeral external rotation reduces risk of rotator cuff compression. Hughes et al. concluded that with the arm in external rotation there was a higher strength ratio (0.73) than with the arm in internal rotation (0.58), which may help the elderly protect their shoulders from developing any pain or dysfunction, since they are better able to maintain the arm in external rotation in elevated positions.

Other Significant Findings

V. Effect of GH plane on GH axial rotation during forward reach task

The biggest group difference for GH axial rotation was found at the 25% and 50% angular positions during the forward reach task. In fact there was increased potential for rotator cuff compression for the elderly group at the 25% angular position based on smaller minimum distances. The minimum linear distance was reduced in the elderly for supraspinatus (SST) to acromion, and CA ligament and infraspinatus (IST) to acromion when compared to the young. For this same task, there were also differences between groups in GH plane of elevation. Analyses were done to find out if the group differences at the 25% angular position (largest mean difference) was due to the effect of GH plane of elevation or purely due to GH axial rotation. Unpaired Student's t-test was used to find significant group differences for GH plane of elevation at 25% angular position. There was a presence of significant difference ($p<0.01$) between groups (Elderly Mean = 4.22°, Young Mean= 15.09°). Keeping the GH plane of elevation constant (analysis done for both groups using the elderly GH plane and then the young GH plane with all other factors constant) a customized MATLAB code was run to calculate the minimum linear distance for both the groups.

Initially the elderly group GH plane of elevation at the 25% angular position during the forward reach task was forced to be constant. The result was reduction in minimum linear distance in the elderly for the same variables when compared to the young. The reduced minimum linear distances for SST to acromion, SST to CA ligament and IST to acromion were 0.1 mm, 1.1 mm and 0.4 mm respectively (Appendix 26, Table A26.1). Keeping the young group GH plane constant the reduction was 0.1 mm for SST to acromion, 1.0 mm for SST to CA ligament and 0.2 mm for IST to acromion (Appendix 26, Table A26.2).

It was noted that GH plane of elevation influenced minimum distances for all the three pairs (SST to acromion, SST to CA ligament and IST to acromion) in both conditions (keeping elderly and young planes constant). In conclusion, it is important to include GH plane of elevation for analyses of GH rotations and minimum linear distance measures.

VI. Exploratory Analyses for the DASH Score

In order to test the influence of the three elderly subjects with higher DASH scores, implying reduced shoulder functional abilities, they were taken out of the statistical computation for exploratory descriptive analyses. The potential concern was these subjects may not be representative of the intended population, and may have resulted in kinematic group differences being larger than expected. Descriptive analyses were completed for kinematic variables with significant group differences. Plots of scapular IR during scapular plane abduction (Figure A6.1) and glenohumeral axial rotation during the forward reach task (Figure A6.2) were computed since they present with visible differences between the original elderly group and the modified elderly group (excluding the three subjects). The reduced elderly group had a consistently higher scapular IR during scapular plane abduction in both the phases by approximately 1° at all four angular positions when compared to the original elderly group (Figure A6.1). The reduced elderly group had a consistently lower glenohumeral external rotation during the forward reach task in both the phases by approximately 1° to 2° at all four angular positions when compared to the original elderly group (Figure A6.2). It was assumed that the modified elderly group were healthier (lower mean DASH score) than the original elderly group (higher mean DASH score). If expected bias was present, lower scapular IR during scapular plane abduction and more glenohumeral ER during the forward reach task were expected, but contrasting results occurred. The rest of the condition combination axial rotation plots between the two groups closely matched in magnitude and direction such that the plots overlapped. Therefore, it is believed that the inclusion of all elderly subjects did not create any abnormal kinematic group differences.

VII. Post hoc Power Analyses

Post hoc power was calculated for scapular internal rotation during scapular plane abduction and touching the head tasks, glenohumeral axial rotation for touching the head task, and static thoracic posture. A post hoc power analysis was computed for the kinematic variables which were thought to have potential meaningful mean differences between groups, yet were not demonstrated to be statistically significant. Two examples are provided in Appendix 27. Post hoc power was calculated for scapular internal rotation during scapular plane abduction resulting in 55% power to find a difference of 6° based on the group variability noted in this study. Post hoc power was computed for scapular internal rotation during touching the head task which resulted in 62% power to find a difference of 6° based on the group variability noted in this study. Post hoc power analysis was completed for glenohumeral external rotation during touching the head task resulting in 55% power to find a difference of 10° based on the group variability noted in this study (Appendix 27). Post hoc power was calculated for the static posture factor which resulted in 54% power to find a difference of 10° based on the group variability noted in this investigation (Appendix 27).

It is possible that with a bigger sample size a significant difference between groups could be achieved, particularly for static thoracic posture. However, more than 50 subjects was impractical for this investigation. It was noted that significant kinematic differences between groups were evident with smaller magnitude in certain condition combinations such as scapular tilting during reaching the back task with a 4° group difference and for thoracic flexion-extension during reaching the wallet task with 0.4 degree group difference. The study was not powered a priori for all variables. Post-hoc power was calculated for axial rotation (scapular and glenohumeral) where values are known to have higher rate of variability and skin motion artifacts compared to other angular values (Hamming et al., 2012; Karduna et al., 2001).

VIII. Clinical Implications

It is believed based on the study results that the shoulder can be painfree and have minimal movement deviations as a natural consequence of aging in the elderly population. Most of the comparisons did not result in kinematic differences between groups. There were no differences between groups in static thoracic posture. It was found that there was reduced dynamic thoracic extension in two tasks, both reaching behind the back for the elderly group. However, the mean differences were small enough to suggest that they were not likely clinically meaningful. This is particularly true considering the added factor that the elderly group had reduced humeral internal rotation range of motion during the task, probably due to reduced flexibility.

Muscle strength loss is inevitable with aging (Larsson et al., 1979; Murray et al., 1985; Young et al., 1985) and it was seen in the elderly group as reduced shoulder strength in all directions tested. However, it was noted that there was balanced strength loss for comparative muscle groups, as evident from strength ratio testing. This raised the possibility that maintenance of strength balance may be a more important factor than overall strength with regard to having painfree shoulder motion in the elderly.

The current study presented with some group differences for shoulder kinematic variables that deserve further consideration. It is believed that certain tasks at specific angular positions can reduce the subacromial space for the elderly group. The concern was in the differences noted in rotator cuff tendon proximity during the forward reaching task. If attempting to develop proactive interventions to minimize development of shoulder symptoms and maximize function with aging, physical therapists and other healthcare professionals should focus their intervention from a global perspective. It is important to consider stretching, strengthening and improving endurance of shoulder musculature, but equally or possibly more important, is to understand techniques to alter abnormal kinematic patterns or maintain appropriate motion sequences during performance of functional tasks. It was also noted that the rotator cuff proximity was most reduced between groups during performance of the forward reach task. It may be of importance to maintain and improve scapular upward rotation and glenohumeral external rotation as they are assumed to have an influence in changing the subacromial space width. Physical therapy approaches might include motor control and biofeedback training to maintain or improve muscles related to proper functioning of scapular upward rotation and glenohumeral external rotation. Focused training of muscles such as serratus anterior and lower trapezius for upward rotation and posterior deltoid, infraspinatus and teres minor for glenohumeral external rotation might help prevent shoulder symptoms. Also maintaining and improving shoulder flexibility with specific and targeted stretching exercises for the shoulder may improve performance of reaching the back where shoulder IR is an important component.

IX. Limitations of the study

The elderly population (mean of 71 years) who volunteered for the study were categorised as a “young elderly” population. There were no particiapnts older than 75 years which would fall under “old” and above 85 years for the “old-old” category. As such, differences between groups may have increased if older subjects were recruited. There was no evidence of a consistent pattern of abnormal scapular kinematics such as decreased scapular UR which may occur in the presence of a RC tear (Endo et al., 2001; Lin et al., 2006; Ludewig & Cook, 2000). As a result, it is believed that RC tear was not consistently present in the asymptomatic elderly population who volunteered for the current study.

Use of surface markers is prone to errors due to skin slip. A comparative study by Karduna et al. (2001) found an increased error rate (more than 5°) for the three scapulothoracic rotations between surface sensor measurement and sensors mounted on bone pins above 120° of humerothoracic elevation. Motion capture through 3D electromagnetic systems using surface sensors are relatively easy to use, faster and not invasive compared to bone-pin and imaging methods that are time consuming, use complex data processing, are expensive and include increased risk for subjects. Scapular motion agrees reasonably accurately between surface sensor methods and the invasive technique if movements are completed below 120° (Karduna et al., 2001). The limitation of skin-slip errors using surface sensors had been minimized by completing the tasks below 120° of humerothoracic elevation (<6° error) where skin motion artifact is lessened (Karduna et al., 2001). Humeral axial rotation was measured simultaneously using electromagnetic surface sensors and invasive bone-pin method by Hamming et al., 2012. The authors concluded that the average error in measuring glenohumeral internal/external rotation was 4° at 30° arm elevation to 6° at 120° arm elevation.

Another limitation of the study is that a single CT scan was used for modelling rotator cuff tendon insertion proximity using group mean values. This approach does not take into account the different body morphology and other individual anatomic variations. However, the research question attempts to answer how group differences based on kinematic factors influence the rotator cuff, rather than the impact of individual anatomical factors. The potential interactions of kinematic and anatomical factors may be of future interest. It was further assumed that the humeral head was centered on the glenoid throughout motions, with no translations factored into the modeling calculations. Humeral head translations would affect the calculations equally between groups, unless translation differences were present between groups. Currently accurate measurement of translations of the humeral head center was not feasible with surface sensors.

An additional limitation is that digitization for thoracic angular measurement was done by palpating the spinous processes. The tester might have incorrectly digitized the spinous processes or erred in counting the number of spinous processes. The impact was minimized as subjects were evaluated by the same tester with systematic bias between groups unlikely. BMI was matched between groups so palpation of spinous process was done using similar technique for both groups.

Finally, hand held dynamometry was used to measure isometric strength which is dependent upon the tester force production. As such, the tester may bias the strength output. The subjects had to meet the strength of the tester. A weaker tester might not be able to produce enough force to overcome the subjects’ strength and “make” the subjects force production. Alternatively, examiner bias might vary force production by judging how much force to apply in looking at the subject. This bias if present, would result in greater strength loss being reported for the elderly than actually existed. In the current study overall measurement error was reduced as the same evaluator determined the strength of all the subjects. Strength differences between groups were consistent with previous literature. Also, an average of two trials was used to quantify strength in this study. Reliability statistics were computed and demonstrated excellent (Portney & Watkins, 2009) reliability (ICC= >0.93 and SEM: <0.05). Any effect of systematic bias, if present, should be eliminated in the ratio calculation and the strength ratios were not different between groups.

X. Future Directions

It is hoped that the result of the current study will help in improving the biomechanical understanding of shoulder motion and strength in the elderly population. Further research is warranted to explore the relationship between shoulder pain and abnormal shoulder kinematics in a symptomatic elderly population. Potential methodological changes to avoid the limitations observed in the current study may include the use of subject-specific imaging to accurately predict rotator cuff tendon proximity to potential impinging structures, and also improve analysis of how and when an individual might develop shoulder mechanical impingement. Non-invasive measurement of humeral head translations in dynamic conditions, not taken into account in the current study, can be achieved through fluoroscopic imaging techniques.

Few group differences existed for the tested conditions and those that were different had small magnitudes. Based on the findings it was believed that the shoulder can be painfree and the natural kinematic consequences during functional motion for aging subjects are minimal, despite range of motion and strength losses. The study elucidated the few variables that were significantly different between the elderly and the young. Based on the present findings it was assumed that maintaining scapular upward rotation and glenohumeral external rotation and strength ratios may prevent the asymptomatic elderly population from developing rotator cuff disease. Possible modification of the forward reach task may protect the elderly from shoulder pain by reducing potential for rotator cuff compression. The researcher believes that specific motions such as the forward reach task should be further investigated between symptomatic and asymptomatic elderly groups to show any presence of group differences with respect to magnitude and direction of motion. Subject-specific image analysis can be done in order to accurately quantify rotator cuff thickness and increase precision of kinematic analyses by adding the humeral translation factor. Immediate effects of exercise positions to find out changes in kinematics and space might help understand specific and targeted exercise preventing shoulder symptoms that may occur due to repeated performance of simulated functional tasks such as the forward reach. Longitudinal assessment of the SA space and rotator cuff soft tissues based on image analysis of targeted exercise intervention might help scientists find causation of reduced SA space and shoulder impingement with aging. In order to improve quality of life of elderly individuals exercise prescription should be further investigated with regard to potential to reduce development of symptomatic shoulder dysfunction.

XI. Summary and Conclusion

Few group differences existed for the tested conditions and those that were different had small magnitudes. Based on the findings it was believed that the natural kinematic consequences of aging with regard to shoulder motion during functional taks are minimal. The study examined group differences for shoulder joint kinematics during dynamic activity of four functional tasks and scapular plane abduction. The rotator cuff tendon insertion proximity to potential impinging structures was measured based on a single CT scan anatomical model. Static and dynamic thoracic posture were measured during the five activities, and shoulder joint isometric strength measures were collected. Three scapulothoracic rotations and glenohumeral axial rotation were analyzed for between group differences during scapular plane abduction, forward reach, reaching the back, reaching for the wallet and touching the head tasks.

Significant differences were detected in some kinematic variables during performance of the five tasks. Scapular internal rotation was more in the elderly group by 7° for scapular plane abduction. The elderly group had more scapular internal rotation by 5° during reaching the back task. Scapular internal rotation was more in the elderly group on average by 7° for reaching the wallet task. Scapular upward rotation was reduced by 5° in the elderly group and glenohumeral external rotation was less on average by 16° in the elderly group during the forward reach task. Scapular posterior tilt was more in the elderly group by 4° for reaching the wallet task. The mean differences between groups were less than 8° for all combination comparisons that were significantly different with the exception of glenohumeral external rotation (<19°) during the forward each task. Minimum linear distance was reduced (below 5.0 mm threshold) in the elderly group during the forward reach task by 25% between supraspinatus to acromion, and 33% between supraspinatus to CA ligament and also by the same amount between infraspinatus to acromion. Reaching the wallet task also resulted in reduced minimum linear distance in the elderly group by 38% between supraspinatus to acromion and 50% between subscapularis to CA ligament, however these later changes were based on submillimeter reductions and are likely not functionally relevent. Based on the findings it was believed that the forward reach task creates maximum potential for rotator cuff compression in the elderly group as compared to the young. On the other hand, the reaching the wallet task had nearly similar risk of impingement between groups, as the minimum linear distance was submillimeter for both groups suggesting that position of the arm during this task is a problem and not aging. The elderly group had reduced extension during dynamic thoracic posture analyses for reaching the back (2°) and reaching the wallet (0.4°) tasks. However, the resultant magnitudes were very small (<2°) and deemed not to be clinically meaningful. Shoulder joint muscle strength was significantly reduced in the elderly group (ranging between 0.08Nm/Kg to 0.13 Nm/Kg) in all directions but the strength ratio did not change between groups, meaning strength losses were symmetrical for the two groups. The inference is that strength loss with age is inevitable but if the ratios remain constant over time then it may be possible to prevent shoulder pain and dysfunction due to rotator cuff issues. It was noted that few differences between groups were found and the degree of these differences were small. It can be surmised thatthe natural kinematic consequences of aging are minimal with regard to functional shoulder motion. Maintaining strength ratios was thought to be protective from developing rotator cuff disease. Modification of the forward reaching and reaching the wallet tasks may be considered during planning shoulder intervention strategies. Application of this knowledge might help plan interventions that can help the shoulder remain painfree and have normal functional status in the elderly.

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APPENDICES

Appendix 1: Consent Form

Understanding Shoulder Pain in the Elderly Population

You are invited to participate in a research study of shoulder joint motion and strength during arm raising activities. We will gather information on your trunk posture in standing and an MRI scan of your shoulder joint will be completed to see if pathology is present. You were selected as a possible participant because you contacted the investigators about this study, you responded to an announcement of this study, or you informed your physician or physical therapist that you were interested in this study. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by Sanjay Sarkar, a PhD student, under the advisement of Dr. Paula Ludewig, PhD, PT. Dr. Ludewig is on faculty in the Program of Physical Therapy within the Department of Physical Medicine and Rehabilitation at the University of Minnesota. Dr. Jonathan Braman, MD, Assistant Professor, Department of Orthopaedic Surgery, University of Minnesota is also a member of the research team.

Study Purpose

Chronic pain leads to disability in the older population and results in muscle weakness with reduced functional abilities. The second most common cause of joint pain is due to shoulder joint problems.
The purpose of the study is to determine if unique biomechanical characteristics exist in a geriatric population that protects them from being affected with anterolateral shoulder pain.

Study Procedures

If you agree to participate in this study, we will ask you to do the following:

1) Provide background information to the investigator (age, height, weight, medical history, and functional limitations).
2) Receive a clinical screening for shoulder motion and pain.
3) Have three motion sensors (about one inch square each) taped to the skin over the acromion, on the sternum, and a thermoplastic cuff strapped to the arm just above the elbow.
4) Identify skeletal landmarks to collect trunk posture data in standing.
5) Elevate your arm actively through several motions within your normal range of movement (overhead and behind the back).

6) Isometric shoulder joint strength in different positions will be quantified by the investigator using a hand held dynamometer.
7) MR scans will be taken following standard shoulder imaging protocols.

All sensors will be removed at the end of the data collection session. The testing will not involve any invasive procedures. You will be asked to participate for 2 sessions lasting up to 2 hours per session. No additional visits are required.

Risks of Study Participation

The study has the following risks:
1) Minor skin irritation from tape used to attach the surface sensors (occurs in less than 5% of subjects)
2) Mild muscle or joint soreness from holding your arm in elevated positions (occurs in less than 10% of subjects).
3) MR scans can cause claustrophobia which is temporary and electromagnetic radiation which we will keep at a minimum level by controlling the number of scans taken.

Benefits of Study Participation

The benefits to study participation are: There are no direct benefits to your participation in this study. Information and data gathered from the study may assist in designing specific and effective exercise protocols to prevent or treat shoulder pain. We hope applying evidence based exercise programs will reduce occurrence, progression and disability of the shoulder due to pain and dysfunction, thereby reducing healthcare cost of aging and improving quality of life.

Alternatives to Study Participation

There is no treatment involved in the study. It is not intended to substitute for any medical care you might seek out for your shoulder pain.

Study Costs/Compensation

You will not incur any costs for your participation, nor will you receive any monetary compensation for participating in this study.

Research Related Injury

In the event that this research activity results in an injury, treatment will be available, including first aid, emergency treatment and follow-up care as needed. Care for such injuries will be billed in the ordinary manner to you or your insurance company. If you think that you have suffered a research related injury, let the study physicians know right away.

Confidentiality

The records of this study will be kept private. In any publications or presentations, we will not include any information that will make it possible to identify you as a subject. Your record for the study may, however, be reviewed by departments at the University with appropriate regulatory oversight. Beyond indicating your participation in the shoulder study, no information will be included in your medical records. To these extents, confidentiality is not absolute. Study data will be encrypted according to current University policy for protection of confidentiality.

Protected Health Information (PHI)

Your PHI created or received for the purposes of this study is protected under the federal regulation known as HIPAA. Refer to the attached HIPAA authorization for details concerning the use of this information.

Voluntary Nature of the Study

Participation in this study is voluntary. Your decision whether or not to participate in this study will not affect your current or future relations with the University, University of Minnesota Medical Center- Fairview, physicians, nor the investigator(s). If you decide to participate, you are free to withdraw at any time without affecting those relationships.

Contacts and Questions

The researchers conducting this study are Sanjay Sarkar, under the advisement of Dr. Paula Ludewig, PhD, PT. You may ask any questions you have now, or if you have questions later, **you are encouraged to** contact them at Program in Physical Therapy, Box 388 MMC, The University of Minnesota, Minneapolis, MN 55455, 612-626-0420 or 612-626-5566.

If you have any questions or concerns regarding the study and would like to talk to someone other than the researcher(s), you are encouraged to contact the Fairview Research Helpline at telephone number 612-672-7692 or toll free at 866-508-6961. You may also contact this office in writing or in person at *Fairview Research Administration, 2433 Energy Park Drive, St. Paul, MN 55108.*

You will be given a copy of this form to keep for your records.

Statement of Consent

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature of Subject___________________________________

Date__________________

Signature of Person Obtaining
Consent____

Date__________________

Appendix 2: Subject Information Form

Understanding Shoulder Function in the Elderly Population

Test Date:

Name:

Date of Birth:

Age:

Sex:

Marital status:

Height:

Weight:

Address:

E- mail:

Phone (Home):

Phone (Cell):

Emergency contact name:

Emergency contact phone:

Ethnic category (check one): __________ Hispanic or Latino
__________ Non-Hispanic or non- Latino

Racial category (check one): __________ American Indian/Alaska Native
__________ Asian
__________ Native Hawaiian or Other Pacific Islander
__________ Black or African American
__________ White

Please call Sanjay Sarkar with questions at 507-382-8946 or 612-626-3298.

Appendix 3: Subject Questionnaire Form

Understanding Shoulder Function in the Elderly Population

(Circle Your Response)

Do you consider yourself left or right-handed? L/R

Side to test _______________

Do you have a history of skin sensitivity or skin allergies, especially with tape Y/N

Do you have a history of fainting secondary to prolonged standing? Y/N

Do you have a history of fainting secondary to pain? Y/N

Have you had exposure to ionizing radiation (X-ray, CT) within the last year? Y/N

Do you have any other diagnosed medical condition? Y/N

If yes: What type? ____

Have you ever injured your shoulder(s)? Y/N

If yes, what type of injury:

Labral tear	Y/N	L/R
Glenohumeral joint dislocation	Y/N	L/R
AC or SC joint instability	Y/N	L/R

If any stabilization was performed?___________________________________

If any displacement was noted?______________________________________

Fracture:	collarbone (clavicle)	Y/N	L/R
	upper arm (humerus)	Y/N	L/R
	shoulder blade (scapula)	Y/N	L/R
Shoulder tendonitis		Y/N	L/R
Shoulder impingement		Y/N	L/R
Rotator cuff tear		Y/N	L/R
Shoulder bursitis		Y/N	L/R
Scoliosis		Y/N	L/R
Shoulder strain		Y/N	L/R

Other:

Describe injury(ies):

When was the injury or onset of symptoms? ______________

Have you ever had surgery on your shoulder(s)? Y/N L/R

If yes, describe: ____

Are you currently experiencing pain in your shoulder(s)? Y/N L/R

If yes, describe: ____

Are you currently experiencing any neck pain? Y/N L/R

If yes, describe: ____

Are you currently experiencing any arm pain, numbness or tingling? Y/N L/R

If yes, describe: ____

Are you currently receiving any treatment for your neck, shoulder(s) or upper limb? Y/N L/R

If yes, describe: ____

Have you ever had any neurological disorder(s)?
[Ex- traumatic brain injury, stroke, peripheral nerve injury or compression affecting the tested upper limb, myasthenia gravis, spinal cord injury, motor neuron disorders] Y/N

If yes, describe: ____

Have you ever had any congenital anomalies and/ or systemic illness affecting the musculoskeletal system? [Ex- Rheumatoid arthritis] Y/N

If yes, describe: ____

Have you ever had any skin infection(s)? Y/N

If yes, describe: ____

Appendix 4: Clinical Examination Form

Understanding Shoulder Function in the Elderly Population

	Left	Right
STANDING		
Shoulder ROM:		
Flexion	________	________
Abduction	________	________
Coronal Plane Abduction (at least 120°)	________	________
Cervical ROM:		
Flexion/ Extension	WNL- Y/N	WNL- Y/N
Bilateral Rotation	WNL- Y/N	WNL- Y/N
Bilateral Side- bending	WNL- Y/N	WNL- Y/N

Visual observation:

Scapular dyskinesis: ____

	Left	Right
Inferior Shoulder Instability Test:		
Sulcus Test	WNL- Y/N	WNL- Y/N

SITTING

	Left	Right
Cervical spine (reproducible *shoulder* symptoms):		
AROM	+/-	+/-
Quadrant Tests	+/-	+/-
Compression/Distraction test	+/-	+/-
Resisted shoulder strength:		
Flexion– arm by the side	_____	_____
Extension– arm by the side	_____	_____
Abduction– arm by the side	_____	_____
ER – arm by the side	_____	_____
IR – arm by the side	_____	_____
Abduction – arm at 90°	_____	_____
ER – arm at 90°	_____	_____
IR – arm at 90°	_____	_____
Impingement Tests:		
Hawkins/Kennedy	+/-	+/-

Neer	+/-	+/-
Jobe	+/-	+/-

Other Tests:

Painful arc	+/-	+/-
Scapular assistance test	+/-	+/-
External rotation resistance test	+/-	+/-

Pain with Palpation:	+/-	+/-

Localization (circle if positive):

Supraspinatus	Bicipital groove	Subscapularis
Coracoid process (Pec minor insertion)	AC joint	Infraspinatus

SUPINE

	Left	**Right**
Shoulder ROM:		
IR (Arm at 90° abd)	WNL- Y/N	WNL- Y/N
ER (Arm at 90° abd)	WNL- Y/N	WNL- Y/N

Shoulder Instability Tests:

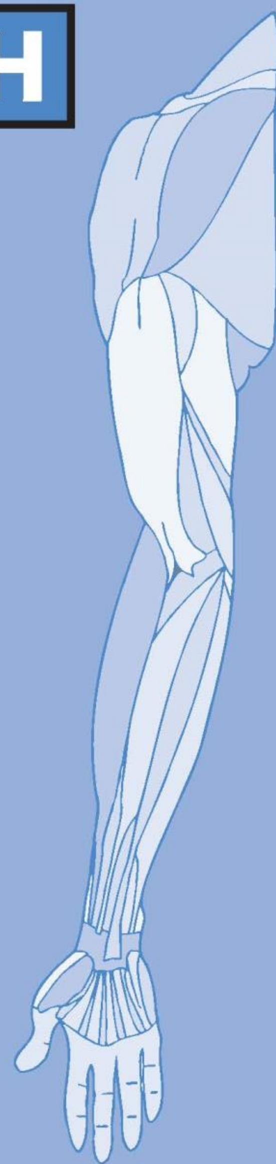
Load and Shift Test (Anterior)	+/-	+/-
Load and Shift Test (Posterior)	+/-	+/-

Other:

Appendix 5: Disabilities of the Arm, Shoulder and Hand (DASH)

DISABILITIES OF THE ARM, SHOULDER AND HAND

THE DASH



INSTRUCTIONS

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

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

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

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

Disabilities of the Arm, Shoulder and Hand

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

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Write.	1	2	3	4	5
3. Turn a key.	1	2	3	4	5
4. Prepare a meal.	1	2	3	4	5
5. Push open a heavy door.	1	2	3	4	5
6. Place an object on a shelf above your head.	1	2	3	4	5
7. Do heavy household chores (e.g., wash walls, wash floors).	1	2	3	4	5
8. Garden or do yard work.	1	2	3	4	5
9. Make a bed.	1	2	3	4	5
10. Carry a shopping bag or briefcase.	1	2	3	4	5
11. Carry a heavy object (over 10 lbs).	1	2	3	4	5
12. Change a lightbulb overhead.	1	2	3	4	5
13. Wash or blow dry your hair.	1	2	3	4	5
14. Wash your back.	1	2	3	4	5
15. Put on a pullover sweater.	1	2	3	4	5
16. Use a knife to cut food.	1	2	3	4	5
17. Recreational activities which require little effort (e.g., cardplaying, knitting, etc.).	1	2	3	4	5
18. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5
19. Recreational activities in which you move your arm freely (e.g., playing frisbee, badminton, etc.).	1	2	3	4	5
20. Manage transportation needs (getting from one place to another).	1	2	3	4	5
21. Sexual activities.	1	2	3	4	5

Disabilities of the Arm, Shoulder and Hand

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
22. During the past week, *to what extent* has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups? *(circle number)*	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
23. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem? *(circle number)*	1	2	3	4	5

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

	NONE	MILD	MODERATE	SEVERE	EXTREME
24. Arm, shoulder or hand pain.	1	2	3	4	5
25. Arm, shoulder or hand pain when you performed any specific activity.	1	2	3	4	5
26. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5
27. Weakness in your arm, shoulder or hand.	1	2	3	4	5
28. Stiffness in your arm, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
29. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? *(circle number)*	1	2	3	4	5

	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
30. I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. *(circle number)*	1	2	3	4	5

DASH DISABILITY/SYMPTOM SCORE = [(sum of n responses) - 1] x 25, where n is equal to the number of completed responses.
n

A DASH score may not be calculated if there are greater than 3 missing items.

DISABILITIES OF THE ARM, SHOULDER AND HAND

WORK MODULE (OPTIONAL)

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

Please indicate what your job/work is:________________________________

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

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for your work?	1	2	3	4	5
2. doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. doing your work as well as you would like?	1	2	3	4	5
4. spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

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

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

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

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.
An optional module score may not be calculated if there are any missing items.

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Appendix 6: Descriptive Subject Data

Table A6.1: DASH Score with percentage of questions (after removing non-shoulder related questions) answered as mild (graded as 2) or moderate (graded as 3) difficulty in performance by the three elderly individuals with an overall score > 5.

Elderly Subjects	**DASH Score**	Mild Difficulty (Grade 2)	Moderate Difficulty (Grade 3)
E09	6.03	18.52%	0%
E11	20.83	33.33%	18.52%
E18	10.83	40.74%	3.70%

Figure A6.1: Elderly and young group means plot with standard error bars at four angular positions during the two phases for scapular IR during scapular plane abduction motion.

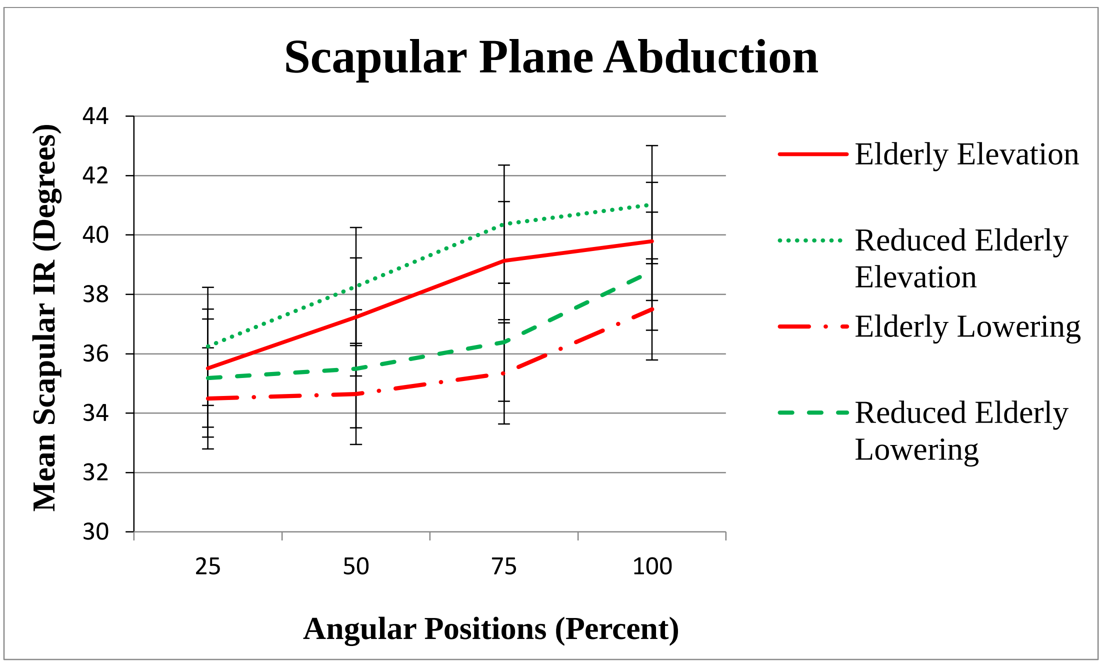

Figure A6.2: Elderly and young group means plot with standard error bars at four angular positions during the two phases for glenohumeral external rotation during forward reach task.

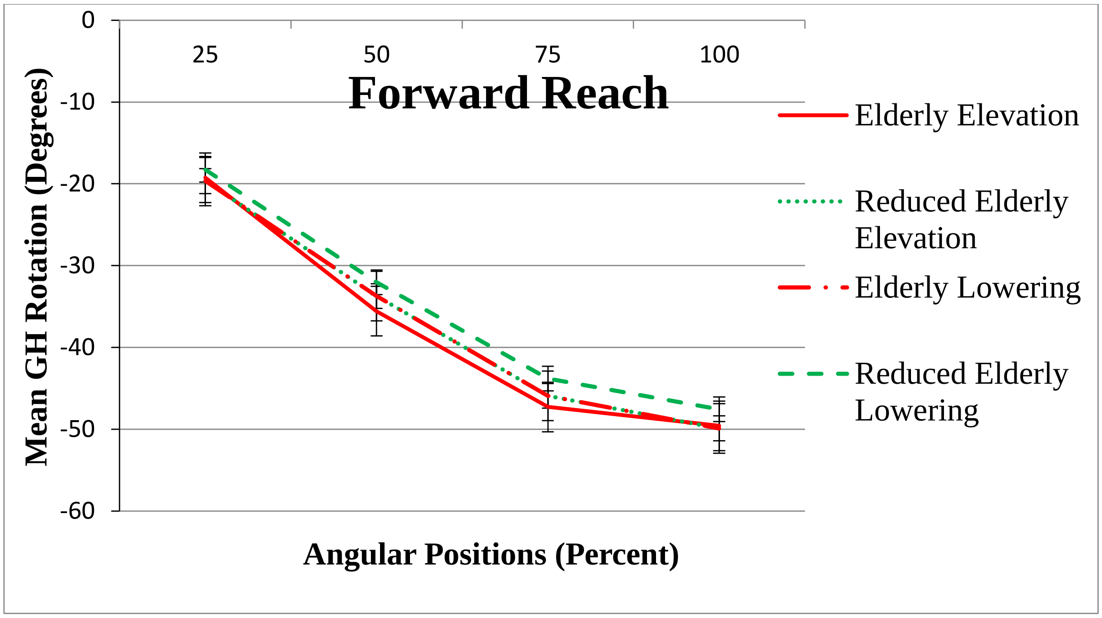

Table A6.2: Percentage of subjects with reduced cervical range of motion for the three separate directions based on visual inspection.

	Elderly		**Young**	
Cervical motions	**Flexion/ Right**	**Extension/ Left**	**Flexion/ Right**	**Extension/ Left**
Flexion-Extension	20%	12%	0%	0%
Bilateral rotation	16%	20%	0%	0%
Bilateral side-bend	40%	40%	0%	4%

Figure A6.3: Total number of subjects able to touch respective thoracic spinous processes with right thumb while maintaining erect posture.

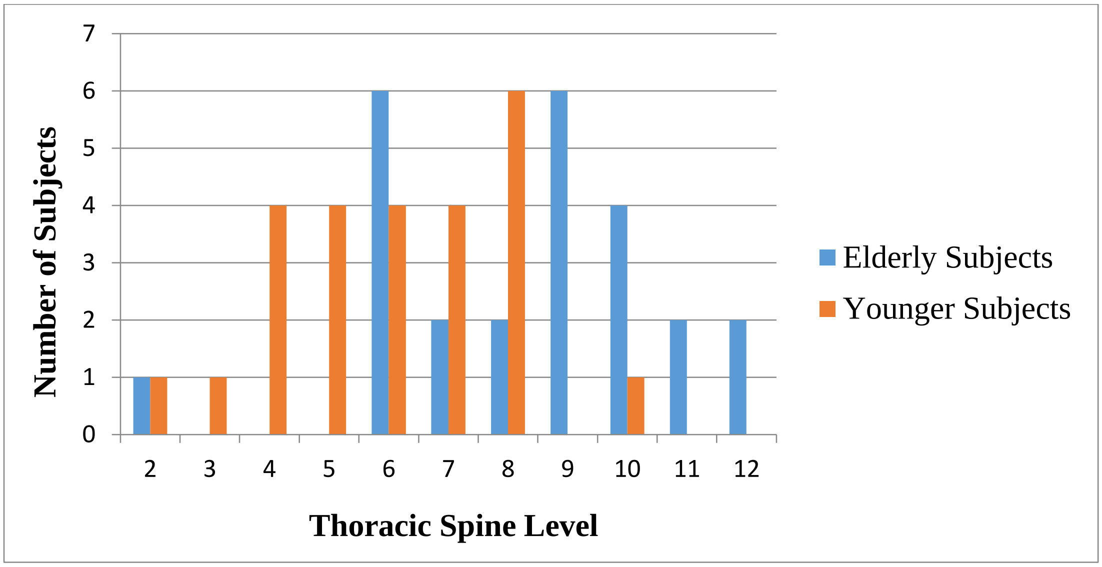

Table A6.3: Special tests for shoulder joint with percentage of subjects testing positive for each test within the two groups.

Tests	Elderly	Young
Sulcus	0%	0%
Load and Shift	0%	0%
Hawkins Kennedy	8%	4%
Neer	0%	0%
Jobe	0%	0%
Painful Arc	0%	0%
External Rotation Resistance	0%	0%

Table A6.4: Work/ Sports history with percentage of subjects who had a history of overhead activities for at least one year and a minimum of two months per year in their lifetime.

Subjects	Overhead Work	Overhead Sports
Elderly males	44.44%	66.67%
Elderly females	18.75%	93.75%
Young males	44.44%	88.89%
Young females	43.75%	93.75%

Appendix 7: Trial Effects for Kinematic Variables

Each cell in the table represents interaction with elevation or lowering, or main effects of the three trials at the specified angular position for each task. Empty cells signify absence of significant effects. Magnitude of effects and specific pairwise trial differences are presented only where greater than 2° difference was noted. Combinations having main effect of repetition only are denoted as repetition effect.

Table A7.1: Effect of trials for all dependent variables at each angular position for the five tasks.

Dependent Variables at Each Angular Position	**Tasks**				
	Forward Reach	**Reaching Back**	**Reaching Wallet**	**Touching Head**	**Scapular Plane Abduction**
Scapular UR[a] 25%	Interaction	Interaction	Interaction	Interaction	Interaction (Trials 1 & 3 difference = 2.1
Scapular UR[a] 50%	Interaction	Interaction	Interaction	Interaction	Interaction
Scapular UR[a] 75%	Interaction	Interaction		Interaction (Trials 1 & 2 difference = 2.1 and Trials 1 & 3 difference = 2.0)	Repetition Effect
Scapular UR[a] 100%	Interaction	Repetition Effect		Interaction	
Scapular Tilt 25%		Interaction			
Scapular Tilt 50%		Interaction	Interaction		
Scapular Tilt 75%	Interaction	Interaction			
Scapular Tilt 100%	Interaction	Interaction			Repetition Effect

Scapular IR[b] 25%	Interaction	Interaction	Interaction		
Scapular IR[b] 50%		Interaction	Interaction		Repetition Effect
Scapular IR[b] 75%		Repetition Effect			
Scapular IR[b] 100%	Interaction				
GH[c] Rotation 25%	Repetition Effect	Interaction	Interaction (Trials 1 & 2 difference = 3.7 and Trials 1 & 3 difference = 3.6)		Repetition Effect
GH[c] Rotation 50%	Interaction		Interaction	Repetition Effect	Interaction (Trials 1 & 3 difference= 2.2)
GH[c] Rotation 75%	Interaction				Repetition Effect
GH[c] Rotation 100%					

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Appendix 8: Reliability of Kinematic Variables

Table A8.1: Intraclass Correlation Coefficients (ICC) and Standard Errors of Measurement (SEM) scores of each dependent variable by group, angle, raising and lowering in scapular plane abduction.

Dependent Variables by group at each angular position and phase	Intraclass Correlation Coefficients	Standard Error of Measurement (degrees)
Elderly Scapular UR[a] 25% Elevation	0.96	1.8
Elderly Scapular UR[a] 25% Lowering	0.96	1.9
Younger Scapular UR[a] 25% Elevation	0.91	1.9
Younger Scapular UR[a] 25% Lowering	0.95	1.5
Elderly Scapular UR[a] 50% Elevation	0.97	1.6
Elderly Scapular UR[a] 50% Lowering	0.97	1.7
Younger Scapular UR[a] 50% Elevation	0.91	1.7
Younger Scapular UR[a] 50% Lowering	0.95	1.6
Elderly Scapular UR[a] 75% Elevation	0.99	1.2
Elderly Scapular UR[a] 75% Lowering	0.98	1.3
Younger Scapular UR[a] 75% Elevation	0.92	1.7
Younger Scapular UR[a] 75% Lowering	0.94	1.7
Elderly Scapular UR[a] 100% Elevation	0.98	1.3
Elderly Scapular UR[a] 100% Lowering	0.98	1.5
Younger Scapular UR[a] 100% Elevation	0.96	1.6
Younger Scapular UR[a] 100% Lowering	0.97	1.5
Elderly Scapular Tilt 25% Elevation	0.95	1.6

Elderly Scapular Tilt 25% Lowering	0.96	1.2
Younger Scapular Tilt 25% Elevation	0.97	1.2
Younger Scapular Tilt 25% Lowering	0.97	1.1
Elderly Scapular Tilt 50% Elevation	0.95	1.8
Elderly Scapular Tilt 50% Lowering	0.97	1.3
Younger Scapular Tilt 50% Elevation	0.97	1.2
Younger Scapular Tilt 50% Lowering	0.96	1.3
Elderly Scapular Tilt 75% Elevation	0.96	1.7
Elderly Scapular Tilt 75% Lowering	0.98	1.4
Younger Scapular Tilt 75% Elevation	0.98	1.1
Younger Scapular Tilt 75% Lowering	0.97	1.1
Elderly Scapular Tilt 100% Elevation	0.98	1.6
Elderly Scapular Tilt 100% Lowering	0.98	1.5
Younger Scapular Tilt 100% Elevation	0.99	0.8
Younger Scapular Tilt 100% Lowering	0.98	1.0
Elderly Scapular IR[b] 25% Elevation	0.98	1.5
Elderly Scapular IR[b,] 25% Lowering	0.99	0.9
Younger Scapular IR[b] 25% Elevation	0.87	2.0
Younger Scapular IR[b] 25% Lowering	0.94	1.3
Elderly Scapular IR[b] 50% Elevation	0.99	1.2
Elderly Scapular IR[b] 50% Lowering	0.99	0.9

Younger Scapular IR[b] 50% Elevation	0.89	1.7
Younger Scapular IR[b] 50% Lowering	0.96	1.1
Elderly Scapular IR[b] 75% Elevation	0.99	1.0
Elderly Scapular IR[b] 75% Lowering	0.99	1.1
Younger Scapular IR[b] 75% Elevation	0.92	1.7
Younger Scapular IR[b] 75% Lowering	0.96	1.4
Elderly Scapular IR[b] 100% Elevation	0.99	1.2
Elderly Scapular IR[b] 100% Lowering	0.99	1.3
Younger Scapular IR[b] 100% Elevation	0.94	2.0
Younger Scapular IR[b] 100% Lowering	0.97	1.8
Elderly Scapular GH[c] 25% Elevation	0.98	2.7
Elderly Scapular GH[c] 25% Lowering	0.98	2.5
Younger Scapular GH[c] 25% Elevation	0.96	3.2
Younger Scapular GH[c] 25% Lowering	0.97	2.4
Elderly Scapular GH[c] 50% Elevation	0.98	2.2
Elderly Scapular GH[c] 50% Lowering	0.99	1.9
Younger Scapular GH[c] 50% Elevation	0.97	2.5
Younger Scapular GH[c] 50% Lowering	0.99	1.6
Elderly Scapular GH[c] 75% Elevation	0.99	1.8
Elderly Scapular GH[c] 75% Lowering	0.99	2.1
Younger Scapular GH[c] 75% Elevation	0.98	1.8

Younger Scapular GH[c] 75% Lowering	0.99	1.6
Elderly Scapular GH[c] 100% Elevation	0.99	1.5
Elderly Scapular GH[c] 100% Lowering	0.99	1.9
Younger Scapular GH[c] 100% Elevation	0.99	1.5
Younger Scapular GH[c] 100% Lowering	0.99	1.2

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A8.2: Intraclass Correlation Coefficients and Standard Error of Measurement scores of each dependent variable by group, angle, raising and lowering during forward reaching task.

Dependent Variables by group at each angular position and phase	Intraclass Correlation Coefficients	Standard Error of Measurement (degrees)
Elderly Scapular UR[a] 25% Elevation	0.97	1.4
Elderly Scapular UR[a] 25% Lowering	0.96	2.1
Younger Scapular UR[a] 25% Elevation	0.96	1.2
Younger Scapular UR[a] 25% Lowering	0.96	1.3
Elderly Scapular UR[a] 50% Elevation	0.97	1.3
Elderly Scapular UR[a] 50% Lowering	0.97	1.7
Younger Scapular UR[a] 50% Elevation	0.98	1.1
Younger Scapular UR[a] 50% Lowering	0.96	1.4
Elderly Scapular UR[a] 75% Elevation	0.98	1.1
Elderly Scapular UR[a] 75% Lowering	0.97	1.5
Younger Scapular UR[a] 75% Elevation	0.97	1.4
Younger Scapular UR[a] 75% Lowering	0.94	1.8

Elderly Scapular UR[a] 100% Elevation	0.98	1.3
Elderly Scapular UR[a] 100% Lowering	0.97	1.6
Younger Scapular UR[a] 100% Elevation	0.94	1.8
Younger Scapular UR[a] 100% Lowering	0.94	1.6
Elderly Scapular Tilt 25% Elevation	0.98	1.2
Elderly Scapular Tilt 25% Lowering	0.95	1.7
Younger Scapular Tilt 25% Elevation	0.98	0.9
Younger Scapular Tilt 25% Lowering	0.97	1.0
Elderly Scapular Tilt 50% Elevation	0.98	1.2
Elderly Scapular Tilt 50% Lowering	0.97	1.4
Younger Scapular Tilt 50% Elevation	0.98	0.8
Younger Scapular Tilt 50% Lowering	0.97	1.1
Elderly Scapular Tilt 75% Elevation	0.98	1.2
Elderly Scapular Tilt 75% Lowering	0.98	1.2
Younger Scapular Tilt 75% Elevation	0.97	1.1
Younger Scapular Tilt 75% Lowering	0.98	1.1
Elderly Scapular Tilt 100% Elevation	0.98	1.3
Elderly Scapular Tilt 100% Lowering	0.98	1.4
Younger Scapular Tilt 100% Elevation	0.97	1.3
Younger Scapular Tilt 100% Lowering	0.98	1.1
Elderly Scapular IR[b] 25% Elevation	0.99	0.9

Elderly Scapular IR[b] 25% Lowering	0.99	1.2
Younger Scapular IR[b] 25% Elevation	0.91	1.3
Younger Scapular IR[b] 25% Lowering	0.94	1.1
Elderly Scapular IR[b] 50% Elevation	0.99	1.1
Elderly Scapular IR[b] 50% Lowering	0.99	1.2
Younger Scapular IR[b] 50% Elevation	0.94	1.2
Younger Scapular IR[b] 50% Lowering	0.94	1.2
Elderly Scapular IR[b] 75% Elevation	0.99	1.0
Elderly Scapular IR[b] 75% Lowering	0.99	1.1
Younger Scapular IR[b] 75% Elevation	0.97	1.0
Younger Scapular IR[b] 75% Lowering	0.96	1.1
Elderly Scapular IR[b] 100% Elevation	0.99	1.4
Elderly Scapular IR[b] 100% Lowering	0.99	1.3
Younger Scapular IR[b] 100% Elevation	0.97	1.2
Younger Scapular IR[b] 100% Lowering	0.97	1.3
Elderly Scapular GH[c] 25% Elevation	0.97	3.4
Elderly Scapular GH[c] 25% Lowering	0.97	3.6
Younger Scapular GH[c] 25% Elevation	0.97	2.6
Younger Scapular GH[c] 25% Lowering	0.96	3.4
Elderly Scapular GH[c] 50% Elevation	0.99	2.2
Elderly Scapular GH[c] 50% Lowering	0.98	3.1

Younger Scapular GH[c] 50% Elevation	0.98	1.9
Younger Scapular GH[c] 50% Lowering	0.97	2.8
Elderly Scapular GH[c] 75% Elevation	0.99	1.8
Elderly Scapular GH[c] 75% Lowering	0.99	1.9
Younger Scapular GH[c] 75% Elevation	0.99	1.6
Younger Scapular GH[c] 75% Lowering	0.98	2.4
Elderly Scapular GH[c] 100% Elevation	0.99	1.7
Elderly Scapular GH[c] 100% Lowering	0.99	2.0
Younger Scapular GH[c] 100% Elevation	0.99	1.7
Younger Scapular GH[c] 100% Lowering	0.98	2.3

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A8.3: Intraclass Correlation Coefficients and Standard Error of Measurement scores of each dependent variable by group, angle, raising and lowering during reaching back task.

Dependent Variables by group at each angular position and phase	Intraclass Correlation Coefficients	Standard Error of Measurement (degrees)
Elderly Scapular UR[a] 25% Elevation	0.96	1.3
Elderly Scapular UR[a] 25% Lowering	0.98	1.0
Younger Scapular UR[a] 25% Elevation	0.97	1.6
Younger Scapular UR[a] 25% Lowering	0.98	1.2
Elderly Scapular UR[a] 50% Elevation	0.97	1.2
Elderly Scapular UR[a] 50% Lowering	0.98	0.9
Younger Scapular UR[a] 50% Elevation	0.98	1.3

Younger Scapular UR[a] 50% Lowering	0.99	0.8
Elderly Scapular UR[a] 75% Elevation	0.97	1.1
Elderly Scapular UR[a] 75% Lowering	0.99	0.7
Younger Scapular UR[a] 75% Elevation	0.97	1.3
Younger Scapular UR[a] 75% Lowering	0.99	0.7
Elderly Scapular UR[a] 100% Elevation	0.98	0.9
Elderly Scapular UR[a] 100% Lowering	0.99	0.6
Younger Scapular UR[a] 100% Elevation	0.98	1.2
Younger Scapular UR[a] 100% Lowering	0.99	0.8
Elderly Scapular Tilt 25% Elevation	0.96	1.2
Elderly Scapular Tilt 25% Lowering	0.97	1.1
Younger Scapular Tilt 25% Elevation	0.96	1.3
Younger Scapular Tilt 25% Lowering	0.97	1.2
Elderly Scapular Tilt 50% Elevation	0.97	1.1
Elderly Scapular Tilt 50% Lowering	0.97	1.0
Younger Scapular Tilt 50% Elevation	0.96	1.3
Younger Scapular Tilt 50% Lowering	0.99	0.8
Elderly Scapular Tilt 75% Elevation	0.97	0.9
Elderly Scapular Tilt 75% Lowering	0.98	0.8
Younger Scapular Tilt 75% Elevation	0.97	1.3
Younger Scapular Tilt 75% Lowering	0.99	0.8

Elderly Scapular Tilt 100% Elevation	0.98	0.9
Elderly Scapular Tilt 100% Lowering	0.98	1.0
Younger Scapular Tilt 100% Elevation	0.99	1.3
Younger Scapular Tilt 100% Lowering	0.98	1.2
Elderly Scapular IR[b] 25% Elevation	0.98	1.3
Elderly Scapular IR[b] 25% Lowering	0.99	0.6
Younger Scapular IR[b] 25% Elevation	0.87	1.7
Younger Scapular IR[b] 25% Lowering	0.96	0.9
Elderly Scapular IR[b] 50% Elevation	0.98	1.2
Elderly Scapular IR[b] 50% Lowering	0.99	0.6
Younger Scapular IR[b] 50% Elevation	0.89	1.7
Younger Scapular IR[b] 50% Lowering	0.95	1.1
Elderly Scapular IR[b] 75% Elevation	0.99	0.9
Elderly Scapular IR[b] 75% Lowering	0.99	0.7
Younger Scapular IR[b] 75% Elevation	0.92	1.4
Younger Scapular IR[b] 75% Lowering	0.95	1.0
Elderly Scapular IR[b] 100% Elevation	0.99	0.9
Elderly Scapular IR[b] 100% Lowering	0.99	0.6
Younger Scapular IR[b] 100% Elevation	0.95	1.3
Younger Scapular IR[b] 100% Lowering	0.97	1.1
Elderly Scapular GH[c] 25% Elevation	0.95	3.5

Elderly Scapular GH[c] 25% Lowering	0.95	3.9
Younger Scapular GH[c] 25% Elevation	0.93	3.4
Younger Scapular GH[c] 25% Lowering	0.94	3.2
Elderly Scapular GH[c] 50% Elevation	0.95	3.4
Elderly Scapular GH[c] 50% Lowering	0.96	3.3
Younger Scapular GH[c] 50% Elevation	0.92	3.7
Younger Scapular GH[c] 50% Lowering	0.94	3.3
Elderly Scapular GH[c] 75% Elevation	0.94	3.6
Elderly Scapular GH[c] 75% Lowering	0.96	3.0
Younger Scapular GH[c] 75% Elevation	0.93	3.5
Younger Scapular GH[c] 75% Lowering	0.96	2.7
Elderly Scapular GH[c] 100% Elevation	0.95	3.8
Elderly Scapular GH[c] 100% Lowering	0.97	2.9
Younger Scapular GH[c] 100% Elevation	0.95	3.6
Younger Scapular GH[c] 100% Lowering	0.93	4.1

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A8.4: Intraclass Correlation Coefficients and Standard Error of Measurement scores of each dependent variable by group, angle, raising and lowering during reaching wallet task.

Dependent Variables by group at each angular position and phase	Intraclass Correlation Coefficients	Standard Error of Measurement (degrees)
Elderly Scapular UR[a] 25% Elevation	0.98	1.0
Elderly Scapular UR[a] 25% Lowering	0.98	1.0

Younger Scapular UR[a] 25% Elevation	0.99	0.9
Younger Scapular UR[a] 25% Lowering	0.98	1.0
Elderly Scapular UR[a] 50% Elevation	0.99	0.8
Elderly Scapular UR[a] 50% Lowering	0.99	0.9
Younger Scapular UR[a] 50% Elevation	0.99	0.9
Younger Scapular UR[a] 50% Lowering	0.99	0.8
Elderly Scapular UR[a] 75% Elevation	0.99	0.7
Elderly Scapular UR[a] 75% Lowering	0.99	0.9
Younger Scapular UR[a] 75% Elevation	0.99	1.0
Younger Scapular UR[a] 75% Lowering	0.99	0.8
Elderly Scapular UR[a] 100% Elevation	0.98	0.9
Elderly Scapular UR[a] 100% Lowering	0.99	0.8
Younger Scapular UR[a] 100% Elevation	0.98	1.0
Younger Scapular UR[a] 100% Lowering	0.99	0.8
Elderly Scapular Tilt 25% Elevation	0.97	1.1
Elderly Scapular Tilt 25% Lowering	0.97	1.1
Younger Scapular Tilt 25% Elevation	0.99	1.2
Younger Scapular Tilt 25% Lowering	0.98	0.7
Elderly Scapular Tilt 50% Elevation	0.98	1.0
Elderly Scapular Tilt 50% Lowering	0.97	1.0
Younger Scapular Tilt 50% Elevation	0.98	1.1

Younger Scapular Tilt 50% Lowering	0.97	0.8
Elderly Scapular Tilt 75% Elevation	0.98	1.0
Elderly Scapular Tilt 75% Lowering	0.98	0.9
Younger Scapular Tilt 75% Elevation	0.99	1.1
Younger Scapular Tilt 75% Lowering	0.99	0.8
Elderly Scapular Tilt 100% Elevation	0.97	0.9
Elderly Scapular Tilt 100% Lowering	0.97	1.1
Younger Scapular Tilt 100% Elevation	0.98	1.3
Younger Scapular Tilt 100% Lowering	0.99	0.9
Elderly Scapular IR[b] 25% Elevation	0.99	1.0
Elderly Scapular IR[b] 25% Lowering	0.99	0.8
Younger Scapular IR[b] 25% Elevation	0.95	1.1
Younger Scapular IR[b] 25% Lowering	0.97	1.0
Elderly Scapular IR[b] 50% Elevation	0.99	0.9
Elderly Scapular IR[b] 50% Lowering	0.99	0.7
Younger Scapular IR[b] 50% Elevation	0.97	0.9
Younger Scapular IR[b] 50% Lowering	0.95	1.2
Elderly Scapular IR[b] 75% Elevation	0.99	0.7
Elderly Scapular IR[b] 75% Lowering	0.99	0.8
Younger Scapular IR[b] 75% Elevation	0.96	1.2
Younger Scapular IR[b] 75% Lowering	0.95	1.2

Elderly Scapular IR[b] 100% Elevation	0.99	0.9
Elderly Scapular IR[b] 100% Lowering	0.99	0.9
Younger Scapular IR[b] 100% Elevation	0.96	1.5
Younger Scapular IR[b] 100% Lowering	0.97	1.1
Elderly Scapular GH[c] 25% Elevation	0.97	3.1
Elderly Scapular GH[c] 25% Lowering	0.98	2.6
Younger Scapular GH[c] 25% Elevation	0.94	3.4
Younger Scapular GH[c] 25% Lowering	0.97	2.4
Elderly Scapular GH[c] 50% Elevation	0.98	2.5
Elderly Scapular GH[c] 50% Lowering	0.98	3.0
Younger Scapular GH[c] 50% Elevation	0.97	2.2
Younger Scapular GH[c] 50% Lowering	0.97	2.3
Elderly Scapular GH[c] 75% Elevation	0.97	2.5
Elderly Scapular GH[c] 75% Lowering	0.97	2.9
Younger Scapular GH[c] 75% Elevation	0.98	2.1
Younger Scapular GH[c] 75% Lowering	0.98	2.0
Elderly Scapular GH[c] 100% Elevation	0.98	2.3
Elderly Scapular GH[c] 100% Lowering	0.98	2.2
Younger Scapular GH[c] 100% Elevation	0.98	1.9
Younger Scapular GH[c] 100% Lowering	0.98	1.9

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A8.5: Intraclass Correlation Coefficients and Standard Error of Measurement scores of each dependent variable by group, angle, raising and lowering during touching head task.

Dependent Variables by group at each angular position and phase	Intraclass Correlation Coefficients	Standard Error of Measurement (degrees)
Elderly Scapular UR[a] 25% Elevation	0.96	1.7
Elderly Scapular UR[a] 25% Lowering	0.98	1.6
Younger Scapular UR[a] 25% Elevation	0.96	1.4
Younger Scapular UR[a] 25% Lowering	0.96	1.7
Elderly Scapular UR[a] 50% Elevation	0.96	1.8
Elderly Scapular UR[a] 50% Lowering	0.98	1.5
Younger Scapular UR[a] 50% Elevation	0.95	1.7
Younger Scapular UR[a] 50% Lowering	0.95	1.8
Elderly Scapular UR[a] 75% Elevation	0.96	1.8
Elderly Scapular UR[a] 75% Lowering	0.98	1.4
Younger Scapular UR[a] 75% Elevation	0.94	2.0
Younger Scapular UR[a] 75% Lowering	0.96	1.9
Elderly Scapular UR[a] 100% Elevation	0.98	1.4
Elderly Scapular UR[a] 100% Lowering	0.99	1.2
Younger Scapular UR[a] 100% Elevation	0.96	2.1
Younger Scapular UR[a] 100% Lowering	0.98	1.6
Elderly Scapular Tilt 25% Elevation	0.98	1.0
Elderly Scapular Tilt 25% Lowering	0.96	1.4

Younger Scapular Tilt 25% Elevation	0.98	1.0
Younger Scapular Tilt 25% Lowering	0.98	1.0
Elderly Scapular Tilt 50% Elevation	0.98	1.0
Elderly Scapular Tilt 50% Lowering	0.98	1.1
Younger Scapular Tilt 50% Elevation	0.98	1.0
Younger Scapular Tilt 50% Lowering	0.98	1.1
Elderly Scapular Tilt 75% Elevation	0.99	1.1
Elderly Scapular Tilt 75% Lowering	0.99	1.1
Younger Scapular Tilt 75% Elevation	0.99	1.0
Younger Scapular Tilt 75% Lowering	0.98	1.1
Elderly Scapular Tilt 100% Elevation	0.98	1.3
Elderly Scapular Tilt 100% Lowering	0.99	1.2
Younger Scapular Tilt 100% Elevation	0.97	1.4
Younger Scapular Tilt 100% Lowering	0.98	1.1
Elderly Scapular IR[b] 25% Elevation	0.99	0.8
Elderly Scapular IR[b] 25% Lowering	0.99	0.8
Younger Scapular IR[b] 25% Elevation	0.93	1.4
Younger Scapular IR[b] 25% Lowering	0.94	1.3
Elderly Scapular IR[b] 50% Elevation	0.99	0.8
Elderly Scapular IR[b] 50% Lowering	0.99	1.0
Younger Scapular IR[b] 50% Elevation	0.92	1.5

Younger Scapular IR[b] 50% Lowering	0.94	1.3
Elderly Scapular IR[b] 75% Elevation	0.99	1.1
Elderly Scapular IR[b] 75% Lowering	0.99	1.0
Younger Scapular IR[b] 75% Elevation	0.94	1.5
Younger Scapular IR[b] 75% Lowering	0.96	1.3
Elderly Scapular IR[b] 100% Elevation	0.99	1.3
Elderly Scapular IR[b] 100% Lowering	0.99	1.0
Younger Scapular IR[b] 100% Elevation	0.96	1.5
Younger Scapular IR[b] 100% Lowering	0.97	1.4
Elderly Scapular GH[c] 25% Elevation	0.97	3.6
Elderly Scapular GH[c] 25% Lowering	0.96	4.6
Younger Scapular GH[c] 25% Elevation	0.96	3.8
Younger Scapular GH[c] 25% Lowering	0.95	4.3
Elderly Scapular GH[c] 50% Elevation	0.97	3.4
Elderly Scapular GH[c] 50% Lowering	0.97	3.9
Younger Scapular GH[c] 50% Elevation	0.96	3.3
Younger Scapular GH[c] 50% Lowering	0.95	3.8
Elderly Scapular GH[c] 75% Elevation	0.99	2.1
Elderly Scapular GH[c] 75% Lowering	0.97	3.0
Younger Scapular GH[c] 75% Elevation	0.98	2.1
Younger Scapular GH[c] 75% Lowering	0.97	2.7

Elderly Scapular GH[c] 100% Elevation	0.99	1.6
Elderly Scapular GH[c] 100% Lowering	0.99	2.0
Younger Scapular GH[c] 100% Elevation	0.98	1.9
Younger Scapular GH[c] 100% Lowering	0.99	1.6

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Appendix 9: Descriptive Analyses of the Kinematic Variables

The tables represent mean and standard deviation for the two groups and for each condition. The mean across subjects is based on the average of three trials for each subject.

Table A9.1: Mean in degrees and standard deviation for the two groups at each angular position during scapular plane abduction for the two phases with negative value indicating upward rotation, anterior tilt, scapular external rotation and glenohumeral external rotation.

Angular Position	Elderly		Younger	
	Elevation	**Lowering**	**Elevation**	**Lowering**
Scapular UR[a] 25	3.3 (8.55)	1.2 (9.15)	0.7 (6.23)	0.4 (6.95)
Scapular UR[a] 50%	-7.3 (9.48)	-9.7 (9.45)	-11.0 (5.60)	-11.0 (6.90)
Scapular UR[a] 75%	-20.8 (10.36)	-22.2 (10.00)	-23.1 (5.94)	-23.4 (6.94)
Scapular UR[a] 100%	-31.7 (10.48)	-31.2 (10.78)	-33.2 (8.10)	-32.4 (8.56)
Scapular Tilt 25%	-10.4 (6.83)	-9.4 (6.30)	-10.7 (6.76)	-11.2 (6.32)
Scapular Tilt 50%	-8.7 (7.53)	-6.5 (7.94)	-8.7 (7.14)	-7.7 (6.42)
Scapular Tilt 75%	-7.6 (8.81)	-3.7 (9.95)	-6.1 (7.41)	-3.7 (6.72)
Scapular Tilt 100%	-3.4 (11.16)	-1.7 (11.98)	-0.8 (7.25)	0.4 (7.53)
Scapular IR[b] 25%	35.5 (10.03)	34.5 (10.95)	31.9 (5.12)	30.3 (5.35)
Scapular IR[b] 50%	37.2 (10.71)	34.7 (11.00)	32.0 (5.06)	30.3 (5.43)
Scapular IR[b] 75%	39.1 (12.57)	35.3 (12.68)	32.2 (5.93)	31.3 (7.05)
Scapular IR[b] 100%	39.8 (15.07)	37.5 (14.91)	32.9 (8.17)	33.3 (9.74)
GH[c] Rotation 25%	-31.0 (18.29)	-31.7 (19.02)	-38.3 (15.17)	-38.4 (14.65)
GH[c] Rotation 50%	-42.7 (17.13)	-42.7 (18.19)	-48.3 (14.05)	-48.0 (14.40)
GH[c] Rotation 75%	-47.9	-48.8	-53.5	-53.2

	(18.21)	(18.71)	(13.80)	(14.26)
GH[c] Rotation 100%	-49.6 (20.83)	-51.0 (21.12)	-54.7 (14.88)	-53.6 (15.41)

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A9.2: Mean in degrees and standard deviation for the two groups at each angular position during forward reach for the two phases with negative value indicating upward rotation, anterior tilt, scapular external rotation and glenohumeral external rotation.

Angular Position	**Elderly**		**Younger**	
	Elevation	**Lowering**	**Elevation**	**Lowering**
Scapular UR[a] 25%	1.4 (8.54)	0.4 (10.05)	-2.7 (6.43)	-2.1 (6.61)
Scapular UR[a] 50%	-6.1 (7.93)	-8.3 (10.03)	-10.8 (6.86)	-10.7 (6.87)
Scapular UR[a] 75%	-15.7 (7.53)	-17.6 (9.18)	-20.9 (7.34)	-21.0 (7.27)
Scapular UR[a] 100%	-27.2 (8.21)	-27.1 (9.08)	-31.4 (7.31)	-30.7 (6.87)
Scapular Tilt 25%	-9.7 (7.68)	-8.1 (7.77)	-10.1 (6.02)	-10.6 (6.12)
Scapular Tilt 50%	-6.9 (7.61)	-5.2 (7.78)	-7.5 (6.15)	-8.9 (6.06)
Scapular Tilt 75%	-5.70 (8.08)	-4.03 (8.49)	-6.45 (6.81)	-6.98 (7.33)
Scapular Tilt 100%	-4.6 (9.46)	-3.7 (9.60)	-5.8 (7.05)	-5.6 (7.60)
Scapular IR[b] 25%	34.4 (10.82)	34.5 (10.64)	29.8 (4.37)	29.5 (4.51)
Scapular IR[b] 50%	37.2 (11.08)	36.4 (11.12)	33.1 (4.95)	32.1 (4.79)
Scapular IR[b] 75%	41.0 (12.15)	40.0 (12.28)	37.6 (5.66)	36.1 (5.88)
Scapular IR[b] 100%	47.0 (13.96)	46.7 (14.51)	46.1 (7.47)	45.9 (7.16)
GH[c] Rotation 25%	-18.6 (18.53)	-19.0 (19.19)	-20.5 (15.12)	-21.5 (15.86)
GH[c] Rotation 50%	-34.9 (18.24)	-33.1 (20.39)	-36.5 (15.21)	-38.0 (15.14)
GH[c] Rotation 75%	-46.7 (18.11)	-45.3 (18.50)	-51.0 (15.50)	-52.2 (15.67)

GH[c] Rotation 100%	-49.0 (18.24)	-49.3 (18.52)	-57.1 (15.50)	-57.1 (16.66)

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A9.3: Mean in degrees and standard deviation for the two groups at each angular position during reaching the back for the two phases with negative value indicating upward rotation, anterior tilt, scapular external rotation and glenohumeral external rotation.

Angular Position	Elderly		Younger	
	Elevation	**Lowering**	**Elevation**	**Lowering**
Scapular UR[a] 25%	8.7 (6.48)	9.8 (6.62)	7.2 (8.55)	8.4 (8.24)
Scapular UR[a] 50%	8.9 (6.64)	10.3 (6.94)	7.7 (8.35)	10.0 (8.37)
Scapular UR[a] 75%	9.7 (6.66)	11.0 (6.92)	8.9 (8.30)	11.4 (8.21)
Scapular UR[a] 100%	11.8 (6.93)	11.9 (7.23)	12.7 (8.32)	13.1 (8.43)
Scapular Tilt 25%	-14.2 (6.00)	-14.9 (5.95)	-15.4 (6.87)	-16.2 (7.03)
Scapular Tilt 50%	-14.0 (5.96)	-15.1 (6.01)	-15.6 (6.89)	-16.6 (7.14)
Scapular Tilt 75%	-14.9 (5.83)	-15.6 (6.34)	-17.2 (7.49)	-17.9 (7.94)
Scapular Tilt 100%	-16.9 (6.29)	-17.3 (7.08)	-21.0 (9.15)	-21.2 (8.87)
Scapular IR[b] 25%	35.8 (9.69)	35.9 (9.64)	33.8 (4.69)	33.6 (4.83)
Scapular IR[b] 50%	36.2 (9.65)	35.7 (9.70)	33.5 (4.87)	32.8 (4.85)
Scapular IR[b] 75%	36.6 (9.93)	35.9 (9.64)	32.8 (4.76)	31.9 (4.73)
Scapular IR[b] 100%	36.1 (10.71)	36.6 (10.85)	32.1 (5.75)	32.3 (5.65)
GH[c] Rotation 25%	4.4 (15.92)	3.0 (16.65)	0.7 (12.62)	0.01 (12.67)
GH[c] Rotation 50%	6.7 (14.23)	2.2 (16.09)	3.7 (11.91)	0.9 (12.98)
GH[c] Rotation 75%	12.0 (14.51)	7. 5 (15.61)	8.0 (12.72)	4.0 (13.43)
GH[c] Rotation 100%	19.0 (17.24)	20.8 (17.64)	16.3 (16.66)	17.3 (15.73)

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A9.4: Mean in degrees and standard deviation for the two groups at each angular position during reaching wallet for the two phases with negative value indicating upward rotation, anterior tilt, scapular external rotation and glenohumeral external rotation.

Angular Position	**Elderly**		**Younger**	
	Elevation	**Lowering**	**Elevation**	**Lowering**
Scapular UR[a] 25%	8.0 (6.80)	9.1 (6.95)	7.5 (7.65)	8.4 (7.78)
Scapular UR[a] 50%	8.3 (7.18)	9.3 (7.15)	8.1 (7.71)	9.2 (7.66)
Scapular UR[a] 75%	8.7 (7.17)	9.3 (7.14)	8.3 (7.69)	9.7 (7.53)
Scapular UR[a] 100%	10.5 (7.60)	9.8 (7.77)	10.5 (7.62)	10.9 (7.27)
Scapular Tilt 25%	-15.4 (6.44)	-15.5 (6.80)	-15.3 (6.35)	-15.4 (6.24)
Scapular Tilt 50%	-15.2 (6.63)	-15.9 (7.03)	-15.4 (6.29)	-15.9 (6.41)
Scapular Tilt 75%	-16.6 (6.41)	-17.3 (6.84)	-17.7 (6.84)	-18.3 (7.14)
Scapular Tilt 100%	-20.4 (6.89)	-20.8 (6.94)	-21.8 (8.27)	-22.1 (8.23)
Scapular IR[b] 25%	35.6 (10.41)	35.8 (10.49)	33.1 (5.05)	33.4 (5.40)
Scapular IR[b] 50%	35.7 (10.40)	35.0 (10.66)	31.7 (5.01)	31.5 (5.18)
Scapular IR[b] 75%	34.8 (10.57)	33.5 (10.39)	28.9 (5.72)	28.1 (5.49)
Scapular IR[b] 100%	31.5 (10.62)	31.5 (10.43)	25.3 (6.99)	26.0 (6.10)
GH[c] Rotation 25%	6.6 (16.69)	8.3 (17.97)	3.4 (13.46)	5.6 (13.35)
GH[c] Rotation 50%	4.3 (16.36)	4.6 (18.83)	-1.4 (13.02)	0.6 (13.27)
GH[c] Rotation 75%	2.1 (15.12)	1.9 (17.18)	-4.3 (13.36)	-2.9 (12.90)
GH[c] Rotation 100%	0.4 (15.84)	4.0 (16.68)	-6.1 (13.63)	-2.8 (13.63)

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A9.5: Mean in degrees and standard deviation for the two groups at each angular position during touching the head for the two phases with negative value indicating upward rotation, anterior tilt, scapular external rotation and glenohumeral external rotation.

Angular Position	Elderly		Younger	
	Elevation	Lowering	Elevation	Lowering
Scapular UR[a] 25%	2.2 (9.05)	1.9 (10.72)	-0.6 (7.16)	0.3 (8.07)
Scapular UR[a] 50%	-6.2 (8.68)	-8.1 (11.12)	-9.4 (7.46)	-9.6 (8.43)
Scapular UR[a] 75%	-16.4 (8.63)	-18.5 (10.57)	-19.1 (8.38)	-19.4 (9.42)
Scapular UR[a] 100%	-27.9 (9.66)	-27.8 (10.13)	-28.7 (9.99)	-28.3 (10.49)
Scapular Tilt 25%	-10.2 (7.21)	-8.4 (6.74)	-10.7 (6.66)	-11.1 (6.63)
Scapular Tilt 50%	-7.9 (7.52)	-5.3 (7.67)	-8.1 (6.83)	-8.0 (6.77)
Scapular Tilt 75%	-6.8 (8.79)	-3.4 (9.08)	-6.5 (7.57)	-6.0 (7.78)
Scapular Tilt 100%	-3.7 (10.14)	-2.3 (10.04)	-3.5 (8.22)	-3.0 (8.17)
Scapular IR[b] 25%	33.9 (10.21)	34.2 (10.71)	29.7 (4.97)	30.5 (5.07)
Scapular IR[b] 50%	36.0 (10.53)	35.1 (11.26)	31.0 (5.38)	30.8 (5.49)
Scapular IR[b] 75%	39.1 (11.60)	37.4 (12.38)	33.3 (6.21)	32.7 (6.71)
Scapular IR[b] 100%	42.2 (13.95)	41.0 (13.80)	36.1 (7.50)	35.9 (8.07)
GH[c] Rotation 25%	-22.0 (20.86)	-20.4 (22.03)	-25.9 (17.76)	-25.7 (18.35)
GH[c] Rotation 50%	-38.1 (18.67)	-34.5 (20.91)	-38.7 (16.87)	-39.5 (16.84)
GH[c] Rotation 75%	-48.2 (17.63)	-43.5 (17.61)	-53.2 (15.49)	-52.6 (16.60)
GH[c] Rotation 100%	-53.2 (18.16)	-53.7 (18.44)	-63.0 (15.07)	-63.3 (15.14)

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Appendix 10: Skewness and Kurtosis for the Kinematic Data

The tables represent skewness (-1 to 1 is the acceptable range; Portney and Watkins, 2009) and kurtosis (1.7 to 10 is the acceptable range; Feldt, 1993) for the two groups during elevation at each angular position for each dependent variable and for each condition.

Table A10.1: Skewness and kurtosis for the two groups at each angular position during scapular plane abduction.

Angular Position	Elderly		Young	
	Skewness	Kurtosis	Skewness	Kurtosis
Scapular UR[a] 25%	0.26	2.76	-0.53	2.43
Scapular UR[a] 50%	0.29	3.16	-0.66	2.80
Scapular UR[a] 75%	0.17	3.14	-0.54	2.30
Scapular UR[a] 100%	-0.24	2.68	-0.39	3.02
Scapular Tilt 25%	-0.80	3.37	0.55	2.69
Scapular Tilt 50%	-0.75	3.16	0.47	2.78
Scapular Tilt 75%	-0.89	3.71	0.46	2.95
Scapular Tilt 100%	-0.91	3.50	0.17	2.41
Scapular IR[b] 25%	0.62	5.18	-0.28	2.33
Scapular IR[b] 50%	0.29	5.26	0.33	2.35
Scapular IR[b] 75%	0.002	5.01	0.70	3.05
Scapular IR[b] 100%	-0.09	3.65	0.42	2.84
GH[c] Rotation 25%	-0.25	2.76	0.08	2.32
GH[c] Rotation 50%	-0.41	2.81	0.12	2.13
GH[c] Rotation 75%	-0.62	2.73	0.22	2.34
GH[c] Rotation 100%	-0.59	2.68	0.27	2.29

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A10.2: Skewness and kurtosis for the two groups at each angular position during forward reach. Bolded values represent those slightly outside of the acceptable range.

Angular Position	Elderly		Young	
	Skewness	Kurtosis	Skewness	Kurtosis
Scapular UR[a] 25%	-0.25	2.30	0.37	2.49
Scapular UR[a] 50%	-0.17	2.19	0.39	2.88
Scapular UR[a] 75%	-0.04	2.36	0.59	2.97
Scapular UR[a] 100%	0.12	3.33	0.69	2.70
Scapular Tilt 25%	**-1.1**	4.20	0.52	3.02
Scapular Tilt 50%	**-1.01**	4.19	0.82	3.66

Scapular Tilt 75%	-0.74	3.68	0.75	3.13
Scapular Tilt 100%	-0.63	3.68	0.11	2.62
Scapular IR[b] 25%	0.80	5.15	-0.16	2.67
Scapular IR[b] 50%	0.50	5.35	-0.27	2.55
Scapular IR[b] 75%	0.14	5.29	-0.31	2.76
Scapular IR[b] 100%	-0.15	4.35	-0.31	3.16
GH[c] Rotation 25%	-0.16	2.83	0.08	2.32
GH[c] Rotation 50%	-0.05	3.27	0.12	2.13
GH[c] Rotation 75%	-0.45	2.97	0.22	2.34
GH[c] Rotation 100%	-0.39	2.71	0.27	2.29

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A10.3: Skewness and kurtosis for the two groups at each angular position during reaching back.

Angular Position	**Elderly**		**Young**	
	Skewness	**Kurtosis**	**Skewness**	**Kurtosis**
Scapular UR[a] 25%	-0.27	3.09	0.82	3.40
Scapular UR[a] 50%	-0.22	2.91	0.81	3.41
Scapular UR[a] 75%	-0.14	2.59	0.79	3.66
Scapular UR[a] 100%	-0.02	2.39	0.83	3.63
Scapular Tilt 25%	-0.63	2.14	0.31	2.60
Scapular Tilt 50%	-0.63	2.10	0.43	2.46
Scapular Tilt 75%	-0.53	1.94	0.40	2.11
Scapular Tilt 100%	-0.38	1.77	0.24	1.93
Scapular IR[b] 25%	0.83	2.17	-0.62	2.43
Scapular IR[b] 50%	0.80	4.06	-0.59	2.63
Scapular IR[b] 75%	0.82	3.83	-0.48	2.77
Scapular IR[b] 100%	1.01	3.79	-0.29	2.86
GH[c] Rotation 25%	-0.21	2.31	-0.15	2.75
GH[c] Rotation 50%	-0.28	3.07	-0.16	2.52
GH[c] Rotation 75%	-0.26	3.11	-0.23	1.89
GH[c] Rotation 100%	-0.34	2.78	-0.10	1.95

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A10.4: Skewness and kurtosis for the two groups at each angular position during reaching wallet. Bolded values represent those slightly outside of the acceptable range.

Angular Position	**Elderly**		**Young**	
	Skewness	**Kurtosis**	**Skewness**	**Kurtosis**
Scapular UR[a] 25%	-0.31	2.31	0.43	2.79
Scapular UR[a] 50%	-0.33	2.29	0.47	2.98

Scapular UR[a] 75%	-0.26	2.47	0.53	2.99
Scapular UR[a] 100%	-0.31	2.71	0.29	2.69
Scapular Tilt 25%	-0.47	2.77	0.43	3.18
Scapular Tilt 50%	-0.30	2.88	0.31	2.63
Scapular Tilt 75%	-0.03	2.28	0.16	2.26
Scapular Tilt 100%	-0.08	2.27	-0.19	2.12
Scapular IR[b] 25%	0.54	3.62	-0.14	2.71
Scapular IR[b] 50%	0.52	3.54	-0.47	2.54
Scapular IR[b] 75%	0.52	3.24	-0.71	3.48
Scapular IR[b] 100%	0.62	3.12	**-1.22**	5.49
GH[c] Rotation 25%	-0.23	2.73	-0.03	2.61
GH[c] Rotation 50%	-0.11	2.72	-0.03	2.58
GH[c] Rotation 75%	-0.28	3.06	-0.09	2.31
GH[c] Rotation 100%	-0.05	2.49	0.04	2.25

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A10.5: Skewness and kurtosis for the two groups at each angular position during touching head. Bolded values represent those slightly outside of the acceptable range.

Angular Position	**Elderly**		**Young**	
	Skewness	**Kurtosis**	**Skewness**	**Kurtosis**
Scapular UR[a] 25%	0.08	2.00	0.06	2.33
Scapular UR[a] 50%	0.18	2.35	0.04	2.48
Scapular UR[a] 75%	0.35	2.60	0.13	2.64
Scapular UR[a] 100%	0.22	2.18	0.36	2.83
Scapular Tilt 25%	-0.87	3.00	0.60	3.17
Scapular Tilt 50%	-0.93	3.27	1.00	4.23
Scapular Tilt 75%	-0.87	3.29	**1.19**	4.48
Scapular Tilt 100%	-0.35	2.83	0.60	3.10
Scapular IR[b] 25%	0.56	3.88	-0.07	2.63
Scapular IR[b] 50%	0.18	3.64	0.06	2.43
Scapular IR[b] 75%	-0.10	3.27	0.007	2.42
Scapular IR[b] 100%	-0.15	2.71	0.28	2.48
GH[c] Rotation 25%	0.13	2.92	-0.08	2.16
GH[c] Rotation 50%	-0.01	2.15	-0.31	2.18
GH[c] Rotation 75%	-0.36	2.24	-0.51	2.91
GH[c] Rotation 100%	-0.88	2.87	-0.03	3.89

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Appendix 11: Effects of covariates (gender and BMI) on the two groups during the two phases at each angular position for all the five tasks

The tables represent correlation of the two potential covariates (gender and BMI) at specific angular positions for each dependent variable during elevation and lowering of the arm for the two groups. Consistent (within and between groups) condition/variable combinations with r > 0.50 were of interest for further consideration in ANCOVA.

Table A11.1: Effect of gender and BMI on the elderly group during the elevation phase at each angular position while doing scapular plane abduction. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.37	0.17
Scapular Tilt 25%	0.20	**-0.52**
Scapular IR[b] 25%	-0.10	0.15
GH[c] Rotation 25%	0.15	**0.50**
Scapular UR[a] 50%	0.34	0.22
Scapular Tilt 50%	0.09	-0.45
Scapular IR[b] 50%	-0.12	0.18
GH[c] Rotation 50%	0.21	0.42
Scapular UR[a] 75%	0.30	0.13
Scapular Tilt 75%	0.20	-0.35
Scapular IR[b] 75%	-0.14	0.24
GH[c] Rotation 75%	0.16	0.42
Scapular UR[a] 100%	0.40	0.08
Scapular Tilt 100%	0.15	-0.29
Scapular IR[b] 100%	-0.16	0.18
GH[c] Rotation 100°	0.10	0.44

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.2: Effect of gender and BMI on the young group during the elevation phase at each angular position while doing scapular plane abduction.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.05	-0.00
Scapular Tilt 25%	0.36	-0.36
Scapular IR[b] 25%	0.32	-0.15
GH[c] Rotation 25%	0.03	0.34
Scapular UR[a] 50%	0.12	-0.10
Scapular Tilt 50%	0.16	-0.21

Scapular IR[b] 50%	0.13	-0.20
GH[c] Rotation 50%	0.03	0.29
Scapular UR[a] 75%	0.17	-0.23
Scapular Tilt 75%	0.21	-0.01
Scapular IR[b] 75%	-0.13	-0.33
GH[c] Rotation 75%	0.00	0.30
Scapular UR[a] 100%	0.02	-0.19
Scapular Tilt 100%	0.18	0.24
Scapular IR[b] 100%	-0.42	-0.46
GH[c] Rotation 100°	-0.08	0.32

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.3: Effect of gender and BMI on the elderly group during the lowering phase at each angular position while doing scapular plane abduction.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.38	0.04
Scapular Tilt 25%	0.14	-0.32
Scapular IR[b] 25%	-0.23	0.19
GH[c] Rotation 25%	0.00	0.45
Scapular UR[a] 50%	0.42	0.02
Scapular Tilt 50%	0.12	-0.40
Scapular IR[b] 50%	-0.21	0.21
GH[c] Rotation 50%	0.10	0.36
Scapular UR[a] 75%	0.47	0.14
Scapular Tilt 75%	0.08	-0.41
Scapular IR[b] 75%	-0.10	0.15
GH[c] Rotation 75%	0.12	0.40
Scapular UR[a] 100%	0.42	0.06
Scapular Tilt 100%	-0.02	-0.42
Scapular IR[b] 100%	-0.05	0.11
GH[c] Rotation 100°	0.08	0.48

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.4: Effect of gender and BMI on the young group during the lowering phase at each angular position while doing scapular plane abduction. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	-0.03	-0.13

Scapular Tilt 25%	0.22	0.31
Scapular IR[b] 25%	-0.50	**-0.51**
GH[c] Rotation 25%	-0.08	0.34
Scapular UR[a] 50%	0.14	-0.21
Scapular Tilt 50%	0.25	0.15
Scapular IR[b] 50%	-0.45	-0.37
GH[c] Rotation 50%	0.02	0.37
Scapular UR[a] 75%	0.22	-0.10
Scapular Tilt 75%	0.27	-0.13
Scapular IR[b] 75%	-0.16	-0.17
GH[c] Rotation 75%	0.08	0.34
Scapular UR[a] 100%	0.08	-0.02
Scapular Tilt 100%	0.35	-0.33
Scapular IR[b] 100%	0.12	-0.13
GH[c] Rotation 100°	-0.01	0.34

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.5: Effect of gender and BMI on the elderly group during the elevation phase at each angular position during the forward reach task. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Positions	**Gender**	**BMI**
Scapular UR[a] 25%	0.29	0.17
Scapular Tilt 25%	0.20	-0.60
Scapular IR[b] 25%	-0.14	0.05
GH[c] Rotation 25%	0.00	**0.58**
Scapular UR[a] 50%	0.32	0.26
Scapular Tilt 50%	-0.10	**-0.57**
Scapular IR[b] 50%	-0.17	0.05
GH[c] Rotation 50%	-0.03	**0.55**
Scapular UR[a] 75%	0.35	0.18
Scapular Tilt 75%	-0.08	**-0.50**
Scapular IR[b] 75%	-0.16	0.07
GH[c] Rotation 75%	-0.05	**0.53**
Scapular UR[a] 100%	0.42	0.06
Scapular Tilt 100%	-0.05	-0.44
Scapular IR[b] 100%	-0.09	0.05
GH[c] Rotation 100°	-0.03	0.49

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.6: Effect of gender and BMI on the young group during the elevation phase at each angular position during the forward reach task. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.01	0.06
Scapular Tilt 25%	0.20	0.20
Scapular IR[b] 25%	0.10	0.15
GH[c] Rotation 25%	-0.25	-0.27
Scapular UR[a] 50%	-0.02	0.01
Scapular Tilt 50%	0.02	-0.17
Scapular IR[b] 50%	-0.06	-0.40
GH[c] Rotation 50%	-0.14	0.32
Scapular UR[a] 75%	-0.06	-0.08
Scapular Tilt 75%	-0.08	0.02
Scapular IR[b] 75%	-0.20	-0.47
GH[c] Rotation 75%	-0.07	0.36
Scapular UR[a] 100%	-0.11	-0.08
Scapular Tilt 100%	0.02	0.14
Scapular IR[b] 100%	-0.18	**-0.59**
GH[c] Rotation 100°	0.02	0.33

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.7: Effect of gender and BMI on the elderly group during the lowering phase at each angular position during the forward reach task. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.35	0.19
Scapular Tilt 25%	-0.28	-0.61
Scapular IR[b] 25%	-0.17	0.06
GH[c] Rotation 25%	-0.03	0.50
Scapular UR[a] 50%	0.32	0.25
Scapular Tilt 50%	-0.16	**-0.60**
Scapular IR[b] 50%	-0.15	0.03
GH[c] Rotation 50%	-0.06	**0.55**
Scapular UR[a] 75%	0.32	0.14
Scapular Tilt 75%	-0.15	-0.53
Scapular IR[b] 75%	-0.13	0.06
GH[c] Rotation 75%	-0.06	**0.51**
Scapular UR[a] 100%	0.32	0.04
Scapular Tilt 100%	-0.02	-0.43

Scapular IR[b] 100%	-0.06	0.06
GH[c] Rotation 100°	-0.07	0.52

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.8: Effect of gender and BMI on the young group during the lowering phase at each angular position during the forward reach task. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.03	0.08
Scapular Tilt 25%	0.28	-0.40
Scapular IR[b] 25%	0.10	-0.33
GH[c] Rotation 25%	-0.12	0.38
Scapular UR[a] 50%	0.13	-0.02
Scapular Tilt 50%	0.10	-0.14
Scapular IR[b] 50%	0.00	-0.42
GH[c] Rotation 50%	-0.09	0.39
Scapular UR[a] 75%	0.08	-0.05
Scapular Tilt 75%	0.07	0.06
Scapular IR[b] 75%	-0.20	**-0.52**
GH[c] Rotation 75%	0.05	0.41
Scapular UR[a] 100%	-0.25	-0.14
Scapular Tilt 100%	0.06	0.15
Scapular IR[b] 100%	-0.14	**-0.61**
GH[c] Rotation 100°	0.15	0.29

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.9: Effect of gender and BMI on the elderly group during the elevation phase at each angular position during the reaching the back task.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.18	-0.05
Scapular Tilt 25%	-0.03	-0.44
Scapular IR[b] 25%	-0.09	0.02
GH[c] Rotation 25%	0.14	0.48
Scapular UR[a] 50%	0.21	-0.02
Scapular Tilt 50%	-0.05	-0.44
Scapular IR[b] 50%	-0.07	0.01
GH[c] Rotation 50%	0.16	0.38
Scapular UR[a] 75%	0.23	-0.00
Scapular Tilt 75%	-0.06	-0.40

Scapular IR[b] 75%	0.03	-0.00
GH[c] Rotation 75%	0.22	0.27
Scapular UR[a] 100%	0.15	-0.04
Scapular Tilt 100%	-0.01	-0.37
Scapular IR[b] 100%	0.20	-0.06
GH[c] Rotation 100°	0.20	0.11

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.10: Effect of gender and BMI on the young group during the elevation phase at each angular position during the reaching the back task. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	-0.07	-0.29
Scapular Tilt 25%	**0.58**	-0.39
Scapular IR[b] 25%	0.05	-0.25
GH[c] Rotation 25%	0.24	0.28
Scapular UR[a] 50%	-0.06	-0.27
Scapular Tilt 50%	**0.59**	-0.36
Scapular IR[b] 50%	0.10	-0.23
GH[c] Rotation 50%	0.15	0.14
Scapular UR[a] 75%	-0.01	-0.33
Scapular Tilt 75%	**0.59**	-0.35
Scapular IR[b] 75%	0.20	-0.23
GH[c] Rotation 75%	0.19	0.10
Scapular UR[a] 100%	-0.03	-0.42
Scapular Tilt 100%	**0.51**	-0.39
Scapular IR[b] 100%	0.36	-0.19
GH[c] Rotation 100°	0.27	0.16

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.11: Effect of gender and BMI on the elderly group during the lowering phase at each angular position during the reaching the back task.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.22	-0.02
Scapular Tilt 25%	-0.05	-0.39
Scapular IR[b] 25%	-0.03	0.04
GH[c] Rotation 25%	0.07	0.47
Scapular UR[a] 50%	0.17	-0.02
Scapular Tilt 50%	-0.05	-0.38

Scapular IR[b] 50%	0.03	0.04
GH[c] Rotation 50%	0.13	0.43
Scapular UR[a] 75%	0.13	-0.02
Scapular Tilt 75%	-0.05	-0.31
Scapular IR[b] 75%	0.05	0.03
GH[c] Rotation 75%	0.14	0.25
Scapular UR[a] 100%	0.06	-0.01
Scapular Tilt 100%	0.07	-0.31
Scapular IR[b] 100%	0.09	-0.05
GH[c] Rotation 100°	0.12	0.23

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.12: Effect of gender and BMI on the young group during the lowering phase at each angular position during the reaching the back task. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	-0.02	-0.29
Scapular Tilt 25%	**0.51**	-0.43
Scapular IR[b] 25%	0.13	-0.24
GH[c] Rotation 25%	0.35	0.34
Scapular UR[a] 50%	0.03	-0.27
Scapular Tilt 50%	**0.51**	-0.42
Scapular IR[b] 50%	0.24	-0.24
GH[c] Rotation 50%	0.29	0.30
Scapular UR[a] 75%	0.03	-0.31
Scapular Tilt 75%	0.50	-0.41
Scapular IR[b] 75%	0.37	-0.24
GH[c] Rotation 75%	0.34	0.17
Scapular UR[a] 100%	-0.02	-0.43
Scapular Tilt 100%	0.47	-0.41
Scapular IR[b] 100%	0.38	-0.13
GH[c] Rotation 100°	0.25	0.20

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.13: Effect of gender and BMI on the elderly group during the elevation phase at each angular position during the reaching wallet task. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.28	0.06
Scapular Tilt 25%	0.08	-0.33

Scapular IR[b] 25%	-0.10	0.07
GH[c] Rotation 25%	0.02	**0.51**
Scapular UR[a] 50%	0.28	0.11
Scapular Tilt 50%	0.10	-0.34
Scapular IR[b] 50%	-0.07	0.07
GH[c] Rotation 50%	0.02	**0.52**
Scapular UR[a] 75%	0.22	0.17
Scapular Tilt 75%	0.08	-0.31
Scapular IR[b] 75%	0.02	0.07
GH[c] Rotation 75%	0.01	0.46
Scapular UR[a] 100%	0.18	0.14
Scapular Tilt 100%	0.00	-0.38
Scapular IR[b] 100%	0.08	0.01
GH[c] Rotation 100°	0.17	0.42

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.14: Effect of gender and BMI on the young group during the elevation phase at each angular position during the reaching wallet task.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	-0.24	-0.17
Scapular Tilt 25%	0.23	-0.38
Scapular IR[b] 25%	0.22	-0.01
GH[c] Rotation 25%	0.10	0.29
Scapular UR[a] 50%	-0.21	-0.15
Scapular Tilt 50%	0.21	-0.39
Scapular IR[b] 50%	0.14	-0.07
GH[c] Rotation 50%	0.01	0.23
Scapular UR[a] 75%	-0.17	-0.16
Scapular Tilt 75%	0.17	-0.42
Scapular IR[b] 75%	0.17	-0.11
GH[c] Rotation 75%	-0.01	0.17
Scapular UR[a] 100%	-0.13	-0.17
Scapular Tilt 100%	0.15	-0.47
Scapular IR[b] 100%	0.35	-0.16
GH[c] Rotation 100°	-0.06	0.07

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.15: Effect of gender and BMI on the elderly group during the lowering phase at each angular position during the reaching wallet task. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.32	0.09
Scapular Tilt 25%	0.12	-0.34
Scapular IR[b] 25%	-0.08	0.07
GH[c] Rotation 25%	0.01	**0.52**
Scapular UR[a] 50%	0.31	0.13
Scapular Tilt 50%	0.10	-0.35
Scapular IR[b] 50%	-0.03	0.07
GH[c] Rotation 50%	0.05	**0.54**
Scapular UR[a] 75%	0.16	0.18
Scapular Tilt 75%	0.06	-0.27
Scapular IR[b] 75%	0.02	0.09
GH[c] Rotation 75%	0.08	**0.53**
Scapular UR[a] 100%	0.13	0.11
Scapular Tilt 100%	-0.01	-0.31
Scapular IR[b] 100%	0.07	0.05
GH[c] Rotation 100°	0.12	**0.51**

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.16: Effect of gender and BMI on the young group during the lowering phase at each angular position during the reaching wallet task.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	-0.22	-0.13
Scapular Tilt 25%	0.24	-0.37
Scapular IR[b] 25%	0.20	-0.00
GH[c] Rotation 25%	0.14	0.33
Scapular UR[a] 50%	-0.22	-0.14
Scapular Tilt 50%	0.20	-0.35
Scapular IR[b] 50%	0.12	-0.05
GH[c] Rotation 50%	0.07	0.32
Scapular UR[a] 75%	-0.15	-0.14
Scapular Tilt 75%	0.13	-0.38
Scapular IR[b] 75%	0.27	-0.10
GH[c] Rotation 75%	0.03	0.21
Scapular UR[a] 100%	-0.13	-0.18
Scapular Tilt 100%	0.16	-0.44

Scapular IR[b] 100%	0.36	-0.12
GH[c] Rotation 100°	-0.07	0.10

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.17: Effect of gender and BMI on the elderly group during the elevation phase at each angular position during the touching the head task. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.36	0.13
Scapular Tilt 25%	-0.01	**-0.64**
Scapular IR[b] 25%	-0.14	0.02
GH[c] Rotation 25%	-0.03	**0.53**
Scapular UR[a] 50%	0.37	0.19
Scapular Tilt 50%	0.03	**-0.58**
Scapular IR[b] 50%	-0.13	0.02
GH[c] Rotation 50%	-0.06	0.43
Scapular UR[a] 75%	0.32	0.12
Scapular Tilt 75%	0.12	-0.50
Scapular IR[b] 75%	-0.12	0.02
GH[c] Rotation 75%	0.00	0.45
Scapular UR[a] 100%	0.34	0.03
Scapular Tilt 100%	0.15	-0.41
Scapular IR[b] 100%	-0.17	-0.03
GH[c] Rotation 100°	0.13	0.42

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.18: Effect of gender and BMI on the young group during the elevation phase at each angular position during the touching the head task.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.15	0.03
Scapular Tilt 25%	0.23	-0.39
Scapular IR[b] 25%	0.10	-0.12
GH[c] Rotation 25%	-0.17	0.23
Scapular UR[a] 50%	0.18	-0.03
Scapular Tilt 50%	0.10	-0.22
Scapular IR[b] 50%	0.01	-0.21
GH[c] Rotation 50%	-0.08	0.24
Scapular UR[a] 75%	0.18	-0.12
Scapular Tilt 75%	0.01	-0.07

Scapular IR[b] 75%	-0.05	-0.31
GH[c] Rotation 75%	0.05	0.34
Scapular UR[a] 100%	0.16	-0.20
Scapular Tilt 100%	0.13	0.12
Scapular IR[b] 100%	-0.29	-0.49
GH[c] Rotation 100°	0.17	0.32

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.19: Effect of gender and BMI on the elderly group during the lowering phase at each angular position during the touching the head task. Bolded values indicate r>0.50.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.36	0.18
Scapular Tilt 25%	-0.06	**-0.71**
Scapular IR[b] 25%	-0.20	0.03
GH[c] Rotation 25%	-0.12	**0.52**
Scapular UR[a] 50%	0.44	0.21
Scapular Tilt 50%	-0.02	**-0.64**
Scapular IR[b] 50%	-0.22	-0.02
GH[c] Rotation 50%	-0.05	**0.51**
Scapular UR[a] 75%	0.35	0.12
Scapular Tilt 75%	0.17	**-0.53**
Scapular IR[b] 75%	-0.23	-0.02
GH[c] Rotation 75%	0.00	0.47
Scapular UR[a] 100%	0.32	0.03
Scapular Tilt 100%	0.16	-0.42
Scapular IR[b] 100%	-0.16	-0.02
GH[c] Rotation 100°	0.18	0.40

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Table A11.20: Effect of gender and BMI on the young group during the lowering phase at each angular position during the touching the head task.

Dependent Variables at Specific Angular Position	Gender	BMI
Scapular UR[a] 25%	0.20	0.08
Scapular Tilt 25%	0.29	0.47
Scapular IR[b] 25%	-0.05	-0.07
GH[c] Rotation 25%	-0.34	0.36
Scapular UR[a] 50%	0.28	-0.04
Scapular Tilt 50%	0.14	-0.24

Scapular IR[b] 50%	-0.22	-0.20
GH[c] Rotation 50%	-0.21	0.35
Scapular UR[a] 75%	0.23	-0.14
Scapular Tilt 75%	0.08	-0.03
Scapular IR[b] 75%	-0.31	-0.34
GH[c] Rotation 75%	-0.10	0.35
Scapular UR[a] 100%	0.17	-0.21
Scapular Tilt 100%	0.16	0.14
Scapular IR[b] 100%	-0.36	-0.49
GH[c] Rotation 100°	0.14	0.27

[a]UR: Upward rotation, [b]IR: Internal rotation, [c]GH: Glenohumeral

Appendix 12: Homogeneity of Variance for the Kinematic Variables

Table A12.1: Circularity/Sphericity tests for conditions and dependent variables with presence of interaction effect only between groups and angles.

Conditions	**Dependent Variables**	**Original p- value**	**Geisser Greenhouse p- value**
Forward Reach	Scapular IR[a]	0.0006*	0.01*
Forward Reach	GH[b] Rotation (BMI)[c]	*0.00**	*0.000001**
Reaching Back	Scapular UR[d]	0.0006*	0.01*
Reaching Back	Scapular Tilt	0.0001*	0.007*
Reaching Back	Scapular IR[a]	0.002*	0.02*
Reaching Wallet	Scapular IR[a]	0.000006*	0.002*

[a]Internal rotation, [b]GH: Glenohumeral, [c]BMI included in the model as covariate, [d]UR: Upward rotation

*Significance level with p<0.05

Appendix 13: Effect of covariates (gender and BMI) for Static Thoracic Posture

Table A13: Effect of the two covariates (gender and BMI) on the two groups for static thoracic posture.

Thoracic Angle between T2 and T11	**Gender**	**BMI**
Elderly	0.36	0.16
Young	-0.05	-0.24

Appendix 14: Trial Effects of Dynamic Trunk Motion

Table A14: Each cell in the table represents effect of the three trials during either elevation or lowering of the arm for the flexion-extension motion based on each of the five tasks. Empty cell signify absence of interaction and main effect of repetition. Combinations having interaction effect with magnitude less than 1° between trials are mentioned as Interaction with the specific trials. Combinations having main effect of repetition only are denoted as Repetition effect.

Trunk Motion	Scapular Plane Abduction	Forward Reach	Reaching Back	Reaching Wallet	Touching Head
Flexion-Extension	Interaction Trial 1 & 3		Repetition Effect		Repetition Effect

Summaries of trial effects for each task are as follows:
Scapular plane abduction: For all the dependent variables repetition 1 was significantly different from repetition 3 during flexion-extension of trunk. Difference in magnitude between trials 1 and 3 was less than 1˚.

Forward reach: There was one interaction between group and repetition for flexion-extension motion, following it up with two factor interaction there was no significant difference.

Reaching the back: There was a main effect of repetition with a magnitude of less than 0.5˚.

Reaching the wallet: There was a main effect of repetition, following it up with two factor interaction there was no significant difference.

Touching the head: There was a main effect of repetition with a magnitude of less than 0.5˚.

Appendix 15: Reliability Statistics (ICC and SEM) for Dynamic Thoracic Posture

Table A15: Intraclass Correlation Coefficients (ICC) and Standard Error of Measurement (SEM) values for flexion-extension trunk motion by each condition and group during the arm elevation phase.

Group, Tasks and Phase during Trunk Flexion-Extension	ICC	SEM (Degrees)
Elderly Scapular Plane Abduction for Elevation	0.72	1.3
Elderly Scapular Plane Abduction for Lowering	0.83	1.0
Young Scapular Plane Abduction for Elevation	0.85	1.1
Young Scapular Plane Abduction for Lowering	0.93	0.8
Elderly Forward Reach for Elevation	0.90	1.5
Elderly Forward Reach for Lowering	0.95	1.1
Young Forward Reach for Elevation	0.80	1.3
Young Forward Reach for Lowering	0.85	1.2
Elderly Reaching Back for Elevation	0.35	1.3
Elderly Reaching Back for Lowering	0.81	0.9
Young Reaching Back for Elevation	0.74	1.1
Young Reaching Back for Lowering	0.79	1.1
Elderly Reaching Wallet for Elevation	0.74	0.9
Elderly Reaching Wallet for Lowering	0.83	0.7
Young Reaching Wallet for Elevation	0.74	1.1
Young Reaching Wallet for Lowering	0.87	1.0
Elderly Touching Head for Elevation	0.73	1.2
Elderly Touching Head for Lowering	0.87	0.7
Young Touching Head for Elevation	0.84	1.0
Young Touching Head for Lowering	0.91	0.8

Appendix 16: Descriptive Analyses for Dynamic Trunk Motions during Performance of the Five Tasks

Table A16.1: Mean and standard deviation of trunk motion during scapular plane abduction.

Flexion-Extension Trunk Motion	Elderly Mean (SD)	Young Mean (SD)
Elevation	0.4° (2.25)	-0.5° (2.82)
Lowering	1.3° (2.32)	1.9° (3.02)

Table A16.2: Mean and standard deviation during forward reach.

Flexion-Extension Trunk Motion	Elderly Mean (SD)	Young Mean (SD)
Elevation	4.5° (4.57)	4.0° (2.62)
Lowering	-4.5° (4.96)	-3.7° (3.00)

Table A16.3: Mean and standard deviation during reaching back.

Flexion-Extension Trunk Motion	Elderly Mean (SD)	Young Mean (SD)
Elevation	1.6° (1.20)	3.5° (1.99)
Lowering	-1.4° (1.84)	-2.8° (2.34)

Table A16.4: Mean and standard deviation during reaching wallet.

Flexion-Extension Trunk Motion	Elderly Mean (SD)	Young Mean (SD)
Elevation	0.3° (1.60)	1.2° (1.95)
Lowering	0.7° (1.63)	0.5° (2.76)

Table A16.5: Mean and standard deviation during touching head.

Flexion-Extension Trunk Motion	Elderly Mean (SD)	Young Mean (SD)
Elevation	-1.1° (2.13)	-1.4° (2.34)
Lowering	1.8° (1.87)	2.3° (2.59)

Appendix 17: Normality Statistics for Dynamic Trunk Motions

Table A17: Skewness and kurtosis values for the flexion-extension dynamic trunk motion for both the groups during performance of the five tasks. Values exceeding the acceptable range are bolded.

Flexion-Extension Trunk Motions	Elderly Skewness	Elderly Kurtosis	Young Skewness	Young Kurtosis
Scapular Plane Abduction Elevation	0.13	2.19	-0.76	3.28
Scapular Plane Abduction Lowering	-0.57	2.53	0.31	2.11
Forward Reach Elevation	0.27	2.46	0.21	3.28
Forward Reach Lowering	-0.53	2.22	-0.60	3.85
Reaching Back Elevation	0.52	2.92	-0.10	2.70
Reaching Back Lowering	-0.08	3.29	-0.79	5.24
Reaching Wallet Elevation	-0.65	4.24	**-1.21**	5.40
Reaching Wallet Lowering	0.40	2.66	**1.38**	4.89
Touching Head Elevation	-0.24	3.26	**-1.49**	6.95
Touching Head Lowering	-0.29	2.87	0.81	4.08

Appendix 18: Association of the covariates gender and BMI on Dynamic Trunk Motions

Tables indicate strength of association of the two covariates (gender and BMI) with flexion-extension trunk motion during arm elevation and lowering for the two groups through the five conditions. Bolded values indicate any combination having r>0.50.

Table A18.1: Association of gender and BMI on flexion-extension during scapula plane abduction.

Flexion-Extension Trunk Motion	Gender	BMI
Elderly Elevation	0.00	-0.08
Younger Elevation	**0.79**	-0.07
Elderly Lowering	-0.21	0.09
Younger Lowering	**-0.79**	-0.02

Table A18.2: Association of gender and BMI on flexion-extension during functional reach.

Flexion-Extension Trunk Motion	Gender	BMI
Elderly Elevation	0.07	0.09
Younger Elevation	0.25	-0.10
Elderly Lowering	-0.20	-0.25
Younger Lowering	-0.27	0.11

Table A18.3: Association of gender and BMI on flexion-extension during reaching back.

Flexion-Extension Trunk Motion	Gender	BMI
Elderly Elevation	0.24	-0.44
Younger Elevation	0.00	0.14
Elderly Lowering	-0.28	0.04
Younger Lowering	-0.05	0.07

Table A18.4: Association of gender and BMI on flexion-extension during reaching wallet.

Flexion-Extension Trunk Motion	Gender	BMI
Elderly Elevation	0.09	-0.32
Younger Elevation	0.49	-0.09
Elderly Lowering	-0.01	0.13
Younger Lowering	-0.21	0.29

Table A18.5: Association of gender and BMI on flexion-extension during touching head.

Flexion-Extension Trunk Motion	Gender	BMI
Elderly Elevation	-0.29	0.14
Younger Elevation	**0.58**	-0.35
Elderly Lowering	-0.03	-0.18
Younger Lowering	**-0.77**	0.35

Appendix 19: Normality (ICC and SEM) Testing for Normalized Torque

Table A19: Intraclass Correlation Coefficients (ICC) and Standard Error of Measurement (SEM) values for all group, direction test combinations.

Torque Measures	ICC	SEM (Nm/Kg)
Elderly Flexion	0.95	0.02
Elderly Abduction	0.98	0.02
Elderly ER[a]	0.96	0.01
Elderly IR[b]	0.93	0.02
Young Flexion	0.97	0.03
Young Abduction	0.93	0.05
Young ER[a]	0.95	0.02
Young IR[b]	0.98	0.02

[a]ER: External Rotation, [b]IR: Internal Rotation

Appendix 20: Mean and Standard Deviation of Normalized Torque

Table A20: Two group descriptive data for flexion, abduction, external rotation (ER) and internal rotation (IR) normalized torque.

Directions	Elderly Group (Mean in Nm/ Kg and SD)	Young Group (Mean in Nm/ Kg and SD)
Flexion	0.57 (0.11)	0.7 (0.15)
Abduction	0.66 (0.13)	0.85 (0.17)
ER	0.27 (0.07)	0.36 (0.09)
IR	0.36 (0.08)	0.49 (0.12)

Appendix 21: Skewness and Kurtosis Values for Normalized Torque

Table A21: Normality data for both groups in the four directions.

Directions	Elderly Group Skewness	Elderly Group Kurtosis	Young Group Skewness	Young Group Kurtosis
Flexion Torque	-0.19	2.84	-0.09	2.47
Abduction Torque	0.08	2.02	0.51	4.73
ER[a] Torque	-0.20	3.09	**1.66**	7.39
IR[b] Torque	-0.11	2.78	1.00	4.68

[a]ER: External rotation, [b]IR: Internal rotation

Appendix 22: Association of the covariates gender and BMI on Normalized Torque

Table A22: The table describes strength of association of the two covariates (gender and BMI) on normalized torque for each of the four directions of strength testing in the two groups.

Normalized Torque	Gender	BMI
Elderly Flexion	**-0.50**	**-0.60**
Elderly Abduction	**-0.64**	-0.36
Elderly ER[a]	-0.46	**-0.60**
Elderly IR[b]	-0.28	**-0.65**
Young Flexion	**-0.76**	-0.03
Young Abduction	-0.45	0.04
Young ER[a]	**-0.69**	0.01
Young IR[b]	**-0.73**	0.03

[a]ER: External rotation, [b]IR: Internal rotation

Appendix 23: Mean and Standard Deviation for Normalized Torque Ratios

Table A23: Descriptive data for normalized torque ratios for both groups.

Direction	Elderly (Mean and SD)	Young (Mean and SD)
Flexion-Abduction Torque Ratio	0.87 (0.14)	0.84 (0.17)
ER[a]-IR[b] Torque Ratio	1.36 (0.27)	1.36 (0.22)

[a]ER: External rotation, [b]IR: Internal rotation

Appendix 24: Skewness and Kurtosis Values for Normalized Torque Ratios

Table A24: Normality for both groups normalized torque ratios.

Directions	Elderly Group Skewness	Elderly Group Kurtosis	Young Group Skewness	Young Group Kurtosis
Flexion-Abduction Torque Ratio	0.47	2.31	0.25	2.89
ER[a]-IR[b] Torque ratio	0.84	2.63	0.81	3.03

[a]ER: External rotation, [b]IR: Internal rotation

Appendix 25: Association of the covariates gender and BMI on Normalized Torque Ratios

Table A25: The table describes strength of association of the two covariates (gender and BMI) on normalized strength ratio for each of the two directions of strength testing in the two groups. All combinations had covariate effect with r<0.50.

Normalized Torque Ratio	Gender	BMI
Elderly Flexion-Abduction	0.06	-0.37
Elderly ER[a]-IR[b]	0.29	0.13
Young Flexion-Abduction	-0.32	-0.06
Young ER[a]-IR[b]	-0.09	0.05

[a]ER: External rotation, [b]IR: Internal rotation

Appendix 26: Effect of glenohumeral plane on minimum linear distances during forward reach task at 25% angular position for raising and lowering phases

Table A26.1: Minimum linear distance between the rotator cuff footprints and the potential impinging structures with the elderly GH plane (Mean= 4.22) constant for both elderly and young groups.

	SST-Acromion (mm)	SST-CA Ligament (mm)	IST-Acromion (mm)
Elderly	2.8	3.7	2.2
Young	2.9	4.8	2.6

Table A26.2: Minimum linear distance between the rotator cuff footprints and the potential impinging structures with the young GH plane (Mean= 15.09) constant for both elderly and young groups.

	SST-Acromion (mm)	SST-CA Ligament (mm)	IST-Acromion (mm)
Elderly	4.2	4.8	2.6
Young	4.3	5.8	2.8

Appendix 27: Post Hoc Power Analyses

Post hoc power for glenohumeral external rotation during touching the head task using ANOVA method of analysis.

$f = s_m/s$

f= Effect size
Pooled standard deviation for 16 condition combinations, s= 17.9
s_m= Standard deviation of group means
$s_m = \sqrt{\{[\Sigma(X_i - X_G)^2]/k\}}$
Number of groups, k= 16
Assumed mean difference= 10°
$X_i - X_G = 5$
$(X_i - X_G)^2 = 5^2 = 25$
$s_m = 5$
f= 0.28
Number of subjects, n= 25
$df_b = 2-1 = 1$
$\alpha = 0.05$
Power= 55%
Post hoc power for static thoracic posture during touching the head task using t-test method of analysis.
$d = [(X_1 - X_2)/\sqrt{\{(\text{Std Dev}(s1+s2))^2/2\}}]$
Assumed mean difference, $X_1 - X_2 = 10°$
Standard deviation of elderly group from current study, s1= 18.76
Standard deviation of young group from current study, s2= 14.94
Effect size, d= 0.59
Number of subjects, n= 25
df= 2-1= 1
$\alpha = 0.05$
Power= 54%