EFFECTS OF FORWARD HEAD AND ROUNDED SHOULDER POSTURE ON SCAPULAR
KINEMATICS, MUSCLE ACTIVITY, AND SHOULDER COORDINATION

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ABSTRACT

CHARLES A. THIGPEN: Effects Of Forward Head And Rounded Shoulder Posture On Scapular Kinematics, Muscle Activity, And Shoulder Coordination (Under the direction of Dr. Darin A. Padua)

Forward head and rounded shoulder posture (FHRSP) has been identified as a potential risk factor for the development of shoulder pain. The mechanism through which forward head and rounded shoulder can facilitate shoulder injury is not well understood. Altered scapular kinematics, muscle activity, and shoulder joint coordination due to FHRSP may lead to the development of shoulder pain. However, there is little evidence to support the influence of FHRSP on scapular kinematics, muscle activity, and shoulder joint coordination. Therefore, the purpose of this study was to compare scapular kinematics, muscle activity, and shoulder joint coordination in individuals with and without FHRSP.

Eighty volunteers without shoulder pain were classified as having FHRSP or ideal posture. An electromagnetic tracking system together with hard-wired surface electromyography was used to collect three-dimensional scapular kinematics concurrently with muscle activity of the upper and lower trapezius as well as the serratus anterior during

loaded shoulder flexion and an overhead reaching task. Separate mixed model analyses of variance were used to compare three dimensional scapular kinematics, muscle activity, and shoulder joint coordination during the ascending and descending phases of the loaded flexion and overhead reaching tasks.

Individuals with FHRSP displayed significant increases in scapular upward rotation, internal rotation, and anterior tipping during the loaded flexion and reaching tasks. Significant decreases in serratus anterior muscle activation during the ascending phase of the flexion and reaching tasks were also noted. These scapular kinematic and muscle activation patterns are similar to those reported in individuals with shoulder pain. Additionally, uncoupled scapulohumeral coordination strategies were also observed for scapular upward rotation and anterior tipping. The observed uncoupling suggests an out-of-phase relationship between the humerus and these scapular rotations in individuals with FHRSP. Considered together, these results suggest FHRSP influences scapular kinematics, muscle activity, and shoulder joint coordination. FHRSP and its effects on shoulder kinematics, muscle activity, and shoulder coordination should be examined as a potential risk factor in the development of shoulder pain. Assessment and treatment of FHRSP should be considered in the prevention and interventions of shoulder pain.

To Rebecca:

You have are the love of my life.

I could not have achieved this goal without you.

I love you.

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"Now to Him who is able to do immeasurably more than all we ask or imagine. To Him be glory in

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CHAPTER I

Introduction

1.1 <u>The Problem of Shoulder Pain</u>

Shoulder pain is a significant health problem. The prevalence of shoulder pain in the general population is reported to range from 16% to 21%.(Urwin, Symmons et al. 1998; Bongers 2001) Shoulder pain related to work injury is reported between 8% and 41% depending on exposure rates and is second only to low back pain in worker's compensation claims.(Stone 1983; McDermott 1986; Leclerc, Chastang et al. 2004; Punnett, Gold et al. 2004) More troubling is that 40% of all shoulder pain persists for at least 12 months.(Van der Heijden 1999) The cost and burden of occupational shoulder injury on society is estimated from $10-15 billion/year.(Washington State 1996) These costs are only reflective of the impact on health care resources and do not reflect costs due to time lost, retraining, and long-term disability associated with shoulder pain. The prevalence, cost, and associated disability due to shoulder injury may be decreased through effective prevention and intervention programs.

1.2 <u>Influence of Postural Alignment on the Shoulder</u>

Posture has been postulated as a risk factor for upper quarter musculoskeletal injuries such as shoulder impingement, nerve entrapments, and thoracic outlet syndrome.(Punnett 1998; Szeto, Straker et al. 2002; Punnett, Gold et al. 2004) Individuals with increased forward head and rounded shoulder posture are thought to be at greater risk to develop shoulder impingement syndrome.(Lukasiewicz 1999; Ludewig and Cook 2000)

Clinicians have postulated that increases in forward head and rounded shoulder posture lead to muscle imbalances which in turn contribute to altered biomechanics and neuromuscular control of the upper extremity.(Kendall, Kendall et al. 1952; Sahrmann 2001) It is also possible that altered and adaptive mechanics cause muscle imbalances. However, the mechanisms contributing to these imbalances are unclear.

A limiting factor in studies examining postural alignment, is that there is no clear definition of ideal or poor head and shoulder posture.(Cureton 1941; Braun 1991; Raine and Twomey 1997) This is due in part to differences in methodology which limit comparison among studies and the establishment of normative postural values. However, general conclusions can be drawn from the literature for what is considered "ideal posture".

Increases in forward head and rounded shoulder posture are related to an increased incidence and severity of shoulder, neck, and interscapular pain.(Greigel-Morris 1992; Greenfield, Catlin et al. 1995) Postural malalignment is thought to facilitate impairments of scapular dysfunction such as altered scapular kinematics, muscle activity, coordination, and strength. Poor postural alignment is often hypothesized to contribute to changes in scapula kinematics and muscle activation. It is theorized that poor postural alignment alters the surrounding musculature's length-tension relationship, thereby altering scapular muscle function and disrupting normal scapular kinematics, strength, muscle activation patterns, and coordination. Individuals who were positioned in a slouched sitting posture have displayed decreases in scapular muscle strength (Kebaetse, McClure et al. 1999), where as protracted and forward scapular positions alone are not associated with decreased strength.(Diveta, Walker et al. 1990) Recently, it has been

shown that collegiate swimmers display increased forward head and rounded shoulder posture, increased shoulder pain, decreased self-reported shoulder function, and decreased shoulder strength when compared to healthy college students.(Layton, Padua et al. 2005) Altered scapular kinematics have also been noted in individuals with forward head and rounded shoulder posture.(Kebaetse, McClure et al. 1999; Finley and Lee 2003) Similar alterations in scapular kinematics and scapulohumeral rhythm (ratio of humeral elevation to scapular upward rotation) are consistently reported in patients with shoulder injuries when compared to healthy shoulders. (Lukasiewicz 1999; Ludewig and Cook 2000; Hebert, Moffet et al. 2002) However, the exact mechanisms of these relationships remain unknown.

Scapular kinematics, muscle activity, and scapulohumeral rhythm (a basic measure of shoulder coordination) have been considered potential risk factors for shoulder injury. (Lukasiewicz 1999; Ludewig and Cook 2000; Hebert, Moffet et al. 2002)   Alterations in scapular kinematics have been consistently reported in patients with shoulder impingement syndrome, adhesive capsulitis, and rotator cuff disease.(Paletta, Warner et al. 1997; Lukasiewicz 1999; Ludewig and Cook 2000; Rundquist, Anderson et al. 2003; McClure, Bialker et al. 2004) Decreases in scapular upward rotation, external rotation, and posterior tipping have been reported in patients with shoulder impingement syndrome.(Lukasiewicz 1999; Ludewig and Cook 2000) One proposed mechanism contributing to these changes is increases in FHRSP. Increases in FHRSP are thought to alter scapulothoracic length tension relationships of peri-scapular muscles thereby impairing normal scapular kinematics. This is supported by observed changes in scapular muscle activation patterns and muscle balance in individuals diagnosed with shoulder

impingement syndrome when compared to healthy shoulders.(Ludewig and Cook 2000; Cools, Witvrouw et al. 2003) Similar changes in scapular kinematics concurrent with altered muscle activity in patients with non-traumatic, multidirectional shoulder instability.(Thigpen, Padua et al. 2005; Thigpen, Padua et al. 2005) Alterations in scapulohumeral rhythm concurrent with altered scapular muscle activity in individuals diagnosed with shoulder impingement syndrome suggest that deficits in shoulder coordination may play a role in the development of shoulder pain.(Ludewig and Cook 2000; Hebert, Moffet et al. 2002)

Altered shoulder joint coordination is considered a clinical manifestation of shoulder pain and dysfunction. Clinically, this coordination deficit is termed scapular dyskinesis and described as uneven and uncoordinated scapular movement.(Kibler 1998; Sahrmann 2001) Traditionally, shoulder coordination has been assessed by scapulohumeral rhythm, defined as the relationship of humeral elevation to scapular upward rotation. These measurements have identified alterations in scapulohumeral rhythm in some patients with shoulder impingement.(Ludewig and Cook 2000; Hebert, Moffet et al. 2002) However, this measure only reflects one plane of scapular motion (upward rotation). Recent evidence suggests individuals with shoulder impingement also have deficits in scapular internal/external rotation and anterior/posterior tipping.(Lukasiewicz 1999; Ludewig and Cook 2000) Therefore, examination of the relationship of humeral elevation to all three planes of scapular movement should be examined.

1.3 <u>A Unique Approach to Shoulder Coordination</u>

Shoulder coordination analyses based on Dynamical Systems Theory tenets may provide important and unique information to fill this void of knowledge. Using this

approach coordination among the knee and ankle joints has been shown in patients with lower extremity musculoskeletal injuries.(Hamill, van Emmerik et al. 1999; Heiderscheit, Hamill et al. 2002; Kurz, Stergiou et al. 2004; Stergiou, Moraiti et al. 2004) The observed uncoupling (bony segments moving out-of-phase) of knee joint motion in pathologic knees may contribute to the development of knee osteoarthritis.(Kurz, Stergiou et al. 2004) Increased wear and tear on the articular cartilage may occur as a result of decreased neuromuscular control which creates unequal joint loading. Similar coordination deficits may impact shoulder injury given the repetitive nature of activities that cause many shoulder injuries. Epidemiological research has shown that increased exposure to repetitive upper extremity tasks that are above shoulder height increase the risk of shoulder injury.(NIOSH 1997; Punnett, Gold et al. 2004) It is thought that the risk of injury increases when increased exposure is combined with postural malalignment.(Borstad and Ludewig 2005; Borstad 2006) Forward head and rounded shoulder posture changes the normal mechanical relationships of muscles and bony structures. Dynamical systems theorists' have shown that altering the initial conditions of the human movement system influence neuromuscular control and coordinative patterns of that system.(Kurz and Stergiou 2004) It is likely then, that shoulder injury and pain are related to changes in shoulder coordinative patterns that reflect alterations in neuromuscular control. Given the demonstrated importance of three dimensional scapular motions in shoulder injury, investigation of shoulder coordination patterns of the humerus at all three scapular motions is warranted.(Ludewig and Cook 2000; McClure, Michener et al. 2001)

Therefore, the overall goal of this study was to compare scapular kinematics, muscle activity, and shoulder joint coordination between individuals with and without forward head and rounded shoulder postural alignment. This was accomplished by identifying 40 individuals with ideal postural alignment and comparing them with 40 individuals with increased forward head and rounded shoulder posture. Selected scapular kinematic, muscle activation, and shoulder joint coordination variables were compared between groups during a loaded shoulder elevation and a forward/overhead, reaching task.

1.4 <u>Operational Definitions</u>

<u>Forward Head Angle:</u> The angle formed between the parallel line extending from C7 to the line connecting C7 to the tragus as measured using Adobe® Photoshop from a lateral view (Figure 1).

<u>Forward Shoulder Angle:</u> The angle formed between the parallel line extending from C7 to the line connecting C7 to the acromion as measured using Adobe® Photoshop from a lateral view (Figure 1).

<u>Ideal posture:</u> Individuals whose forward head angle is less than or equal to 36º and forward should angle less than or equal to 22º was assigned to this group (Figure 2).

<u>Forward head and rounded shoulder posture:</u> Individuals whose forward head angle is greater than or equal to 46º and forward should angle is greater than 52º was assigned to this group (Figure 3).

<u>Loaded Condition:</u> A weight equal to 2% of the participant's body weight was used during each humeral elevation task.

Forward flexion task: The participant stood and lift a weight equal to 2% of their body weight with their arm aligned in the sagittal plane beginning with the arm at rest by their side and proceeding to greater than 150º angle of humeral elevation.

Forward reaching task: The participant stood and lifted a weight equal to 2% of their body weight to a standard shelf position. The shelf was positioned so that the goal for the task is to move the weight from a height equal to their greater trochanter to a shelf at the height of their head. Additionally, the target was anterior measured to the length of their arm and perpendicular to their midline.

Baseline humeral elevation: The angle of humeral elevation when the arm is at rest beside the participant.

Ascending phase of motion: Humeral motion from baseline humeral elevation until the participant's maximum humeral elevation angle.

Descending phase of motion: Humeral motion from the participant's maximum humeral elevation angle until the baseline humeral elevation angle.

Beginning of phase: Is defined as the point when the humeral elevation angle is greater than the baseline humeral elevation angle for 10 consecutive frames.

End of phase: Is defined as the point when the humeral elevation angle is equal to the baseline humeral elevation angle for 10 consecutive frames.

60°, 90°, 120° of shoulder elevation: The sampled humeral elevation angles at 30° intervals beginning at the baseline humeral elevation angle and ending when humeral elevation returns to baseline.

<u>60°, 90°, 110° of functional reaching task:</u> The sampled humeral elevation angles at 30°

intervals beginning at the baseline humeral elevation angle and ending when humeral

elevation returns to baseline.

<u>Scapular upward/downward rotation:</u> Scapular motion approximately in the frontal plane

that occurs about an axis approximately perpendicular to the scapula. Upward rotation

moves toward a position so that the glenoid faces superiorly during humeral elevation

and downward rotation moves toward a position where the glenoid faces inferiorly during

the descending phase of humeral elevation. Previous research consistently reports

increasing angles of upward rotation during the ascending phase of humeral elevation and

a reversal of this path during the descending phase.(McClure, Michener et al. 2001)

<u>Scapular internal/external rotation:</u> Scapular motion approximately in the transverse

plane that occurs about the long axis of the scapula. Internal rotation is motion which

moves toward a position where the face of the glenoid faces anteriorly and external

rotation moves toward a position where the glenoid faces posteriorly. Previous research

generally reports increasing scapular rotation until humeral elevation angles greater than

110°, then increasing external rotation through maximum humeral elevation and a

reversal of this pattern during descending phase of humeral elevation. Differences in

previous research are attributed to methodological differences in the plane of humeral

elevation, definition of local and reference axes systems, and Euler angle sequence. (van

der Helm 1997; Karduna, McClure et al. 2000; McClure, Michener et al. 2001)

<u>Scapular anterior/posterior tipping:</u> Scapular motion approximately in the sagittal plane

that occurs about an axis through the scapular spine. Posterior tipping rotates so that the

anterior acromion moves upwards during humeral elevation and reverses this path during

descending humeral elevation. Previous research agrees on the direction and pattern of

scapular anterior/posterior tipping but there are minor differences reported on the range

of posterior tipping during humeral elevation. These differences are attributed to plane of

humeral elevation and the definition of the local and reference axes systems.(van der

Helm 1997; Karduna, McClure et al. 2000; McClure, Michener et al. 2001)

Scapular protraction/retraction: Scapular translation forward around the thorax

(protraction) or backwards toward the spine (retraction). Scapular protraction is

essentially a combination of scapular internal rotation and anterior tipping.(Borstad and

Ludewig 2005)

Scapular elevation/depression: Scapular translation superiorly or inferiorly where the

acromion and medial border of the scapula move the same linear distance.

Surface Electromyography (EMG) Mean Amplitude: The average amplitude of electrical

activity for a given muscle expressed as a percentage of maximum activation. This value

is representative of the rate and amount of neuromuscular input to a muscle. Alterations

in EMG activation are suggestive of changes in muscle function.

Phase Angle: This angle is calculated from the displacement(x axis)/velocity (y axis)

phase portrait. It quantifies the behavior of a segment and is used to calculate the

continuous relative phase. The phase angle (Θ) derived by translating the phase portrait

Cartesian coordinates (x,y) to polar coordinates (r, Θ).

Continuous relative phase: The difference between the distal phase angle and the

proximal phase angle that quantifies coordination between two segments.

Mean absolute relative phase (MARP): MARP is calculated from the ensemble average

of the continuous relative phase curve. MARP is the average absolute value of all the

points of the mean ensemble curve. MARP values range from 0º - 180º with lower values representing a more in phase relationship between the two segments and higher values an out of phase relationship.

Deviation phase (DP): DP is the average of the standard deviations of all the points of the ensemble curve. DP is a measure of stability of the organization of the neuromuscular system. A low DP value suggests a more stable neuromuscular system while a high DP suggests less stability in the neuromuscular system.

1.5 **Limitations/Assumptions**

The following limitations and assumptions apply to this study:

1. Forward head and shoulder angles calculated from reflective markers on bony landmarks were representative of head and shoulder girdle postural alignment.

2. Subjects assumed a standing posture that was representative of their normal posture during the postural evaluation.

3. Gender bias between postural groups did not affect the results of the study.

4. Kinematic data obtained from the skin mounted sensors on the scapula and humerus were representative of the true motion of these segments.

5. EMG data obtained from a specific part of a muscle was representative of the muscle activity for the entire muscle.

6. Subjects provided a true maximal voluntary isometric contraction during EMG data normalization.

1.6 <u>Delimitations</u>

The following are delimitations apply to this study:

1. Eighty subjects (40 assigned to the ideal postural alignment group and 40 assigned to the forward head and rounded shoulder group) were recruited from the university community.

2. All subjects were healthy and free from shoulder injury in the past 6 months prior to data collection.

3. Kinematic data was collected from the thorax, scapula, and humerus using an electromagnetic tracking system.

4. EMG data was collected for the upper trapezius, lower trapezius, and serratus anterior muscles.

1.7 <u>Statement of the problem</u>

The overall goal of this study was to compare scapular kinematics, muscle activity, and shoulder joint coordination between individuals with and without forward head and rounded shoulder posture. This was accomplished by comparing 40 individuals with ideal postural alignment to 40 individuals with increased forward head and rounded shoulder posture. Selected scapular kinematic, muscle activation, and shoulder joint coordination variables were compared between groups during two loaded humeral elevation tasks.

Understanding of the relationship between postural alignment and shoulder kinematics and neuromuscular control is important in developing clinical assessments, identifying individuals who may be at risk for injury, and guiding interventions to prevent shoulder pain and injury. The results of this study suggest that forward head and rounded

shoulder posture contribute to alterations in scapular kinematics, muscle activity, and shoulder coordination patterns. It is likely that these altered mechanics may increase the risk of suffering shoulder pain and injury. These results are the first to demonstrate the influence of altered postural alignment on scapular kinematics, muscle activity, and shoulder coordination during overhead/forward reaching tasks. Finally, these results lay the foundation for future research aimed at the prevention and treatment of shoulder pain and injury.

1.8 <u>Independent Variables</u>

Three independent variables used during this study were:

1. Posture (Ideal forward head and shoulder posture vs. Forward head and rounded shoulder posture)

2. Phase of humeral elevation (Ascending vs. Descending)

3. Arc of humeral elevation 60-90° and 91-120°

1.9 <u>Dependent Variables</u>

Twelve dependent variables used during this study were:

Scapular Kinematics

1. Upward/downward rotation angles

2. Internal/external rotation angles

3. Posterior/anterior tipping angles

4. Upward/downward rotation range of motion

5. Internal/external rotation range of motion

6. Posterior/anterior tipping range of motion

Mean Amplitude EMG for

7. Upper trapezius

8. Lower trapezius

9. Serratus anterior

Coordination Analyses

10. Mean absolute relative phase (MARP) angles for loaded forward flexion and for the forward reaching task.

11. Deviation phase (DP) angles for loaded forward flexion and for the forward reaching task.

1.10 <u>Research Questions</u>

1. Are there differences between individuals with and without forward head and rounded shoulder postural alignment for scapular kinematics during loaded forward flexion and a forward reaching task?

   a. Compare scapular ranges of motion for upward rotation, internal rotation, and posterior tipping between groups for the ascending and descending phases of loaded forward flexion.

   b. Compare scapular ranges of motion for upward rotation, internal rotation, and posterior tipping between groups for the ascending and descending phases of a loaded forward reaching task.

   c. Compare scapular angles upward rotation, internal rotation, and posterior tipping angles between groups at 60°, 90°, and 120° for the ascending and descending phases of loaded forward flexion.

d.   Compare scapular upward rotation, internal rotation, and posterior tipping angles between groups at 60°, 90°, and 110° for the ascending and descending phases of a loaded forward reaching task.

2.   Are there differences between individuals with ideal and forward head and rounded shoulder postural alignment for scapular muscle activation during loaded forward flexion and a forward reaching task?

a.   Compare mean amplitude EMG of the upper trapezius (UT), lower trapezius (LT), and serratus anterior (SA) between groups for the ascending and descending phases of loaded forward flexion.

b.   Compare mean amplitude EMG of the upper trapezius (UT), lower trapezius (LT), and serratus anterior (SA) between groups for the ascending and descending phases of a loaded forward reaching task.

3.   Are there differences between individuals with ideal and forward head and rounded shoulder postural alignment for measures of shoulder joint coordination?

a.   Compare mean absolute relative phase (MARP) values and deviation phase (DP) values of the relative humeral and scapular movement patterns between groups during the ascending and descending phases of loaded forward flexion.

b.   Compare mean absolute relative phase (MARP) values and deviation phase (DP) values of the relative humeral and scapular between groups during the ascending and descending phases of loaded forward reaching task.

1.11 <u>Hypotheses</u>

Scapular Kinematics

1. Individuals with forward head and rounded shoulders will exhibit less scapular upward rotation, greater internal rotation, and less posterior tipping angles for 60-90° and 90-120° arcs of motion during the ascending and descending phases of loaded forward flexion compared to the ideal posture group.

2. Individuals with forward head and rounded shoulders will exhibit less scapular upward rotation, greater internal rotation, and less posterior tipping angles for 60-90° and 90-110° during the ascending and descending phases of a loaded forward reaching task compared to the ideal posture group.

3. Individuals with forward head and rounded shoulders will exhibit less scapular upward rotation, greater internal rotation, and less posterior tipping angles at 60°, 90°, and 120° of humeral elevation during the ascending and descending phases of loaded forward flexion compared to the ideal posture group.

4. Individuals with forward head and rounded shoulders will exhibit less scapular upward rotation, greater internal rotation, and less posterior tipping angles at 60°, 90°, and 110° of humeral elevation during the ascending and descending phases during loaded reaching task compared to the ideal posture group.

EMG

4. Individuals with forward head and rounded shoulders will exhibit increased mean amplitude EMG of the upper trapezius and decreased mean amplitude EMG for the lower trapezius, and serratus anterior for the ascending and descending phases of loaded forward flexion compared to the ideal posture group.

5. Individuals with forward head and rounded shoulders will exhibit increased mean amplitude EMG of the upper trapezius and decreased mean amplitude EMG for the lower trapezius, and serratus anterior during the ascending and descending phases of loaded reaching task compared to the ideal posture group.

Coordination Analyses

9. Individuals with forward head and rounded shoulders will exhibit altered mean absolute relative phase angles and increased deviation phase angles of the humerus and scapula movement patterns between groups during the ascending and descending phases of loaded forward flexion compared to the ideal posture group.

10. Individuals with forward head and rounded shoulders will exhibit altered mean absolute relative phase angles and increased deviation phase angles of the humerus and scapula movement patterns between groups during the ascending and descending phases of loaded forward reaching task compared to the ideal posture group

CHAPTER II

Literature Review

2.1 <u>Introduction</u>

Shoulder pain is a significant source of musculoskeletal pain and disability.

Postural evaluation has historically been an integral component of the musculoskeletal

evaluation based on the assumed link between postural deviations and the development of

shoulder pain. (Kendall, Kendall et al. 1952) Assessment of scapular and head

positioning relative to the thorax has been emphasized in the treatment of shoulder

pain.(Sahrmann 2001) However, research has failed to clearly establish a link between

upper quarter postural dysfunction and the development of shoulder pain. There is

emerging evidence that these changes in scapular motion are due to altered scapular

positioning caused by adaptive shortening of the pectoralis minor.(Borstad 2004)

Additionally, altered scapular kinematics and muscle activity have been identified in

patients with shoulder pain.(Ludewig and Cook 2000; Hebert, Moffet et al. 2002)

Increased glenohumeral and scapular strength as well as normalization of scapular

kinematics has been demonstrated with improvements in head and shoulder

posture.(Kebaetse, McClure et al. 1999; Wang, McClure et al. 1999; Smith, Kotajarvi et

al. 2002) These strides in understanding the importance of the three dimensional scapular

motions in normal shoulder function are tempered by recent evidence suggesting that

resolution of shoulder impingement syndrome is not the result of improved scapular

kinematics. (McClure, Bialker et al. 2004) Therefore, the link between altered scapular kinematics and postural malalignment is much needed evidence guiding the prevention and treatment of shoulder pain. Additionally, the ability to objectively assess scapular dyskinesia is limited to research settings. Unique analyses may clarify the nature of scapular dyskinesia and its role in the development of shoulder pain contributing to the development of new methods of clinically assessing scapular dysfunction. One such method is a coordination analysis based on the tenets of dynamical systems theory. This analysis will allow for the examination of the inherent coupling between the scapula and humerus during shoulder movements. In addition, this approach provides a theoretical framework to understand motor behavior as it relates to coordination and variability in movement.

Therefore the purpose of this literature review is to establish the scope and problem that is shoulder pain, suggest possible modifiable risk factors, describe the proposed relationship between altered posture and shoulder pain, discuss the current understanding of scapular kinematics and muscle function, as well as highlight the limitations to the traditional biomechanical analyses of shoulder motion. Finally, a brief historical perspective on dynamical systems theory is provided as it relates to variability in human movement, the role of movement variability and musculoskeletal injury, and the examination of issues and techniques important to the application of coordination analyses.

2.2 <u>Posture and Shoulder Pain</u>

2.2.1 Incidence, Prevalence, and Cost of Shoulder Pain

Shoulder pain is a significant musculoskeletal problem affecting as many as 2.5% of the population at any one time and up to 67% of the population will suffer shoulder pain in their lifetime. (Luime, Koes et al. 2004)   Higher point prevalence rates of approximately 21% in the general population in the Netherlands (Bongers 2001) as opposed to lower rates of 16% in Britain have been reported.(Urwin, Symmons et al. 1998) The prevalence of shoulder pain is self-reported at 15% in the automobile manufacturing industry with rates decreasing to 11% when confirmed by clinical signs and symptoms.(Punnett 1998; Punnett, Gold et al. 2004) Similar to other cross-sectional studies investigating the occurrence rate and risk factors impacting shoulder pain, the narrow scope of the industry studied (automobile manufacturing) limits the generalization to the larger population due to the variation in exposure type and rate. This observation is supported by the wide range of shoulder pain incidence from 8% to 41% in workers across several occupations.(Leclerc, Chastang et al. 2004) Across all occupations the exposure to sustained and repetitive shoulder tasks has been shown to be predictive of an increased risk of developing shoulder pain. These results suggest that exposure is an important determinant in the development of shoulder pain.

The exact cost of work related upper extremity musculoskeletal disorders is not clear due to the aforementioned limitations in assessing injury rates. Musculoskeletal pain accounts for $193 billion dollars in direct costs each year, this is 2.5% of the United States gross domestic product.(Yelin, Herrndorf et al. 2001) Shoulder pain accounts for 19% of this cost, approximately $39 billion dollars. This is consistent with recent

evidence suggesting $7 billion of direct health care expenses spent in the treatment of shoulder pain.(Johnson, Crosley et al. 2005) These values are based on the general population. More conservative estimates suggest that approximately $166.8 million is spent on work related upper extremity disorders in the working population of the United States.(Washington State 1996) Extrapolating these data to the entire population, only $5 billion per year is spent on upper extremity disorders with shoulder pain accounting for approximately $1-1.5 billion of this total.

However, these costs are only reflective of the impact on direct health care costs and do not reflect the indirect costs associated with the time lost from work, retraining, and long-term disability effects associated with shoulder pain.(Washington State 1996) Additionally, these costs are from a workman's compensation database and only reflect shoulder pain attributable and paid for by the worker's compensation agency. The actual costs of shoulder pain are likely significantly greater when considering both the direct and indirect costs. It is important to note that in both general population studies shoulder pain was second only to low back pain in injury rates, which were 20-22%.(Stone 1983; McDermott 1986; Leclerc, Chastang et al. 2004; Punnett, Gold et al. 2004; Johnson, Crosley et al. 2005) This is consistent with work-related injury rates in the United States where upper extremity disorders are second only to low back pain in injury prevalence and incidence.(NIOSH 1997) More troubling is that shoulder pain does not appear to be self-limiting with less than 40% of patients having shoulder pain persisting for at least 1 year.(Van der Heijden 1999) The poor recovery from shoulder pain is due to a number of factors including use of tests and measures with undemonstrated validity, specificity, and sensitivity limiting the accuracy of clinical diagnoses. (Van der Heijden 1999; Ludewig

and Borstad 2003; McClure, Bialker et al. 2004; Michener, Walsworth et al. 2004)

<u>Furthermore there is a lack of evidence to promote a consensus in the treatment of shoulder pain, lack of follow up, limited number of studies identifying physical impairments associated with shoulder pain, and even fewer effective interventions based on these impairments. The cost, rate of occurrence, and difficult resolution of shoulder pain combined with the current deficits in the body of knowledge highlight the importance of identifying risk factors in order to develop effective preventative and treatment programs.</u>

2.2.2 Risk Factors for the Development of Shoulder Pain

The development of shoulder pain is multifactorial in nature and the risk factors can broadly be classified into those related to exposure, biomechanical, psychosocial, and other confounding factors. There are a number of investigations which have utilized cross-sectional designs to examine workplace factors and the development of shoulder pain.(Bjelle, Hagberg et al. 1981; Hagberg and Wegman 1987; Punnett 1998; Nahit, Macfarlane et al. 2001) These studies have consistently shown moderate to strong associations between the development of shoulder pain and sustained and repetitive overhead work, holding tools while working with the arms raised, as well as time spent in awkward postures. Combinations of these biomechanical factors increase the strength of the associations between groups of risk factors and the development of shoulder pain, especially the combination of high repetition and work above acromial height. (Hagberg and Wegman 1987; NIOSH 1997) Additionally, combinations of these mechanical factors have been strongly associated with pain at multiple sites. (Nahit, Macfarlane et al. 2001) This suggests that the impact of these biomechanical factors not only affect the

shoulder, but contribute to the development of pain up and down the kinetic chain. Together, these results support prevention and intervention strategies aimed at addressing multiple factors and sites of pain throughout the kinetic chain.

These conclusions are somewhat tempered because of the cross-sectional study design used in the identification of the aforementioned risk factors. Cross-sectional studies are limited by the likelihood of survival bias, meaning that only the individuals who tolerate a given job or with a set of risk factors remain in a given job. (Gerr, Marcus et al. 2004) However, there are a few prospective longitudinal studies which concur with the results of cross-sectional studies. (Marcus, Gerr et al. 2002; Andersen, Kaergaard et al. 2003; Leclerc, Chastang et al. 2004) These studies have established that there is an exposure-response relationship for shoulder pain by showing that any non-neutral working posture (whether dynamic or static) increases the likelihood of developing shoulder pain. Finally, the longitudinal study design controls for the effect of age on the relationship of these mechanical risk factors in the development of shoulder pain. A series of investigations in the automobile manufacturing industry have been extremely valuable in confirming the aforementioned cross-sectional and longitudinal results. (Punnett 1998; Punnett and van der Beck 2000; Punnett, Gold et al. 2004) The large sample of observations with excellent follow up and control of confounders allowed the identification of a combination of biomechanical factors, defined broadly as postural strain, to be the most important predictor for shoulder pain development. These factors together can be described as working in a non-neutral posture during a repetitive overhead task. Increased postural strain is exemplified by a more forward head and slouched posture resulting in increased activity of the upper trapezius. (Kleine, Schumann

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et al. 1999) Similar increases in upper trapezius activity have been noted in individuals who are experiencing shoulder pain. (Bjelle, Hagberg et al. 1981; Ludewig and Cook 2000) Treatment programs with components aimed at improving head and shoulder posture have been shown to be effective in resolving shoulder pain. (Bang and Deyle 2000; Ludewig and Borstad 2003; McClure, Bialker et al. 2004; Haahr, Ostergaard et al. 2005)   Also, preventative measures have decreased the complaints of neck and shoulder pain while increasing productivity. (Lutz, Starr et al. 2001) While the current evidence points to the repetitive nature of overhead work in the development of shoulder pain, not every person exposed to these risk factors develops shoulder pain. More specific modifiable biomechanical risk factors such as postural alignment, faulty movement patterns, strength, and endurance may yield insight into the mechanisms underlying the development of shoulder pain. For effective prevention and treatment programs to succeed, they must be based on addressing established modifiable risk factors associated with the development of shoulder pain. Otherwise we are left to trial and error with moderately effective or ineffective prevention and intervention programs.

2.2.3 Proposed Effects of Altered Posture

Historically, the examination of postural alignment has been proposed as an essential part of the basic musculoskeletal evaluation. (Kendall, Kendall et al. 1952; Magee 1987) Several authors have suggested an integrated, logical paradigm detailing the influence of altered postural alignment on musculoskeletal pain and function.(Kendall, Kendall et al. 1952; Janda 1965; Sahrmann 2003) Assumed relationships between the articular, neural, and myofascial systems are thought to influence the ability of the movement system to function at an optimal level. Optimal function is described as the

ability to use the body with minimal energy expenditure, stress, and strain on the articular and myofascial structures.(Kendall, Kendall et al. 1952) Ideal postural alignment has been defined as skeletal alignment which facilitates minimal energy, stress, and strain on the body during a given task.(Kendall, Kendall et al. 1952) Clinical theory suggests that postural alignment changes the length-tension relationships of muscles, thus altering the force producing capabilities. This in turn decreases the effectiveness of the required force couples and subsequent altered movement system kinematics, muscle function, and coordination. Specific impairments thought to develop from altered postural alignment include stretch induced muscle weakness and adaptive muscle length changes, which in turn result in substitution and compensation patterns by other muscles in order to accomplish a given task. (Kendall, Kendall et al. 1952; Janda 1965; Sahrmann 2003) These compensations are thought to result in less efficient movement patterns that when repeated enough predispose the body to injury. Based on these assumptions expert clinicians recommend the inclusion of postural alignment assessment during the musculoskeletal evaluation.

The musculoskeletal system is mutable by nature and is therefore prone to adaptation. Alterations in postural alignment as the result of or in conjunction with repeated movement patterns are thought to facilitate length associated adaptations in the musculotendinous complex having mechanical and neural consequences. Resting posture is thought to effect the biomechanical system just as initial positioning effects the constraints of any mechanical system.(Sahrmann 2002) Alterations in head and shoulder posture are proposed to change the length tension relationship of the shoulder girdle muscles leading to changes in normal shoulder mechanics and neuromuscular

function.(Kendall, Kendall et al. 1952; Janda 1965) These changes in the movement system are required because initial positioning of segments within a mechanical system alter the moment requirements needed in order to initiate movement as well as control segmental motion. Resulting length associated changes to the muscular and neural systems include: altered moment arm length, potential for cross bridge formation, passive contributions from the myofascial unit, as well as possible inhibitions from reflex arcs.(Gossman, Sahrmann et al. 1982) Changes in moment arm length and cross bridge formation will directly impact the amount of force needed at any given instance to generate the required moment for the movement system. Passive contributions from the musculotendinous complex, ligaments, and fascial components may increase or decrease the required force at different positions within a given task. Finally, the ability of an individual muscle to recruit an adequate number of motor units as well as modulate the rate of firing for proper coordinative patterns may be impacted by changes in the length of the muscle spindles and force transmitted through the Golgi Tendon Organs.(Sordberg 1983) These basic physiological principles are the foundation for the clinical relevance of postural assessment.

Postural alignment is thought to be the result of habitual and repetitive posturing suggesting there is an adaptive nature to postural malalignment. Certain postures of the upper extremities assumed at home, work, and during sleep place anterior muscles in shortened positions so that adaptive muscle shortening and antagonist muscle lengthening create a cycle of relative muscle strength imbalance.(Novak and Mackinnon 1997) It is proposed that this muscle length and strength imbalances will alter the efficiency of normal muscle contraction and cause muscles to be used at a mechanical

disadvantage.(Kendall, Kendall et al. 1952) These authors attribute pectoralis minor tightness to several factors, including forward head posture, thoracic flexion, and scapular abduction (protraction). Others have cited lower trapezius weakness and scapular instability as significant contributors to altered postural alignment of the scapula.(Sahrmann 2001; Magarey and Jones 2003) Several studies have investigated these hypothesized mechanisms in an effort to improve preventative and intervention shoulder rehabilitation programs.(Gossman, Sahrmann et al. 1982; Diveta, Walker et al. 1990; Wang, McClure et al. 1999; Roddey 2002)

2.3 Evidence Relating Postural Dysfunction and Shoulder Pain

2.3.1 Postural Alignment, Impairments, and Clinical Correlates

Several studies have investigated postural alignment, proposed impairments, and clinical correlates. Patients with shoulder pain have demonstrated a scapular rest position of increased protraction (lateral and anterior motion of the scapula around the thorax) and downward rotation compared to healthy controls in the clinical setting.(Greenfield, Catlin et al. 1995) It has been hypothesized that in response to the observed alterations in scapular resting position, peri-scapular muscle imbalances result and may lead to alterations neuromuscular control, scapular winging (internal rotation), and scapular dysrhythmia during upper extremity elevation. This study compared thirty subjects with unilateral or bilateral shoulder pain and thirty pain-free subjects. The results showed greater forward head position and less passive humeral elevation ROM in the patient group when compared to the healthy group. Passive humeral elevation ROM was significantly greater in the uninvolved extremity compared to the involved extremity in

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the patient group. There were no observed differences between groups for scapular protraction, scapular rotation, scapular symmetry, or mid-thoracic kyphosis. Scapular protraction and scapular upward/downward rotation in the patient group were correlated among the postural variables. No other within-group comparisons were statistically significant.

There are several limitations that should be considered when evaluating these results. Several potential confounding variables were the broad age range of subjects (17 to 65 years), the occupational or recreational activities of subjects, heterogeneous patient diagnoses which included bursitis, adhesive capsulitis, instability, and subacromial impingement. Additionally, there was no mention of statistical power to detect a meaningful difference if one had existed. Furthermore, limitations of 2-D analysis of the 3-D scapular position and orientation have been previously demonstrated, possibly introducing angular projection errors.(de Groot 1999) Finally, the scapular measurements also were not normalized to the size of each subjects' scapula, nor does the formula for scapular upward rotation necessarily measure that variable. A true lateral translation of the scapula would be falsely calculated as an increase in upward rotation.(Borstad 2004)

Other studies have attempted to determine the relationship between forward head and rounded shoulder posture with upper quadrant musculoskeletal disorders. The incidence and severity of postural abnormalities in two age groups of healthy subjects were determined and then analyzed for associations with pain.(Griegel-Morris, Larson et al. 1992) The convenience sample of eighty-eight healthy volunteers was divided into two age groups: 20 to 35 year-old (n=58) and 36 to 50 year-old (n=30). Each subject

answered a pain questionnaire to determine the location, frequency, and perceived severity of pain in the thoraco-cervical-shoulder region. Forward head, thoracic kyphosis, and rounded shoulders were operationally defined as the outcome measures using criteria established by Kendall and McCreary (1993). Then, frequency counts and percentages of abnormalities were calculated. These analyses demonstrated no significant difference between the groups in the incidence of postural faults. There were no significant group differences observed between severity of postural abnormality (based on a 6-point severity scale) or pain frequency and severity. The incidence of pain however, did significantly increase in patients with more severe postural abnormalities. Severe kyphosis, forward head, and rounded shoulders were significantly related to the incidence of interscapular pain. No relationships were found between severe rounded shoulders and either pectoral or shoulder pain.

This analysis included only healthy volunteers and attempted to correlate postural deviations with musculoskeletal pain.(Griegel-Morris, Larson et al. 1992) Comparison of their findings to a population of individuals with upper quarter musculoskeletal pain may have provided better insight into the posture/pain relationship. The findings of this study cannot make inference into cause and effect because of the use of the healthy population. Another limitation of the study is the potential for recall bias and subjectivity in answering the pain questionnaire, which could result in either under- or over-reporting of pain. The finding that the reported incidence of pain increased significantly in those with more severe postural abnormalities may suggest that only with extreme postural faults do tissues become pain producing. Another possibility is that postural abnormalities in addition to other factors, such as previous injury or occupational demands, may influence

the incidence of pain. None of these other factors were analyzed as covariates in this study.

Other authors have investigated the relationship of postural measures and the effects of postural alignment on specific impairments such as strength.(Culham and Peat 1994) The relationship of thoracic sagittal plane alignment to shoulder complex position was compared between individuals classified as normal and with increased kyphosis.(Culham and Peat 1994) The authors hypothesized that increased kyphosis would cause the scapula to protract and tip forward by following the contour of the thorax. Fifty-seven women, aged 50 to 85 years, were examined for thoracic posture and classified into normal, thoracic, or thoraco-lumbar kyphotic groups. Shoulder complex measures were made by comparing lines connecting anatomical landmarks to lines in one of the three cardinal planes. Sagittal plane measures included scapular forward tipping angle relative to the vertical and to the upper thoracic spine, and the angle formed by the long axis of the humerus relative to vertical and to the medial border of the scapula. Transverse plane measures were the protraction angle of the scapular spine relative to the coronal axis, the retraction angle of the clavicle relative to the coronal axis and to the scapular spine, humeral internal rotation relative to the coronal plane and to the scapular spine. Frontal plane measurements included scapular abduction (medial border relative to horizontal), medial to lateral elevation of the clavicle, humeral abduction relative to vertical and to the medial border of the scapula. All measures were normalized to account for size differences among subjects.

Results showed increased anterior tilting of the scapula relative to vertical in the kyphotic groups compared to the normal group. However, when examining the tilt angle

relative to the thoracic spine, only the thoracic kyphosis group was significantly different. Scapular abduction angle, equivalent to the amount of upward rotation, was not significantly different between the groups. In the transverse plane, the thoracic kyphosis group had a significant increase in scapular protraction compared to the other groups. The authors proposed that the changes seen in shoulder complex position are related to thoracic spine curvature, but are more highly related to thoracic cage shape changes as a result of increased thoracic sagittal spine curvature. This conclusion is based on the findings that the thoracic kyphosis group demonstrated significantly increased upper (slope of T1downward) and lower (slope of T12 upward) thoracic spine measures in addition to a significantly greater kyphosis angle. The same group also demonstrated all the scapular position changes, including the relative position findings that were not demonstrated in the other non-normal group. Baseline differences in mean values of age, height, and mass were analyzed, with no significant differences demonstrated between the groups.

The measurement method used comparing lines created by joining palpated anatomical landmarks to the cardinal planes may introduce projection error as this 2-D method attempts to quantify 3-D position and orientation.(de Groot 1999) Validity and reliability of these measures were also not reported. Finally, power and effect sizes were not reported for the non-significant differences.

The relationship of scapular muscle force production and resting position has been investigated by examining the effects of forward shoulder position on scapular protractor and retractor strength. (Diveta, Walker et al. 1990) Isometric peak muscular force was measured with a calibrated hand-held dynamometer on sixty healthy subjects.

Normalized scapular abduction (protraction) measurements were performed by palpating three scapular and thoracic spine landmarks, connecting the landmarks with an unmarked string, and subsequently measuring the string with a tape measure. Pearson product-moment correlations were determined between normalized muscular forces and the scapular abduction measurements.

Correlation between scapular abduction and scapular retractor force (rhomboids and middle trapezius) was calculated at $r = .20$, while scapular abduction and protractor force (pectoralis minor and serratus anterior) correlation was calculated at $r = .14$. Ratios of protractor to retractor force were calculated to evaluate the presence of muscle imbalances and their relationship was calculated at $r = .01$. The authors conclude that a strong, direct relationship between the measured variables does not exist and that the assumption relating isometric muscle force and posture may be incorrect.

Several limitations should be considered when interpreting the results of this study. The sample studied was made up of fairly young (age 22 to 35 years) subjects with no exposure to occupations or activities that may lead to the postulated muscle adaptations. Additionally, peak isometric muscle force was used for comparison. Peak force production is likely not representative of the actual function of these muscles as these muscles are considered stabilizing muscles, not prime mover muscles. Large standard deviations for muscle force measurements observed with small standard deviations for scapular abduction measurements may have contributed to the low correlation values. The measurement of scapular abduction alone is likely not reflective of the positional and rotational changes caused by forward shoulder. This measurement only quantifies lateral movement around the thorax. Actual anterior and inferior

positioning or scapula or scapular rotations would not be reflected in this measure. Recent studies have shown the importance of 3-D scapular motion related to decreased excursion of the pectoralis minor.(Borstad 2004) The muscle force measurements were made in the positions which placed the muscle in an advantageous position where optimum muscle length should produce near maximum values. It is possible that if the pectoralis minor and middle trapezius were tested in a shortened or lengthened position, respectively, the force values and correlations would be stronger. Finally, the position used to test the middle trapezius has recently been shown to recruit more muscle activity for the lower trapezius than the middle trapezius, thereby bringing into question the validity of this test for middle trapezius strength.(Michener, Boardman et al. 2004) Furthermore, no significant differences were observed between lower and middle trapezius muscle activity when traditional manual muscle testing positions were compared.(Ekstrom, Donatelli et al. 2003) Future studies should use multiple measurements of scapular positioning, consider the role of the lower trapezius, and investigate other impairments that may result for postural malalignment of the upper quarter.

2.3.2 Effects of Interventions on Postural Dysfunction

Interventions to correct forward head and rounded shoulder posture have been investigated in both clinical and laboratory settings.(Kebaetse, McClure et al. 1999; Wang, McClure et al. 1999; Roddey 2002) A sample of 38 healthy subjects were classified by resting head and shoulder posture as defined by Kendall(1952) as either normal, mild forward head and rounded shoulder posture, or marked forward head and rounded shoulder posture. Then scapular abduction was measured as described by Diveta

et al.(1990). Subjects were randomly assigned to either a treatment or control group then given common pectoral stretching exercises. Each group's posture was reassessed after 2 weeks by measuring their forward head angle and scapular abduction.

Forward head angle and scapular abduction improved following the treatment for the moderate forward head and rounded shoulder group. The authors concluded that clinicians may expect individuals with the greatest forward head and rounded shoulder posture to respond the most from a stretching intervention. Additionally, the authors noted limitations of mostly female, young (18-25), and healthy sample. Finally, while the change scores presented were less than 3% of the scapular abduction measure a moderate (.61) effect size was observed. This suggests that in a healthy, young population posture can be improved as measured by scapular abduction.

The effects of exercise interventions and shoulder posture have also been examined on three-dimensional scapular kinematics. (Wang, McClure et al. 1999) Twenty subjects asymptomatic for shoulder pain but with forward shoulder posture were analyzed for scapular kinematics. At entry into the study, anatomical landmarks from the subjects' scapula, and spine, as well as two points from a plastic bar strapped to the humerus were digitized with an electromechanical digitizer. These digitized points gave position and orientation coordinates for the landmarks, which were then processed to give segmental position and orientation. Data were collected at rest (arm at side), abducted in the scapular plane to horizontal, and at maximum abduction in the scapular plane. After the initial data collection, subjects were instructed in a six-week home exercise program. The program was designed to mimic a clinical regimen aimed at restoring muscle balance around the shoulder girdle. The program included resisted strengthening exercises using

thera-band, as well as a corner stretch for the pectoralis muscles. The exercise program was performed three times per week for six weeks. Ten repetitions of pectoralis stretches were performed and were held for ten seconds each, with five repetitions added every two weeks.

Decreased scapular upward rotation and increased scapular internal rotation at horizontal were observed following the intervention. There was also a decrease in scapular superior translation at horizontal and a decrease in upper thoracic inclination at all three positions. The authors discuss the decreased scapular upward rotation in light of previous work that has shown that decreased upward rotation was demonstrated in subjects with subacromial impingement.(Lukasiewicz 1999) They propose that perhaps the strengthening program created stronger muscles to stabilize the scapula on the thorax, allowing improved efficiency of motion. Another possible explanation proposed is stronger rotator cuff muscles to facilitate glenohumeral motion. The explanation for increased internal rotation given is that increased strength of the upper portion of the serratus anterior promoted this motion.

Limitations include the use of three static, rather than continuous measurements. Repeating palpation and digitization at these three positions may introduce error. In addition, the group was not symptomatic for shoulder pain so patient motivation may have been limited. No occupational or recreational activities were considered as covariates. It was also a relatively young population and results might not be similar with an older population.

Ludewig and Borstad(2000) examined the effects of a home exercise program on shoulder pain and function in construction workers. Workers with shoulder pain

consistent with shoulder impingement and confirmed with a clinical examination were randomized into an exercise group or control group. The exercise intervention consisted of two stretching exercises, two strengthening exercises, and one relaxation exercise. A daily bilateral pectoralis minor stretch was included in the eight-week exercise program. A subjective survey determined the effects of the exercises on shoulder pain and function. There was a statistically significant interaction of group and time. Subjects in the intervention group demonstrated significant improvements in pain and satisfaction with their shoulder, and improvements in work-related pain and disability scores at post-test.

McClure et al (2004) completed a similar study evaluating the effects of a supervised exercise program on three-dimensional scapular kinematics, physical impairments, and functional limitations in patients diagnosed with shoulder impingement syndrome. Thirty-nine patients completed the 6-week program which consisted of strengthening and stretching of both the glenohumeral and scapular impairments often reported in patients with shoulder impingement syndrome. Three-dimensional scapular kinematics, glenohumeral range of motion, thoracic posture, glenohumeral isometric strength, and self-reported pain and function were recorded pre and post intervention.

Increases in glenohumeral muscle force for internal and external rotation, glenohumeral internal and external rotation, concurrent with decreases in self reported pain, increased function, and increased satisfaction. No differences were observed for scapular kinematics or thoracic posture. Glenohumeral internal rotation range of motion and external rotation strength were significantly correlated with increases in self report scores. It was concluded that these physical impairments are important to address in patients with shoulder impingement syndrome.

While the exercise program seems be effective, these results are limited by the lack of control group, dropout rate, and progression of the exercise program. The authors note the limitations as a result of no control group and dropout rate constraining conclusions by the unknown natural history of shoulder pain. The absence of observed changes in scapular kinematics is likely due to the lack of emphasis on humeral elevation in the exercise program. Passive humeral elevation did not increase during the treatment program. Therefore given the coupled nature of humeral and scapular motion it is not surprising that not differences were observed in scapular kinematics. The difficulty in observing differences in scapular kinematics has been noted by several authors and is due to high between subject variability and the measurement error associated with skin motion.(van der Helm 1997; Ludewig and Cook 2000)

2.3.3 Effects of Thoracic Posture on the Shoulder

The effects of thoracic position on shoulder range of motion, strength, and three-dimensional scapular kinematics has also been examined.(Kebaetse, McClure et al. 1999) Three-dimensional scapular position and orientation at rest, abducted to horizontal, and at maximum abduction were recorded in thirty-four subjects in both a slouched and an erect sitting position. A computerized measuring system with potentiometers was used to digitize skeletal landmarks and define the three-dimensional position and orientation of the scapula. The Euler or Cardan angle sequence used for determining scapular orientations was not reported.

There were significant differences in the scapular kinematic variables between the two thoracic postures. There was less scapular upward rotation and posterior tipping between 90° and maximum abduction in the slouched posture concurrent with increased

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internal rotation from rest to 90° and 90° to maximum in the slouched posture when compared to the erect posture. There was also a decrease in maximum abduction range of motion in the slouched posture, which the authors contribute to the decreased scapular upward rotation and posterior tilt.

The scapular kinematics in this study was measured with the arm actively held in a static position, rather than during a continuous active movement. This may have influenced the kinematics due to the influence of fatigue and by the subjects holding or "setting" their position and using a different muscle pattern than the one used during active elevation. In addition, the subjects were all healthy and without recognized postural deviations. The results of this analysis cannot be assumed to be consistent in those individuals who possess postural deviations of the thoracic spine.

Similar results were reported by Finley and Lee(2003) using comparable methods except their measurements were during active arm elevation in the scapular plane. They evaluated sixteen healthy adult volunteers performing arm elevation in the scapular plane while sitting erect and again while slouched. Three-dimensional orientation data from the scapula, humerus and trunk were recorded during these elevations for later comparison. The rotation sequences were not reported for the scapular and humeral rotations, but only that reported values were described relative to a 0° reference position.

There were no statistically significant interactions, but the main effect of posture was statistically significant for scapular posterior tipping and internal rotation. Consistent with Kebaeste (1999) the scapula demonstrated less posterior tipping and greater internal rotation in the slouched position. The authors also report that at rest, the

scapula demonstrated significantly less posterior tipping and upward rotation in the slouched posture.

The methodology used in this study was unique in that the scapular motions were determined relative to a 0° reference position, rather than relative to the trunk. This methodology is inconsistent with other analyses in that no local anatomical coordinate systems are established and no Cardan sequences are used. The scapular rotations as described may be misleading because no local axis system about which rotations take place is defined. Comparing the motion values with other analyses should be done with caution. Another limitation was that angles above 90° humeral elevation were not analyzed. Further, the amount of thoracic kyphosis was not quantified.

Collectively, the literature is unable to conclusively demonstrate a consistent relationship or effect of postural adaptations to muscle strength, shoulder function, or pain. The conclusions that are warranted based on the epidemiological and biomechanical studies available are:

1. There is a relationship between the incidence of pain and increased severity of postural deviations in healthy individuals and those with shoulder pain.

2. Exposure to multiple risk factors including increased repetition, awkward postures, and shoulder motion over acromial height places an individual at increased risk of developing shoulder pain.

3. Changes in head and shoulder posture affect three-dimensional kinematics.

4. The mechanisms linking postural deviations and shoulder pain is unclear.

2.4 Evaluation of Forward Head and Rounded Shoulder Posture

The perceived role of posture has not changed over the last 70 years. In 1932 the Orthopedics and Body Mechanics Subcommittee of the Hoover White House Conference on Child Health and Protection defined posture as; "The mechanical correlation of the various systems of the body with special references to the skeletal, muscular, and visceral systems and their neurological associations."(Hoover White House Conference 1932) In other words, good posture and body mechanics were viewed as the foundations of motor development and normal human movement. Classical evaluation of postural alignment evolved from this view and is performed with patient standing while the clinician assesses the skeletal alignment of the kinetic chain in the sagittal and frontal plane. (Kendall, Kendall et al. 1952) Variations of this model have been proposed but no real change from the original model proposed by Kendall and associates has occurred. This model is based on the assumption that goal of optimal skeletal alignment is to perfectly balance about a midline through the center of mass both in the sagittal and frontal plane. Optimal skeletal alignment about the center of mass would allow for minimal force production and therefore minimal energy expenditure for postural stabilization. Elderly individuals with poor sagittal plane posture demonstrate an increased incidence of falls, greater center of mass sway area, and sway velocity when compared to matched controls.(Sinaki, Brey et al. 2004) Patients with increased forward head angles also have decreased endurance of their cervical extensor muscles. These functional deficits and decreased postural stability yields evidence to support the construct validity of this

model. Furthermore, the head and neck account for approximately 8-10% of body mass which would significantly alter the balance of moments requiring other postural compensations requiring more force to maintain postural stability.(Leveau 1992) This is a likely explanation for the observed increase electromyographic (EMG) activity in posterior neck muscles and upper trapezius concurrent with increasing forward head posture even while at rest.(Hagberg, Harms-Ringdahl et al. 2000) Additionally, decreased endurance of the cervical extensors appears to be associated with forward head posture in patients with cervical pain. (Grimmer and Trott 1998)

While postural alignment is defined as the relationship of all the segments as a whole, adjacent segments are often considered in smaller groups during the musculoskeletal evaluation. Specifically, head and shoulder posture is proposed to be associated with the development and persistence of neck and shoulder pain(Kendall, Kendall et al. 1952; Sahrmann 2001). It is unclear however, what normal values of resting head and shoulder posture are for a given population of patients given their age, gender, and lifestyle.

Given the prominence of postural evaluation during the musculoskeletal examination, there are relatively few studies that have attempted to establish baselines and normative values for head and shoulder posture. The majority of investigations have focused on the validity and reliability of clinical measures but with little attention to the range of normal values and their relationship to pathology.(Diveta, Walker et al. 1990; Garrett 1993; Gibson, Goebel et al. 1995) Comparisons of head and shoulder posture have been made between limited samples of asymptomatic and symptomatic individuals, men and women, and under various conditions thought to influence posture(Diveta,

Walker et al. 1990; Greigel-Morris 1992; Kebaetse, McClure et al. 1999). Gender is suggested to influence head and shoulder posture, but is inconclusive given the small sample sizes of these methods.(Hanten, Lucio et al. 1991; Raine and Twomey 1997; Hanten, Olson et al. 2000)

Two different approaches have been taken to assess head and shoulder posture. One is based on some variation of Kendall's classic model (Cureton 1941; Kendall, Kendall et al. 1952), while the other has attempted to look at resting posture in view of total range of cervical motion available.(Hanten, Lucio et al. 1991; Grimmer 1997) Several authors have recommended the evaluation of the head and shoulder girdle to the thorax in the evaluation and treatment of shoulder pain. (Kendall, Kendall et al. 1952; Kibler 1998; Sahrmann 2001) Ideal postural alignment of the head and shoulder is suggested to be when the tragus and the acromion are aligned over a vertical plumbline extending superiorly from the fifth metatarsal head. While this is proposed as the "ideal" alignment, it is acknowledged that no one has perfect postural alignment. (Kendall, Kendall et al. 1952) Head and shoulder girdle "normal" resting posture in fact seem to be slightly anterior to the vertical plumbline. (Hanten, Lucio et al. 1991; Peterson, Blankenship et al. 1997; Raine and Twomey 1997; Lukasiewicz 1999) Each of these studies observed natural resting posture of the head and shoulder to be anterior to the thorax. While definition of "ideal" posture requires the head to be centered over the shoulders, hips, and feet, this postural alignment is not reported in the literature. Even so, head and shoulder posture seem to be a stable measure over time demonstrating good to excellent ICC values.(Braun 1991; Raine and Twomey 1997; Hanten, Olson et al. 2000) This is supported when results are compared on a similar scale. While each study used

different assessment methods of head and shoulder posture, mean and standard deviations are comparable when adjusted to the same scale (Figure 1 and Table 1). This observation suggests that forward head and shoulder posture is a real phenomenon and not a function of study design or measurement methodology.

Head and shoulder posture has classically been defined in relation to the thorax. Forward head posture has been described as having a "poke neck" concurrent with a forward shoulder thrust and is thought to be reflective of overall musculoskeletal health and fitness. (Cureton 1941) The descriptive statistics and distribution of the large sample (644) of college males provides a valuable picture of posture in a young population. Posture does not seem to significantly change with age with mean values falling well within 1 standard deviation within single studies comparing age groups and across studies. (Table 1) Among all of the studies reviewed, group means for forward head angle ranged from 41˚ to 54˚ ± 4˚ to 7˚. The consistency of forward head angle among studies as well as across different populations suggests that it is a valid measure of forward head posture.

Hanten (1991; 2000) and Grimmer (1997; 1998) have approached head posture in a different manner. They have suggested that it is important to assess an individuals resting posture in relation to their total available range of linear or angular excursion. This is generally performed by having the patient completely retract (posterior) and protract (anterior) their head. Then, comparisons of the resting posture are made as a percentage or at the end ranges of the motion. Differences in linear excursion has been reported between gender and cervical pain.(Hanten, Olson et al. 2000) Additionally, differences in upper and lower cervical excursion angles have been noted in patients with

cervical pain with no differences noted between genders.(Grimmer and Trott 1998) While these studies have demonstrated differences between patients with and without cervical pain, they have not been studied in patients with shoulder pain. The relationship of excursion measures to the development of shoulder pain is unclear. Based on the limited research using these measures, it is difficult to interpret and apply these measures to delineate postural groups.

Several limitations of the previously described studies should be noted. The values reported were converted to a standard scale and were not originally calculated as such. Many of the studies' procedures are not fully described limiting their reproducibility. The use of homogenous samples for any one study limits the generalizability of these values. It is not clear comparing these results if males and females have different head and shoulder posture. However, even with these limitations it is likely that increasing computer use and sedentary lifestyles result in an increased forward head and rounded shoulder posture.

There is a limited amount of literature and overall lack of controlled studies evaluating the effect of posture on shoulder function. Finley et al(2003) and Kebaetse et al(1999) are the only two studies to specifically address the effects of altered head and shoulder posture. While these studies have the advantage of a within subjects design, they are limited by the nature of the adaptive changes due to postural malalignment. It is likely that these changes are not immediate but instead impact movement patterns over a period of time. The observed changes in these studies are similar to altered patterns of scapular kinematics in patients diagnosed with shoulder impingement syndrome. These results suggest that the development of shoulder pain is at the very least related to the

development of shoulder pain. It is likely that these changes may even be a component

of underlying mechanism directly attributable to changes in shoulder girdle movement

patterns and in turn shoulder pain.   However, there is no research giving direct support

for the proposed relationship between postural malalignment, alterations in movement

patterns, and the eventual development of shoulder pain. The relationship between

postural alignment and altered movement patterns, muscle function, and coordination

must first be established before investigations examining the relationship of postural

alignment, altered movement patterns, and shoulder pain can be explored. In conclusion,

1. Many methods have been proposed to evaluate forward head and rounded
   shoulder posture but few have been replicated in multiple studies limiting their
   usefulness..

2. While some methods have been shown to be less reliable, no single method has
   been demonstrated to be superior in assessing forward head and rounded shoulder
   posture.

3. Forward head angle and forward shoulder angle offer good measures of head and
   shoulder posture with several benefits:

   a. Demonstrated reliability

   b. Do not need to be normalized to height as with translations

   c. Previous studies large sample sizes indicate possible normative values

   d. Observed differences for both measures in the same study in individuals
      with neck and shoulder pain

4. Forward head and rounded shoulder posture has not been consistently observed in
   individuals with shoulder pain.

2.5 <u>Scapular Kinematics</u>

2.5.1 Normal Scapular Kinematics

Normal shoulder motion is dependent on synchronous movement of the scapula, clavicle, and humerus on the thorax. The shoulder is able to achieve maximal mobility while maintaining stability by the complex interaction of its active and passive components. (Warner 1993) The scapula is stabilized and rotated on the thorax by the axioscapular musculature providing the humeral head a stable platform on which to function. This dynamic coordination between the scapula and humerus also positions the rotator cuff muscles at an optimal length for maximum contraction to further stabilize the humeral head in the glenoid fossa during shoulder movement. (Paine and Voight 1993) For these reasons synchronous motion of the scapula is thought to be vital to normal shoulder function.

Scapular motion is described by three rotations and two positions/translations. The three rotations are scapular upward/downward rotation, internal/external rotation, and anterior/posterior tipping (Figure 2). The two translations are protraction/retraction and elevation/depression (Figure 2). Scapular motion has been studied for some 80 years beginning with two–dimensional (2D) methods such as goniometry(Doody, Freedman et al. 1970), radiography(Inman, Saunders et al. 1944; Bagg and Forrest 1988; Paletta, Warner et al. 1997), and Moire' topography.(Warner, Michelli et al. 1992) These studies have assessed scapular motion during humeral elevation in the scapular plane (humerus positioned 30°-40° anterior of frontal plane), (Inman, Saunders et al. 1944; Bagg and Forrest 1988; Paletta, Warner et al. 1997) frontal plane, (Stookey 1920; Inman, Saunders et al. 1944; Koh, Grabiner et al. 1998) sagittal plane, (Inman, Saunders et al. 1944; Koh,

Grabiner et al. 1998; McClure, Michener et al. 2001), and wheelchair transfers (Finley, McQuade et al. 2005) (Table 2). These results have most often been reported as the scapulohumeral rhythm, which is defined as the ratio of scapula upward rotation relative to humeral elevation. (Codman 1934) Stookey (1920) first investigated scapulohumeral rhythm defining three distinct phases of humeral elevation: from 0-60°, 60°-115°, and 115° to maximum shoulder elevation. During the initial phase of humeral elevation large variations in the amount of scapular upward rotation were observed. The middle phase was described as the classic idea of scapulohumeral rhythm 2° of humeral elevation for every 1° of scapular upward rotation. Then, during the last phase progressively more scapular rotation contributed to the overall elevation of the humerus. Inman et al.(1944) observed that the scapulohumeral rhythm was 2:1 over the entire arc of humeral elevation in the frontal plane. In agreement with previous reports they observed that during the first 30°-60° of elevation, scapular upward rotation was highly variable among subjects and termed this the "setting phase". Other investigators have reported the scapulohumeral rhythm to be anywhere from 1.25:1 to 3:2 depending on the plane of humeral elevation (frontal, scapular, sagittal) and arc of elevation evaluated.(Freedman and Munro 1966; Bagg and Forrest 1988) Differences in methodology make it difficult to compare results across studies to gain an appreciation of why there are such large discrepancies in their observations. The literature, however, seems to support a non-linear pattern of scapular upward rotation relative to glenohumeral elevation progressing from 2:1 in the early phases (30°-100°) and 3:2 (100°-max)in successive phases.(Paletta, Warner et al. 1997)

Until recently, specific patterns of scapular motion had only been defined using 2D analyses as humeral elevation was performed in the scapular and frontal planes.

Three-dimensional (3D) kinematics have now been described for shoulder motion during elevation in the frontal, scapular, and sagittal plane,(Ludewig, Cook et al. 1996; Hebert, Moffet et al. 2000; McClure, Michener et al. 2001) as well as during wheelchair transfers.(Finley, McQuade et al. 2005)   Patterns of increasing scapular internal rotation followed by external rotation above 90º of humeral elevation, posterior tipping and upward rotation of the scapula are reported during humeral elevation in all planes. The increase in scapular external rotation seems to be some what abrupt and may be related to the range of humeral rotation.(van der Helm and Pronk 1995) In contrast, several authors have reported scapular internal rotation during elevation ranging from 0° to 34°. (McQuade and Smidt 1998; Meskers, Vermeulen et al. 1998) Discrepancies in the literature when comparing absolute values of scapular internal/external rotation are due to definition of local axis systems, choice of Euler angle rotations, arc of elevation, and plane of humeral elevation evaluated. (van der Helm and Pronk 1995; Koh, Grabiner et al. 1998) However, a pattern of increasing scapular internal rotation during initial stages of humeral elevation followed by scapular external rotation above 90° of humeral elevation is supported across the literature. In conclusion,

1. Normal scapular motion during the first 80°-90° humeral elevation is
   a. Increasing upward rotation, posterior tipping and internal rotation
   b. Protraction, and elevation

2. Above 90° the scapula
   a. Continues to upwardly rotate and posteriorly tip
   b. Begins to externally rotate
   c. Maintains the amount of protraction and continues to elevate

2.5.2 Alterations in Scapular Kinematics

Altered scapula kinematics are reported in patients with instability (Ozaki 1989; Warner, Michelli et al. 1992; Paletta, Warner et al. 1997), impingement(Lukasiewicz 1999; Ludewig and Cook 2000; Hebert, Moffet et al. 2002), rotator cuff tears(Warner, Michelli et al. 1992; Paletta, Warner et al. 1997) , and adhesive capsulitis(Vermeulen, Stokdijk et al. 2002; Rundquist, Anderson et al. 2003). Early initiation of upward rotation has been documented in patients with adhesive capsulitis,(Vermeulen, Stokdijk et al. 2002; Rundquist, Anderson et al. 2003) shoulder impingement, and rotator cuff tears.(Inman, Saunders et al. 1944; Paletta, Warner et al. 1997) Irregular and uncontrolled upward rotation during elevation has been reported in patients with glenohumeral instability. (Poppen and Walker 1976; Warner, Michelli et al. 1992) It is now apparent that decreases in scapular external rotation and posterior tipping may contribute to shoulder impingement.(Lukasiewicz 1999; Ludewig and Cook 2000; McClure, Bialker et al. 2004) Together these changes in scapular motion are thought to reflect compensatory movement strategies related to the underlying shoulder pathology.

These results support the historical emphasis on the clinical evaluation of patterns of scapular motion and postural position during examination of the shoulder used to guide the treatment of shoulder dysfunction.(Codman 1934; Kibler 1998) Altered scapular motion may increase stress on the muscular, capsular, and ligamentous structures, placing the shoulder at risk for atraumatic instability(Warner and Boardman III 1999; Weiser, Lee et al. 1999), impingement, or other types of shoulder pathology.(Sahrmann 2001; Wilk, Meister et al. 2002) It remains unclear whether scapular dysfunction is a contributing factor or compensatory mechanism to shoulder

pathology. It has been suggested that atraumatic shoulder instability and impingement are the result of scapular dysfunction while rotator cuff tears and adhesive capsulitis are compensatory dysfunctions.(Paletta, Warner et al. 1997) Pink et al.(1996) suggests that by detecting asynchronous scapular motion before symptoms present in overhead athletes, clinicians can prevent shoulder impingement and glenohumeral instability. For effective prevention and treatment programs to be implemented understanding the prognostic value of evaluating altered scapular motion and the mechanism(s) which lead to this dysfunction is important.

Examination of the scapula during the evaluation of patient's shoulder pain is supported by recent studies demonstrating the effectiveness in decreasing associated symptoms with an exercise regimen.(Ludewig and Borstad 2003; McClure, Bialker et al. 2004) These studies demonstrated exercise programs with components to normalize scapular strength, flexibility, and motion are effective in reducing the signs and symptoms associated with shoulder impingement syndrome. What is not clear is if scapular kinematics change as a result of treatment. McClure et al(2004) did not observe changes in scapular kinematics in a group of patients diagnosed with shoulder impingement syndrome. While others have observed scapular kinematics become more like normal movement patterns following interventions for loss of glenohumeral range of motion and stretching of the anterior chest wall. (Wang, McClure et al. 1999; Vermeulen, Stokdijk et al. 2002) Aside from source of the shoulder pathology differences in variables compared may be important. Vermeulen et al (2002) compared the slope of the scapulohumeral rhythm for all three motions while McClure et al (2004) compared angles at different arcs of humeral elevation.   This may be important as changes in

scapulohumeral rhythm would be sensitive to how the motion changed during arcs of humeral elevation where comparisons made at multiple levels of humeral elevation would not reflect the pattern of scapular motion. Regardless, it seems that the evaluation of scapular motion and related impairments is important in the treatment of shoulder dysfunction.

Another significant void in the current literature is the evaluation of scapular kinematics during functional tasks. Finely et al(2005) is the only study to evaluate a functional task. This task is important for individuals confined to a wheelchair. However no studies to date have evaluated scapular kinematics during functional tasks associated with shoulder pain such as reaching or overhead throwing type motions. The use of single plane elevation motions is important when evaluating the shoulder in that it allows for standard comparison of scapular motions. However, it may be a limitation of previous research given the tightly coupled nature of humeral elevation and scapular motion. Such a controlled type of motion may drastically reduce an individual's degrees of freedom and force people to move in a similar fashion. This may explain why such small differences in scapular angles are reported between individuals with and without shoulder pain. Given the evidence implicating forward reaching as a significant risk factor in the development of shoulder pain it is important to understand how the scapula moves during a functional movement pattern. Additionally, a forward reaching task is similar to symptom provoking maneuvers used in an musculoskeletal exam of the shoulder. A functional reaching task therefore, may provide a good model to investigate for mechanisms associated with the development of shoulder pain. In conclusion,

1. Altered scapular motion is

    a. Decreases in upward rotation, posterior tipping, and external rotation.

    b. Decreases in protraction coupled with increases in elevation

2.5.3 Validity and Reliability Of Three Dimensional Scapular Kinematics

Scapular motion has been evaluated for criterion validity for elevation in the sagittal, frontal, and scapular planes, as well as internal/external rotation at 90° of abduction. (Karduna, McClure et al. 2001; Vermeulen, Stokdijk et al. 2002) Only 8 and 10 subjects were used in each study while reliability data was only reported for the scapular plane by Karduna et al (2001), while Vermeulen et al (2002) did not report any reliability data. As these methods have become more widespread in use the results from different researchers and across diverse populations suggest face validity to these methods. Despite the limited studies evaluating the validity of non-invasive scapular tracking, these methods seem to offer reasonable representations of dynamic scapular motion.

Reliability is important in the interpretation and use of any kinematic data. Several authors have used different methods to evaluate reliability with good to excellent results depending on the humeral elevation task evaluated. Ludewig and Cook (1996) reported between trial reliability with $ICC_{(2,1)}$ values ranging from 0.89-0.94. Reliability measures were only reported from trial to trial for motions other than elevation in the scapular plane. Wang et al (1999) has reported $ICC_{(2,k)}$ values of 0.6 to 0.85 with scapular internal rotation being the least reliable during elevation in the scapular plane as compared between days. Thigpen et al(2005) results are in agreement with Wang et al (1999)and

Finley and Lee (2003) reporting good to excellent repeatability of scapular rotation curves for humeral elevation in the frontal, scapular, and sagittal planes. Comparison of coefficient of multiple correlation (CMC) values suggested that scapular rotation measures are repeatable between trials within the same testing session, but less repeatable between testing sessions and days. Sagittal plane elevation consistently yielded the highest CMC values for all scapular rotations. Scapular internal rotation yielded the lowest CMC values for all planes of humeral elevation. These results suggest sagittal plane elevation should be considered for the evaluation of scapular rotations, especially scapular internal rotation.

2.5.4 Methodological Considerations for Collection of Kinematic Data

International Society of Biomechanics-Shoulder Group Recommendations

The International shoulder group was formed in 1996 in an effort to create standards for data collection and processing techniques for those studying the shoulder. This group is made up of the leading researchers in the field of shoulder biomechanics. They have published a series of recommendations for defining bony segments, Euler angle sequences for segmental and joint rotations, as well as suggestions for world and segment axes systems.(International Society of Biomechanics Shoulder Group 1998; International Society of Biomechanics Shoulder Group 2002) The main discrepancies between different research groups investigating scapular kinematics remain in definition of the glenohumeral joint and proximal end of the humerus, Euler angle sequence, and definition of bony segments. A series of investigations from the Delft Shoulder Group in the Netherlands have shown the helical axes method to be the best at predicting the instant center of rotation during shoulder movement.(Meskers, van der Helm et al. 1998;

Veeger 2000) The methods used in this project will follow the latest recommendations

(2002) for definition of bony segments, global and local axes systems, and Euler angles

sequences.

Acromial Method

The acromial method is a dynamic method collecting the data throughout the

range of active motion in contrast to the static methods that sample scapular landmarks at

multiple static positions throughout the range of motion. The electromagnetic sensor is

placed on the broad flat surface of the postero-lateral acromion of the subject. Bony

landmarks (posterior-lateral acromion, root of the spine at the medial border, inferior

angle) are then digitized to represent the scapula. Movement of the acromion is detected

by the attached electromagnetic sensor is then used to represent scapular rotation and

translation.

The acromial method has been used to investigate shoulder kinematics (Ludewig

et al., 2002;Ludewig and Cook, 2000;McQuade and Smidt,1998; McQuade *et al.*, 1998).

The acromial method is advantageous because shoulder kinematics can be dynamically

assessed. Results from Johnson et al (2001) and Graichen et al (2000) suggest that static

methods report smaller amount of motion when compared to dynamic methods. While

these static measures have differentiated between shoulder pathologies, dynamic motion

analysis may be able to differentiate better between populations as well as describe more

completely shoulder motion in symptomatic and asymptomatic pathological groups.

Dynamic motion analysis allows for the integration of kinematic data with

electromyographic (EMG) and kinetic data to evaluate the difference in patterns of

muscle activation and joint function in shoulder pathologies. Dynamic motion analysis

also allows for the simulation of functional activities that have been implicated in contributing to shoulder dysfunction.

Several studies offer precautions when collecting and interpreting data using dynamic motion analysis of scapular motions (Karduna *et al.*, 2001). Many studies have used electromagnetic sensor systems to evaluate shoulder kinematics both in vivo and in vitro.(Harryman II, Sidles et al. 1990; van der Helm and Pronk 1995; Ludewig, Cook et al. 1996; McClure, Michener et al. 2001) Reliability and validity have been reported for measurement of humeral and scapular motion both in vitro and in vivo. (An, Jacobsen et al. 1988; Harryman II, Sidles et al. 1990; van der Helm and Pronk 1995; Ludewig, Cook et al. 1996; McClure, Michener et al. 2001) Electromagnetic devices have been used to monitor glenohumeral translation in three-dimensional fashion both in vitro and in vivo.(Harryman II, Sidles et al. 1992; Borsa, Sauers et al. 2001; Sauers, Borsa et al. 2001) Criterion validity has been reported for techniques by which the sensors are attached to the skin measuring planar translation and three-dimensional scapular motion (Borsa *et al.*, 2001;McClure *et al.*, 2001;Karduna et al. 2000) Accuracy has been reported for sensor to skin methods to be within 0.5° to 4° and 2.5-10 mm (Johnson *et al.*, 2001; McClure *et al.*, 2001; Sauers *et al.*, 2001; Meskers *et al.*, 1999) with accuracy increasing with smaller testing spaces (1 m^3) and velocities are kept relatively slow. (Meskers *et al.*, 1999; Ludewig *et al.*, 2002; McQuade *et al.*, 2002) Methods to estimate the instant center of rotation of the glenohumeral joint have been proposed by Veeger (2000) and Meskers et al (1998) with reported measurement errors less than 1° and 2-3 mm per axis.

Digitizing is an important part of utilizing the Motion Monitor System ® (Innovative Sports Training, Inc. Chicago, IL). Several authors have reported reliability

using the digitizing procedures as described by the International Society of Biomechanics shoulder protocol.(Ludewig 1996; Meskers, Vermeulen et al. 1998; de Groot 1999) Three-dimensional kinematic analysis using the acromial method offers a relatively simple and efficient tool to investigate shoulder pathology in a clinical or research setting. Dynamic evaluation of motions outside of the scapular plane may offer greater insight into the mechanisms of shoulder pathology.

Velocity and Load

The effects of velocity of humeral elevation and load lifted during humeral elevation on scapular kinematics have received limited attention.(de Groot, Valstar et al. 1998; McQuade and Smidt 1998) To date, investigations examining scapular kinematics have controlled the velocity of humeral elevation. However, no rationale has been given for this methodological consideration. While controlling velocity may decrease the variability between subjects, it also may limit the ability to observe alterations in scapular kinematics. De Groot (de Groot, Valstar et al. 1998) has reported no differences in scapulohumeral rhythm with changes in velocity. This suggests that there is no need to control velocity when examining scapular kinematics. Increases in scapulohumeral rhythm have been reported due to increased load during humeral elevation.(McQuade and Smidt 1998; Pascoal, van der Helm et al. 2000) The observed increases in upward rotation over 30˚ humeral elevation arcs suggests greater scapular motion is required to achieve equal levels of humeral elevation when lifting a load. This may enhance the ability to see differences in scapular kinematics as it would place higher demands on the scapular muscles and require larger ranges of scapular motion for a given motion or task. Finally, examining a task with no load and controlled velocity is not reflective of how the

upper extremity functions. The shoulder's main function is to place the hand in space in order to move and manipulate objects. Evaluation of scapular kinematics should reflect this loaded, self selected velocity condition of functional shoulder tasks.

2.5.5 Kinematic Data Processing

As with any 3-D biomechanical study not using bone pins, skin movement artifact introduces error into the data signal. While studies have shown this error to be consistent, increased noise in any data signal is not desirable especially when derivatives of the original signal are calculated.(Karduna, McClure et al. 2001) Skin movement artifact is of concern at the shoulder and especially the scapula, given the increased amounts of muscle and skin between the electromagnetic sensor and the bony segment. Following previous researchers(van der Helm and Pronk 1995; Ludewig 1996; McClure, Michener et al. 2001), kinematic data in this project was sampled @ 50Hz. Then, they were smoothed using a recursive Butterworth (4th order) low pass filter set at 6.79 Hz based on sampling frequency. However, upon evaluation of the scapular velocities it became clear that in order for appropriate analyses of the coordination data to take place this was not clean enough. Therefore, a spectral analysis was performed and subsequent residual analysis which revealed 99.9% of the signal to be present @ 11-12 Hz. Following Giakas's (Giakas and Stergiou 2004) recommendations of 4-times this number for sampling frequency affirms that 50Hz is appropriate. Residual analyses revealed a significant change in the slope of the curves at 2.5 to 3.0 Hz. (Figure 8). Therefore, subsequent coordinate data has been filtered at 3.5 Hz before calculation of angular and velocity data.

2.6 <u>Electromyography</u>

2.6.1 Rationale of Surface Electromyography

Surface electromyography (EMG) provides a window into the muscle recruitment strategies and therefore muscle function used to generate the segmental motion required for a given motor task.(Edgerton, Wolf et al. 1996) Patterns of EMG activity reflect the neural inputs to the motor neuron pool and are indicative of neuromuscular control strategies for a given movement task. Alterations in EMG patterns for a muscle or set of muscles are used to identify deficits in muscle function and help to fully understand human movement strategies. Neural adaptations due to pathology and/or over stretching of the musculotendinous unit are thought to influence the force-length-velocity relationships thereby decreasing the load capacity of that muscle or muscles. Hypotheses for both hyperactivity and hypoactivity have been suggested as a result of these neural adaptations. (Edgerton, Wolf et al. 1996) Neural adaptations of the phasic muscles (e.g., upper trapezius and pectoralis major: responsible for force and velocity generation) are thought to become hyperactive while tonic muscles (e.g., serratus anterior and rotator cuff: responsible for postural stabilization) become hypoactive. (Janda 1965) Understanding alterations in these muscles individually as well as their relationship to each other provide valuable insights into normal and adaptive neuromuscular control strategies. Ratios of EMG activity allow for these relationships to be quantitatively expressed and compared between motor tasks and individuals with and without shoulder pain. (Edgerton, Wolf et al. 1996; Cools, Witvrouw et al. 2003)   Examination of scapular muscle function by analyzing patterns of EMG activity and muscle balance ratios have laid the foundation for the fundamental understanding of normal and abnormal shoulder

mechanics.(Inman, Saunders et al. 1944; Glousman, Jobe et al. 1988; Ludewig and Cook 2000; Cools, Witvrouw et al. 2003)

2.6.2 Normal Scapular Muscle Function

Normal scapular muscle function facilitates a smooth, coordinated rotation and lateral translation of the scapula on the thoracic wall during humeral elevation. During overhead activities such as reaching and throwing normal scapular muscle force couples stabilize the scapula allowing for the absorption and transference of forces and moments from the upper extremity to and from the trunk and lower extremity. (Kibler 1998) These force couples work in synergies with one another facilitating optimal shoulder function. (Pink, Scenar et al. 1996) Proper scapular positioning is crucial for normal glenohumeral mechanics because the muscles forming the glenohumeral force couples originate from the scapula. The deltoid works in concert with the rotator cuff to center the humeral head in the glenoid fossa and prevent excessive superior migration as well as to stabilize the humerus in the sagittal plane restricting excessive anterior-posterior translation. (Warner 1993) Alterations in scapular positioning have been shown to result in increased stress on the anterior/inferior glenohumeral ligaments and cause superior migration of the humeral head.(Graichen, Bonel et al. 1999; Weiser, Lee et al. 1999) Scapular positioning apparently alters the ability of the rotator cuff to keep the humeral head centered in the glenoid. It is thought that this contributes to acquired anterior glenohumeral instability and shoulder impingement syndrome.(Jobe, Giangarra et al. 1991; Kibler 1998)

Dynamic scapular stabilization and neuromuscular control therefore, is required for optimal shoulder function. This stabilization and control is accomplished by scapular muscle force couples interacting in different combinations with the degree of scapular

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elevation, rotation and protraction. These force couples tether the scapula from every corner preventing any scapular lag or winging. (Pink, Scenar et al. 1996) The trapezius muscle forms a force couple with the serratus anterior. As the serratus anterior contracts, its force tends to draw the scapula laterally around the chest wall. This displacement is resisted by the lower trapezius fibers, which seem to operate at a constant length to stabilize the scapular axis of rotation. The upper fibers of the trapezius simultaneously exert an upward rotation moment about the frontal plane axis, complementing the downward moment created by the serratus anterior. However, the upper trapezius is suggested to be more important in acromial elevation than scapular upward rotation. The lower trapezius together with the serratus anterior are thought to produce the needed moment for scapular upward rotation or resisting scapular downward rotation during humeral elevation.(Bagg and Forrest 1986; Pink, Scenar et al. 1996) The middle trapezius fibers have a very short moment arm due to their close proximity to the frontal plane axis of rotation, especially during the early phases of humeral elevation thereby limiting their ability to generate an upward rotary moment. However, as the scapula translates laterally and upwardly rotates its moment arm increases as the axis of rotation moves laterally along the spine of the scapula.(Bagg and Forrest 1986; Bagg and Forrest 1988) The middle and lower fibers are positioned to control and stabilize the scapula in the transverse and sagittal planes. Normal activation ratios and temporal recruitment patterns between the different parts of the trapezius are thought to be essential in maintaining the proper scapular position during elevation.(Edgerton, Wolf et al. 1996) The upper and lower fibers work together in the frontal plane preventing excessive scapular elevation or depression, while the middle and lower fibers control scapular

upward rotation produced by the upper fibers. Scapular stabilization seems to be accomplished by working concurrently with the force couple with the serratus anterior and pectoralis minor. (Cools, Witvrouw et al. 2003) Scapular muscle patterns of EMG activity during humeral elevation have consistently affirmed Inman et al.'s (1944) initial observations of increasing scapular muscle activity with increasing humeral elevation up to about 70˚ - 90˚ then a plateau through 120˚ -130˚ followed by another increase in scapular muscle activity through maximum elevation.(Bagg and Forrest 1986; Ludewig, Cook et al. 1996) Each of the scapular stabilizers (upper and lower trapezius as well as serratus anterior) demonstrates a similar pattern of muscle activity during elevation across the planes of humeral elevation. These scapular force couples also show a similar pattern of increasing activity up to about 80˚ of shoulder elevation then plateauing through 120˚ of elevation then increasing again through maximum shoulder elevation.(Inman, Saunders et al. 1944; Bagg and Forrest 1986) Scapular stabilizers are thought to respond to the torque about the shoulder joint regardless of the shoulder motion. (Pearl, Perry et al. 1992) To date no studies have evaluated scapular muscle activity during a functional task, therefore it is unknown what the response of the scapular stabilizers are during functional activities. In conclusion,

Normal scapular muscle activity is characterized by:

1. Concurrent increases in amplitude of the serratus anterior and upper trapezius up through maximum humeral elevation.

2. Increased activity of the middle and lower trapezius beginning at 90˚ of humeral elevation and continuing through maximum elevation.

3. Decreasing upper trapezius activity throughout the descending phase of humeral elevation.

4. Continued high levels of lower trapezius and serratus anterior activity through 120° of humeral elevation then decreasing pattern of activity.

2.6.3 Alterations in Scapular Muscle Function

Alterations in scapular muscle activity have been evaluated after fatigue and shoulder injury. Scapular muscle activity has proven difficult to fatigue in isolation. Therefore, studies have used methods which with global shoulder fatigue protocols. Shoulder fatigue elicited by repeated humeral elevation and humeral external rotation have yielded similar results with decreases in scapular posterior tipping and upward rotation.(McQuade, Dawson et al. 1998; Tsai, McClure et al. 2003) The decreases is upward rotation yield an overall decrease in scapulohumeral rhythm.(McQuade and Smidt 1998) Muscle activation patterns also change following fatigue of the shoulder girdle as evidence by alterations latency times of the trapezius following shoulder fatigue. (Cools, Witvrouw et al. 2003) These latency patterns are similar to those seen in patients with shoulder impingement syndrome. (Cools, Witvrouw et al. 2003) Latent onset of the middle and lower trapezius to an arm perturbation suggests altered function of the middle and lower trapezius following fatigue and due to shoulder pathology. This is consistent with observed alterations in scapular muscle activity during arm elevation in patients with shoulder impingement syndrome. (Ludewig and Cook 2000) Increased upper trapezius and lower trapezius activity and decreased activity of the serratus anterior were reported concurrent with decreases in scapular posterior tipping, upward and external rotation.

Decreases in serratus anterior activity have also been reported in patients diagnosed with anterior shoulder instability.(Glousman, Jobe et al. 1988; McMahon, Jobe et al. 1996)

Abnormal scapular muscle function has been associated with individuals with shoulder pathology and following shoulder fatigue. These changes in muscle function have been observed concurrent with changes in scapular kinematics and scapulohumeral rhythm.(McQuade, Dawson et al. 1998; Ludewig and Cook 2000) In summary, shoulder pathology and fatigue seem to affect scapular muscle patterns in a similar manner, including increases in upper and lower trapezius activity and decreases in serratus anterior activity. These effects seem to be clearer while lifting a load and at higher angles of arm elevation. This is reasonable considering the increased moment requirements placed on the shoulder by a load and the increasing scapular stabilization required at higher ranges of shoulder elevation.

The characteristics of abnormal scapular muscle activity are:

1. Increased upper trapezius activity during humeral elevation concurrent with early onset of activation.

2. Decreased activity of the lower trapezius and serratus anterior concurrent with late onset of activation.

2.7 Coordination Analyses based on Dynamical Systems Theory

2.7.1 Background and Rationale of Application to the Shoulder

The current framework for understanding the musculoskeletal and neuromuscular mechanisms of the shoulder are based on traditional biomechanics. Glenohumeral and scapulothoracic joint kinematics as well as electromyographic analyses have been used to examine the mechanisms of shoulder movement patterns.(Inman, Saunders et al. 1944;

Karduna, McClure et al. 2001) These traditional approaches are limited in their ability to capture the complexity of the shoulder girdle due to an almost infinite number of degrees of freedom available to create movement patterns. Understanding the organization of these components therefore, is limited to descriptions and comparisons of isolated humeral, scapular, and clavicular kinematics as well as electromyographic studies. Most previous research (Freedman and Munro 1966; van der Helm and Pronk 1995; Hebert, Moffet et al. 2000; Karduna, McClure et al. 2001) has controlled the plane of shoulder motion when assessing the shoulder complex and only analyzed humeral elevation. Research demonstrates a strong linear relationship between scapula and humeral joint motions during humeral elevations tasks performed in a single plane. These studies have developed a foundation for understanding shoulder movement but restrict a complete understanding of shoulder movement patterns. Due to the strong linear relationship between scapula and humeral motions it may be necessary to investigate multi-planar, functional tasks to better understand the relationship between scapula and humeral joint motions. Only Finley et al.(2005) has examined the shoulder complex during a functional task by evaluating scapular kinematics over arcs of humeral elevation during a wheel chair transfer. <u>Research has not investigated scapula and humeral joint motions during other functional tasks that are commonly associated with shoulder pain, such as overhead reaching.</u>

The lack of fully understanding of the relationship between scapula and humeral motions is highlighted by recent studies that have shown no change in scapula positioning following a training program even though individuals demonstrated significant improvements in shoulder function.(McClure, Bialker et al. 2004) It seems

that new measures are needed to assess neuromuscular control of the shoulder girdle. New techniques and measures such as coordination analyses based on Dynamical Systems Theory tenets may provide a unique, low dimensional (one number representing several constructs) measure of shoulder neuromuscular control. In addition, these measures based on dynamical systems theory can be used to examine the shoulder during traditional planar elevations as well as functional shoulder movement patterns that are associated with shoulder pain development.

The application of dynamical systems theory to complex human movement systems has challenged traditional views of variability as only random noise and movement error. (Davids, Glazier et al. 2003) Variation in movement patterns are now recognized to provide a source for self organization.(Van Emmerik and van Wegen 2000; Davids, Glazier et al. 2003) Research examining postural control and gait patterns has shown that movement pattern variability is normal and that alterations in movement variability are associated with neural and musculoskeletal pathology. (Kurz and Stergiou 2004) Decreases in variability over an entire movement pattern may place an individual at risk for repetitive strain injuries while increases in variability during transitional points (e.g. from shoulder flexion to extension at the peak shoulder elevation) of a movement pattern indicates a loss of neuromuscular control.(Hamill, Van Emmerik et al. 1999; Kurz and Stergiou 2004; Stergiou, Moraiti et al. 2004)

2.7.2 Principles of Dynamical Systems Theory in Human Movement

Application of dynamical systems theory represents a paradigm shift in how the role of variability in human movement is considered when attempting to understand normal and pathological movement patterns. This paradigm shift seeks to evaluate the

variability in contrast to the traditional biomechanical approach that assumes variability

is evidence for incorrect human movement patterns. Dynamical systems theory has been

applied in research investigating postural control and gait patterns and has been shown to

provide a valuable window into the complex interactions between the skeletal, muscular,

and neural sub-systems as they interface with the environment.(Hamill, Van Emmerik et

al. 1999; Davids, Glazier et al. 2003; Kurz and Stergiou 2004) Movement patterns are

thought to develop synergistic organizations of these sub-systems which represent

multiple degrees of freedom. This organization arises from anatomical (skeletal

alignment) and biomechanical factors (length-tension relationships) as well as

environmental and task constraints. (Kurz and Stergiou 2004) Specifically, a window into

the neuromuscular sub-system is provided by modeling segments as oscillating

pendulums. Use of this model is based on the assumption that there is energy transferred

with each oscillation. If this assumption is met then the principles of thermodynamics

govern segment behavior over time. Energy transfer during segmental oscillations

indicates that the segment is in a limit cycle system and was attracted to a closed,

periodic orbit. Therefore, perturbations affecting energy transfer will determine the path

of the segment. The path of motion that a segment returns to is termed an attractor

state.(Kurz and Stergiou 2004)

While multiple degrees of freedom can be coupled in slightly different ways, the

neuromuscular system is drawn toward an equilibrium state. (Kurz and Stergiou 2004)

Dynamical systems theory defines this state of equilibrium as an attractor state. Preferred

movement patterns of the lower extremity during gait have been shown to have a limit

cycle shape and exhibit the properties of an attractor state.(Stergiou, Bates et al. 2003)

As the shape of this limit cycle changes it reflects alterations in the trajectory of the

segment's path of motion. The plot of a segment's displacement on the x-axis and

velocity on the y-axis can reveal the dynamics of the attractor (i.e., limit cycle shape) and

is termed a phase plot. Humeral and scapular motion can be described in a similar

fashion during repetitive movement such as shoulder flexion/extension. It is evident from

the plots that there is variability in every cycle. Traditionally this has been described as

biological noise within a movement system. However, dynamical systems theory

embraces this variability as evidence of the neuromuscular system's flexibility and

adaptability to explore new solutions based on a given situation's constraints.(Kurz and

Stergiou 2004)

Simultaneous evaluation of two limit cycles provides unique information as to the

coupling or uncoupling of two oscillating segments during a movement cycle since the

neuromuscular system synergistically organizes itself across many joints. Phase locking,

entrainment, and structural stability are three properties of coupled limit cycles and have

been described as the "intrinsic dynamics" of an oscillator. Phase locking is the state

where the two limit cycle oscillators are coupled and stable. Entrainment describes the

interaction between the two limit cycles characterized by instability and discontinuity and

may include a possible phase shift. The ability or inability of an individual to remain in

its preferred phase locking relationship despite perturbations or changes in the initial

conditions of the system is a movement system's structural stability. (Kurz and Stergiou

2004)

For example, one would expect scapular upward rotation and humeral elevation to

be a coupled and phase locked pattern unless there was a significant perturbation. Let's

assume the scapular upward rotators (serratus anterior and upper trapezius) become fatigued, we would expect a change in the phase locking relationship. This change will be manifested in the respective phase plots. If this change in shape was very uneven and discontinuous, then it would be described as entrainment.   In contrast, if the phase locking pattern remained unchanged after fatigue, the scapular to humeral phasing relationship would be described as demonstrating increased structural stability. These characterizations of shoulder movement patterns may be valuable in describing the shoulder's response to changes in initial conditions such as altered skeletal alignment or pathology.

The coupling between two segments' oscillations during repetitive movements can be represented by relative phase measures.(Kurz and Stergiou 2004) These measures provide a quantitative measure of the coordinative patterns of the segments analyzed. Relative phase measures can be evaluated to examine the stability and organization of the neuromuscular system. Deficiencies in the neuromuscular system may also be characterized by differences in relative phasing patterns between healthy and pathological shoulders. Increases in variability during a movement cycle are thought to be indicative of an unstable movement patterns.(Kurz and Stergiou 2004) Decreases in variability in the relative phasing relationships about transition states have been identified in patients with low back pain, patellofemoral pain, post anterior cruciate ligament repair, and Parkinson's disease.(Heiderscheit, Hamill et al. 2002; Kurz and Stergiou 2004; Kurz, Stergiou et al. 2004) The ability of the relative phase measure capture the interplay between moving segments by compounding both their displacements and velocities in a

single variable highlights the advantage of this approach over traditional biomechanical methodology.

The relative phase measure is defined as an order parameter by dynamical systems theory. This parameter now expresses in one value the same type of input that the joint receptors respond after and during a perturbation. It has been suggested that the relative phase value is superior to traditional biomechanical variables and is more sensitive to changes in the neuromuscular system.(Kurz and Stergiou 2004) Changes in relative phasing relationships tend to be discontinuous and can be the result of changing the constraints of the task such as velocity, obstacle height, shoe surface, or additional weight.(Stergiou, Jensen et al. 2001; 2003; Kurz and Stergiou 2004; Kurz and Stergiou 2004) The mechanism facilitating this phase shift is termed a control parameter. Natural motor development and neuromuscular dysfunction have been examined as control parameters when investigating phasing relationships.(Kurz and Stergiou 2003; Kurz and Stergiou 2004) Alterations in postural alignment change the initial conditions for a given movement pattern thereby representing a control parameter. Thus, individuals demonstrating increases in forward head and rounded shoulders posture may exhibit an altered relative phasing relationship between the scapula and humerus in comparison to individuals with ideal postural alignment. Relative phase measures should capture the changes imposed by the control parameter and provide valuable information regarding the neuromuscular system's organization that controls the shoulder girdle.

2.7.3 Coordination Analyses in Human Movement

Comparing healthy individuals to those with diagnosed neural and musculoskeletal pathology has shown alterations in joint coordination between these

groups(Heiderscheit, Hamill et al. 2002; Davids, Glazier et al. 2003; Kurz and Stergiou 2003; Kurz, Stergiou et al. 2004; Stergiou, Moraiti et al. 2004) Specifically, coordination analyses based on the principles of dynamical systems has provided new insights into the effect of musculoskeletal pathology on human movement patterns.(Heiderscheit, Hamill et al. 2002; Kurz, Stergiou et al. 2004) Recent evidence has established a framework for understanding the role of altered coordinative patterns in chronic lower extremity injuries. (Stergiou and Bates 1997; Hamill, Van Emmerik et al. 1999; DeLeo, Dierks et al. 2004) Alterations in coordinative patterns of the ankle and knee have been identified in individuals with patellofemoral pain and following anterior cruciate ligament reconstruction. (Stergiou and Bates 1997; Hamill, Van Emmerik et al. 1999; Heiderscheit, Hamill et al. 2002; DeLeo, Dierks et al. 2004; Kurz, Stergiou et al. 2004) These differences have been demonstrated between legs in the same individual and between healthy individuals and those with lower extremity pathology. The observed uncoupling of the segmental movements in pathologic knees is suggested to contribute to the development of knee osteoarthritis. It is thought that increased wear and tear on the articular cartilage occurs as a result of decreased neuromuscular control which allows unequal joint loading.

These observed alterations in lower extremity coordinative patterns may have significant implications for shoulder injury given the nature of many activities that are risk factors for shoulder injury. Epidemiological research has shown increased exposure to repetitive overhead tasks as a risk factor for shoulder injury.(Punnett 1998; Punnett and van der Beck 2000; Punnett, Gold et al. 2004) It is likely then that shoulder injury and pain are related to changes in shoulder coordinative patterns reflecting alterations in

neuromuscular control of the shoulder. Given the role of repetitive functional tasks in the development of shoulder pain, coordination analyses would seem to provide a valuable methodology for understanding normal and pathological shoulder movement patterns.

The shoulder has a tremendous number of degrees of freedom among its neuromuscular and musculoskeletal components. This yields a very robust neuromuscular system that is able to respond to the many constraints placed on it while retaining its function. This may allow for compensatory movement patterns to go undetected by current biomechanical measures. Relatively small mean group differences in scapular kinematics are seen with the presence of shoulder pathology.(Ludewig and Cook 2000; Hebert, Moffet et al. 2002) These differences do not seem to resolve as symptoms and shoulder pain improve.(McClure, Bialker et al. 2004) Therefore, application of dynamical systems theory paradigm which embraces the inherent variability during shoulder movement may provide new insights into the coordinative patterns of the shoulder.

2.7.4 Shoulder Joint Coordination Analyses

Coordination analyses of shoulder movement patterns seek to identify and quantify the relationship between the scapula and the humerus. First a qualitative assessment of the organization of the neuromuscular system controlling the shoulder should be performed by plotting a phase portrait. As previously mentioned, a phase portrait (or plot) is created by graphing the angular displacement (x-axis) versus its angular velocity (y-axis). Examination of this plot allows for identification of changes in the control mechanisms of shoulder motion. The path of the curve (or trajectory) can be followed clockwise from zero to assess the behavior of the segment. Changes in the

dynamics of the system are indicated by the number of times the path crosses zero and cusps (sudden changes) in the path. Increasing crosses of zero and the number of cusps provide initial evidence of decreased or less neuromuscular control of the shoulder. (Kurz and Stergiou 2004)

The phase angle for a given segment is calculated from the phase portrait by transforming the Cartesian (x,y) coordinates to polar (r,θ) coordinates with a radius r and a phase angle θ.(Kurz and Stergiou 2004)

$$\theta_i = \tan^{-1}\left(\frac{Yi}{Xi}\right)$$

The angle formed between the horizontal and r for each point i is the phase angle at this point.

Relative phase is reflective of the coordination or interaction between two adjacent segments. To calculate the relative phase, the phase angle for every point i^{th} data point of the proximal segment from the corresponding i^{th} point of the distal segment over the movement cycle.(Kurz and Stergiou 2004)

$$\Phi_{i\text{ relative phase angle}} = \theta_{i\text{ proximal phase angle}} - \theta_{i\text{ distal phase angle}}$$

Plotting the relative phase of two segments over a movement cycle is termed a continuous relative phase plot.(Kurz and Stergiou 2004) This plot can be inspected for changes coordination by examining the slope. Relative phase values closer to 0˚ suggest a more coupled or in-phase relationship between two segments while values closer to 180˚ suggest an uncoupled or out-of-phase relationship. In-phase means that the two segments move in the same fashion and in the same direction, while out-of-phase means the segments move in a different fashion in the opposite direction. Positive values

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indicate the distal segment is leading the proximal segment and negative values the

converse. A positive slope indicates the distal segment is moving faster than the

proximal segment while a negative slope indicates the distal segment is moving slower.

Similar to the phase portraits visual inspection of the continuous relative phase curve

allows identification of local minima, maxima, cusps, and the number of reversals during

a movement cycle. This qualitative information can help better differentiate between

normal and pathological movement patterns.(Kurz and Stergiou 2004)

Calculation of mean absolute relative phase (MARP) and deviation phase (DP)

allow for statistical comparison of differences between relative phase angles. Each

continuous relative phase curve can be quantified in one term, the mean absolute relative

phase (MARP). This value reflects whether the oscillating segments are in or out of

phase during a movement cycle. The MARP value is calculated by averaging the

absolute value of all the points of the mean ensemble curve.(Kurz and Stergiou 2004)

$$\text{MARP} = \sum_{i=1}^{N} \frac{|\phi relativephase|}{N}$$

Additionally, the deviation phase (DP) can be calculated to determine the

variation over the entire relative phase curve. This value is reflective of the stability of

the neuromuscular system during a movement pattern. DP is calculated by averaging the

standard deviations (SD) of all the points over the entire mean ensemble curve.(Kurz and

Stergiou 2004)

$$\text{DP} = \frac{\sum_{i=1}^{N} SDi}{N}$$

The mean ensemble curve is the curve generated by averaging all single cycle relative phase curves. This will require normalization of all single cycle relative phase curves to a fixed number of points (i.e., 100).

2.7.5 Normalization of Phase Portraits

Questions have been raised as to whether kinematic data should be normalized when using coordination analyses to examine human movement.(Kurz and Stergiou 2004) Additionally, the ability of the relative phase angle to capture the collective state of the neuromuscular system has been discussed in the literature. When two segments are not oscillating in a 1:1 frequency there are observed integer multiple peaks in the power spectrum. As the difference in oscillating frequency grew larger conclusions were drawn that relative phase by itself does not adequately capture the coordination between two segments. However, using nonlinear differential equations relative phase measures were shown to quantify coordination between two oscillators. Further analyses showed that the dominant frequency components were an order magnitude larger and therefore able to capture the nature of coordinative patterns. Based on this no normalization is recommended to remove integer artifacts when calculating relative phase angles to determine in or out of phase relationships between segments.(Kurz and Stergiou 2004)

Others have suggested that normalization to the amplitudes of each phase portrait are necessary prior to calculating the relative phase angle. (Hamill, Haddad et al. 2000) It is thought that the segment with the largest amplitude will dominate the relative phase measure thereby biasing the coordination analysis. The dynamic qualities of the phase portrait should be kept after normalizing which would produce a scalar multiple of the original phase portrait.(Hamill, Haddad et al. 2000) However, normalizing in this fashion

has been shown to alter the dynamic qualities of the oscillating lower extremity segment.(Kurz and Stergiou 2002) This is due to different scaling factors applied to the velocity and displacement data distorting the original phase portrait. Since alterations in phase portraits are thought to be indicative of changes in the organization or stability of the neuromuscular system these normalization techniques should be used with caution. Additionally, it does not appear that amplitude differences would result in skewed relative phase angles. Since the arctan function is a ratio, differences in amplitude are removed with the phase angle calculation. When differences in oscillating frequencies are present between two segments artifacts in the relative phase measures are produced. Unfortunately, current normalization routines alter the original data when removing the artifacts. Therefore use of MARP and DP are recommended as normalization does not seem to be required for these values. (Kurz and Stergiou 2004)

2.7.6 Clinical Implications of Coordination Analyses

Forward head and rounded shoulder posture changes the normal mechanical relationships of muscles and bony structures. Dynamical systems theorists' have shown that altering the initial conditions of the human movement system influence neuromuscular control and coordinative patterns of that system.(Kurz and Stergiou 2004) It is likely then, that shoulder injury and pain are related to changes in shoulder coordinative patterns that reflect alterations in neuromuscular control. Alterations in shoulder joint coordination are cited as a clinical manifestation of shoulder dysfunction.(Kibler 1998; Voight 2000) Clinically, this is often termed scapular dyskinesis and described as uneven and uncoordinated scapular movement. However, devising a valid and reliable movement classification system has proven difficult.(Kibler,

Uhl et al. 2002) Traditional measures of shoulder coordination have been assessed by scapulohumeral rhythm, defined as the relationship of humeral elevation to scapular upward rotation. Alterations in scapulohumeral rhythm following shoulder fatigue and concurrent with shoulder impingement and rotator cuff tears have been reported.(McQuade, Dawson et al. 1998; Ludewig and Cook 2000; Hebert, Moffet et al. 2002; Mell, LaScalaza et al. 2005) However, alterations in scapulohumeral rhythm are not noted in all patients with following shoulder pathology.

This is likely due to the fact that the most consistent reports in the literature are with alterations in scapular internal rotation and posterior tipping and not upward rotation. Examination of the relationship of humeral motion to scapular internal/external rotation and anterior/posterior tipping is therefore important. Additionally, changes in the measures used in the application of coordination analyses based on dynamical systems theory has been shown to be visually perceptible for upper extremity motion.(Zaal and Bingham 2000) This is important considering that scapular dyskinesis is evaluated clinically using simple visual procedures. Also supporting the use of this approach for this project is the influence of mechanical impairments due to faulty upper quarter posture. In the dynamical systems paradigm this would decrease the degrees of freedom and alter the demands on the movement system. It is likely then that these changes in movement patterns were reflected in alterations in coordinative patterns of the shoulder. The importance of 3-D shoulder kinematics, clinical visual evaluation of scapular dyskinesis, and the likely impact of mechanical constraints on the shoulder suggest examining shoulder movements using a coordination analysis, is likely to provide new and valuable insights into the mechanisms of shoulder function.

CHAPTER III

Methods

3.1 <u>Procedures</u>

3.1.1 Recruitment and Population

Participants were recruited from the university population at The University of North Carolina-Chapel Hill. Participants were recruited through two informational mass emails sent to the university population. Participants were included if they are between the ages of 18 and 60 and met specific postural alignment criteria to be included into either the ideal posture or forward head and shoulder posture groups. Subjects were excluded if they had a history of shoulder surgery, humeral, clavicular, scapular, cervical, or thoracic fracture, if they were currently receiving any treatment for shoulder or neck pain, or other upper extremity injury that limited use of their dominant upper extremity. The dominant arm (arm they would throw a ball with) was used for testing in all subjects.

Prior to testing participants completed an informed consent form and underwent a postural screening using the BioPrint® postural analysis system (Biotonix Inc., Montreal). Postural screening was performed to ensure that participants meet the inclusion criteria for the ideal posture and forward head and shoulder posture groups. Postural screening included measurement of forward head and forward shoulder angles. Forty participants were assigned to the ideal posture group (FHA) $\leq$ 36˚ and a forward shoulder angle (FSA) $\leq$ 22˚ (Figure 1 & 2) and 40 participants to the forward head and rounded shoulder posture group (FHA) $\geq$ 46˚ and a forward shoulder angle (FSA) $\geq$ 52˚ (Figure 1 & 3).

Participants were excluded if their postural measures did not fall within the stated criteria for either the ideal posture or forward head and shoulder posture groups.

3.1.1 Postural Alignment Grouping Criteria

The postural alignment criteria were based on forward head and shoulder angles collected from an initial postural screening of 310 individuals from the university population. Descriptive characteristics of these individuals appear in Table 5. Frequency histograms were plotted and measures of skewness and kurtosis assessed for forward head and shoulder angles to confirm normality of these measures. Head and shoulder angles approximately displayed a normal distribution therefore, the mean and standard deviations were used to represent the data. Cutoffs for each group were determined as the mean ± 1 standard deviation for the head angle (41°) and shoulder angle (37°) and represent an attempt to create two distinctly separate postural alignment groups. Ninety-two of the three hundred-ten individuals screened met these criteria (29%). Forty-seven individuals were assigned to the ideal posture group and 45 to the forward head and rounded shoulder posture group. Twelve individuals did not schedule a return appointment yielding 40 participants in each group. All Participants were scheduled for a 90 minute testing session within 1 month of the initial screening. Participants were asked to avoid upper extremity weight lifting and overhead activities on either day of testing. All biomechanical data was collected and stored in the Sports Medicine Research Laboratory at the University of North Carolina at Chapel Hill. Initial screening took 10 minutes. Participants were then scheduled for a 90 minute testing session within 1 month.

Testing during the second session occurred at the Sports Medicine Research Laboratory. Three dimensional shoulder kinematic and EMG analyses was conducted to assess humeral and scapular angles as well as scapular muscle activity during the ascending (up) and descending (down) phases of arm elevation tasks. Specifically, humeral elevation, scapular upward/downward rotation (UR), scapular external/internal rotation (IR), and scapular posterior/anterior tipping (PT) were collected. Scapular angles were compared at the 60°, 90°, and 120° of humeral elevation for the ascending and descending phases of the flexion task. Scapular angles were compared at the 60°, 90°, and 110° of humeral elevation for the ascending and descending phases of the reaching task. Scapular ranges of motion and mean amplitude EMG was also compared during the ascending and descending phases of humeral elevation for both tasks.

Each of these dependent variables was examined during a loaded arm elevation flexion task (arm in front of body) and a forward-overhead reaching task. Participants were asked to perform 25 cycles of arm elevation or forward reaching task at a self selected speed during testing. The tasks were counterbalanced and participants rested 5 minutes between each task to reduce the effects of fatigue, possible learning effects, and task order. During testing the participants were asked to rate their level of exertion using the Borg's rating of perceived exertion (RPE) scale.(Borg 1998) This scale has been used in both reaching and overhead throwing tasks to quantify fatigue.(Snook and Ciriello 1991; Tripp, Bowell et al. 2004) Each subject was asked to report their RPE during each task after the 15th, 20th, and 25th repetitions.

3.2 <u>Data Collection</u>

3.2.1 Postural Analyses

The BioPrint postural analysis system was used for postural assessments. Reflective markers were placed over the right tragus (ear), chin, labella (between eyes), acromion, C_7, T_7, posterior superior iliac spine, and anterior superior iliac spine. Participants then stood 40 cm in front of the scaled backdrop and were given standard instructions to increase reliability of their normal resting postural alignment. High resolution (5.0 mega pixels) digital images were taken then uploaded to a personal computer for analysis.

3.2.2 Measurement of Shoulder Kinematics

A Flock of Birds® (Ascension Technologies, Inc., Burlington, VT) electromagnetic motion analysis system controlled by the Motion Monitor® (Innovative Sports Training, Inc. Chicago, IL) software was used to assess scapular kinematics at a sampling rate of 50 Hz. The primary component of the electromagnetic tracking system is a standard range DC transmitter containing three orthogonal coils that generates an electromagnetic field. The system incorporates a series of three sensors/receivers that record the electromagnetic flux in the field generated by the transmitter and conveys the signals to a recording computer via hard wiring.

Three electromagnetic tracking sensors were attached to: 1.) The thorax over the spinous process of T3, 2.) The dominant shoulder over the broad flat surface of the scapular acromion, 3.) The posterior one third of the upper arm with the sensor over the area of least muscle mass to minimize potential sensor movement. In order to assess the shoulder kinematics, reconstruction of the bony segments were performed following the International Society of Biomechanics-Shoulder Group Recommendations and have been

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used in previous studies.(International Society of Biomechanics Shoulder Group 2002)

The bony landmarks were: T_{12}, medial and lateral epicondyle of the humerus, T_8, xyphoid

process, C_7, sternal notch, spine of the scapula at the medial border, posterior-acromion

of the scapula, inferior angle of the scapula, and the glenohumeral joint rotation center.

The glenohumeral joint center was defined by the point that moves least with respect to

the scapula when the humerus is moved through short arcs ($\leq 45°$) as calculated by a least

squares algorithm and has been shown to best represent the glenohumeral joint center.

(Veeger 2000)

The electromagnetic transmitter was positioned on a custom stand allowing for the

establishment of a global reference system. The global reference system axes were

defined such that the Y-axis was designated as positive in the superior direction, the X-

axis was designated as positive to the left, and the Z-axis was designated as negative, all

relative to the participant. The local axes systems all aligned with the reference axes of

the electromagnetic system to simplify data reduction. (Figures 5-7)

3.2.3 Measurement of Muscle Activity

EMG analyses were performed to measure the muscle activation amplitude of

serratus anterior, upper trapezius, and lower trapezius muscles using a Delsys Bagnoli-8

EMG System (Boston, MA), with differential amplification, CMRR >80 dB, input

impedance >1015//0.2 ohm//pF, SNR >40 dB using an 8 channel amplifier. The EMG

signal was amplified by a factor of 1000 over a bandwith of 0.01 to 2,000 Hz, passed via

an A/D converter (National Instruments, Austin, TX) sampling at 1000 Hz then corrected

for DC

bias. The raw EMG data was collected by the Motion Monitor® software and stored for

analysis. The electrodes were 19.8 mm wide and 35 mm long with 10 mm between contacts.

Before applying surface electrodes, the participant's skin was shaved, cleaned with alcohol and lightly abraded to ensure good electrode contact and transmission. We fixed a bar Ag/AgCl single differential surface electrode (Delsys Inc., Boston, MA) on the midpoint of each muscle belly perpendicular to the muscle fiber direction using surgical tape and adhesive stickers. Electrodes were placed according to previously published guidelines in of the serratus anterior, upper trapezius, and lower trapezius muscles' fibers in the following arrangement.

> *Serratus anterior:* below the axilla, anterior to latissimus dorsi, placed over 4th through 6th ribs angled at 30° above the nipple line
>
> *Upper trapezius*: one half the distance from the mastoid process to the root of the spine approximately at the angle of the neck and shoulder
>
> *Lower trapezius:* two finger widths lateral to the inferior angle of the scapula on a 45° angle towards T10.

The specified electrode placement has been used in a number of studies.(Glousman, Jobe et al. 1988; Cools, Witvrouw et al. 2003; Michener, Boardman et al. 2005) A carbon reference electrode was placed over the non-involved acromion. Isometric manual muscle tests were performed to ensure accurate placement of electrodes and to measure and record maximal voluntary isometric contraction (MVIC) EMG. The MVIC measures were taken for 3 trials and averaged for normalization of muscle activity during each task.

Manual muscle tests to determine MVIC was performed according to the procedures described by Michener et al.(2005) using a hand-held dynamometer (HHD) (CDS 300 strength dynamometer, Chatillion®, Largo, FL). Prior to testing, participants performed one sub-maximal contraction to familiarize themselves with proper form for each manual muscle test. Following this warm-up and learning session, participants performed three maximal voluntary isometric contractions measured with a HHD for each muscle with 1 minute rest between each muscle and 30 seconds between each trial. The peak mean force for a 5 second period was recorded. Mean amplitude values for the three trials demonstrated good reliability for each muscle with $ICC_{(2,1)}$ values ranging from 0.74 to 0.87 therefore, mean amplitude EMG data was expressed as a percentage of MVIC (%MVIC).

Serratus Anterior MVIC Assessment

Testing of the serratus anterior were performed with the participant in the sitting position with their arm elevated in the scapular plane to approximately 120° degrees. The tester was positioned standing beside the participant and gave the instructions to "lift your arm out and up, don't let me push you down". The tester gave a downward force on the superior aspect of the arm at the elbow while providing pressure at the lateral, inferior angle of the scapula inwards for 5 seconds. The participant was then be instructed to "relax". This position has been shown to yield the most reliable and highest MVIC values for the serratus anterior.(Ekstrom, Donatelli et al. 2003; Ludewig, Hoff et al. 2004; Michener, Boardman et al. 2005)

Upper Trapezius MVIC Assessment

Testing of the upper trapezius was performed with the participant seated with their arms at their side. The tester stood behind the participant and gave the instructions to "shrug their shoulders straight up" and hold that position. The tester provided a downward force on the superior aspect of the acromion and back of the head for 5 seconds. The participant was then be instructed to "relax".(Ekstrom, Donatelli et al. 2003; Ludewig, Hoff et al. 2004)

Lower Trapezius MVIC Assessment

Testing of the lower trapezius was performed with the participant lying supine on a table with their arms extended over their head. The tester stood on the dominant shoulder and gave the instructions to "lift both arms up placing your shoulder blades in your opposite back pocket". The tester provided a downward force on the superior aspect of the acromion for 5 seconds. The participant will then be instructed to "relax".(Ludewig, Hoff et al. 2004; Michener, Boardman et al. 2005)

After the setup was completed, participants completed the humeral elevation and forward reaching tasks. The humeral elevation task required the participant to lift a weight equal to 3% of their body weight while following a 2-inch target on the wall with their hand (Figure 9). The 3% loading rate was selected through pilot testing which allowed all subjects to complete 25 repetitions of each task. Loads greater than 3% limited heavier subjects from achieving this goal. The target was placed in the sagittal plane in line with their dominant arm acromion. The sagittal plane was be defined as the plane perpendicular to a line through their fifth metatarsal head. Participants were asked to complete their full range of motion at a self selected speed.

The forward reaching task required the participant placing a weight equal to 2% of their body weight from a stool adjusted to the height of the greater trochanter (hip) on their dominant side to a customized shelf equal to their height plus 20% (Figure 10 & 11). The target was placed perpendicular to the dominant AC joint, the length of their ulnar styloid anterior to the participant. Participants placed their weight on the target and a standard goniometer was used to ensure humeral elevation relative to their trunk was greater than 120°. Participants performed 5 practice trails to become familiar with the procedures before testing. Each task was performed 25 times in a random order in an attempt to prevent an order effect. Participants rested 5 minutes between tasks to prevent fatigue.

3.3 Data Reduction and Processing

3.3.1 Kinematic Data

Three-dimensional coordinates of the digitized bony landmarks were calculated using the Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL). Segment reference frames were defined according to the recommendations set forth by the Shoulder Group of the International Society of Biomechanics.(Wu, van der Helm et al. 2005) Humeral motions were calculated as the Euler angles of the humerus relative to the thorax reference frame in the following order of rotations: internal-external rotation about Y axis, elevation about the Z' axis, and internal-external rotation about the Y" axis(An, Browne et al. 1991). Scapular motions were calculated as the Euler angles of the scapula relative to the thorax reference frames in the following order of rotations: internal/external rotation about the Y axis, upward-downward rotation about the Z' axis, and posterior-anterior tilting about the X" axis(Karduna, McClure et al. 2000; Wu, van

der Helm et al. 2005). Kinematic data were smoothed through a Butterworth a low pass digital-filter (4th order, recursive, zero phase lag) at an estimated optimum cutoff frequency of 3.5 Hz. The estimated optimum cutoff was determined after performing a spectral analysis for each kinematic variable. All humeral and scapular rotation spectral plots were similar (Figure 8).

3.3.2 EMG Data

Post-acquisition, all EMG data was band-pass filtered (10 – 350 Hz) using a Butterworth filter (4th order, recursive, zero-phase lag). The data was rectified then the root mean square error (RMS) of the EMG signal over a 20 ms time constant was taken to further smooth the data.

3.4 Data Processing

3.4.1 Reduction for Scapular Kinematic and Electromyographic Analyses

The average of trials 2-6 of each task were used for assessment of mean scapular angles. Scapular upward rotation, internal rotation, and posterior tilting angles were selected using custom Matlab (Mathworks, Natick, MA) code to identify angles at 60°, 90°, and 120° of humeral elevation during the ascending and descending phases of the forward flexion task. Scapular angles were identified at 60°, 90°, and 110° of the forward reaching task. Each of the scapular and humeral kinematic variables demonstrated excellent reliability with $ICC_{(2,1)}$ values ranging from 0.92 to 0.99. Scapular ranges of motion (ROM) were calculated from 30° to 120° of humeral elevation for the ascending and descending phases of humeral elevation.

Mean amplitude EMG was used to represent muscle activation over the ascending and descending phases of humeral elevation for the upper trapezius, lower trapezius, and

serratus anterior. These were the same arcs used to calculate the scapular ROM for the ascending and descending phases of shoulder motion. The mean amplitude EMG over each phase of motion was averaged across each of the 5 trials and used for statistical analyses. Each of the scapular EMG variables demonstrated good reliability with $\text{ICC}_{(2,1)}$ values ranging from 0.68 to 0.85.

3.4.2 Reduction for Coordination Analyses

The humeral and scapular kinematic data was analyzed using custom Matlab code to calculate mean relative phase (MARP) and deviation phase (DP) values. Shoulder kinematic data was further smoothed using a cubic spline routine. The tolerance of the spline routine was set at .7 where 0 is a perfect least squares fit between the first and last point of the data sequence, and 1 is the natural spline.

Shoulder kinematic data then was fit to 101 points for 15 repetitions for humeral elevation and each scapular motion. Only 15 repetitions were selected based on the potential effects of fatigue. This was supported by a significant increase in PRE values from 13 at the 15th repetition, to 15 at the 20th repetition, to 17 at the 25th repetition. Angular position and angular velocity was plotted to create phase portraits for humeral elevation, scapular upward rotation, internal rotation, and posterior tipping. The relative phase was calculated between humeral elevation and each scapular motion. Relative phase for a given segment was calculated from the phase angle of each phase portrait. The phase portrait path was transformed from Cartesian (x,y) to polar (r,θ) with a radius r and a phase angle θ. The angle formed by the radius was calculated as: (Kurz and Stergiou 2004)

$$\Theta_i = \tan^{-1}\left(\frac{Yi}{Xi}\right)$$

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The angle formed between the horizontal and r for each point i was the phase angle.

The relative phase angle between each of the scapular rotations and humeral elevation was then calculated as the difference between the proximal segment's phase angle and the distal segment's phase angle:(Kurz and Stergiou 2004)

$$\Phi_{i \text{ relative phase angle}} = \theta_{i \text{ proximal phase angle}} - \theta_{i \text{ distal phase angle}}$$

Calculation of mean absolute relative phase (MARP) and deviation phase (DP) allowed for statistical comparison of differences between relative phases. Each continuous relative phase curve was quantified in one term, the mean absolute relative phase (MARP). This value reflects whether the oscillating segments are in or out of phase during a movement cycle. The MARP value was calculated by averaging the absolute value of all the points of the mean ensemble curve.(Kurz and Stergiou 2004)

$$MARP = \sum_{i=1}^{N} \frac{|\phi relativephase|}{N}$$

Additionally, the deviation phase (DP) was calculated to determine the variation over the entire relative phase curve. This value is reflective of the stability of the neuromuscular system during a movement pattern. DP was calculated by averaging the standard deviations (SD) of all the points over the entire mean ensemble curve.(Kurz and Stergiou 2004)

$$DP = \frac{\sum_{i=1}^{N} SDi}{N}$$

The mean ensemble curve is the curve generated by averaging all single cycle relative phase curves. This required normalization of all single cycle relative phase curves to a fixed number of points (i.e., 101) for each task.

3.5 Statistical Analysis

3.5.1 Study Power

Based on the values presented in Table 3 a moderate to large effect size (Cohen's d) ranging from .5 to 1.55 may be observed. This will allow for clinically meaningful conclusions to be drawn from any observed differences in scapular kinematics, muscle activity, and shoulder joint coordination. These power calculations assume a two-sided Type I error rate of 0.05 in a dependent t-test. Table 3 shows the study's power, displaying the mean difference, standard deviation, and power for each dependent variable based on pilot data. The table shows the most conservative values for each of the dependent variables. These values are

Table 3. Estimated study power for each dependent variable (n = 80)

Dependent Variable	Mean Difference	Stdev.	Power
Scapular Upward Rotation	10°	15°	.80
Scapular Internal Rotation	7°	10°	.80
Scapular Posterior Tipping	10°	15°	80
Upper Trapezius (% of Max muscle activity)	60%	80%	.90
Lower Trapezius (% of Max muscle activity)	50%	80%	.90
Serratus Anterior (% of Max muscle activity)	55%	80%	.90
MARP for UR, IR, PT	4°	7°	.70
DP for UR, IR, PT	18°	25°	.70

consistent with previous work using the same methodology.(Thigpen, Padua et al. 2005; Thigpen, Padua et al. 2005). The pilot data was collected on 10 participants, 6 with forward head and rounded shoulder (FHA = 51°, FSA = 114°) compared with 4 participants with ideal posture (FHA = 41°, FSA = 154°). These calculations suggest sufficient power to detect differences for all dependent variables between groups for each research question.

3.5.2 Analysis Plan:

Separate mixed model 2 (phase) X 2 (arc of motion) X 2 (group) ANOVAs for were performed for scapular upward rotation, internal rotation, posterior tipping angles during the loaded flexion and reaching tasks. Separate mixed model 2 (phase) X 2 (group) ANOVAs were performed for scapular upward rotation, internal rotation, posterior tipping range of motion as well as serratus anterior, upper trapezius, and lower trapezius mean amplitude EMG (Table 4). Separate mixed model 2 (phase) X 2 (group) ANOVAs were performed for scapular upward rotation, internal rotation, posterior tipping MARP and DP values. Tukey's post hoc analysis was preformed for each significant main and interaction effects to assess which scapular kinematic, EMG, or coordination dependent variables differed over each phase or arc of motion during both tasks (tasks were not compared). Statistical significance for all comparisons was set a priori at $\alpha = 0.05$.

CHAPTER IV

Summary of Results

4.10 <u>Introduction</u>

The results of each research question are briefly summarized in this chapter.

Minimal interpretation is provided as the two included manuscripts have addressed all

research questions. The results are organized by Research Question. A brief

interpretation follows each question. To determine differences between groups, p-values

and effect sizes were used. I have also included 95% confidence intervals (CI) to add to

the statistical evidence for the conclusions to the questions posed. Main and interaction

effects not involving group are not reported or discussed as they did not pertain to the

research questions.

The most important finding in this study is that individuals with forward head and

rounded shoulder posture displayed altered scapular kinematic, muscle activation, and

shoulder coordination patterns in comparison to individuals with ideal posture. This was

observed in individuals with reported healthy shoulders. These results support the theory

that FHRSP alters shoulder movement in potentially negative ways. Additionally, these

results suggest that a simple clinical measure of head and shoulder posture provides

important information about shoulder function. Prevention and intervention programs for

the shoulder girdle should include examination and treatments aimed at FHRSP. Future

studies should investigate the influence of FHRSP on the development of shoulder pain and if improving FHRSP normalizes shoulder movement patterns.

4.20 <u>Participants</u>

Volunteers were recruited from the university population through informational mass emails. The postural alignment criteria were based on data collected from during screening of 310 individuals on head and shoulder postural alignment. Descriptive characteristics of these individuals appear in Table 5. Frequency histograms were plotted and measures of skewness and kurtosis assessed for forward head and shoulder angles to confirm normality of these measures. Head and shoulder angles approximately displayed a normal distribution. Therefore, the mean and standard deviations were used to represent the data. Cutoffs for each group were determined as the mean ± 1 standard deviation for the head and shoulder angle (Table 5). The FHRSP was 1 standard deviation above the mean and the ideal posture group was 1 standard deviation below the mean (Table 6). Thus these groups represent two distinctly different postural alignment groups.

Excessive kyphosis was defined in a similar manner. The mean thoracic angle plus one standard deviation was 50˚. These data represent a similarly aged sample of 300 subjects.(Vialle, Levassor et al. 2005) One standard deviation is also similar to the average increase in thoracic kyphosis reported to induce changes in scapular kinematics.(Kebaetse, McClure et al. 1999)

Participants were excluded if their postural measures did not fall within the stated group criteria. Ninety-two of the 310 individuals screened met these criteria (29%). Forty-seven individuals were assigned to the ideal posture group and 45 to the FHRSP

group. Twelve individuals did not schedule a return appointment yielding 40 participants in each group.

Reflective markers were placed over the right tragus (ear), chin, labella (between eyes), acromion, C_7, T_7, posterior superior iliac spine, and anterior superior iliac spine. Participants then stood 40 cm in front of the scaled backdrop and were given standard instructions to increase reliability of their normal resting postural alignment. High resolution (5.0 mega pixels) digital images were then uploaded to a personal computer for processing. Adobe Photoshop® was used to measure head and shoulder angles. FHA and FSA demonstrated excellent intrasession reliability (FHA = $ICC_{(2,1)}$= 0.92, SEM = 2° and FSA $ICC_{(2,1)}$= 0.89, SEM = 5°) and between day reliability (FHA = $ICC_{(2,k)}$= 0.78, SEM = 4° and FSA $ICC_{(2,k)}$= 0.72, SEM = 7°).

Based on these criteria 80 individuals were tested and data was analyzed as detailed in the methods chapter. Their results and brief interpretation follow.

4.30 <u>Research Question 1</u>

4. *Are there differences between individuals with and forward head and rounded shoulder postural alignment for scapular kinematics during loaded forward flexion and a forward reaching task?*

   e. **Compare scapular ranges of motion for upward rotation, internal rotation, and posterior tipping between groups for the ascending and descending phases of loaded forward flexion.**

There was not a significant difference between postural groups for scapular internal/external rotation or scapular posterior/anterior tipping range of motion (Table 7). There was a significant difference between postural groups for scapular upward rotation

range of motion. These results indicate that on average individuals in the FHRSP group displayed greater scapular upward rotation range of motion in comparison to the ideal posture group. The mean difference of scapular upward rotation range of motion between groups was 5° (ES = 0.34) (Figure 12).

f. Compare scapular ranges of motion for upward rotation, internal rotation, and posterior tipping between groups for the ascending and descending phases of a loaded forward reaching task.

There was not a significant difference between postural groups for scapular internal/external rotation or scapular upward rotation range of motion (Table 7). There was a significant difference between postural groups for scapular posterior/anterior tipping range of motion.   These results indicate that on average individuals in the FHRSP group displayed less scapular anterior tipping range of motion in comparison to the ideal posture group. The mean difference of scapular anterior tipping range of motion between groups was 2° (ES = 0.36) (Figure 13).

g. Compare scapular angles upward rotation, internal rotation, and posterior tipping angles between groups at 60°, 90°, and 120° for the ascending and descending phases of loaded forward flexion.

Scapular Internal/External Rotation Angles

There was a significant main effect for group on scapular internal rotation (p = 0.02) (Table 8). There was not a significant interaction effect between humeral elevation angle and postural group on scapular internal rotation angle. There was not a significant interaction effect between phase of humeral elevation and postural group on scapular internal rotation angle.   There was not a significant interaction effect between phase of

humeral elevation, angle of humeral elevation and postural group on scapular internal rotation angle. These results indicate that on average individuals in the FHRSP group displayed greater scapular internal rotation in comparison to the ideal posture group (Figure 14). The mean difference of scapular internal rotation between groups was 8° (ES = 0.52).

Scapular Upward/Downward Rotation Angles

There was no significant main effect for postural group on scapular upward rotation (Table 8). There was not a significant interaction effect between phase of humeral elevation and postural group on scapular internal rotation angle. There was a significant interaction effect between postural groups on humeral elevation angle ($p < 0.001$). Tukey's post hoc test revealed significant differences between groups and individual humeral elevation angles (Mean Significant Difference (MSD) = 2.8°). These results indicate that the scapula was more upwardly rotated for the FHRSP group at 120° during the ascending and descending phases of humeral elevation in comparison to the ideal posture group. The mean difference between postural groups for scapular upward/downward rotation was 5° (ES = 0.51) (Figure 15).

Scapular Anterior/Posterior Tipping Angles

There was no significant main effect for postural group on scapular anterior/posterior tipping (Table 8). There was not a significant interaction effect between humeral elevation angle and postural group. There was a significant interaction effect between phase of humeral elevation and postural group on scapular internal rotation angle ($p = 0.019$). Tukey's post hoc test revealed significant differences between groups and individual humeral elevation angles (Mean Significant Difference (MSD) = 1.3°).

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These results indicate that on average during ascending and descending phases of humeral elevation the scapula was more anteriorly tipped for the FHRSP group in comparison to the ideal posture group. The mean difference between postural groups for scapular anterior/posterior tipping was 3° for the ascending phase and 4° for the descending phase (ES = .32) (Figure 16).

h. **Compare scapular upward rotation, internal rotation, and posterior tipping angles between groups at 60°, 90°, and 110° for the ascending and descending phases of a loaded forward reaching task.**

Scapular Internal/External Rotation Angles

There was a significant main effect for group on scapular internal rotation (p < 0.001) (Table 9). There was not a significant interaction effect between humeral elevation angle and postural group on scapular internal rotation angle. There was not a significant interaction effect between phase of humeral elevation and postural group on scapular internal rotation angle. These results indicate that on average individuals in the FHRSP group displayed greater scapular internal rotation in comparison to the ideal posture group. The mean difference of scapular internal rotation between groups was 10° (ES = 0.60) (Figure 17).

Scapular Upward/Downward Rotation Angles

There was no significant main effect for postural group on scapular upward rotation (Table 9). There was not a significant interaction effect between humeral elevation angle and postural group on scapular internal rotation angle. There was not a significant interaction effect between phase of humeral elevation and postural group on

scapular internal rotation angle. These results indicate there were no significant

differences in scapular upward rotation during the reaching task.

Scapular Anterior/Posterior Tipping Angles

There was no significant main effect for postural group on scapular

anterior/posterior tipping (Table 9). There was not a significant interaction effect between

humeral elevation angle and postural group on scapular anterior/posterior tipping angle.

There was not a significant interaction effect between phase of humeral elevation and

postural group on scapular anterior/posterior tipping angle. These results indicate there

were no significant differences in scapular anterior/posterior tipping angles during the

reaching task.

Interpretation

Our results suggest that individuals with FHRSP display altered scapular

kinematic patterns during shoulder flexion and overhead reaching tasks. Individuals with

FHRSP remained in more scapular internal rotation throughout the flexion and reaching

tasks. These subjects also displayed greater scapular upward rotation range of motion

during the ascending phase of both tasks. Additionally, individuals with FRHSP showed

increases in scapular anterior tipping during the shoulder flexion task. Increases in

scapular upward rotation angles were also observed at 120° of the ascending and

descending phases of the shoulder flexion task. These alterations in scapular kinematics

were observed with concurrent decreases in serratus anterior activity during the

ascending phase of the overhead tasks. These results support the clinical theory that

FHRSP impacts shoulder mechanics. These alterations were observed in healthy

shoulders without shoulder pain suggesting that FHRSP alone may influence scapular

mechanics. Head and shoulder posture, scapular kinematics, and muscle activity should be examined as potential risk factors in the development of shoulder pain.

The observed increases in scapular internal rotation and anterior tipping in individuals with FHRSP are consistent with previous reports examining the effects of posture on three-dimensional scapular kinematics.(Kebaetse, McClure et al. 1999; Finley and Lee 2003; Borstad 2004) Individuals with FHRSP displayed greater scapular anterior tipping angles when compared to individuals with ideal posture. The increase of 3°-4° is similar to increases in scapular anterior tipping following increases in thoracic kyphosis(Kebaetse, McClure et al. 1999; Finley and Lee 2003) and short pectoralis minor length.(Borstad 2004) In the current study the FHRSP group demonstrated scapula internal rotation angles that were 8º and 10º greater than the ideal posture group during the reaching and flexion tasks, respectively. The increase in scapular internal rotation are similar to alterations reported in healthy shoulders with short pectoralis minor length(Borstad 2004) but smaller than increases reported concurrent with increased in thoracic kyphosis.(Kebaetse, McClure et al. 1999; Finley and Lee 2003) The greater scapular internal rotation angles may have been the result of study design plane of humeral elevation. Previous studies acutely altered spinal alignment to facilitate a more FHRSP.(Kebaetse, McClure et al. 1999; Finley and Lee 2003) In contrast, we created two distinct postural groups to examine the effects of FHRSP on scapular kinematics. By limiting the amount of excessive thoracic kyphosis our results reflect changes in the scapular position upon the thorax. The plane of humeral elevation also has been reported to influence the contribution of scapular rotations to total shoulder motion. The tasks in this study were more anterior to scapular plane elevation used in previous studies.(Koh,

Grabiner et al. 1998; Hebert, Moffet et al. 2002) These factors likely combined to influence the magnitude of differences in scapular internal rotation between studies. Considering these studies together(Kebaetse, McClure et al. 1999; Finley and Lee 2003; Borstad 2004), increasing thoracic kyphosis seems to affect scapular internal rotation less than FHRSP or short pectoralis minor length.(Borstad 2004)

These studies also reported decreases in scapular upward rotation as the result of increasing thoracic kyphosis(Kebaetse, McClure et al. 1999; Finley and Lee 2003) or no difference in individuals with short pectoralis minor lengths.(Borstad 2004) We observed increases in scapular upward rotation angle and range of motion in individuals with FHRSP.   Previous reports of decreased scapular upward rotation are most likely due to methods of inducing postural malalignment.(Kebaetse, McClure et al. 1999; Finley and Lee 2003) Acutely increasing thoracic kyphosis would increase the length of levator scapulae by positioning the scapula more anterior and inferior on the thorax. Increasing the length and orientation of the upper trapezius may have limited the ability of the scapula to upwardly rotate during humeral elevation. In contrast, FHRSP would shorten the levator scapulae and upper trapezius allowing for increased scapular upward rotation. However, since thoracic kyphosis was controlled in this study the scapular position was most different in the transverse plane. Our results are also inconsistent with the absence of changes in scapular upward rotation in healthy shoulder with pectoralis minor tightness.(Borstad 2004) Apparently, pectoralis minor tightness does not result in changes in scapular upward/downward rotation. This suggests that FHRSP has a more global effect on scapular kinematics while pectoralis minor tightness primarily affects scapular tipping and internal rotation.

5. *Are there differences between individuals with ideal and forward head and*

   rounded shoulder postural alignment for scapular muscle activation during

   loaded forward flexion and a forward reaching task?

   c. **Compare mean amplitude EMG of the upper trapezius (UT), lower**

      trapezius (LT), and serratus anterior (SA) between groups for the

      ascending and descending phases of loaded forward flexion.

Serratus Anterior

There was no significant main effect for postural group on the serratus anterior

(Table 10). There was a significant interaction effect between humeral elevation phase

by postural group on serratus anterior activity ($p = 0.02$). Tukey's post hoc test revealed

significant differences between groups and individual humeral elevation angles (MSD =

6%). These results indicate that the serratus anterior in the FHRSP group was less active

during the ascending phase of humeral elevation in comparison to the ideal posture

group. The mean difference between postural groups for serratus anterior activity was

12% during the flexion task (ES = 0.26) (Figure 18).

Upper Trapezius

There was no significant main effect for postural group on upper trapezius activity

(Table 10). There was not a significant interaction effect between humeral elevation

angle and postural group on scapular upper trapezius activity. These results indicate

there were no significant differences in upper trapezius activity during the flexion task.

Lower Trapezius

There was no significant main effect for postural group on lower trapezius activity (Table 10). There was not a significant interaction effect between humeral elevation angle and postural group on scapular lower trapezius activity. These results indicate there were no significant differences in lower trapezius activity during the flexion task.

d. Compare mean amplitude EMG of the upper trapezius (UT), lower trapezius (LT), and serratus anterior (SA) between groups for the ascending and descending phases of a loaded forward reaching task.

Serratus Anterior

There was no significant main effect for postural group on the serratus anterior (Table 10). There was a significant interaction effect between humeral elevation phase by postural group on serratus anterior activity ($p = 0.041$). Tukey's post hoc test revealed significant differences between groups and individual humeral elevation angles (MSD = 5%). These results indicate that the serratus anterior in the FHRSP group was less active during the ascending phase of humeral elevation in comparison to the ideal posture group. The mean difference between postural groups for serratus anterior activity was 5% during the flexion task (ES = 0.33) (Figure 19).

Upper Trapezius

There was no significant main effect for postural group on upper trapezius activity (Table 10). There was not a significant interaction effect between humeral elevation angle and postural group on scapular upper trapezius activity. These results indicate there were no significant differences in upper trapezius activity during the flexion task.

Lower Trapezius

There was no significant main effect for postural group on lower trapezius activity (Table 10). There was not a significant interaction effect between humeral elevation angle and postural group on scapular lower trapezius activity. These results indicate there were no significant differences in lower trapezius activity during the flexion task.

Interpretation

Individuals with FHRSP displayed decreases in serratus anterior activity during the ascending phase of overhead tasks in comparison to individuals with ideal posture. This may explain concurrent observations of altered patterns of scapular kinematics. The serratus anterior is the only scapular muscle with the potential to participate in force-couples to control all three scapular rotations. Therefore, decreased serratus anterior activity is thought to contribute to alterations in scapular kinematics.(Ludewig and Cook 2000) This is supported by the differences in serratus activation and observed kinematic changes during each task. During the flexion task a 12% decrease in serratus activation occurred with an increase in scapular anterior tipping and upward rotation. However, serratus activation decreased to 5% and no kinematic changes occurred specific to the ascending phase of the reaching task. The maximum angle compared for the reaching task was 110°, while the maximum angle was 120° for the flexion task. The observed differences in scapular kinematics and serratus anterior activity suggest that at higher ranges of humeral elevation the serratus anterior controls scapular anterior/posterior tipping and may actually limit scapular upward rotation. This seems paradoxical until one considers the role of the serratus anterior in its force couple with upper trapezius. The upper trapezius has more fibers with longer moment arms positioned to create

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upward rotation. Therefore, the role of the serratus may be to prevent excessive upward rotation maintaining optimal length-tension relationships of other muscles. These results support rehabilitative focus on the serratus anterior in individuals with FHRSP, especially in the higher ranges of humeral elevation. Focus on facilitating serratus anterior activity during the higher ranges of humeral elevation may facilitate normal scapular upward rotation and posterior tipping.

The absence of differences observed in trapezius activity may be due to the population tested, task performed, or measure of muscle activity selected. The population tested reported healthy shoulders with no positive tests for shoulder pain. Alterations in upper and lower trapezius timing and activity have only been reported in patients diagnosed with shoulder pain.(Ludewig and Cook 2000; Cools, Witvrouw et al. 2003; Matias and Pascoal 2006) It is possible that alterations in trapezius function are related to the presence of shoulder pain. Alterations in trapezius activity may be a compensatory mechanism to avoid pain or a contributing factor to the development of shoulder pain.

The observed similarities in trapezius activity also may have been the result of task selection. The trapezius increases its activity as the plane of humeral elevation moves from the sagittal plane to the frontal plane.(Inman, Saunders et al. 1944; Bagg and Forrest 1986) It is possible that the forward nature of these activities did not require high levels of recruitment of the trapezius muscles. Decreased requirements in trapezius activity during overhead elevation tasks may not have elicited differences in these healthy shoulders. Additionally, mean amplitude of each phase of the overhead reaching tasks were used as dependent variables. Given that there was very little activity in both groups

during the descending phases, it is possible that any differences were blurred by analyzing the entire ascending phase. Future studies should use multi-planar tasks, examine smaller arcs of motion for differences in muscle activity, and prospectively evaluate trapezius activity between healthy and painful shoulders.

We are not aware of any published literature examining scapular muscle activity in relation to alterations in head and shoulder posture. Our results are in agreement with reports of increased scapular muscle activity during the ascending phase of humeral elevation for all scapular muscles.(Bagg and Forrest 1986; Ekstrom, Donatelli et al. 2003) Decreases in serratus anterior activity has also been reported in patients diagnosed with shoulder impingement and instability.(Ludewig and Cook 2000; Matias and Pascoal 2006)

4.50 <u>Research Question 3</u>

6. ***Are there differences between individuals with ideal and forward head and rounded shoulder postural alignment for measures of shoulder joint coordination?***

   c. **Compare mean absolute relative phase (MARP) values and deviation phase (DP) values of the relative humeral and scapular movement patterns between groups during the ascending and descending phases of loaded forward flexion.**

Mean Absolute Phase Values

Scapular Upward/Downward Rotation and Humeral Elevation

There was not a significant main effect involving group (Table 11) or a group by phase interaction for scapular upward/downward rotation-humeral elevation MARP

values. These results indicate that on average the FHRSP and ideal posture groups displayed similar coordinative patterns between scapula upward/downward rotation and humeral elevation during the ascending and descending phases of the flexion task (Figure 20).

Scapular Internal/External Rotation and Humeral Elevation

The coordinative patterns between scapula internal/external rotation and humeral elevation during the flexion task were also not affected by posture group or phase of motion. Statistical analyses revealed no significant main effects for postural group (Table 11) and phase of humeral elevation, as well as, no significant group by phase interaction for scapular internal/external rotation-humeral elevation MARP values (Figure 21).

Scapular Anterior/Posterior Tipping and Humeral Elevation

Scapula anterior/posterior tipping and humeral elevation MARP values were influenced by posture group and phase of humeral elevation. There were significant main effects for group (p = 0.01ES = 0.42). However, there was no significant interaction between phase of humeral elevation and postural group on scapular anterior/posterior tipping-humeral elevation MARP values. These results indicate that on average individuals in the FHRSP group displayed greater uncoupling between the humerus and scapular anterior/posterior tipping during humeral elevation in comparison to the ideal posture group (Figure 22). The mean difference of scapular anterior/posterior tipping-humeral elevation MARP values between groups was 14° (Figure 23).

<u>*Deviation Phase Values*</u>

Scapular Upward/Downward Rotation and Humeral Elevation

There was not a significant main effect for group on scapular upward/downward rotation-humeral elevation DP values (Table 12). There was not a significant interaction effect between phases of humeral elevation on scapular upward/downward rotation-humeral elevation DP values. There was not a significant main effect for phase of humeral elevation on scapular upward/downward rotation-humeral elevation DP values. These results indicate that on average the stability of the scapular upward/downward rotation-humeral elevation coordinative pattern was similar when comparing individuals with forward head and rounded shoulder posture and those with ideal posture (Figure 25).

Scapular Internal/External Rotation and Humeral Elevation

There was a significant main effect for postural group on scapular internal/external rotation-humeral elevation DP values (Table 12). There was not a significant interaction effect between phase of humeral elevation and postural group on scapular internal/external rotation-humeral elevation DP values. These results indicate that on average the FHRSP group displayed more stable coordinative patterns for scapular internal/external rotation and humeral elevation.

Scapular Anterior/Posterior Tipping and Humeral Elevation

There was not a significant main effect for group on scapular anterior/posterior tipping-humeral elevation DP values (Table 12). There was not a significant interaction effect between phase of humeral elevation and postural group on scapular anterior/posterior tipping-humeral elevation DP values. These results indicate that on average the stability of the scapular anterior/posterior tipping-humeral elevation

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coordinative pattern was similar when comparing individuals with forward head and rounded shoulder posture and those with ideal posture.

    d. **Compare mean absolute relative phase (MARP) values and deviation phase (DP) values of the relative humeral and scapular between groups during the ascending and descending phases of loaded overhead reaching task.**

Mean Absolute Relative Phase Values

Scapular Upward/Downward Rotation and Humeral Elevation

    There were no a significant main effects involving group (Table 11) or phase however, there was a significant interaction effect between phase of humeral elevation on scapular upward/downward rotation-humeral elevation MARP values ($p = 0.05$, ES = 0.45). Tukey's post hoc test revealed that the FHRSP group displayed greater scapular upward/downward rotation-humeral elevation MARP values during the ascending phase of the reaching task(MSD = 2°). These results suggest that on average, the FHRSP displayed a less coupled coordinative pattern between the humerus and scapula upward rotation during the ascending phase of the reaching task (Figure 25).

Scapular Internal/External Rotation and Humeral Elevation

    The scapulohumeral coordinative patterns between the humerus and scapula internal/external rotation were similar during the overhead reaching task between the FHRSP and ideal posture groups. There were no significant main effects for postural group (Table 12) or phase of humeral elevation on scapular internal/external rotation MARP values as well as, no significant interaction effect between phase of humeral

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elevation and postural group on scapular internal/external rotation MARP values (Figure 26).

Scapular Anterior/Posterior Tipping and Humeral Elevation

There was not a significant main effect for group on scapular anterior/posterior tipping-humeral elevation MARP values (Table 11). There was not a significant interaction effect between phase of humeral elevation and postural group on scapular anterior/posterior tipping-humeral elevation MARP values (Figure 27).

<u>Deviation Phase Values</u>

Scapular Upward/Downward Rotation and Humeral Elevation

There was not a significant main effect for group on scapular anterior/posterior tipping-humeral elevation DP values (Table 12). There was not a significant interaction effect between phase of humeral elevation and postural group on scapular anterior/posterior tipping-humeral elevation DP values. These results indicate that on average the stability of the scapular upward/downward rotation-humeral elevation coordinative pattern was similar when comparing individuals with forward head and rounded shoulder posture and those with ideal posture.

Scapular Internal/External Rotation and Humeral Elevation

There was not a significant main effect for postural group on scapular internal/external rotation DP values (Table 12). There was not a significant interaction effect between phase of humeral elevation and postural group on scapular internal/external rotation DP values. These results indicate that on average the stability of the scapular internal/external rotation-humeral elevation coordinative pattern was

similar when comparing individuals with forward head and rounded shoulder posture and those with ideal posture.

Scapular Anterior/Posterior Tipping and Humeral Elevation

There was not a significant main effect for group on scapular anterior/posterior tipping-humeral elevation DP values (Table 12). There was not a significant interaction effect between phase of humeral elevation and postural group on scapular anterior/posterior tipping-humeral elevation DP values. These results indicate that on average the stability of the scapular anterior/posterior tipping-humeral elevation coordinative pattern was similar when comparing individuals with forward head and rounded shoulder posture and those with ideal posture.

Interpretation

The observed increases in MARP values indicate that individuals with FHRSP display less coupled scapulohumeral coordinative patterns for scapular upward/downward rotation during the ascending phase of the reaching task. Individuals with FHRSP also displayed less coupled scapular anterior/posterior tipping during the entire flexion task. Decreased DP values for scapular internal/external rotation during the flexion task indicate a less variable scapulohumeral coordinative pattern for individuals with FHRSP during the flexion task. Together, these differences suggest altered scapular control strategies between individuals with and without FHRSP.

Individuals with FHRSP increased MARP values indicate a less coupled coordinative pattern between scapular upward/downward rotation and humeral elevation during the ascending phase of the overhead reaching task. Visual inspection reveals the observed increases in MARP values were the result of a negative shift in relative phase

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during the first 25% of the overhead reaching task (Figure 3). The negative shifts in relative phase during the early and late phases of both tasks indicate the humeral phase angles were greater than those of the scapula. However, humeral velocity between groups was not different between groups. Therefore, differences in relative phase angles between groups were due to altered control of scapula. This negative shift by the FHRSP group may reflect a more distal control strategy for scapular upward/downward rotation during the early and late portions of the reaching task.

The out-of-phase and more distal control strategy in individuals with FHRSP may represent a loss of dynamic scapular stability during the early and late phases of humeral elevation. The scapula is almost entirely stabilized by peri-scapular musculature. In the upper ranges of humeral elevation muscles and joints moving toward their end range may provide passive scapular stability. The lack of passive stability in the mid-ranges of humeral elevation would require increased dynamic stability and neuromuscular control. This is supported by examining the relative phase curves for scapular upward/downward rotation during the reaching task (Figure 7). Scapular upward rotation-humeral elevation relative phase show increased coupling during the middle portion of the reaching task. This is supported by the shift in scapulohumeral rhythm (SHR) from 2:1 in the mid-ranges, to 1:1 in the upper ranges of humeral elevation.(Inman, Saunders et al. 1944; Bagg and Forrest 1988) The shift in SHR indicates an increase in the rate of scapular upward rotation in the upper ranges of humeral elevation which is similar to the observed increase in coupling during the middle of the reaching task.

The decrease in SHR is likely the result of the capsuloligamentous and musculature about the shoulder girdle engaging the scapula at higher ranges of humeral

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elevation. The increase in passive tension as tissues are pulled taut necessitates humeral elevation and scapular upward rotation becomes more coupled by decreasing the degrees of freedom available to the movement system. The taut tissues also increase the passive stability about the scapula requiring less dynamic stability required to facilitate humeral elevation. The less coupled scapulohumeral coordination for upward/downward rotation suggests a decrease in dynamic stability and control during the early and late phases of the reaching task.

Increased MARP values for the FRHSP group were also observed for scapular anterior/posterior tipping and humeral elevation during the flexion task. The increase in the FHRSP group's MARP values indicates scapular anterior/posterior tipping and humeral elevation were less coupled during the flexion task. The FHRSP also displayed a negative shift in the relative phase curve indicating a more distal control strategy over the entire movement cycle of both tasks (Figure 7). The increase in humeral elevation and more anteriorly tipped resting position are possible explanations for the less coupled and distal control strategy by individuals with FHRSP. The plane of humeral elevation influences the contribution of scapular rotations to total shoulder elevation, and sagittal plane humeral elevation elicits a greater contribution of scapular anterior/posterior tipping.(van der Helm and Pronk 1995; Hebert, Moffet et al. 2000) Furthermore, as humeral elevation angles increase the rate of scapular posterior tipping increases.(Karduna, McClure et al. 2001; McClure, Michener et al. 2001) Since all individuals used more humeral elevation during the flexion task compared to the reaching task (31°), it is reasonable to conclude that these differences occurred during the upper ranges of humeral elevation. This is supported by the visual separation of the ideal and

FHRSP relative phase curves during the middle portion of the flexion task. Individuals in the FHRSP group also presented with an increase in resting scapular anterior tipping position (9°). This would place the posterior structures in a lengthened position thereby engaging scapular posterior tipping at a lower humeral elevation angle during the reaching task. Similar to scapular upward/downward rotation during the reaching task the altered passive tension may contribute to the altered scapular control strategy.

A decrease in the FHRSP group's DP values for scapular internal/external rotation indicates a more stable movement pattern during the reaching task. The smaller DP values suggest individuals with FHRSP scapular internal/external rotation pattern used a less variable scapular movement pattern when compared to individuals with ideal posture. This more stable movement pattern is likely the result of the smaller range of available scapular internal/external rotation to each group. The FHRSP group was in a more internally rotated position at rest (14°). The physiological limits of the scapula to protract and internally rotate around the thorax are limited by the posterior musculature. Since the FHRSP group was much farther into this range there were less degrees of freedom available to the movement system. The flexion task was standardized to the sagittal plane perpendicular to the 5th metatarsal of the testing arm. This task required minimal shoulder girdle horizontal adduction compared to the reaching task. Shoulder girdle horizontal adduction was likely accomplished by combining humeral adduction, scapular protraction, and scapular internal rotation. Since thoracic motion was minimized, the ideal posture group would have more degrees of freedom available compared to the FHRSP group. Considered together, the results across all three scapular

rotations suggest that the demands of each task highlighted scapulohumeral coordination

strategy differences between individuals with and without FHRSP.

Appednix A. Tables

Table 1. Comparison of postural measures of forward head and rounded shoulder posture are presented with adjusted forward head angle to standardize comparison with the current projects definition.

Author (Year)	Study Results (n)	Postural Measure	Mean (SD)	Adjusted FHA Mean (SD)
(Braun and Amundson 1989)	Asymptomatic Males (20)	Forward Head Angle C_7 to Tragus from horizontal Range of Motion	$52° \pm 5°$ $34° \pm 8°$	$48° \pm 5°$
		Shoulder Angle Acromion to C_7 Range of Motion	$99° \pm 18°$ $64° \pm 24°$	
(Braun 1991)	Asymptomatic Males (20)	Forward Head Angle C_7 to Tragus from horizontal	$52° \pm 4°$	$48° \pm 4°$
		Shoulder Angle Acromion to C_7	$101° \pm 16°$	
	Asymptomatic Females (20)	Forward Head Angle C_7 to Tragus from horizontal	$55° \pm 5°$	$45° \pm 5°$
		Shoulder Angle Acromion to C_7	$112° \pm 11°$	
	Symptomatic Females (9) *Forward head angle significantly different between asymptomatic males and females*	Forward Head Angle C_7 to Tragus from horizontal	$48° \pm 3°$	$52° \pm 3°$
		Shoulder Angle Acromion to C_7	$122° \pm 16°$	

Table 1. Comparison of postural measures of forward head and rounded shoulder posture are presented with adjusted forward head angle to standardize comparison with the current projects definition.

Reference	Population	Measure	Value	Adjusted forward head angle
(Cureton 1941)	College age males (644)	Forward Head Angle C_7 to Tragus from horizontal	54° ± 6°	46° ± 3°
(Diveta, Walker et al. 1990)	30 Male compared to 30 Female No correlation between TSD and middle trapezius, pectoralis minor strength, or ratio of strength	Shoulder Translation Vertical line through C_7 to front of humeral head	5 ± 2 cm	
		Scapular Abduction (TSD)	22 ± 2 cm	
(Garrett 1993)	40 patients diagnosed with either cervical or shoulder pain	Head Translation Perpendicular distance from C_7 to anterior forehead	17 ± 2 cm	
(Greenfield, Catlin et al. 1995)	Asymptomatic (30)	Forward Head Angle C_7 to Tragus from horizontal	47° ± 7°	43° ± 7°
		Shoulder Abduction (TSD)	2 ± .1 cm	
	Symptomatic (Shoulder Pain) (30)	Forward Head Angle C_7 to Tragus from horizontal	52° ± 5°	48° ± 5°
(Peterson, Blankenship et al. 1997)	Increased forward head angle compared to non-patient group Asymptomatic (25) Visually classified into with or without forward shoulder posture	Shoulder Abduction (TSD) Shoulder Thrust Perpendicular distance from C_7 to anterior acromion	2 ± .1 cm 7 ± 2 cm	
(Raine and Twomey 1997)	Asymptomatic Males and Females (160)	Forward Head Angle C_7 to Tragus from horizontal	133° ± 7°	43° ± 7°
		Shoulder Angle Acromion to C_7	53° ± 14°	

Table 1. Comparison of postural measures of forward head and rounded shoulder posture are presented with adjusted forward head angle to standardize comparison with the current projects definition.

(Harrison 1996)	Asymptomatic (41)	*Forward Head Angle* C$_7$ to Tragus from horizontal	49° ± 7°	41° ± 7°
		Head Translation Perpendicular distance from wall to tragus	8 ± 3 cm	
		Shoulder Translation Perpendicular distance from wall to posterior acromion	6 ± 2 cm	
	Symptomatic (Cervical Pain) (10)	*Forward Head Angle* C$_7$ to Tragus from horizontal	49° ± 4°	41° ± 4°
	No differences observed between patient and non-patient groups	*Head Translation* Perpendicular distance from wall to tragus	7 ± 2 cm	
		Shoulder Thrust Perpendicular distance from wall to posterior acromion	6 ± 1 cm	
(Roddey 2002)	38 College age students classified as:			
	Mild forward head and rounded shoulder posture	*Scapular Abduction(TSD)*	43 ± 2.4 cm	
	Moderate forward head and rounded shoulder posture	*Scapular Abduction(TSD)*	45 ± 4.8 cm	

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Table 2.   Scapulothoracic rotations reported by various authors adapted from
            McClure et al (2001).

Author	Method	Plane Shoulder ROM	Mean Scapular Motion
Inman et al (1944)	2 D Radiographs	Flexion 30°-150°	50° Upward Rotation
Doody et al (1970)	2-D Goniometry	Abduction 30°-150°	40° Upward Rotation
Poppen and Walker (1976)	2-D Radiographs	Scaption 5°-176°	59° Upward Rotation
Bagg and Forrest (1988)	2-D Photographic	Scaption 0°-168°	64° Upward Rotation
McQuade et al (1995)	3-D Electromagnetic (Static)	Scaption 0°-135°	32° Upward Rotation 31° Posterior Tilt 67° Medial Rotation
van der Helm and Pronk (1995)	3-D Electromagnetic (Static)	Flexion 0°-180°	60° Upward Rotation 30° Posterior Tilt -25° Medial Rotation
		Abduction 0°-180°	60° Upward Rotation 30° Posterior Tilt -25° Medial Rotation
Ludewig et al (1996)	3-D Electromagnetic (Static)	Scaption 0°-140°	34° Upward Rotation 15° Posterior Tilt -13° Medial Rotation
Meskers et al (1998)	3-D Electromagnetic (Quasi-static)	Flexion 0°-150°	58° Upward Rotation 24° Posterior Tilt 0° Medial Rotation
		Abduction 0°-150°	60° Upward Rotation 13° Posterior Tilt 3° Medial Rotation
McClure et al (2001)	3-D Electromagnetic (Dynamic)	Flexion 16°-153°	46° Upward Rotation 31° Posterior Tilt -26° Medial Rotation
		Scaption 11°-147°	50° Upward Rotation 30° Posterior Tilt -24° Medial Rotation -24° Medial Rotation

Table 3. Data Analyses: Data Analysis Plan

Research Questions	Description	Dependent Variable	Comparison	Method
1	Differences in scapular kinematics during humeral elevation and forward, overhead reaching task	Scapular upward rotation, internal rotation, and posterior tipping range of motion and angles for the ascending and descending phases of humeral elevation	Ideal posture vs. Forward head, rounded shoulder posture for each task	Separate Mixed Model Analysis of Variance for each elevation task
2	Differences in scapular muscle activity during humeral elevation and forward, overhead reaching task	Upper and lower trapezius, and serratus anterior mean amplitude EMG over the ascending and descending phases of humeral elevation	Ideal posture vs. Forward head, rounded shoulder posture for each task	Separate Mixed Model Analysis of Variance for each elevation task
3	Differences in scapular and humeral coordination during humeral elevation and forward, overhead reaching task	MARP and DP values for scapular upward rotation, internal rotation, and posterior tipping relative to humeral elevation	Ideal posture vs. Forward head, rounded shoulder posture for each task	Separate Mixed Model Analysis of Variance for each elevation task

Table 4. Instructions for Borg Rating of Perceived Exertion (RPE) Scale (Borg 1998)

While doing physical activity, we want you to rate your perception of exertion. This feeling should reflect how heavy and strenuous the exercise feels to you, combining all sensations and feelings of physical stress, effort, and fatigue. Do not concern yourself with any one factor such as leg pain or shortness of breath, but try to focus on your total feeling of exertion. Look at the rating scale below while you are engaging in an activity; it ranges from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion." Choose the number from below that best describes your level of exertion. This will give you a good idea of the intensity level of your activity, and you can use this information to speed up or slow down your movements to reach your desired range.

Try to appraise your feeling of exertion as honestly as possible, without thinking about what the actual physical load is. Your own feeling of effort and exertion is important, not how it compares to other people's. Look at the scales and the expressions and then give a number.

6 No exertion at all	14
7	15 Hard (heavy)
Extremely light (7.5)	
8	16
9 Very light	17 Very hard
10	18
11 Light	19 Extremely hard
12	20 Maximal exertion
13 Somewhat hard	

Interpretation:

9 corresponds to "very light" exercise. For a healthy person, it is like walking slowly at his or her own pace for some minutes

13 on the scale is "somewhat hard" exercise, but it still feels OK to continue.

17 "very hard" is very strenuous. A healthy person can still go on, but he or she really has to push him- or herself. It feels very heavy, and the person is very tired.

19 on the scale is an extremely strenuous exercise level. For most people this is the most strenuous exercise they have ever experienced.

Borg RPE scale
© Gunnar Borg, 1970, 1985, 1994, 1998

Table 5. Descriptive statistics for screened volunteers (n=310)

Characteristics		Mean	SD
Male (n= 132)	Age (years)	30.8	17.3
Forward Head Angle		42.4	4.9
Forward Shoulder Angle		32.6	14.3
Female (n= 178)	Age (years)	36.6	16.4
Forward Head Angle		44.6	5.4
Forward Shoulder Angle		40.3	17.7
All (n=310)	Age (years)	34.2	11.9
Forward Head Angle		41.1	5.2
Forward Shoulder Angle		37.4	15.3

Table 6. Descriptive statistics for study participants (n=80)

Group	Characteristics		Mean	SD
Ideal Posture	Male (n= 21)	Age (years)	32.6	13.3
		Height (cm)	178.4	7.6
		Mass (kg)	72.5	11.3
	Female (n= 19)	Age (years)	34.4	12.6
		Height (cm)	165.8	6.9
		Mass (kg)	60.1	11.2
Forward Head and Rounded Shoulder Posture	Male (n= 15)	Age (years)	39.1	12.5
		Height (cm)	177.0	7.3
		Mass (kg)	95.1	19.5
	Female (n= 25)	Age (years)	35.0	11.3
		Height (cm)	161.7	6.7
		Mass (kg)	77.3	15.4

Table 7. Scapular rotation range of motion (mean ± SD) during the ascending and descending phases of the flexion and overhead reaching tasks.

Scapular Rotation Range of Motion	Group	Ascending Mean (SD)	Descending Mean (SD)	Group Mean (SD)	F-Ratio	P value (L)
Flexion Task						
Scapular Upward Rotation	FHRSP	36 (7)	35 (9)	35 (12) *	8.103	0.006
	Ideal	31 (9)	29 (10)	30 (15) *		
Scapular Internal Rotation	FHRSP	20 (7)	7 (5)	13 (6)	2.085	0.153
	Ideal	19 (5)	5 (4)	12 (5)		
Shoulder Posterior Tipping	FHRSP	7 (6)	9 (7)	8 (7)	0.076	0.783
	Ideal	8 (6)	9 (7)	9 (7)		
Reaching Task						
Scapular Upward Rotation	FHRSP	24 (13)	21 (13)	23 (13)	0.002	0.965
	Ideal	25 (10)	20 (9)	23 (10)		
Scapular Internal Rotation	FHRSP	14 (7)	13 (9)	14 (8)	0.50	0.824
	Ideal	14 (6)	13 (6)	13 (6)		
Shoulder Posterior Tipping	FHRSP	6 (6)	5 (5) †	5 (6)	1.930	0.196
	Ideal	7 (5)	7 (5) †	7 (5)		

* Scapular upward/downward rotation range of motion for FHRSP group > ideal posture group
† Scapular anterior/posterior tipping range of motion for FHRSP group < ideal posture group during the descending phase of reaching task.

$F_{1,78}$= 5.025, p = 0.025, MSD = 1°, Mean Difference = 2°; Ideal CI (5-8) FHRSP CI (5-7)

Table 8. Scapular rotation angles (mean ± SD) during the ascending (Asc) and descending (Dsc) phases of the flexion task. Confidence intervals only presented for significant main or interaction effects.

Flexion Task Scapular Rotation Angles	Group	FHRSP Mean (SD)	FHRSP 95% CI (LCI – UCI)	Ideal Mean (SD)	Ideal 95% CI (LCI – UCI)	F-Ratio		P valu
Scapular Upward/Downward	60 Asc	15 (7)	14 – 20	15 (10)	14 – 19	Group effect	1.369	0.246
	90 Asc	28 (8)	27 – 33	26 (12)	24 – 31			
	120 Asc	40 (10)*	32 – 39	35 (13)*	37 – 44	Angle X Group	* 10.217	< 0.0(
	120 Dsc	40 (11)*	32 – 39	35 (13)*	37 – 44			
	90 Dsc	31 (9)	27 – 33	28 (12)	24 – 31	Phase X Group	0.048	0.827
	60 Dsc	18 (8)	14 – 20	18 (11)	14 – 19			
Scapular Internal/External	60 Asc	45 (9)		36 (12)		Group effect	† 10.554	0.002
	90 Asc	45 (10)		40 (12)				
	120 Asc	46 (11)		39 (13)		Angle X Group	0.473	0.624
	120 Dsc	45 (9)		37 (13)				
	90 Dsc	48 (10)		40 (13)		Phase X Group	0.202	0.654
	60 Dsc	47 (13)		39 (12)				
Group Mean		47 (13) †	43 – 50	39 (13) †	35 – 42			
Scapular Anterior/Posterior	60 Asc	-8 (7)		-5 (8)		Group effect	2.396	0.126
	90 Asc	-9 (9)		-5 (11)				
	120 Asc	-5 (10)		-1 (12)		Angle X Group	1.246	0.061
	120 Dsc	-2 (11)		1 (11)				
	90 Dsc	-7 (9)		-4 (11)		Phase X Group	‡ 5.707	0.019
	60 Dsc	-9 (7)		-6 (9)				
Ascending Phase Means		-7 (7) ‡	-10 – -4	-4 (7) ‡	-6 – -1			
Descending Phase Means		-6 (7) ‡	-9 – -3	-3 (7) ‡	-6 – 0			

* FRHSP group's scapular upward rotation angle at 120° > ideal posture group
† FHRSP group's scapular internal rotation angle > ideal posture group
‡ FHRSP group's scapular anterior tipping angle > ideal posture group during the ascending and descending phase (MSD = 3°)

Table 9. Scapular rotation angles (mean ± SD) during the ascending (Asc) and descending (Dsc) phases of the overhead reaching task. Confidence intervals only presented for significant main or interaction effects.

Overhead Reaching Task Scapular Rotation Angles	Group	FHRSP Mean (SD)	FHRSP 95% CI (LCI – UCI)	Ideal Mean (SD)	Ideal 95% CI (LCI – UCI)	F-Ratio	P value
Scapular Upward/Downward	60 Asc	15 (7)		15 (10)		Group effect 0.001	0.981
	90 Asc	28 (8)		26 (12)		Angle X Group 1.639	0.197
	120 Asc	40 (10)		35 (13)		Phase X Group 3.767	0.056
	120 Dsc	40 (11)		35 (13)			
	90 Dsc	31 (9)		28 (12)			
	60 Dsc	18 (8)		18 (11)			
Ascending Phase Means		23 (7)		24 (7)			
Descending Phase Means		26 (7)		25 (7)			
Scapular Internal/External	60 Asc	39 (10)		31 (11)		Group effect * 14.436	< 0.0(
	90 Asc	47 (10)		37 (13)		Angle X Group 0.823	0.441
	120 Asc	45 (14)		37 (12)		Phase X Group 0.542	0.464
	120 Dsc	50 (11)		39 (14)			
	90 Dsc	47 (11)		37 (11)			
	60 Dsc	39 (11)		31 (12)			
Group Mean		45 (12) *	41 – 48	35 (13) *	32 – 39		
Scapular Anterior/Posterior	60 Asc	-2 (21)		0 (14)		Group effect 0.306	0.582
	90 Asc	-1 (25)		2 (19)		Angle X Group 0.864	0.424
	120 Asc	-4 (21)		1 (13)		Phase X Group 2.296	0.850
	120 Dsc	1 (27)		4 (20)			
	90 Dsc	1 (26)		3 (19)			
	60 Dsc	-2 (23)		0 (15)			

* Average scapular internal rotation angle for FHRSP group > ideal posture group

Table 10. Scapular muscle activity values (mean %MVIC ± SD) for upper trapezius, lower trapezius, and serratus anterior during the ascending and descending phases of the flexion and overhead reaching tasks.

Scapular Muscle Activity	Group	FHRSP Mean (SD)	FHRSP 95% CI (LCI – UCI)	Ideal Mean (SD)	Ideal 95% CI (LCI – UCI)	Phase X G F-Ratio
Flexion Task						
Upper Trapezius	Ascending	69 (30)	61 – 78	33 (14)	28 – 37	0.204
	Descending	66 (27)	57 – 75	32 (14)	27 – 37	
Lower Trapezius	Ascending	54 (29)	40 – 67	24 (12)	19 – 29	0.411
	Descending	58 (51)	44 – 71	28 (19)	24 – 34	
Serratus Anterior	Ascending	61 (25)*	52 – 69	73 (29)*	66 – 81	5.642
	Descending	29 (14)	25 – 33	31 (12)	27 – 35	
Reaching Task						
Upper Trapezius	Ascending	73 (28)	63 – 81	70 (27)	61 – 78	0.420
	Descending	32 (13)	28 – 36	32 (12)	28 – 36	
Lower Trapezius	Ascending	27 (14)	20 – 33	26 (23)	19 – 32	0.405
	Descending	15 (8)	11 – 18	15 (14)	11 – 19	
Serratus Anterior	Ascending	54 (18)*	48 – 61	60 (22)*	54 – 66	4.322
	Descending	23 (10)	19 – 27	22 (14)	18 – 26	

* Serratus anterior muscle activity for FHRSP group < ideal posture group during the ascending phase of flexion and reaching task.

Table 11. Mean Absolute Relative Phase (MARP) values (degrees) for each scapular rotation during ascending and descending phases of the flexion and overhead reaching tasks.

Scapular Rotation	Phase	Ascending Mean (SD)	Descending Mean (SD)	Group Mean (SD)	F-Ratio	P value	9 (L
Shoulder Flexion							
Scapular Upward Rotation	FHRSP	9 (13)	11 (11)	11 (12)	0.008	0.927	
	Ideal	9 (17)	12 (14)	10 (15)			
Scapular Internal Rotation	FHRSP	30 (16)	31 (7)	31 (12)	0.611	0.437	
	Ideal	32 (17)	34 (13)	33 (15)			
Shoulder Posterior Tipping	FHRSP	59 (29)	52 (23)	55 (26)*	6.844	0.011	
	Ideal	43 (24)	39 (21)	41 (22)*			
Reaching Task							
Scapular Upward Rotation	FHRSP	12 (15) †	10 (13)	11 (12)	0.008	0.927	
	Ideal	8 (11) †	10 (11)	10 (15)			
Scapular Internal Rotation	FHRSP	8 (4)	12 (6)	13 (5)	0.983	0.325	
	Ideal	11 (17)	14 (18)	10 (18)			
Shoulder Posterior Tipping	FHRSP	61 (32)	65 (29)	63 (31)	1.824	0.111	
	Ideal	51 (34)	57 (32)	54 (33)			

* MARP values for FHRSP group > ideal posture group
† MARP values for FHRSP group > ideal posture group during the ascending phase of reaching task.
$F_{(1,78)} = 3.99$, p = 0.049, MSD = 3, Mean Difference = 4
Ideal CI (4-12) FHRSP CI (8-16)

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Table 12. Deviation Phase (DP) values (degrees) for each scapular rotation during ascending and descending phases of the flexion and overhead reaching tasks.

Scapular Rotation	Phase	Ascending Mean (SD)	Descending Mean (SD)	Group Mean (SD)	F-Ratio	P value	9 (L
Shoulder Flexion							
Scapular Upward Rotation	FHRSP	5 (5)	5 (4)	5 (5)	0.120	0.730	
	Ideal	4 (3)	5 (3)	5 (3)			
Scapular Internal Rotation	FHRSP	10 (6)	8 (5)	9 (6) *	4.186	0.44	
	Ideal	13 (8)	11 (6)	12 (7) *			
Shoulder Posterior Tipping	FHRSP	13 (6)	15 (8)	14 (7)	0.007	0.932	
	Ideal	15 (8)	14 (8)	14 (8)			
Reaching Task							
Scapular Upward Rotation	FHRSP	7 (6)	5 (4)	6 (5)	0.024	0.879	
	Ideal	6 (4)	6 (5)	6 (4)			
Scapular Internal Rotation	FHRSP	8 (3)	7 (3)	8 (3)	0.000	0.999	
	Ideal	8 (3)	7 (3)	8 (3)			
Shoulder Posterior Tipping	FHRSP	21 (13)	21 (12)	21 (7)	0.059	0.809	
	Ideal	23 (11)	21 (10)	22 (8)			

* DP values for the FHRSP group < ideal posture group

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Table 12. Deviation Phase (DP) values (degrees) for each scapular rotation during ascending and descending phases of the flexion and overhead reaching tasks.

Scapular Rotation	Phase	Ascending Mean (SD)	Descending Mean (SD)	Group Mean (SD)	F-Ratio	P value	9 (L
Shoulder Flexion							
Scapular Upward Rotation	FHRSP	5 (5)	5 (4)	5 (5)	0.120	0.730	
	Ideal	4 (3)	5 (3)	5 (3)			
Scapular Internal Rotation	FHRSP	10 (6)	8 (5)	9 (6) *	4.186	0.44	
	Ideal	13 (8)	11 (6)	12 (7) *			
Shoulder Posterior Tipping	FHRSP	13 (6)	15 (8)	14 (7)	0.007	0.932	
	Ideal	15 (8)	14 (8)	14 (8)			
Reaching Task							
Scapular Upward Rotation	FHRSP	7 (6)	5 (4)	6 (5)	0.024	0.879	
	Ideal	6 (4)	6 (5)	6 (4)			
Scapular Internal Rotation	FHRSP	8 (3)	7 (3)	8 (3)	0.000	0.999	
	Ideal	8 (3)	7 (3)	8 (3)			
Shoulder Posterior Tipping	FHRSP	21 (13)	21 (12)	21 (7)	0.059	0.809	
	Ideal	23 (11)	21 (10)	22 (8)			

* DP values for the FHRSP group < ideal posture group

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Appednix B. Figures

Figure 1. Forward head angle (FHA) measured from the vertical anteriorly to a line connecting the tragus and the C_7 marker. Forward shoulder angle (FSA) measured from the vertical posteriorly to a line connecting the C_7 marker and the acromial marker.
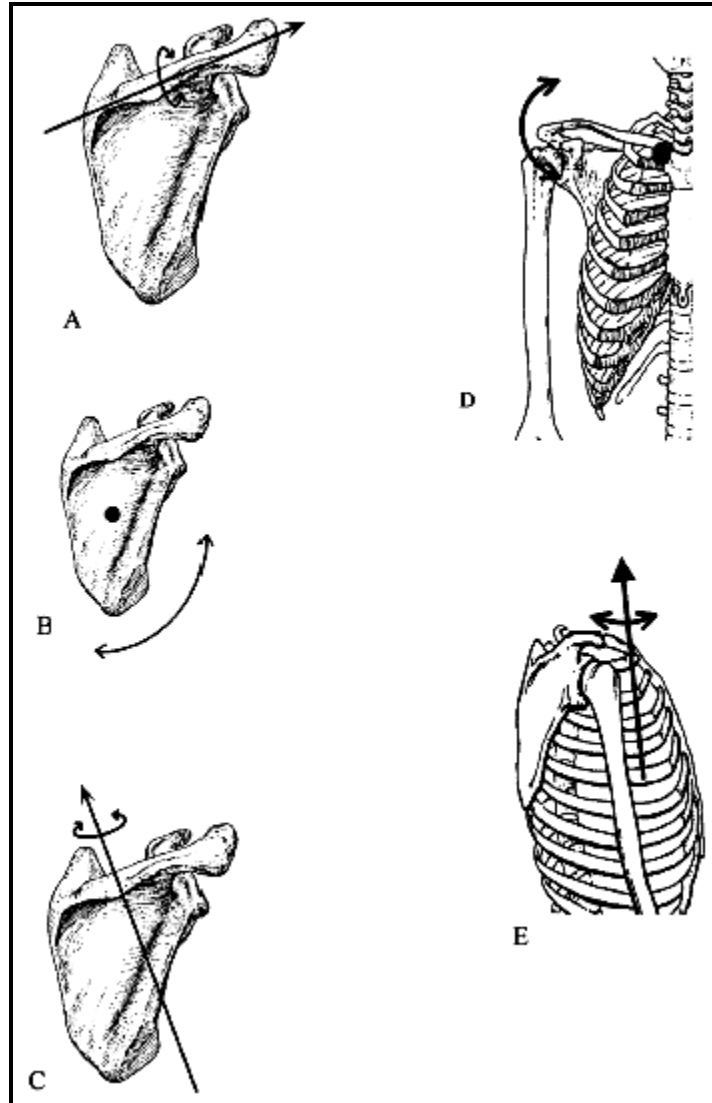
Figure 2. Three rotations and two translations used to completely describe scapular
motion. (from McClure et al. (2004))
   A. Scapular Posterior/ Anterior Tipping
   B. Scapular Upward/ Downward Rotation
   C. Scapular Internal/ External Rotation
   D. Scapular Elevation/ Depression
   E. Scapular Protraction/ Retraction
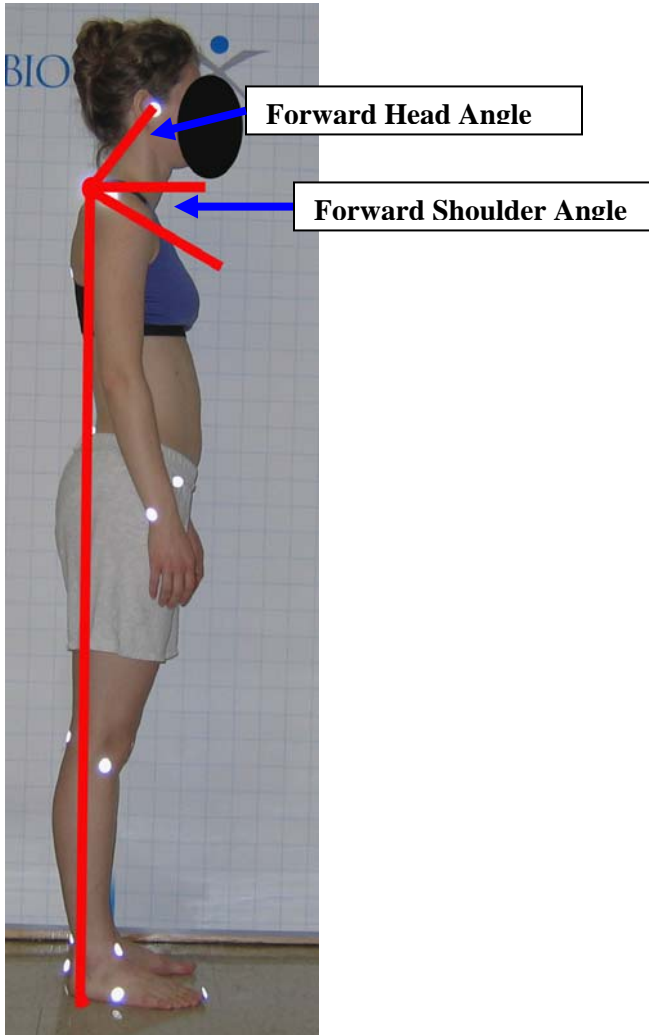
Figure 3. Example of ideal forward
head and shoulder posture
Forward Head Angle = 38˚
Forward Shoulder Angle = 20˚
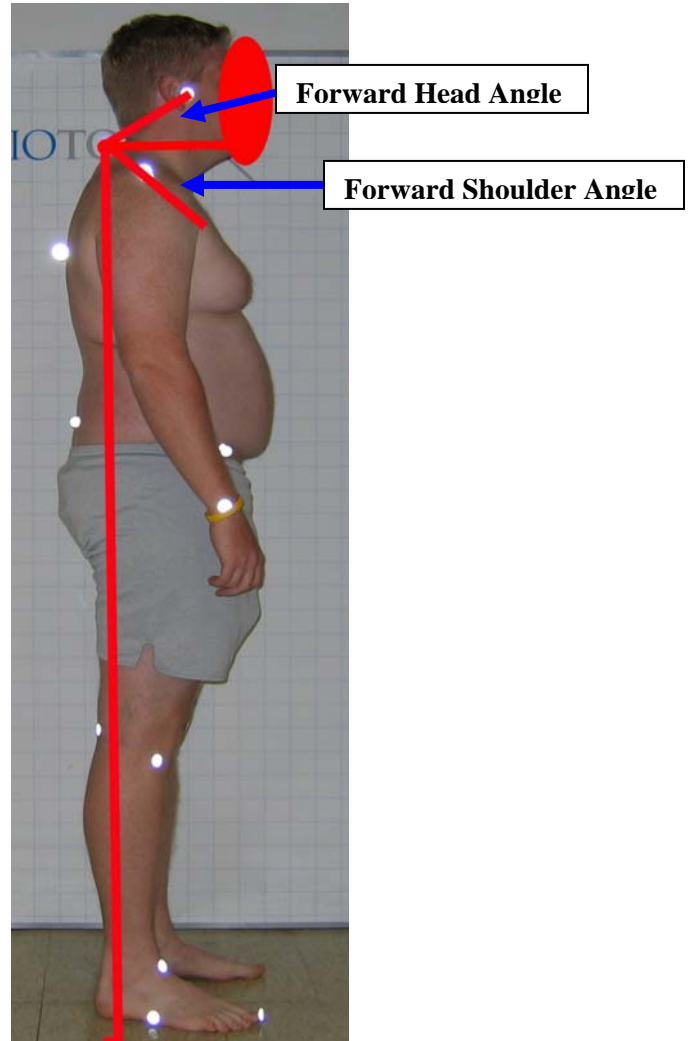
Figure 4. Example of forward head
and shoulder postural posture
Forward Head Angle = 55˚
Forward Shoulder Angle = 60˚
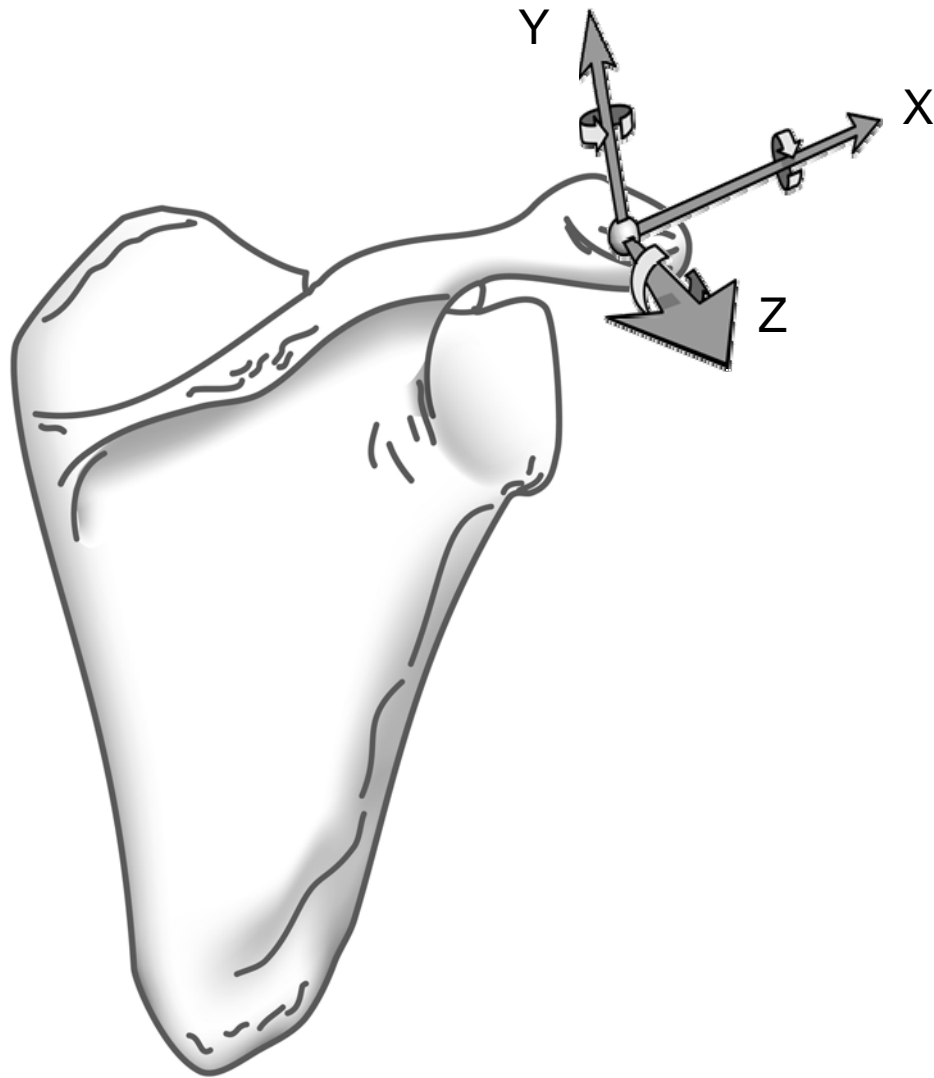
Figure 5. Scapular local axis system and bony landmarks
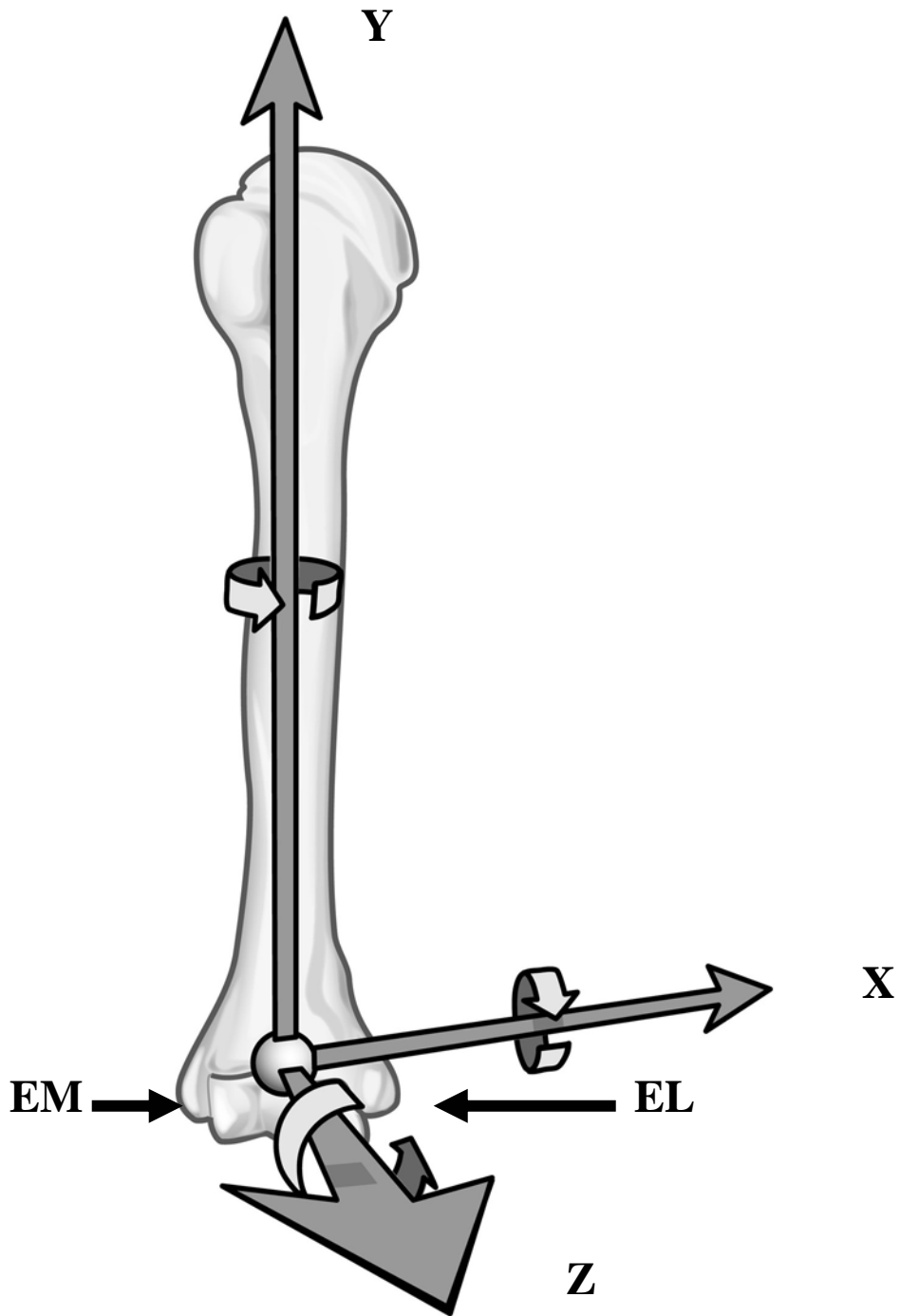
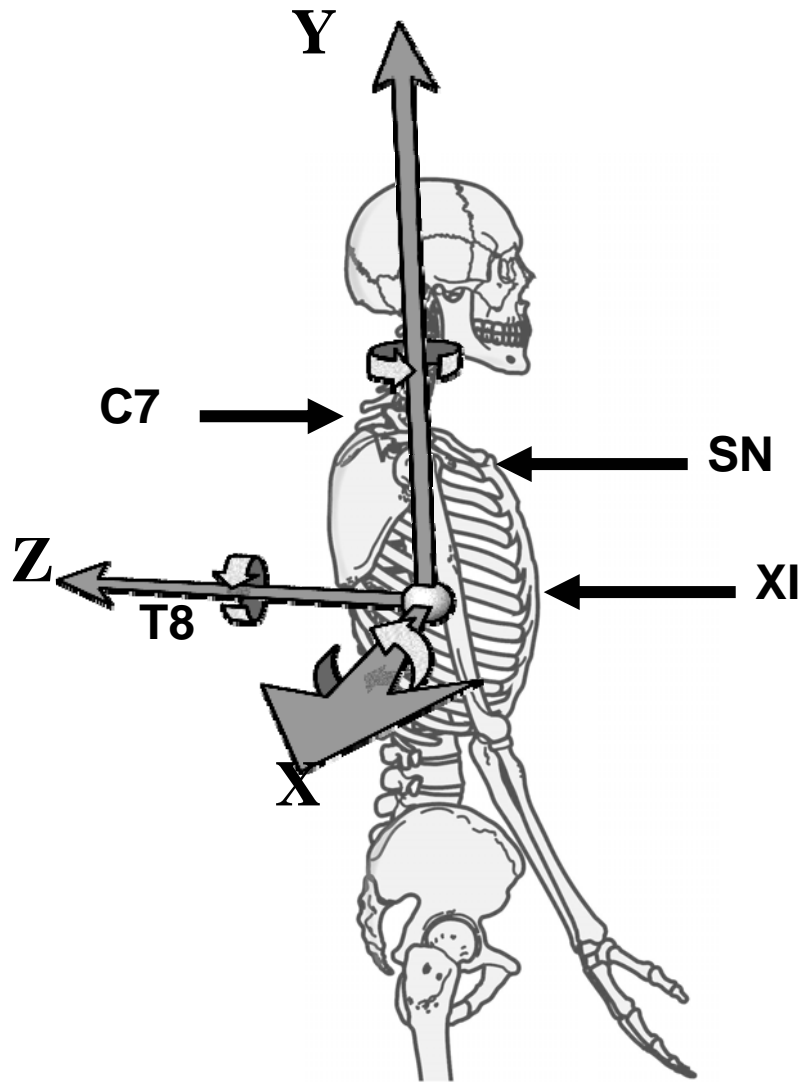Figure 6. Humeral local axis system and bony landmarks

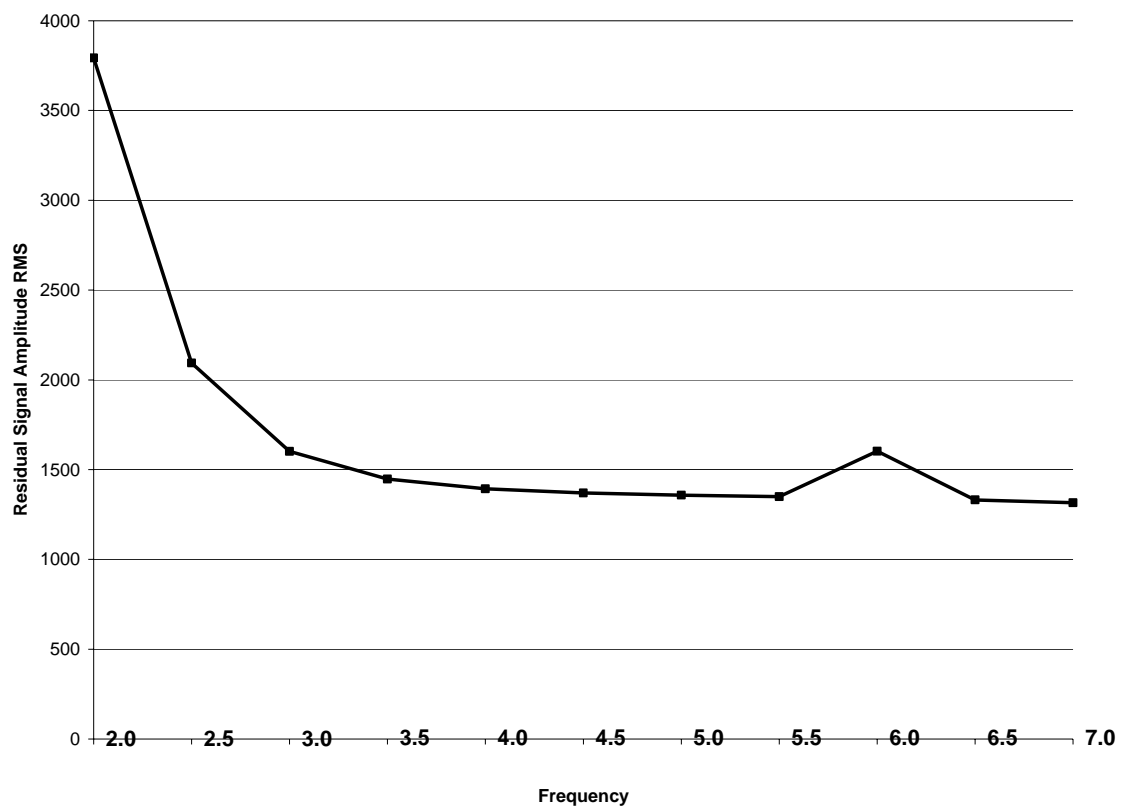Figure 7. Thoracic local axis system and bony landmarks

Figure 8. Residual analyses for humeral coordinate data

Figure 9. Posterior view of the flexion task showing the arm in line with the target


Figure 10. Posterior view of the reaching task showing the target on the shelf to be on the midline and in front of the participant


Figure 11. Sagittal view of reaching task with participant arms length (to ulnar styloid) back from the shelf.

Figure 12. Individuals with forward head and rounded shoulder posture
(FHRSP) used a greater range of scapular upward rotation during the
flexion task.
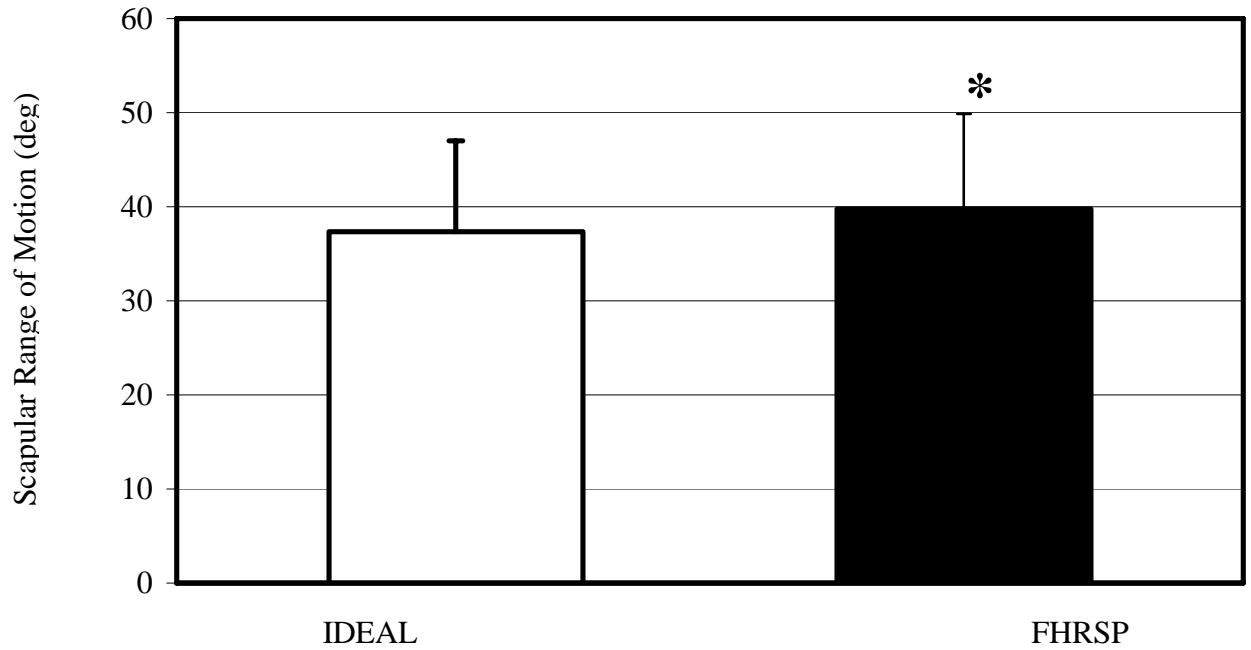
* p = 0.006
Mean difference = 5°

Figure 13. Individuals with forward head and rounded shoulder posture (FHRSP) displayed a less scapular anterior tipping range of motion during the descending phase of the reaching task.
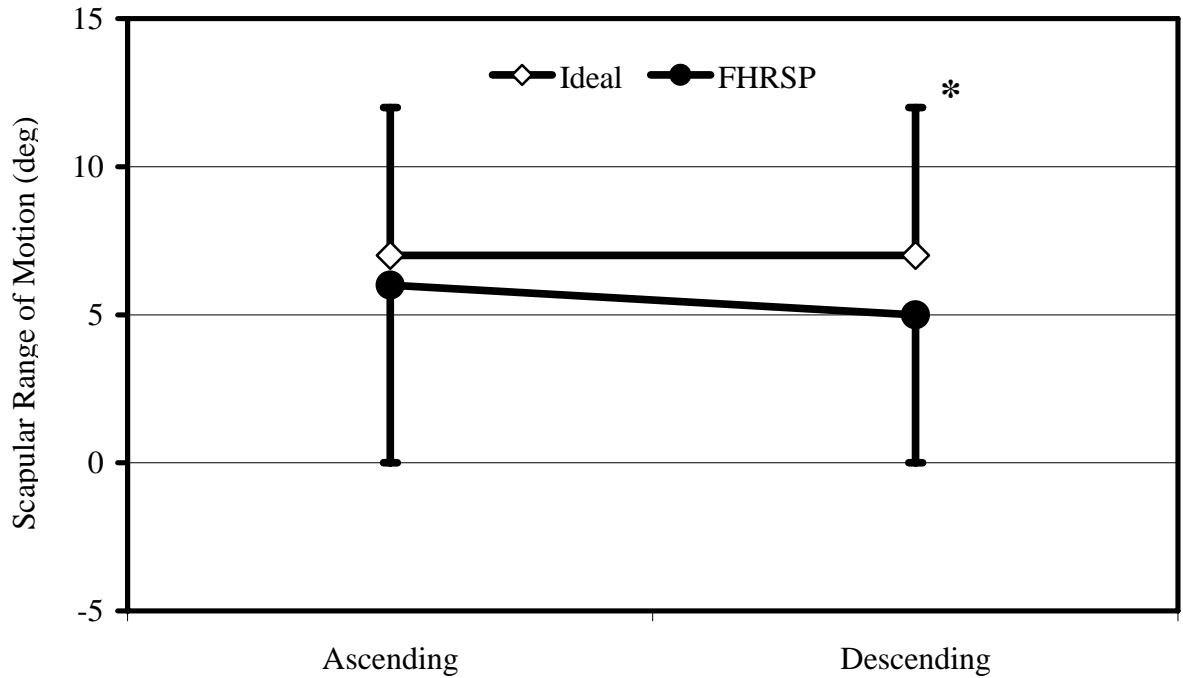
*p = 0.025
MSD = 1°
Mean difference = 2°

Figure 14 Individuals with forward head and rounded shoulder posture (FHRSP) displayed a greater average scapular internal rotation angle during the flexion task.
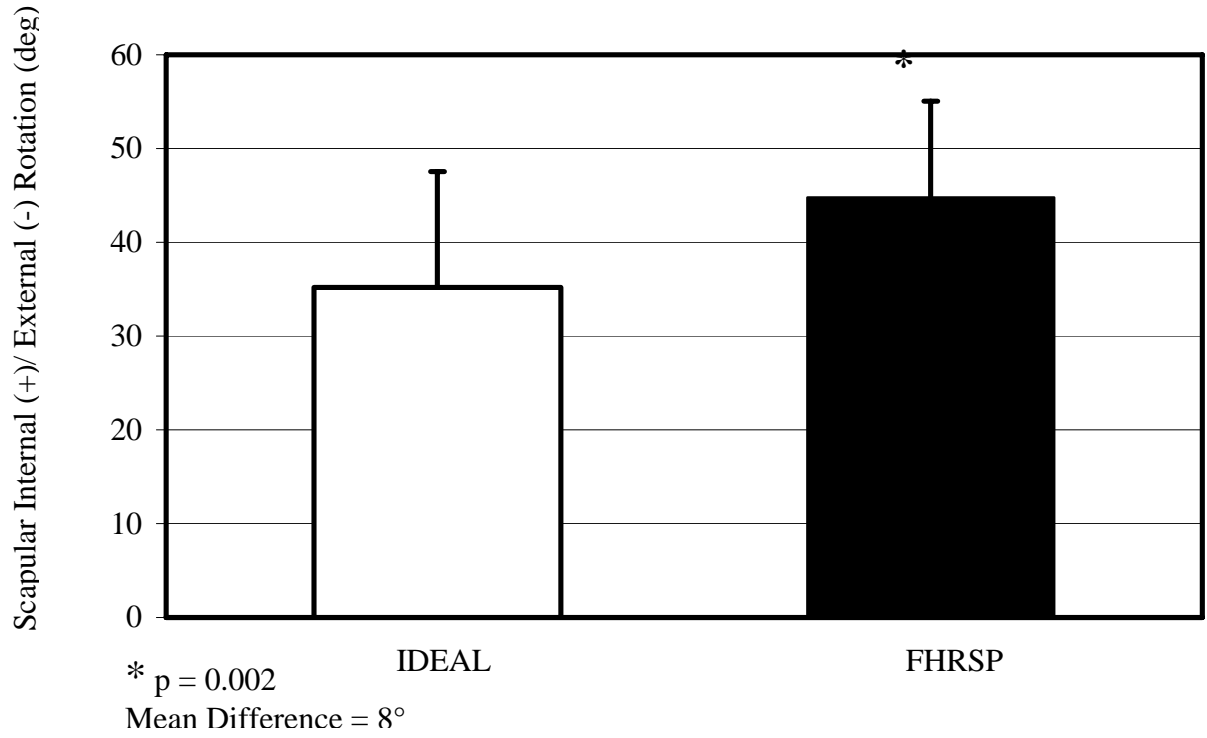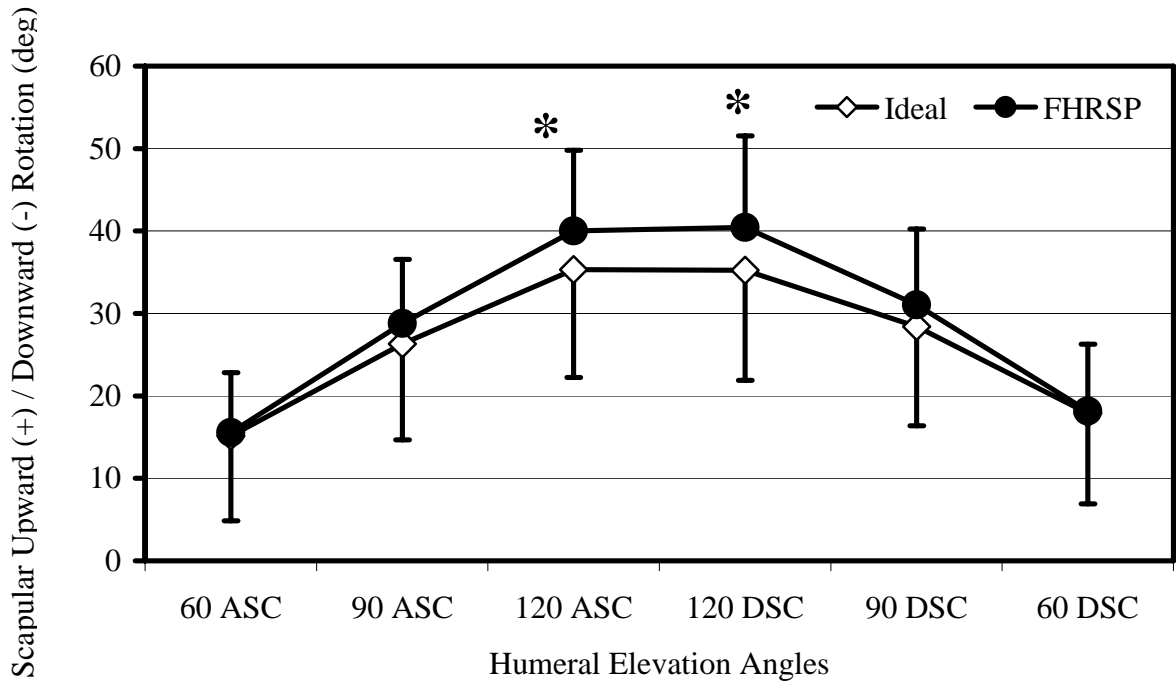

* p = 0.002
Mean Difference = 8°

Figure 15. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed a greater scapular upward rotation angle at 120° of humeral elevation during the ascending and descending phases of the flexion task.

* p < 0.001
MSD = 3°
Mean difference at 120° ASC = 5°
Mean difference at 120° DSC = 5°

Figure 16. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed greater average scapular anterior tipping angles during the ascending and descending phases of humeral elevation during the flexion task.
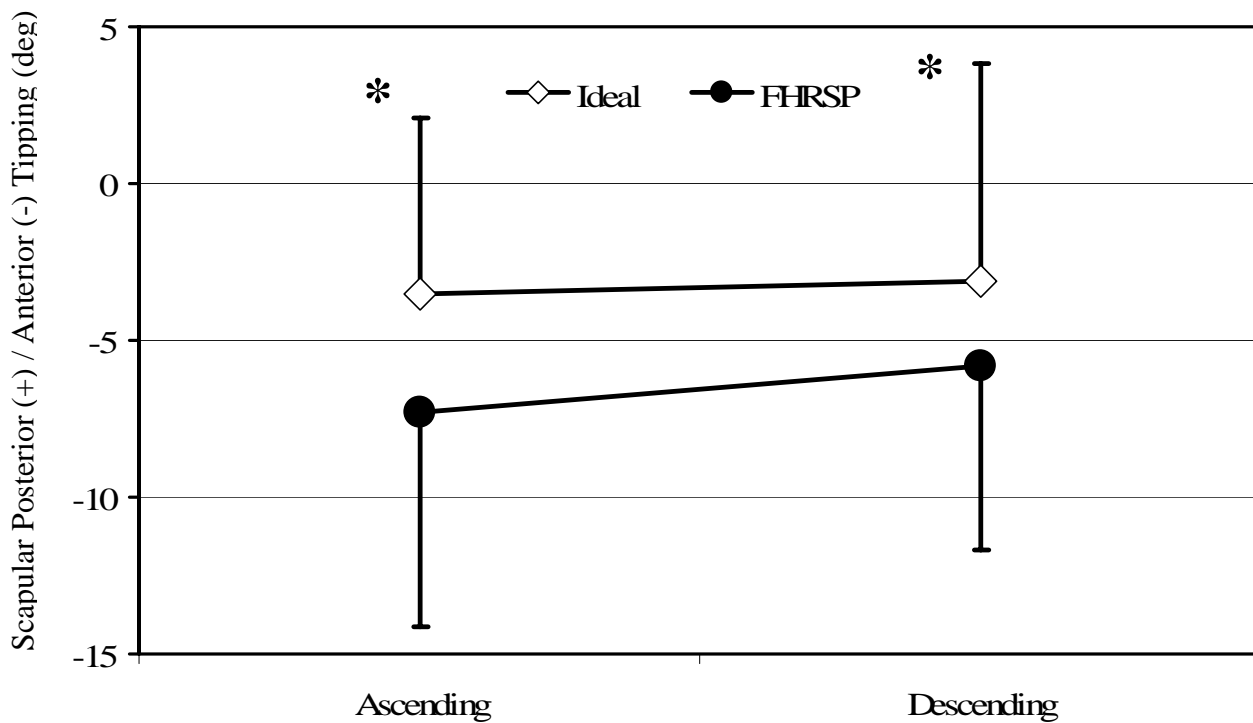
* p = 0.02
MSD = 1°
Mean difference for ASC= 3°
Mean difference for DSC = 4°

Figure 17. Individuals with forward head and rounded shoulder posture (FHRSP) displayed a greater average scapular internal rotation angle during the reaching task.

* p < 0.001
Mean Difference = 10°

Figure 18. Individuals with forward head and rounded shoulder posture
(FHRSP) displayed less serratus anterior activity during the
ascending phase of the flexion task.

* p = 0.021
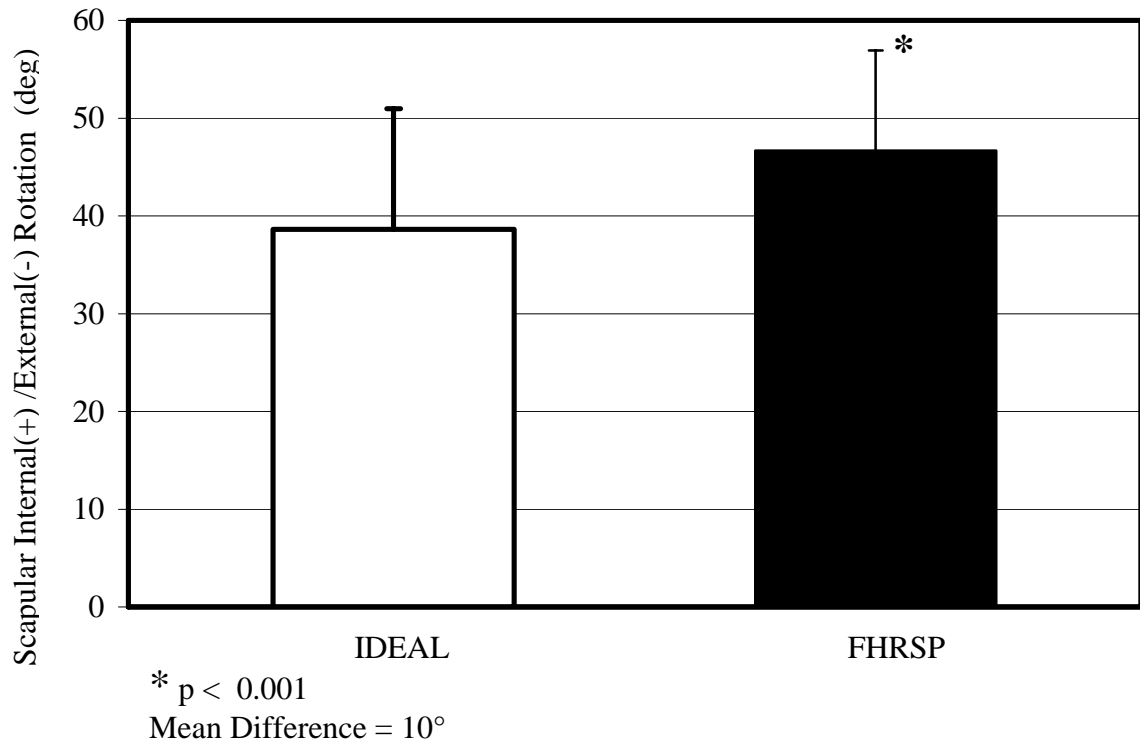MSD = 6%
Mean difference = 12 %

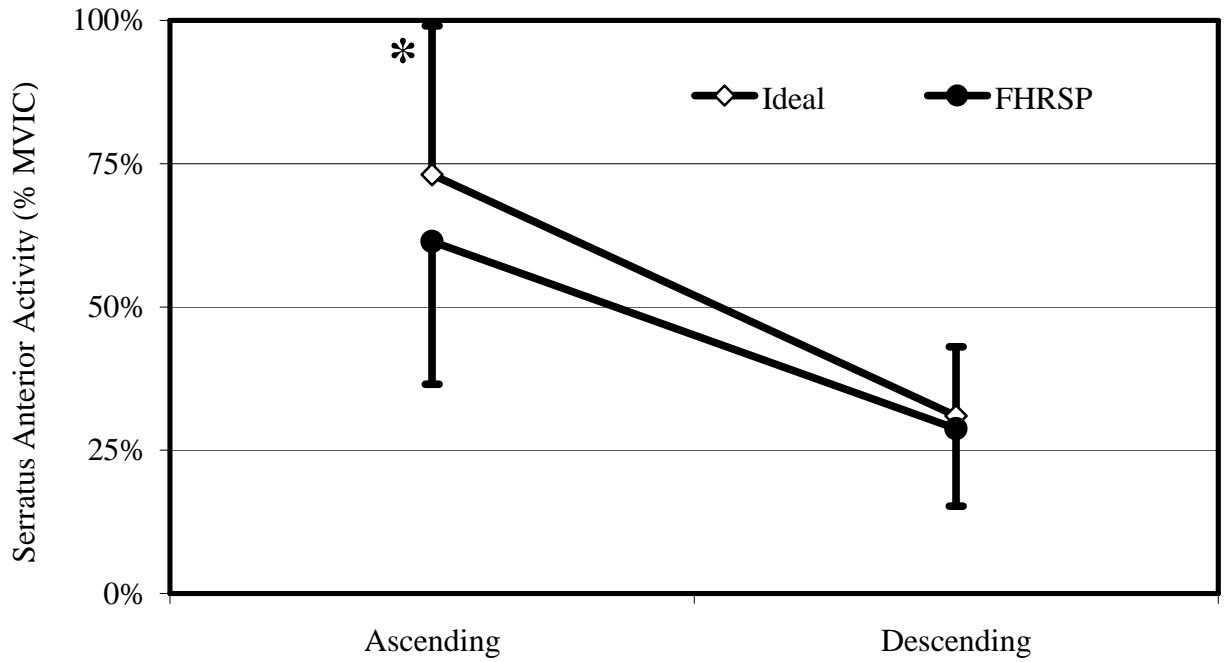Figure 19. Individuals with forward head and rounded shoulder posture (FHRSP) displayed less serratus anterior activity during the ascending phase of the reaching task.
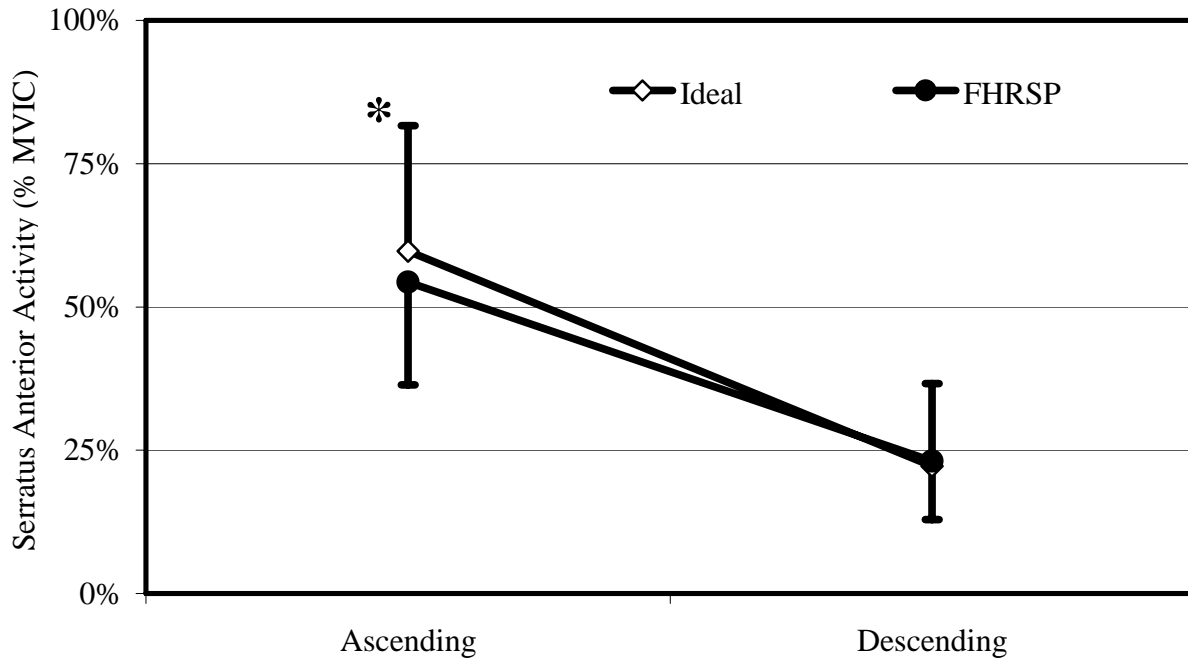
* p = 0.04
MSD = 5%
Mean difference = 6 %

Figure 20. Individuals displaying forward head and rounded shoulder posture
(FHRSP) displayed similar scapular upward/downward rotation-humeral
elevation continuous relative phase curves during the flexion task.

Figure 21. Individuals displaying forward head and rounded shoulder posture
(FHRSP) displayed similar scapular internal/external rotation-humeral
elevation continuous relative phase curves during the flexion task.

Figure 22. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed similar scapular anterior/posterior tipping-humeral elevation continuous relative phase curves during the flexion task.
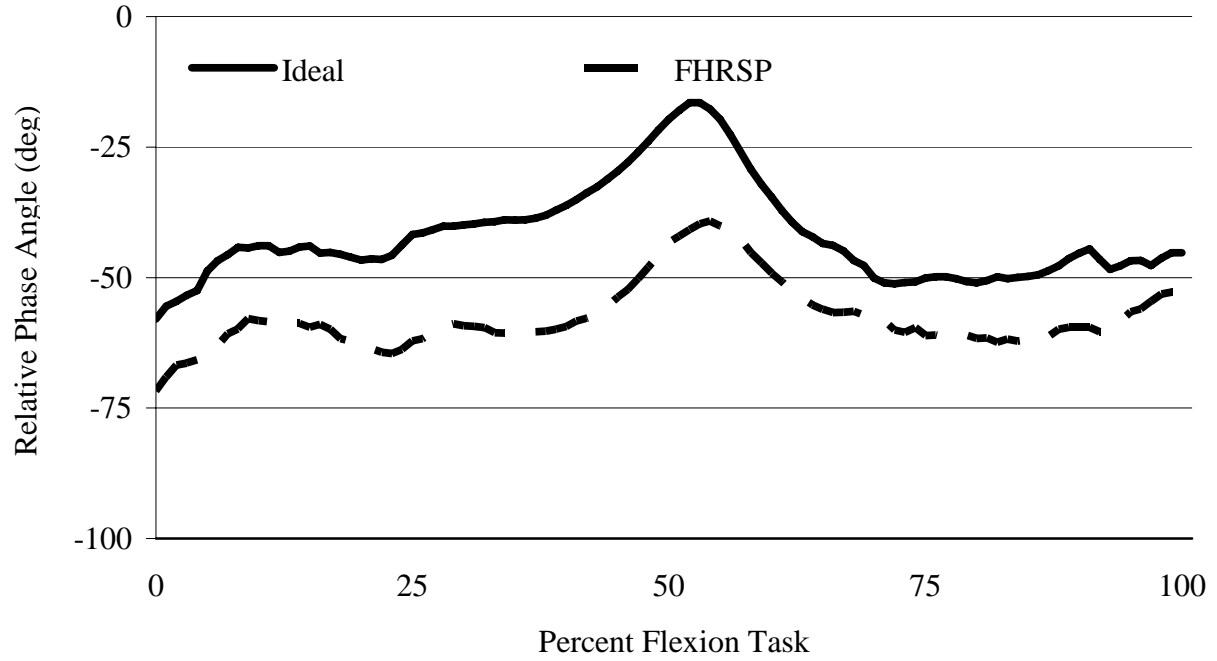
Figure 23. Individuals with forward head and rounded shoulder posture (FHRSP) displayed larger scapular anterior/posterior tipping-humeral elevation mean absolute relative phase values during the flexion task.
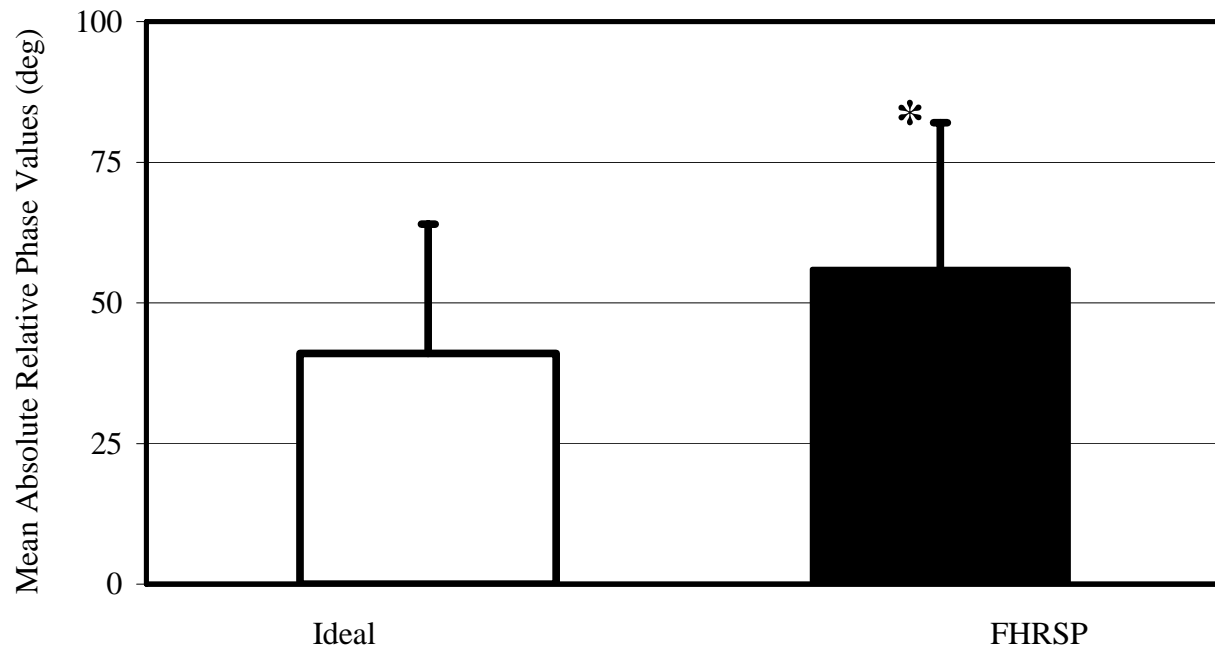
$*F_{1,78} = 6.84, \quad p = 0.01$
ES = 0.42

Figure 24. Individuals with forward head and rounded shoulder posture (FHRSP) displayed smaller scapular internal/external rotation-humeral elevation deviation phase values during the flexion task.
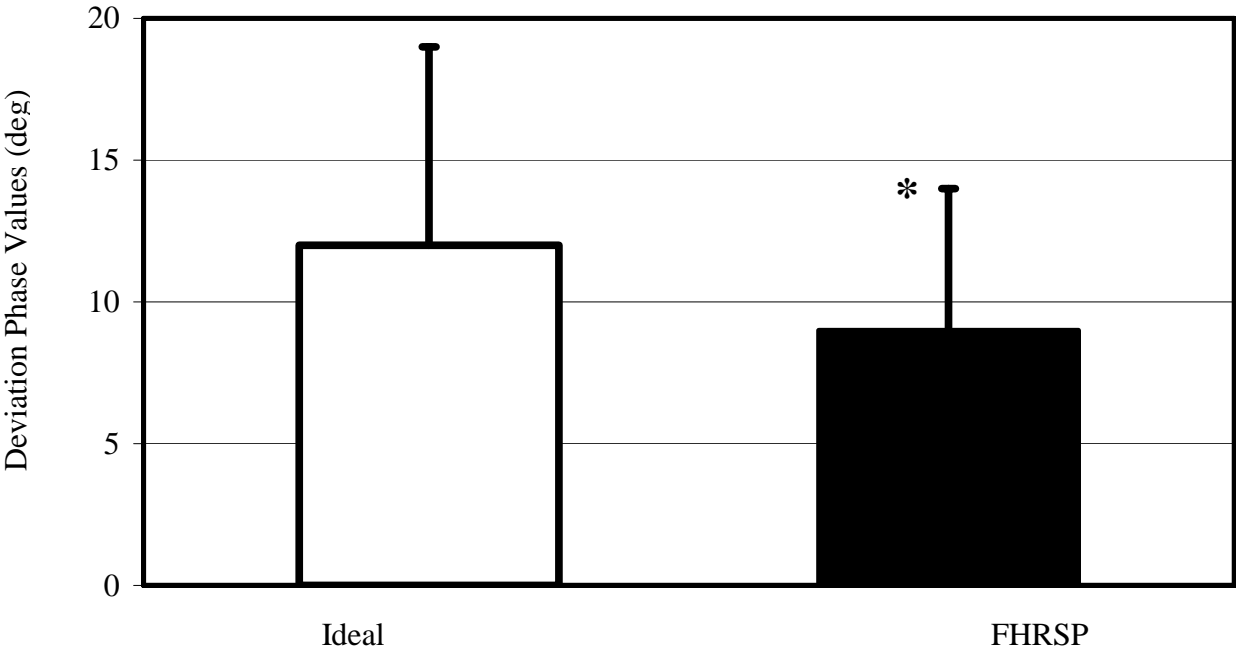
* $F_{1,78} = 4.19$, p = 0.044
ES = 0.46

Figure 25. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed similar scapular upward/downward rotation-humeral elevation continuous relative phase curves during the reaching task.
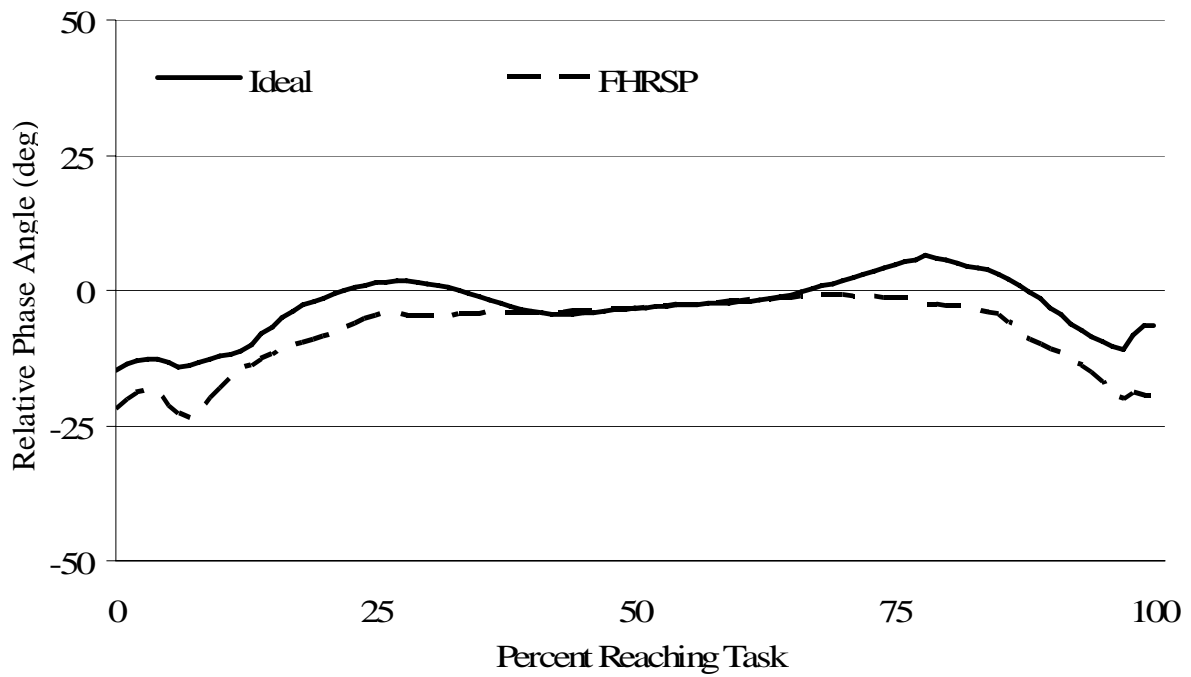
Figure 26. Individuals with forward head and rounded shoulder posture (FHRSP) displayed larger scapular upward/downward rotation-humeral elevation mean absolute relative phase values during ascending phase of the reaching task.

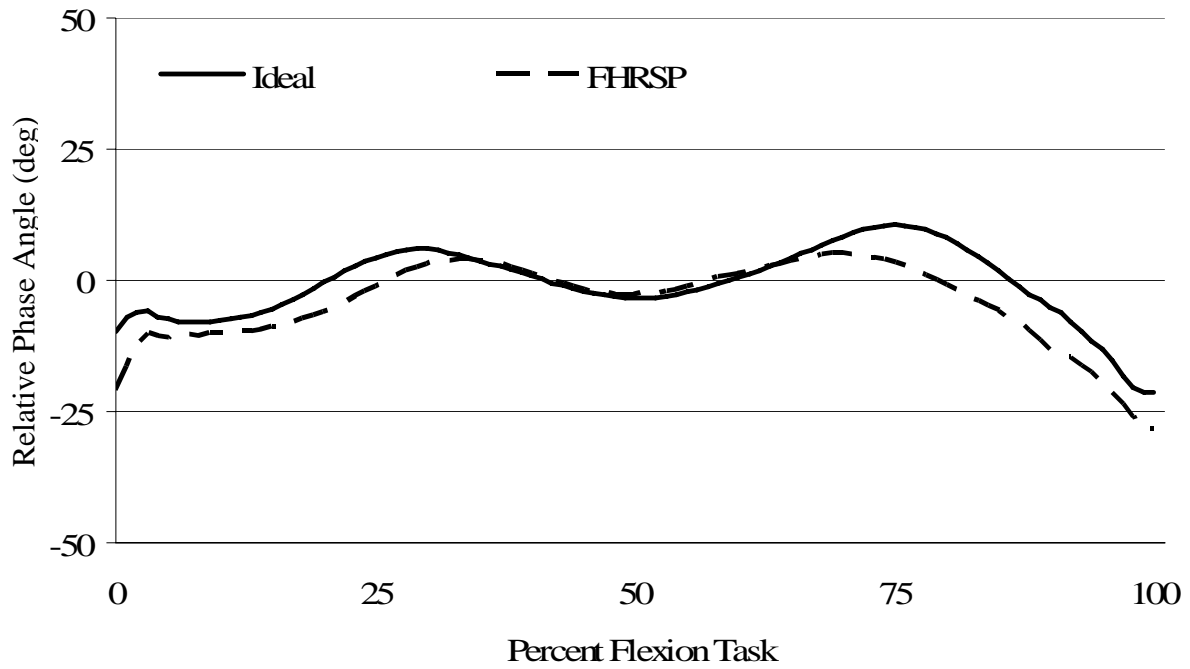$*F_{1,78} = 3.90$, p = 0.05
ES = 0.45
MSD = 2°
Mean Difference 4°

Figure 27. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed similar scapular internal/external rotation-humeral elevation continuous relative phase curves during the reaching task.
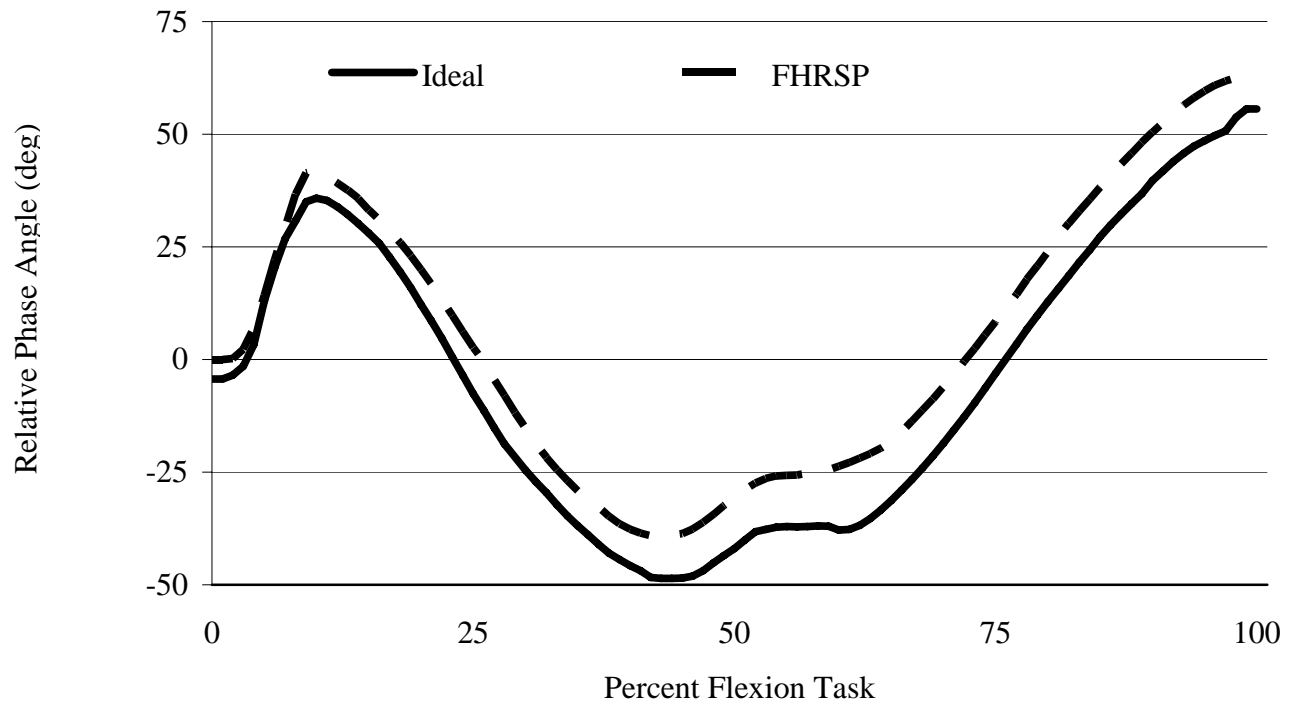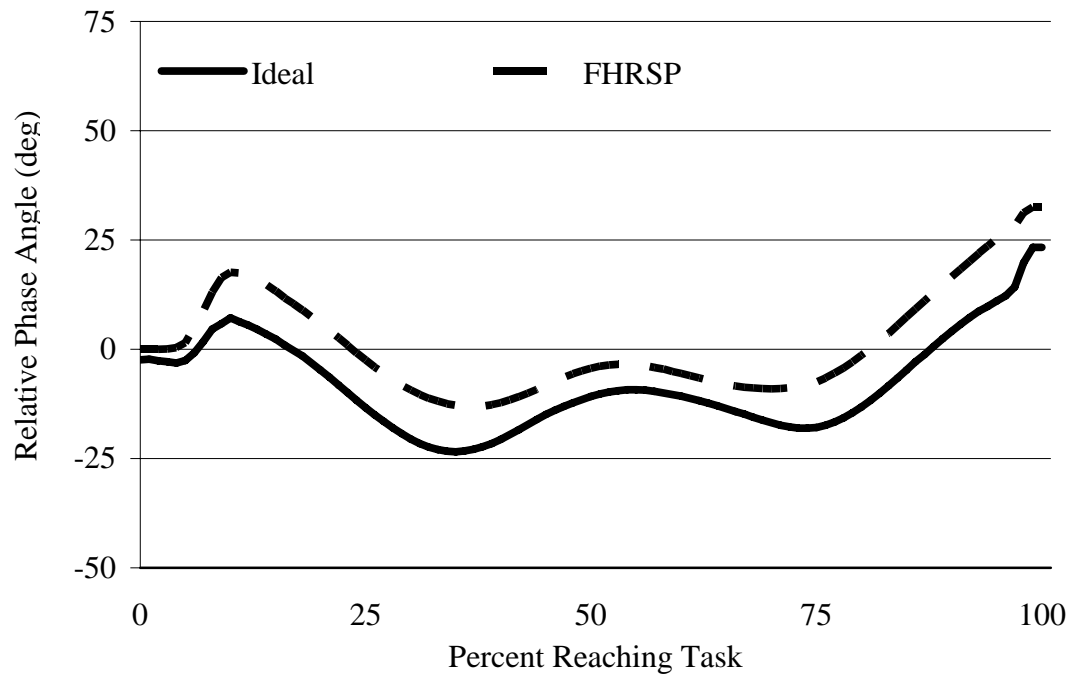
Figure 28. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed similar scapular anterior/posterior tipping-humeral elevation continuous relative phase curves during the reaching task.
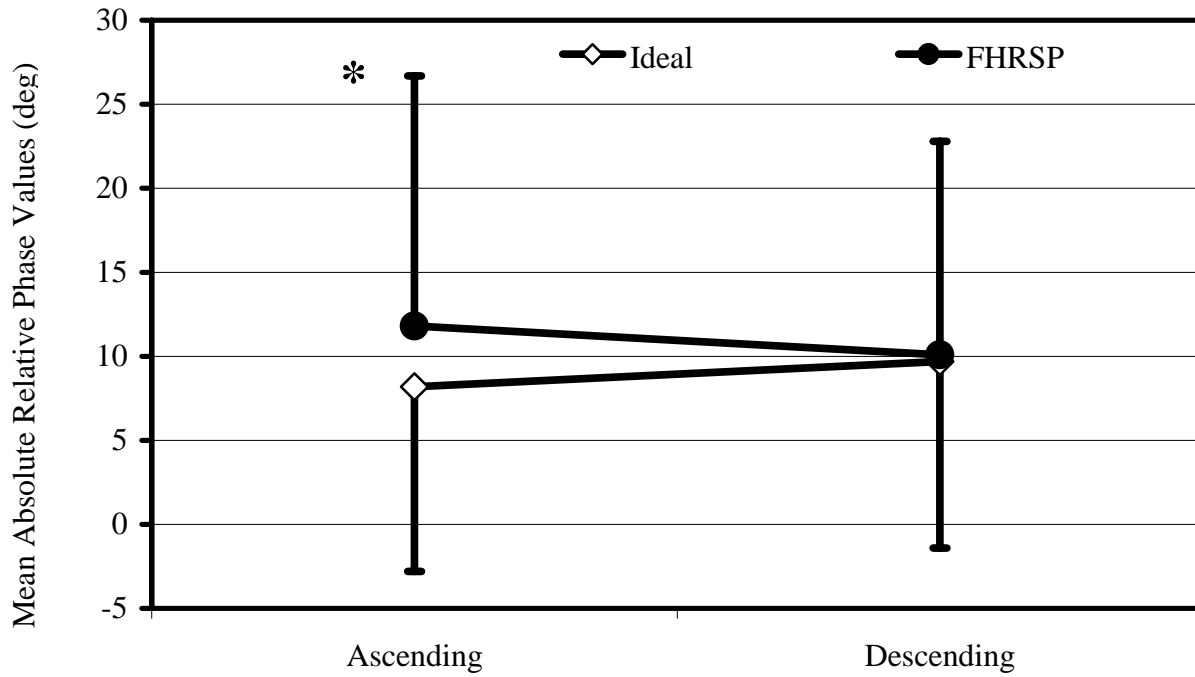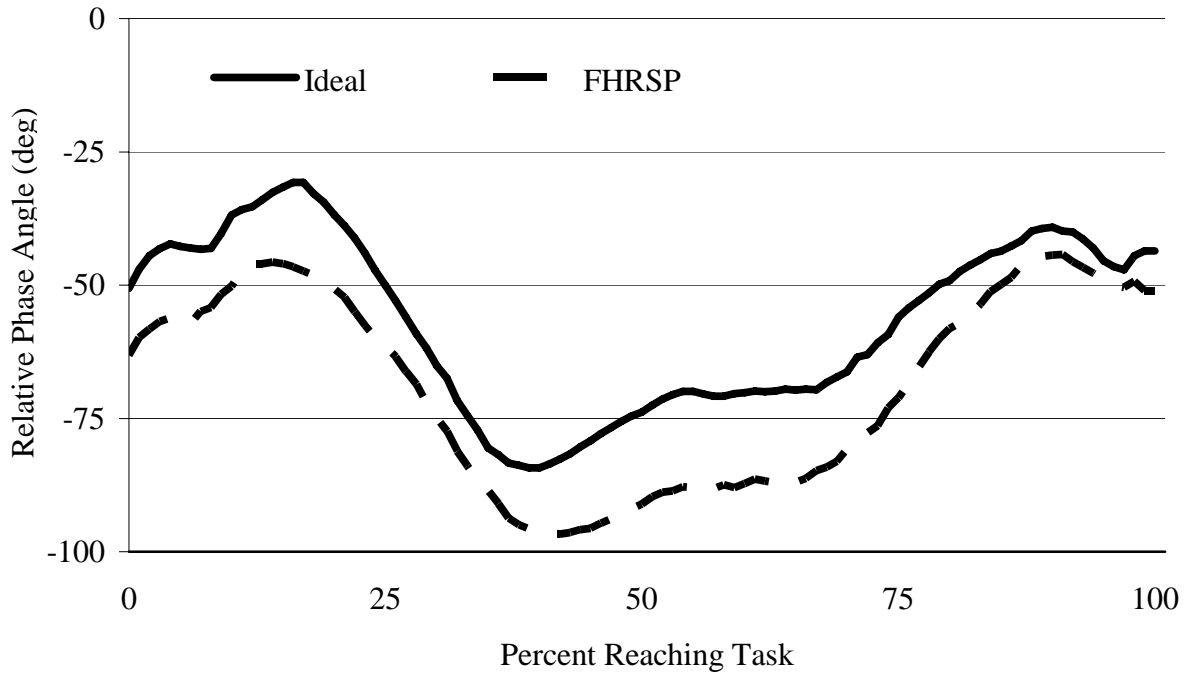
Appendix C. Manuscript One

Effects of Forward Head and Rounded Shoulder Posture on Scapular Kinematics

and Muscle Activity in Healthy Shoulders

Abstract

Study Design: Two group comparison

Objective: The purpose of this study was to compare scapular kinematics and muscle activity between individuals with and without forward head and rounded shoulder posture (FHRSP).

Background: FHRSP, altered scapular kinematics, and muscle activity have been reported in patients with shoulder pain. However, it is unclear if alterations in scapular kinematics are the result of alterations in posture or in response to shoulder pain.

Methods and Measures: Eighty volunteers without shoulder pain were classified as having FHRSP or ideal posture. Scapular kinematics were collected concurrently with upper and lower trapezius as well as the serratus anterior muscle activity using an electromagnetic tracking system together with electromyography. Separate mixed model analyses of variance were used to compare three dimensional scapular kinematics and muscle activity between individuals with and without FHRSP during the ascending and descending phases of a loaded flexion and overhead reaching task.

Results: There were significant main effects for group on scapular internal rotation angle. There were also significant interaction effects between group and phase of task showing differences in upward rotation, anterior tipping, and decreased serratus anterior. The FHRSP group displayed increased scapular internal and upward rotation, as well as increased anterior tipping with decreases in serratus anterior activity during the flexion and reaching tasks.

Conclusions: Individuals with FHRSP displayed alterations in scapular kinematic and serratus anterior muscle activation patterns similar to those reported in individuals with

shoulder pain. These results suggest FHRSP should be considered in the prevention and treatment of shoulder pain.

Key Words: shoulder, reaching, biomechanics, three-dimensional

Introduction

Shoulder pain is reported to occur in up to 21% of the general population[1, 2] and cost an estimated $39 billion annually.[3] These costs reflect the impact on health care resources, but do not include the costs due to time lost, retraining, and long-term disability associated with shoulder pain. Shoulder injury rates are reported to increase to 41% in occupational settings.[4-7] In addition, 40% of all shoulder pain is reported to persist for at least one year.[8] Due to the high incidence, cost, and long term disability of shoulder pain it is necessary to identify potential risk factors for developing shoulder pain.

Occupational risk factors for shoulder pain include repetitive overhead use (> 60° of shoulder elevation), prolonged overhead work, and increased loads raised above shoulder height.[9] However, these factors are difficult to modify based on the demands of many occupational settings. Therefore, research investigating the role of modifiable risk factors associated with shoulder pain is needed to develop intervention strategies that may be implemented to reduce the occurrence, cost, and disability of shoulder pain.

Forward head and rounded shoulder posture (FHRSP), altered scapular kinematics and muscle activity are suggested as potential risk factors in the development of shoulder pain.[6, 10-14] This is based on observed alterations in scapular kinematics and muscle activity in patients with shoulder impingement syndrome and rotator cuff disease.[12-14] FHRSP is thought to alter the length-tension relationships of the shoulder girdle muscles, thereby altering muscle function and disrupting normal shoulder kinematics and muscle activation patterns.[15, 16] This is supported by increases in scapular internal rotation and anterior tipping during humeral elevation in healthy shoulders with shortened pectoralis

minor length.[17] Additionally, improving shoulder posture has been shown to normalized scapular kinematics.[11] Increasing thoracic kyphosis and forward neck angle has been shown to decrease scapular upward rotation, internal rotation, and posterior tipping.[5, 7] Increases in forward neck angle has also been shown to increase upper trapezius and levator scapulae muscle activity.[7] Together these studies suggest that head and shoulder posture influence scapular kinematics and muscle activity.

These studies have focused on acute alterations in spinal alignment and its indirect effect on scapular kinematics.[1, 5, 7] This may not reflect the adaptive changes in that are hypothesized to occur as the result of altered posture.[6, 9] Additionally, there is limited research demonstrating the effect of posture on scapular kinematics.[11] Increases in scapular external rotation and posterior tipping have been reported following a stretching program but there was no comparison group in this study.[11] Therefore, it is unclear if individuals with FHRSP display alterations in scapular kinematics and muscle activity.

Furthermore, research examining the presence FHRSP, alterations in scapular kinemtics, and muscle activity has occurred in patients with shoulder pain.[18-21] The presence of shoulder pain during testing is a major limitation in these studies. It is unclear if observed differences in posture, scapular kinematics, or muscle activity are related to the underlying shoulder pain or are the result of FHRSP. Additionally, it is unlikely that all patients with overuse shoulder pain display FHRSP. Based on these limitations, a cross-sectional case control study comparing healthy shoulders in individuals with or without FHRSP is warranted.

Therefore, the purpose of this study was to compare scapular kinematics and muscle activity between healthy shoulders in individuals with and without FHRSP. We

hypothesized that individuals with FHRSP would display decreases in scapular upward rotation, external rotation, posterior tipping, serratus anterior activity, and lower trapezius activity as well as increased upper trapezius activity when compared to individuals with ideal head and shoulder posture.

Methods

Participants were recruited from the university population at The University of North Carolina-Chapel Hill through two informational mass emails sent to the university population. Inclusion criteria for the study included being aged between 18 and 60 and meeting the specific postural alignment criteria. Subjects were excluded if they reported a history of shoulder surgery, current shoulder pain limiting activities, upper extremity injury limiting activites, cervical or thoracic fracture, displayed functional or structural scoliosis, excessive thoracic kyphosis[22]. The dominant arm (arm used to throw a ball) was used for testing in all subjects.

Postural Analysis

Prior to testing participants completed an informed consent form and underwent a postural screening using the BioPrint® postural analysis system (Biotonix Inc., Montreal) to ensure that participants met the inclusion criteria for the ideal posture and forward head and shoulder posture groups. Postural screening included measurement of forward head angle (FHA) and forward shoulder angle (FSA).

Postural Alignment Criteria

The postural alignment criteria were based on data collected from during a pilot study of 310 individuals. Descriptive characteristics of these individuals appear in Table 2. Frequency histograms were plotted and measures of skewness and kurtosis assessed for

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forward head and shoulder angles to confirm normality of these measures. Head and shoulder angles approximately displayed a normal distribution. Therefore, the mean and standard deviations were used to represent the data. Cutoffs for each group were determined as the mean $\pm$ 1 standard deviation for the head and shoulder angle (Table 1). The FHRSP was 1 standard deviation above the mean and the ideal posture group was 1 standard deviation below the mean (Table 2). The ideal posture group criteria was defined as FHA $\leq 36°$ and FSA $\leq 22°$ (Figure 1 & 2). The FHRSP group criteria was defined as FHA $\geq 46°$ and FSA $\geq 52°$ (Figure 1 & 3). Subject demographics for the ideal posture group (n=40) and the FHRSP group (n=40) are listed in Table 1. Thus these groups represent an attempt to create two distinctly different postural alignment groups.

Excessive kyphosis was defined in a similar manner. The mean thoracic angle plus one standard deviation was 50°. These data represent a similarly aged sample of 300 subjects.[22] One standard deviation is also similar to the average increase in thoracic kyphosis reported to induce changes in scapular kinematics.[23]

Participants were excluded if their postural measures did not fall within the stated group criteria. Ninety-two of the 310 individuals screened met these criteria (29%). Forty-seven individuals were assigned to the ideal posture group and 45 to the FHRSP group. Twelve individuals did not schedule a return appointment yielding 40 participants in each group.

Reflective markers were placed over the right tragus (ear), chin, labella (between eyes), acromion, C_7, T_7, posterior superior iliac spine, and anterior superior iliac spine. Participants then stood 40 cm in front of the scaled backdrop and were given standard instructions to increase reliability of their normal resting postural alignment. High

resolution (5.0 mega pixels) digital images were then uploaded to a personal computer for processing. Adobe Photoshop® was used to measure head and shoulder angles. FHA and FSA demonstrated excellent intrasession reliability (FHA = $ICC_{(2,1)}$= 0.92, SEM = 2° and FSA $ICC_{(2,1)}$= 0.89, SEM = 5°) and between day reliability (FHA = $ICC_{(2,k)}$= 0.78, SEM = 4° and FSA $ICC_{(2,k)}$= 0.72, SEM = 7°).

Kinematic Assessment

All Participants were scheduled for a 90 minute testing session within 1 month of the initial screening. Participants were asked to avoid upper extremity weight lifting and overhead activities on either day of testing. During this testing session three-dimensional shoulder kinematic and EMG data were collected to assess humeral and scapular angles as well as scapular muscle activity during the ascending (>29° to >119°) and descending (<120° to >30°) phases of loaded shoulder flexion and reaching tasks.

A Flock of Birds® (Ascension Technologies, Inc., Burlington, VT) electromagnetic motion analysis system controlled by the Motion Monitor® (Innovative Sports Training, Inc. Chicago, IL) software was used to assess scapular kinematics at a sampling rate of 50 Hz. The primary component of the electromagnetic tracking system is a standard range DC transmitter containing three orthogonal coils that generates an electromagnetic field. The system incorporates a series of three sensors/receivers that record the electromagnetic flux in the field generated by the transmitter and conveys the signals to a recording computer via hard wiring.

Three electromagnetic tracking sensors were attached to: 1.) The thorax over the spinous process of T3, 2.) The dominant shoulder over the broad flat surface of the scapular acromion, 3.) The posterior one third of the upper arm with the sensor over the

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area of least muscle mass to minimize potential sensor movement. In order to assess the shoulder kinematics, reconstruction of the bony segments was performed following the International Society of Biomechanics-Shoulder Group Recommendations. [24] The bony landmarks were: T_{12}, medial and lateral epicondyle of the humerus, T_8, xyphoid process, C_7, sternal notch, spine of the scapula at the medial border, posterior-acromion of the scapula, inferior angle of the scapula, and the glenohumeral joint rotation center. The glenohumeral joint center was defined by the point that moves least with respect to the scapula when the humerus is moved through short arcs ($\leq 45°$) as calculated by a least squares algorithm and has been shown to best represent the glenohumeral joint center. [25]

The electromagnetic transmitter was positioned on a custom stand allowing for the establishment of a global reference system. The global reference system axes were defined such that the Y-axis was designated as positive in the superior direction, the Z-axis was designated as positive to the right, and the X-axis was designated as positive anterior, all relative to the participant. The local axes systems all aligned with the reference axes of the electromagnetic system to simplify data reduction.

Humeral elevation, scapular upward/downward rotation (UR), scapular external/internal rotation (IR), and scapular posterior/anterior tipping (PT) were collected for later comparison. Scapular angles were compared at the 60°, 90°, and 120° of humeral elevation for the ascending and descending phases of the flexion task. Scapular angles were compared at the 60°, 90°, and 110° of humeral elevation for the ascending and descending phases of the reaching task. Each of the scapular and humeral kinematic variables demonstrated excellent between trial reliability with $ICC_{(2,1)}$ values ranging from 0.92 to 0.99. Scapular ranges of motion and mean amplitude EMG were also

compared during the ascending and descending phases of humeral elevation for both tasks.

Each of these dependent variables was examined during a loaded arm elevation flexion task (arm in front of body) and a forward-overhead reaching task. Participants were asked to perform 25 cycles of arm elevation or forward reaching task at a self selected speed during testing. The tasks were counterbalanced and participants rested 5 minutes between each task to reduce the effects of fatigue, possible learning effects, and task order.

Muscle Activity Assessment

EMG analyses were performed to measure the muscle activation amplitude of serratus anterior, upper trapezius, and lower trapezius muscles using a Delsys Bagnoli-8 EMG System (Boston, MA), with differential amplification, Common Mode Rejection Ration >80 dB, input impedance >1015//0.2 ohm//pF, Signal to Noise Ratio >40 dB using an 8 channel amplifier. The EMG signal was amplified by a factor of 1,000 over a bandwidth of 0.01 to 2,000 Hz, passed via an A/D converter (National Instruments, Austin, TX) sampling at 1000 Hz then corrected for DC bias. The raw EMG data was collected by the Motion Monitor® software and stored for analysis.

Before applying surface electrodes the participant's skin was cleaned with alcohol then a bar Ag/AgCl single differential surface electrode (Delsys Inc., Boston, MA) on the midpoint of each muscle belly perpendicular to the muscle fiber direction using surgical tape and adhesive stickers. The electrodes were 19.8 mm wide and 35 mm long with 10 mm between contacts. Electrodes were placed in the following arrangement:

Serratus anterior: below the axilla, anterior to latissimus dorsi, placed over 4th

through 6th ribs angled at 30° above the nipple line

Upper trapezius: one half the distance from the mastoid process to the root of the

spine approximately at the angle of the neck and shoulder

Lower trapezius: two finger widths lateral to the inferior angle of the scapula on a

45° angle towards T10.

The specified electrode placement has been used in a number of studies.[26-28] A carbon

reference electrode was placed over the non-involved acromion.

Separate maximal voluntary isometric contractions (MVIC) were performed using

a hand-held dynamometer (HHD) (CDS 300 strength dynamometer, Chatillion®, Largo,

FL) for the serratus anterior, upper trapezius, and lower trapezius.[28] EMG activity was

recorded for each muscle as subjects performed the MVIC. During MVIC testing the

subjects were instructed to push with maximal effort against the HHD for 5-seconds. The

average EMG amplitude during middle 1-second time period was determined for each of

the three trials performed for each MVIC test. The data from the middle 1-second time

period was then averaged across the three trials and used to normalize the EMG data

recorded during the loading flexion and reaching tasks. Thus, EMG data during the

loaded flexion and reaching tasks are expressed as a percentage of MVIC (% MVIC).

There was a 30-second rest period allowed between each trial during MVIC testing for a

given muscle. A 1-minute rest period was allowed between MVIC testing for each

muscle group. Prior to MVIC testing all subjects performed practice trials of each test to

familiarize them with the testing procedures. Mean EMG amplitude values for the three

trials demonstrated good reliability for each muscle with $ICC_{(2,1)}$ values ranging from 0.74 to 0.87.

After the setup was completed, participants completed the humeral elevation and forward reaching tasks. The humeral elevation task required the participant to lift a weight equal to 3% of their body weight in the sagittal plane in line with the acromion of their dominant arm. The sagittal plane was be defined as the plane perpendicular to a line through their fifth metatarsal head. Participants were asked to complete their full range of motion at a self selected speed.

The overhead reaching task required the participant placing a weight equal to 3% of their body weight from a resting position at their side up to a customized shelf equal to their height plus 15%. This height and weight reflect a moderate overhead task as defined by the National Institute of Occupational Safety and Health's reaching guidelines.[8] The target was placed perpendicular to the dominant AC joint, the length of their ulnar styloid anterior to the participant. Participants performed 5 practice trials to become familiar with the procedures before performing 25 repetitions of each task. Task order was randomized and subjects rested 5 minutes between tasks to prevent fatigue.

<u>Data Reduction and Processing</u>

Kinematic Data

Three-dimensional coordinates of the digitized bony landmarks were calculated using the Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL). Segment reference frames were defined according to the recommendations set forth by the Shoulder Group of the International Society of Biomechanics.[24] Humeral motions were calculated as the Euler angles of the humerus relative to the thorax reference frame

in the following order of rotations: internal-external rotation about Y axis, elevation about the Z' axis, and internal-external rotation about the Y" axis.[29] Scapular motions were calculated as the Euler angles of the scapula relative to the thorax reference frames in the following order of rotations: internal/external rotation about the Y axis, upward-downward rotation about the X' axis, and posterior-anterior tilting about the Z" axis.[24, 30] Kinematic data were smoothed through a Butterworth a low pass digital-filter (4th order, recursive, zero phase lag) at an estimated optimum cutoff frequency of 3.5 Hz.

The average of trials 2-6 of each task were used for assessment of mean scapular angles. Scapular upward rotation, internal rotation, and posterior tipping angles were selected using custom Matlab (Mathworks, Natick, MA) code to identify angles at 60°, 90°, and 120° of humeral elevation during the ascending and descending phases of the flexion task and the overhead reaching task. Scapular ranges of motion (ROM) were calculated from 30° to 120° of humeral elevation for the ascending and descending phases of humeral elevation for the flexion task and from 30° to 110° for the reaching task.

EMG Data

Post-acquisition, all EMG data were band-pass filtered (10 – 350 Hz) using a Butterworth filter (4th order, recursive, zero-phase lag). The data were further smoothed and rectified by taking the root mean square error (RMS) of the EMG signal over a 20 ms time constant.

Mean EMG amplitude were used to represent muscle activation over the ascending and descending phases of humeral elevation for the upper trapezius, lower trapezius, and serratus anterior. These were the same arcs used to calculate the scapular

ROM for the ascending and descending phases of shoulder motion. The mean EMG amplitude over each phase of motion was averaged across the 5 trials and used for statistical analyses. Each of the scapular EMG variables demonstrated good reliability with $ICC_{(2,1)}$ values ranging from 0.73 to 0.85.

Statistical Analysis

Scapular Rotation Angles

Separate mixed model ANOVA (group x angle x phase) were used to compare scapular upward rotation, internal rotation, and posterior tipping angles (dependent variables) between the ideal and forward head and rounded shoulder groups (independent variable). Each analyses involved angles (60°, 90°, and 120°) and phases (ascending and descending) of humeral elevation as within participant factors. Statistical significance was set a priori at $\alpha < .05$ for all analyses. Tukey's post hoc analyses were performed to investigate significant main effects and interactions.

Scapular Range of Motion and Muscle Activity

Separate mixed model ANOVA (group x phase) were used to compare scapular upward rotation, internal rotation, and posterior tipping range of motion as well as were used to compare upper trapezius, lower trapezius, and serratus anterior muscle activity (dependent variables) between the ideal and FHRSP groups (independent variable). Each analysis involved two phases (ascending and descending) of humeral elevation as within participant factors. Statistical significance was set a priori at $\alpha < .05$ for all analyses. SPSS for Windows software (version 13.0, SPSS Inc, Chicago, IL) was used for all statistical analyses.

Results

Scapular Rotation Angles

There were significant differences between postural groups for scapular internal rotation angle during the flexion task (Table 3) and reaching task (Table 4). These results indicate that on average individuals in the FHRSP group displayed greater scapular internal rotation angles in comparison to the ideal posture group during both tasks (Figure 4 & 5). The mean difference of scapular internal rotation angles between groups was 8° (Effect Size (ES) = 0.52) for the flexion task and 10° (ES = 0.60) the reaching task.

There was also a significant difference in scapular upward/downward rotation and scapular anterior/posterior tipping angle during the flexion task (Table 3). Tukey's post hoc test revealed the FHRSP group displayed greater upward rotation angles at 120° during the ascending and descending phases of humeral elevation in comparison to the ideal posture group (Mean Significant Difference (MSD) = 2.8°). The mean difference between postural groups for scapular upward/downward rotation was 5° (ES = 0.51) (Figure 6).

Tukey's post hoc test also revealed that on average during ascending and descending phases of humeral elevation the scapula was more anteriorly tipped for the FHRSP group in comparison to the ideal posture group (MSD = 1.3°). The mean difference between postural groups for scapular anterior/posterior tipping angles was 3° for the ascending phase and 4° for the descending phase of the flexion task. (ES = .32) (Figure 7).

There were no significant main or interaction effects involving postural group on scapular upward rotation angles or anterior/posterior tipping angles during the reaching task (Table 4).

Scapular Range of Motion

There was a significant difference between postural groups for scapular upward rotation range of motion during the flexion task and scapular anterior/posterior tipping range of motion during the descending phase of the reaching task (Table 5). These results indicate that on average individuals in the FHRSP group displayed greater scapular upward rotation range of motion in comparison to the ideal posture group during the flexion task. The mean difference of scapular upward rotation range of motion between groups was 5° (ES = 0.45) (Figure 8). Additionally, individuals with FHRSP used less anterior tipping range of motion during the descending phase of the reaching task. The mean difference for scapular anterior/posterior tipping range of motion between groups was 2° during the descending phase of the reaching task (ES = 0.36) (Figure 9).

There was not a significant difference between postural groups for scapular upward/downward rotation during the reaching task, scapular posterior/anterior tipping range of motion during the flexion task or for scapular internal/external rotation range of motion during either task (Table 5).

Muscle Activity

Serratus Anterior

There was a significant interaction effect between humeral elevation phase by postural group on serratus anterior activity during the flexion task and the reaching task. Tukey's post hoc test revealed that the serratus anterior in the FHRSP group was less active during the ascending phase of flexion task (MSD = 5%) and the reaching task (MSD = 6%) in comparison to the ideal posture group. The mean difference between

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postural groups for serratus anterior activity was 12% during the flexion task (ES = 0.38) and 6% during the reaching task (ES = 0.33) (Figure 10 &11).

Upper Trapezius and Lower Trapezius

There were no significant main or interaction effects for postural group on upper trapezius or lower trapezius activity during the flexion or reaching tasks (Table 5). These results indicate there were no significant differences in upper or lower trapezius activity during these tasks.

Discussion

The purpose of this study was to compare scapular kinematics and muscle activity between healthy shoulders in individuals with and without FHRSP. Our results suggest individuals with FHRSP display altered scapular kinematic patterns during shoulder flexion and overhead reaching tasks. Individuals with FHRSP remained in more scapular internal rotation throughout the flexion and reaching tasks. These subjects also displayed greater scapular upward rotation range of motion during the ascending phase of both tasks. Additionally, individuals with FRHSP showed increases in scapular anterior tipping during the shoulder flexion task. Increases in scapular upward rotation angles were also observed at 120° of the shoulder flexion task. These alterations in scapular kinematics were observed with concurrent decreases in serratus anterior activity during the ascending phase of the overhead tasks. These results support the clinical theory that FHRSP impacts shoulder mechanics. These alterations were observed in healthy shoulders without shoulder pain suggesting that FHRSP alone may influence scapular mechanics. Head and shoulder posture, scapular kinematics, and muscle activity should be examined as potential risk factors in the development of shoulder pain.

The observed increases in scapular internal rotation and anterior tipping in individuals with FHRSP are consistent with previous reports examining the effects of posture on three-dimensional scapular kinematics.[17, 23, 31] Individuals with FHRSP displayed greater scapular anterior tipping angles when compared to individuals with ideal posture. The increase of 3°-4° is similar to increases in scapular anterior tipping following increases in thoracic kyphosis[23, 31] and short pectoralis minor length.[17] In the current study the FHRSP group demonstrated scapula internal rotation angles that were 8º and 10º greater than the ideal posture group during the reaching and flexion tasks, respectively. The increase in scapular internal rotation are similar to alterations reported in healthy shoulders with short pectoralis minor length[17] but smaller than increases reported concurrent with increased in thoracic kyphosis.[23, 31] The greater scapular internal rotation angles may have been the result of study design plane of humeral elevation. Previous studies acutely altered spinal alignment to facilitate a more FHRSP.[23, 31] In contrast, we created two distinct postural groups to examine the effects of FHRSP on scapular kinematics. By limiting the amount of excessive thoracic kyphosis our results reflect changes in the scapular position upon the thorax. The plane of humeral elevation and method of data collection also has been reported to influence the contribution of scapular rotations to total shoulder motion.[3, 4, 10] The tasks in this study were more anterior to scapular plane elevation used in previous studies.[11, 32] These factors likely combined to influence the magnitude of differences in scapular internal rotation between studies. Considering these studies together[17, 23, 31], increasing thoracic kyphosis seems to affect scapular internal rotation less than FHRSP or short pectoralis minor length.[17]

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These studies also reported decreases in scapular upward rotation as the result of increasing thoracic kyphosis[23, 31] or no difference in individuals with short pectoralis minor lengths.[17] We observed increases in scapular upward rotation angle and range of motion in individuals with FHRSP. Previous reports of decreased scapular upward rotation are most likely due to methods of inducing postural malalignment or data collection and reduction methodolgy.[23, 31] Since thoracic kyphosis was controlled in this study the scapular position was most different in the transverse plane. This may contribute to the discrepancies between our results and previous studies acutely altering thoracic posture. Additionally, differences in the use of Cardan vs. Euler angle sequencing and static vs. dynamic methods of data collection have been suggested to contribute to varying results in scapular kinematics during similar tasks.[3, 4, 10] Our results are also inconsistent with the absence of changes in scapular upward rotation in healthy shoulder with pectoralis minor tightness.[17] Apparently, pectoralis minor tightness does not result in changes in scapular upward/downward rotation. This suggests that FHRSP has a more global effect on scapular kinematics while pectoralis minor tightness primarily affects scapular tipping and internal rotation.

The combined effects of the observed scapular kinematic patterns during the overhead tasks likely decreased the subacromial space in individuals with FHRSP. The pattern of scapular kinematics in those with FHRSP is thought to carry significant clinical importance as similar scapula kinematic patterns have been shown to decrease the size of the subacromial space and therefore the volume of the supraspinatus outlet.[33-38] Scapular protraction is essentially a combination of scapular internal rotation and anterior tipping[33] Increases in scapular protraction have been shown to decrease the size of the subacromial

space, thereby decreasing the volume of the rotator cuff outlet.[33] Increases in the subacromial space have also been reported with increases in scapular retraction, which is analogous to scapular external rotation.[38] Furthermore, decreases in the subacromial space have been shown to be concurrent with increases in acromial tilt, which is analogous to anterior tipping.[37] This concept is further supported by associated changes in acromiohumeral distance as a result of altered scapular motion in individuals with shoulder impingement.[36] While these changes are relatively small decreases in acromiohumeral distance (3-8 mm) in individuals with symptomatic shoulder impingement syndrome[34, 35], the decreased subacromial space seems to have clinical importance. Graichen and co-authors[36] noted that even small decreases (3 mm) in acromiohumeral distance resulted in a concomitant 68% decrease of the subacromial space. This significant decrease in the subacromial space is thought to contribute to compression of the underlying structures. When considered together, these studies suggest that even small changes in scapular motion may significantly decrease the supraspinatus outlet volume. Based on these studies it has been suggested that a 12°-17° of change in scapular position (difference in scapular internal rotation + anterior tipping) is important.[17, 33, 37] On average, individuals with FHRSP displayed increased a change in scapular position across these two rotations ranging from 11°-14° for the two tasks. Considering our results in light of previous research it is likely then that the subacromial space was decreased in individuals with FHRSP.

The observed increases in scapular upward rotation may have been a compensatory mechanism aimed at maintaining the length-tension relationships of the deltoid-rotator cuff force couple. Observed increases in scapular internal rotation and

anterior tipping would lengthen the posterior rotator cuff potentially pulling the muscle into the descending limb of the length tension curve. Increases in upward rotation would shorten the posterior cuff and shift the length tension curve back within a more favorable range. This would allow for more optimal force generation patterns by the posterior rotator cuff and deltoid thereby maintaining this force couple. This is supported by observed decreases in shoulder strength in response alterations in scapular position.[23, 39]

These increases in scapular upward rotation may have compounded the decrease in the subacromial space and increase forces on subacromial tissues.[40, 41] Increases in upward rotation have been shown to increase superior humeral head migration and contact forces within the subacromial space [40, 41]. This would likely increase the compression and shear stress placed upon the subacromial contents.

While the subacromial space was likely decreased in individuals with FRHSP, they did not exhibit signs or symptoms of shoulder impingement syndrome. A possible explanation is the limited exposure to overhead activities in this population. Only 3 subjects reported participating in overhead activities greater than 3 hours per week. It is probable that increased rates of exposure to overhead activities for individuals with FHRSP would lead to the development of shoulder pain.

Decreased serratus anterior activity during the ascending phase of overhead tasks may help explain the alterations in scapular kinematics. The serratus anterior is the only scapular muscle with the potential to participate in force-couples to control all three scapular rotations. Therefore, decreased serratus anterior activity is thought to contribute to alterations in scapular kinematics.[13] This is supported by the differences in serratus activation and observed kinematic changes during each task. During the flexion task a

12% decrease in serratus activation occurred with an increase in scapular anterior tipping and upward rotation. However, serratus activation decreased to 5% and no kinematic changes occurred specific to the ascending phase of the reaching task. The maximum angle compared for the reaching task was 110°, while the maximum angle was 120° for the flexion task. The observed differences in scapular kinematics and serratus anterior activity suggest at higher ranges of humeral elevation the serratus anterior controls scapular anterior/posterior tipping and may actually limit scapular upward rotation. This seems paradoxical until one considers the role of the serratus anterior in its force couple with upper trapezius. The upper trapezius has more fibers with longer moment arms positioned to create upward rotation. Therefore, the role of the serratus may be to prevent excessive upward rotation maintaining optimal length-tension relationships of other muscles. These results support rehabilitative focus on the serratus anterior in individuals with FHRSP, especially in the higher ranges of humeral elevation. Focus on facilitating serratus anterior activity during the higher ranges of humeral elevation may facilitate normal scapular upward rotation and posterior tipping.

The absence of differences observed in trapezius activity may be due to the population tested, task performed, or measure of muscle activity selected. The population tested reported healthy shoulders with no positive tests for shoulder pain. Alterations in upper and lower trapezius timing and activity have only been reported in patients diagnosed with shoulder pain.[13, 27, 42] It is possible that alterations in trapezius function is related to the presence of shoulder pain. Alterations in trapezius activity may be a compensatory mechanism to avoid pain or a contributing factor to the development of shoulder pain.

The observed similarities in trapezius activity also may have been the result of task selection. The trapezius increases its activity as the plane of humeral elevation moves from the sagittal plane to the frontal plane.[43, 44] It is possible that the forward nature of these activities did not require high levels of recruitment of the trapezius muscles. Decreased requirements in trapezius activity during overhead elevation tasks may not have elicited differences in these healthy shoulders. Additionally, mean amplitude of each phase of the overhead reaching tasks were used as dependent variables. Given that there was very little activity in both groups during the descending phases, it is possible that any differences were blurred by analyzing the entire ascending phase. Future studies should use multi-planar tasks, examine smaller arcs of motion for differences in muscle activity, and prospectively evaluate trapezius activity between healthy and painful shoulders.

Our results do not agree with previous reports of increased upper trapezius and decreased lower trapezius activity concurrent with increased forward neck angle.[7] This study used a repeated measures design to examine the effects of increasing forward neck angle on scapular kinematics and muscle activity. The discrepancy between these results and our observations may be due to task selection (flexion vs. scapula plane elevation). As mentioned previously, different planes of shoulder elevation challenge the scapula in different ways.[2] The more frontal plane activity may have stressed the trapezius muscles more eliciting differences better than in our study. [2] These differences in results may also be the result of the design of the study. Our study used a between subjects, case control design allowing us to compare apparently healthy shoulders' scapular muscle activity and likely reflecting the chronic effects of FHRSP. Previous research has used a repeated

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measures design, which would better reflect the acute effects of altering head posture. Finally, our subjects displayed alterations in head and shoulder posture while Ludewig et al[7] only reported the change in neck angle. It is possible that alterations in neck posture effect scapular muscle activity differently than the concurrent alterations in head and shoulder posture used in our study.

Observed alterations in scapular kinematics and muscle activity in individuals with FHRSP have important clinical implications in the prevention and treatment of shoulder pain. Our results suggest FHRSP should be considered in the prevention and treatment of shoulder pain. FHRSP appears to negatively influence scapular kinematics and scapular muscle activity. It is unclear if improving FHRSP will yield concurrent changes in scapular kinematics and muscle activity. Recent work by Lewis et al[46] has shown changing one or more postural components improves symptoms and increases shoulder elevation in patients diagnosed with shoulder impingement syndrome. However, they did not show a difference in head and shoulder posture between patients with shoulder impingement and healthy controls. Additionally, McClure et al[14] has shown that generally scapular kinematics do not change in patients with resolved subacromial impingement syndrome. These results suggest not all patients with shoulder impingement syndrome present with altered head and shoulder posture or scapular kinematics. Likewise, the large standard deviations observed in this study suggest that not all individuals with FHRSP displayed abnormal patterns of scapular kinematic and muscle activity. Together these studies suggest that they may be subgroups of individuals who have differing etiology and mechanisms contributing to their shoulder impingement.

Therefore, when evaluating patients with overuse shoulder pain it is important to be cognizant that their symptoms may be due to FHRSP, short pectoralis minor length, altered scapular kinematics, tight posterior capsule, and/or rotator cuff weakness. Future research should seek to establish these subgroups of clinical correlates to improve prevention and treatment of shoulder pain. Prospective studies should also examine potential risk factors for shoulder pain allowing for the most effective clinical algorithms and prevention programs.

Several limitations should be considered in the interpretation and application of these results. The cross sectional-case control design limits a cause and effect relationship to be drawn between alterations in scapular kinematics, muscle activity and FHRSP. Additionally, all subjects reported no current shoulder pain limiting the application of these results to healthy shoulders. There was a female gender bias for the FHRSP group despite a concerted effort to control for this factor. Comparisons were reanalyzed using an analysis of covariance on gender and no changes in statistical values were noted. Therefore, the gender bias did not affect these results.

The skin based sensors used in this study only give a representation of scapular and humeral kinematics. However, this method has been validated and shown to be reliable within humeral elevation ranges from 30°-120°.[47-49] The sampled ranges of humeral elevation were within these limits, thus we are confident they are an accurate representation of scapular motion. The lack of a direct measure of supraspinatus outlet volume limits absolute conclusions based on our results. However, our conclusions are based on integration of our results with the current literature available and it is reasonable

to conclude that the supraspinatus outlet volume is likely decreased in individuals with FHRSP.[36, 50, 51]

Conclusions

The results of this study suggest that healthy shoulders in individuals with FRHSP display altered scapular kinematics and serratus anterior muscle activity. This supports the clinical theory assuming changes in shoulder function in the presence of FHRSP. Prevention and rehabilitation programs aimed at treating shoulder pain should include assessment and interventions to improve head and shoulder posture. Future studies should examine the influence of pain on FHRSP and scapular kinematics and muscle activity. Prospective studies should also seek to evaluate establish posture, scapular kinematics, muscle activity, and strength as potential risk factors for the development of shoulder pain.

Table 1. Descriptive statistics for screened volunteers (n=310)

Characteristics		Mean	SD
Male (n= 132)	Age (years)	30.8	17.3
Forward Head Angle		42.4	4.9
Forward Shoulder Angle		32.6	14.3
Female (n= 178)	Age (years)	36.6	16.4
Forward Head Angle		44.6	5.4
Forward Shoulder Angle		40.3	17.7
All (n=310)	Age (years)	34.2	11.9
Forward Head Angle		41.1	5.2
Forward Shoulder Angle		37.4	15.3

Table 2. Descriptive statistics for study participants (n=80)

Group	Characteristics		Mean	SD
Ideal Posture	Male (n= 21)	Age (years)	32.6	13.3
		Height (cm)	178.4	7.6
		Mass (kg)	72.5	11.3
	Female (n= 19)	Age (years)	34.4	12.6
		Height (cm)	165.8	6.9
		Mass (kg)	60.1	11.2
Forward Head and Rounded Shoulder Posture	Male (n= 15)	Age (years)	39.1	12.5
		Height (cm)	177.0	7.3
		Mass (kg)	95.1	19.5
	Female (n= 25)	Age (years)	35.0	11.3
		Height (cm)	161.7	6.7
		Mass (kg)	77.3	15.4

Table 3. Scapular rotation angles (mean ± SD) during the ascending (Asc) and descending (Dsc) phases of the flexion task. Confidence intervals only presented for significant main or interaction effects.

Flexion Task Scapular Rotation Angles	Group	FHRSP Mean (SD)	FHRSP 95% CI (LCI – UCI)	Ideal Mean (SD)	Ideal 95% CI (LCI – UCI)	F-Ratio		P value
Scapular Upward/Downward	60 Asc	15 (7)	14 – 20	15 (10)	14 – 19	Group effect		0.246
	90 Asc	28 (8)	27 – 33	26 (12)	24 – 31	1.369		
	120 Asc	40 (10)*	32 – 39	35 (13)*	37 – 44	Angle X Group		< 0.00
	120 Dsc	40 (11)*	32 – 39	35 (13)*	37 – 44	* 10.217		
	90 Dsc	31 (9)	27 – 33	28 (12)	24 – 31	Phase X Group		0.827
	60 Dsc	18 (8)	14 – 20	18 (11)	14 – 19	0.048		
Scapular Internal/External	60 Asc	45 (9)		36 (12)		Group effect		0.002
	90 Asc	45 (10)		40 (12)		† 10.554		
	120 Asc	46 (11)		39 (13)		Angle X Group		0.624
	120 Dsc	45 (9)		37 (13)		0.473		
	90 Dsc	48 (10)		40 (13)		Phase X Group		0.654
	60 Dsc	47 (13)		39 (12)		0.202		
Group Mean		47 (13) †	43 – 50	39 (13) †	35 – 42			
Scapular Anterior/Posterior	60 Asc	-8 (7)		-5 (8)		Group effect		0.126
	90 Asc	-9 (9)		-5 (11)		2.396		
	120 Asc	-5 (10)		-1 (12)		Angle X Group		0.061
	120 Dsc	-2 (11)		1 (11)		1.246		
	90 Dsc	-7 (9)		-4 (11)		Phase X Group		0.019
	60 Dsc	-9 (7)		-6 (9)		‡ 5.707		
Ascending Phase Means		-7 (7) ‡	-10 – -4	-4 (7) ‡	-6 – -1			
Descending Phase Means		-6 (7) ‡	-9 – -3	-3 (7) ‡	-6 – 0			

* FRHSP group's scapular upward rotation angle at 120° > ideal posture group
† FHRSP group's scapular internal rotation angle > ideal posture group
‡ FHRSP group's scapular anterior tipping angle > ideal posture group during the ascending and descending phase (MSD = 3°)

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Table 4. Scapular rotation angles (mean ± SD) during the ascending (Asc) and descending (Dsc) phases of the overhead reaching task. Confidence intervals only presented for significant main or interaction effects.

Overhead Reaching Task Scapular Rotation Angles	Group	FHRSP Mean (SD)	FHRSP 95% CI (LCI – UCI)	Ideal Mean (SD)	Ideal 95% CI (LCI – UCI)	F-Ratio	P value
Scapular Upward/Downward	60 Asc	15 (7)		15 (10)		Group effect 0.001	0.981
	90 Asc	28 (8)		26 (12)		Angle X Group 1.639	0.197
	120 Asc	40 (10)		35 (13)			
	120 Dsc	40 (11)		35 (13)		Phase X Group 3.767	0.056
	90 Dsc	31 (9)		28 (12)			
	60 Dsc	18 (8)		18 (11)			
Ascending Phase Means		23 (7)		24 (7)			
Descending Phase Means		26 (7)		25 (7)			
Scapular Internal/External	60 Asc	39 (10)		31 (11)		Group effect * 14.436	< 0.00
	90 Asc	47 (10)		37 (13)		Angle X Group 0.823	0.441
	120 Asc	45 (14)		37 (12)			
	120 Dsc	50 (11)		39 (14)		Phase X Group 0.542	0.464
	90 Dsc	47 (11)		37 (11)			
	60 Dsc	39 (11)		31 (12)			
Group Mean		45 (12) *	41 – 48	35 (13) *	32 – 39		
Scapular Anterior/Posterior	60 Asc	-2 (21)		0 (14)		Group effect 0.306	0.582
	90 Asc	-1 (25)		2 (19)		Angle X Group 0.864	0.424
	120 Asc	-4 (21)		1 (13)			
	120 Dsc	1 (27)		4 (20)		Phase X Group 2.296	0.850
	90 Dsc	1 (26)		3 (19)			
	60 Dsc	-2 (23)		0 (15)			

* Average scapular internal rotation angle for FHRSP group > ideal posture group

Table 5. Scapular rotation range of motion (mean ± SD) during the ascending and descending phases of the flexion and overhead reaching tasks.

Scapular Rotation Range of Motion	Group	Ascending Mean (SD)	Descending Mean (SD)	Group Mean (SD)	F-Ratio	P value
Flexion Task						
Scapular Upward Rotation	FHRSP	36 (7)	35 (9)	35 (12) *	8.103	0.006
	Ideal	31 (9)	29 (10)	30 (15) *		
Scapular Internal Rotation	FHRSP	20 (7)	7 (5)	13 (6)	2.085	0.153
	Ideal	19 (5)	5 (4)	12 (5)		
Shoulder Posterior Tipping	FHRSP	7 (6)	9 (7)	8 (7)	0.076	0.783
	Ideal	8 (6)	9 (7)	9 (7)		
Reaching Task						
Scapular Upward Rotation	FHRSP	24 (13)	21 (13)	23 (13)	0.002	0.965
	Ideal	25 (10)	20 (9)	23 (10)		
Scapular Internal Rotation	FHRSP	14 (7)	13 (9)	14 (8)	0.50	0.824
	Ideal	14 (6)	13 (6)	13 (6)		
Shoulder Posterior Tipping	FHRSP	6 (6)	5 (5) †	5 (6)	1.930	0.196
	Ideal	7 (5)	7 (5) †	7 (5)		

* Scapular upward/downward rotation range of motion for FHRSP group > ideal posture group

† Scapular anterior/posterior tipping range of motion for FHRSP group < ideal posture group during the descending phase of reaching task.
$F_{1,78}= 5.025$, p = 0.025, MSD = 1°, Mean Difference = 2°
Ideal CI (5-8) FHRSP CI (5-7)

Table 6. Scapular muscle activity values (mean %MVIC ± SD) for upper trapezius, lower trapezius, and serratus anterior during the ascending and descending phases of the flexion and overhead reaching tasks.

Scapular Muscle Activity	Group	FHRSP Mean (SD)	FHRSP 95% CI (LCI – UCI)	Ideal Mean (SD)	Ideal 95% CI (LCI – UCI)	Phase X Gr F-Ratio
Flexion Task						
Upper Trapezius	Ascending	69 (30)	61 – 78	33 (14)	28 – 37	0.204
	Descending	66 (27)	57 – 75	32 (14)	27 – 37	
Lower Trapezius	Ascending	54 (29)	40 – 67	24 (12)	19 – 29	0.411
	Descending	58 (51)	44 – 71	28 (19)	24 – 34	
Serratus Anterior	Ascending	61 (25)*	52 – 69	73 (29)*	66 – 81	5.642
	Descending	29 (14)	25 – 33	31 (12)	27 – 35	
Reaching Task						
Upper Trapezius	Ascending	73 (28)	63 – 81	70 (27)	61 – 78	0.420
	Descending	32 (13)	28 – 36	32 (12)	28 – 36	
Lower Trapezius	Ascending	27 (14)	20 – 33	26 (23)	19 – 32	0.405
	Descending	15 (8)	11 – 18	15 (14)	11 – 19	
Serratus Anterior	Ascending	54 (18)*	48 – 61	60 (22)*	54 – 66	4.322
	Descending	23 (10)	19 – 27	22 (14)	18 – 26	

* Serratus anterior muscle activity for FHRSP group < ideal posture group during the ascending phase of flexion and reaching task.
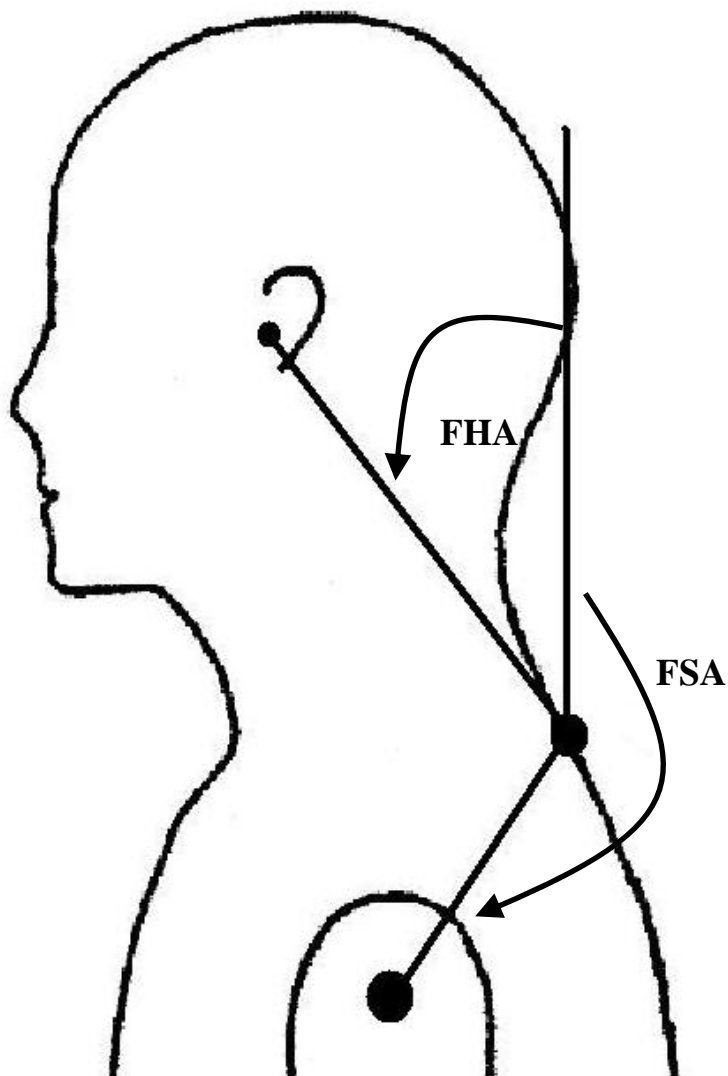
Figure 1. Forward head angle (FHA) measured from the vertical anteriorly to a line connecting the tragus and the C_7 marker. Forward shoulder angle (FSA) measured from the vertical posteriorly to a line connecting the C_7 marker and the acromial marker.
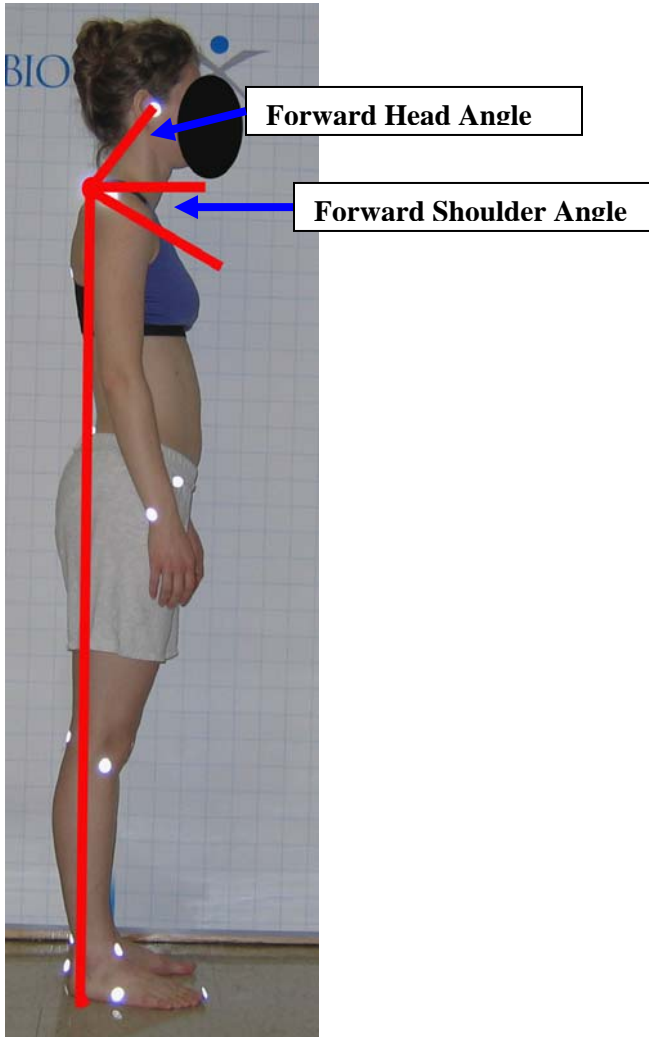
Figure 2. Example of ideal forward head and shoulder posture
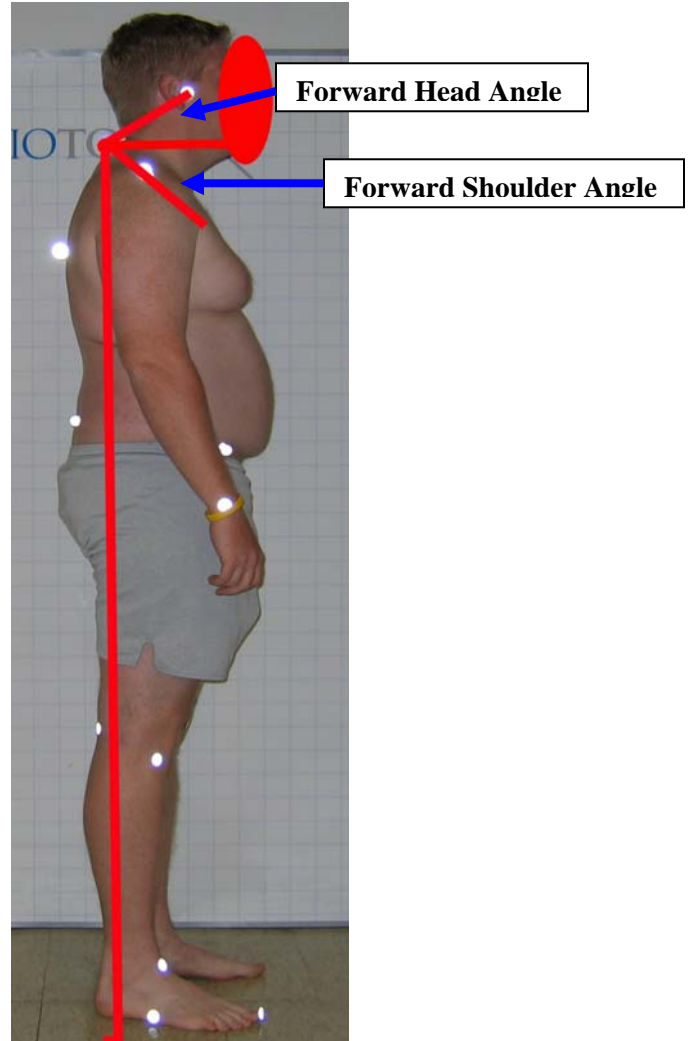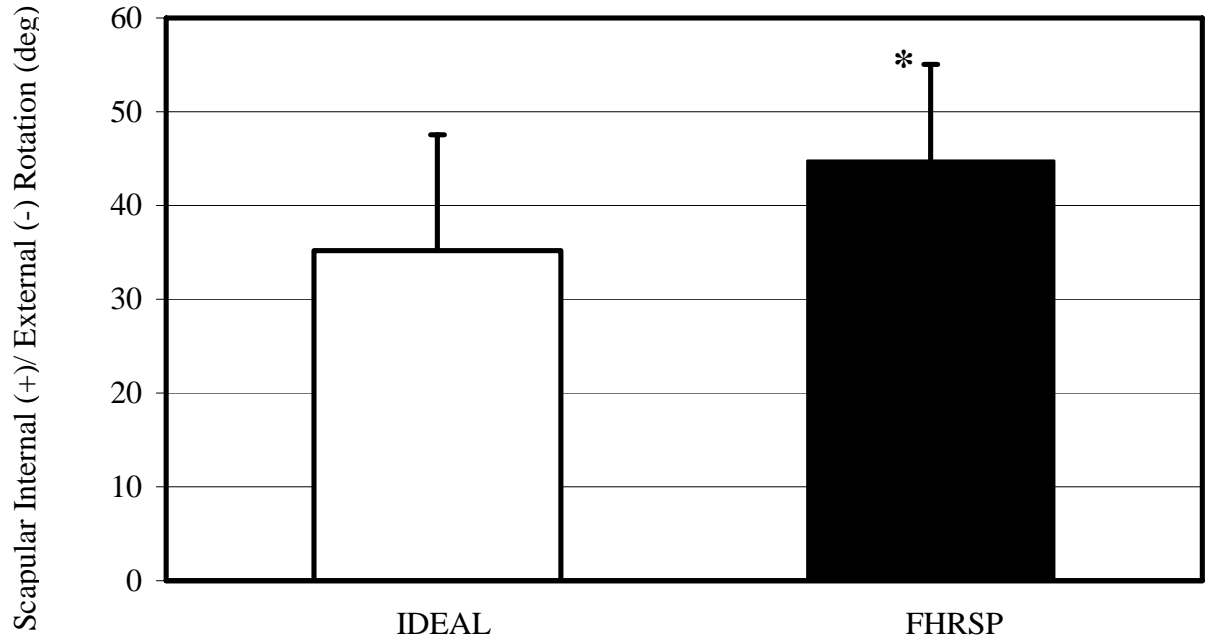
Forward Head Angle = 38˚
Forward Shoulder Angle = 22˚

Figure 3. Example of forward head and shoulder posture

Forward Head Angle = 55˚
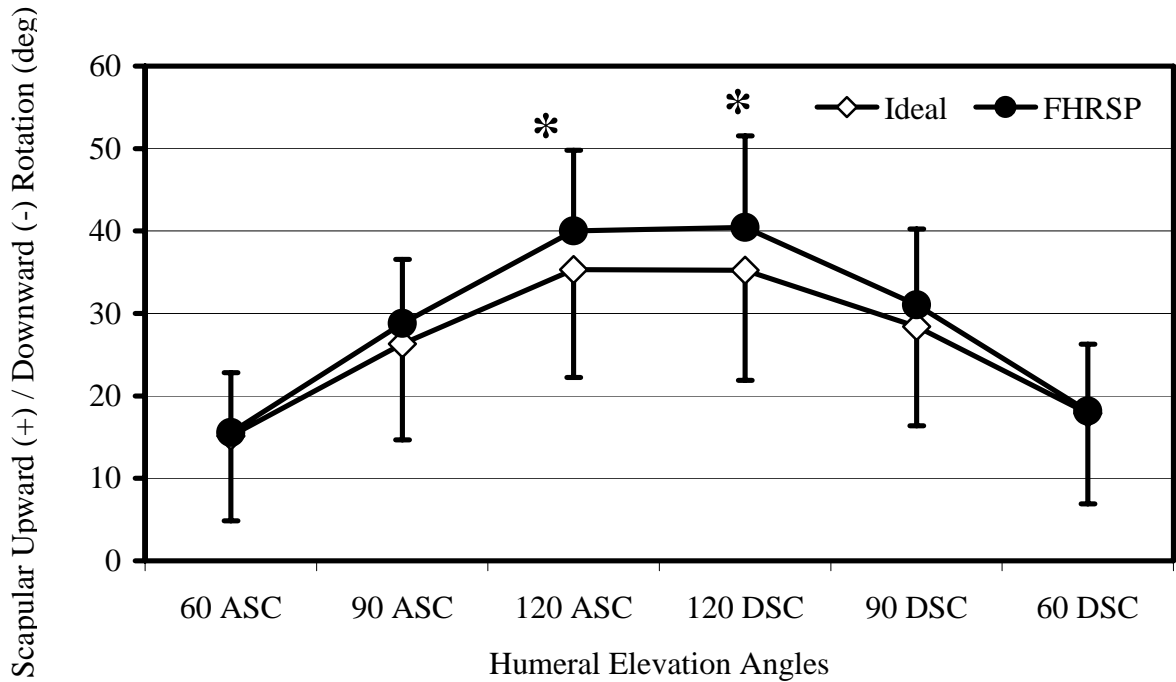Forward Shoulder Angle = 60 ˚

Figure 4 Individuals with forward head and rounded shoulder posture (FHRSP) displayed a greater average scapular internal rotation angle during the flexion task.
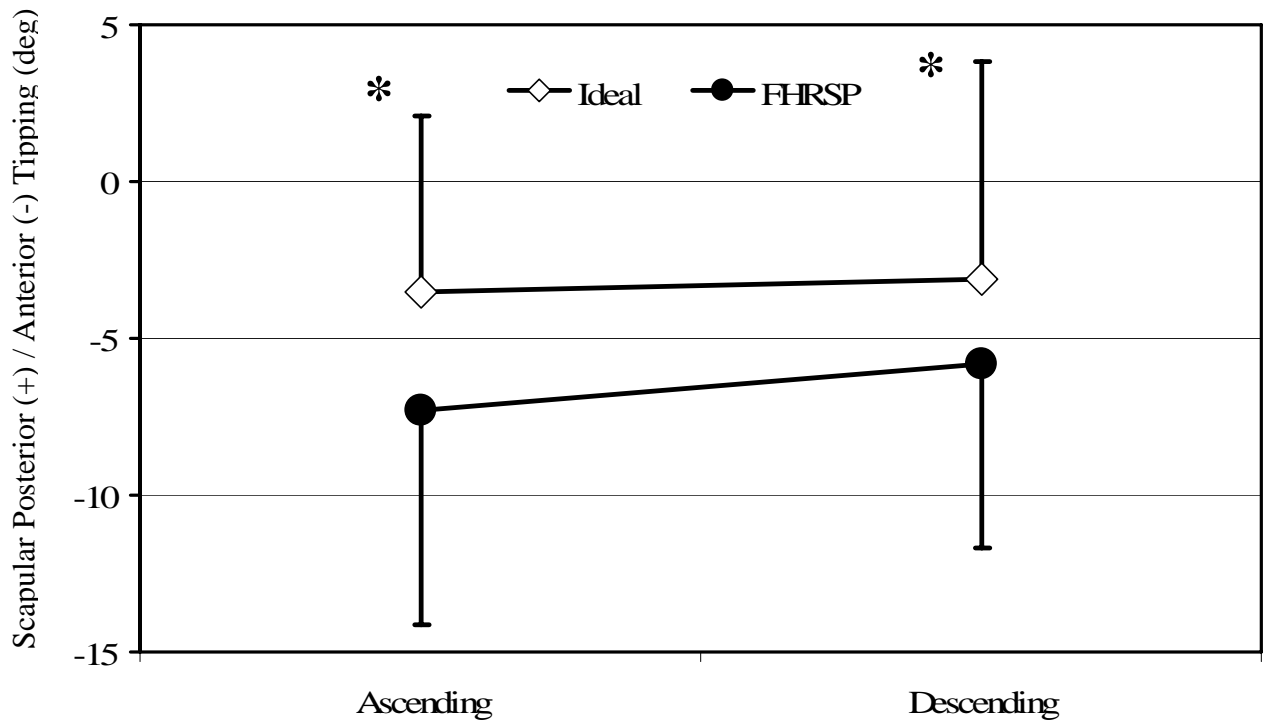

* p = 0.002
Mean Difference = 8°

Figure 5 Individuals displaying forward head and rounded shoulder posture
(FHRSP) displayed a greater scapular upward rotation angle at 120° of
humeral elevation during the ascending and descending phases of the
flexion task.

* p < 0.001
MSD = 3°
Mean difference at 120° ASC = 5°
Mean difference at 120° DSC = 5°

Figure 6 Individuals displaying forward head and rounded shoulder posture
(FHRSP) displayed greater average scapular anterior tipping angles during
the ascending and descending phases of humeral elevation during the
flexion task.

* p = 0.02
MSD = 1°
Mean difference for ASC= 3°
Mean difference for DSC = 4°

Figure 7. Individuals with forward head and rounded shoulder posture (FHRSP)
displayed a greater average scapular internal rotation angle during the
reaching task.

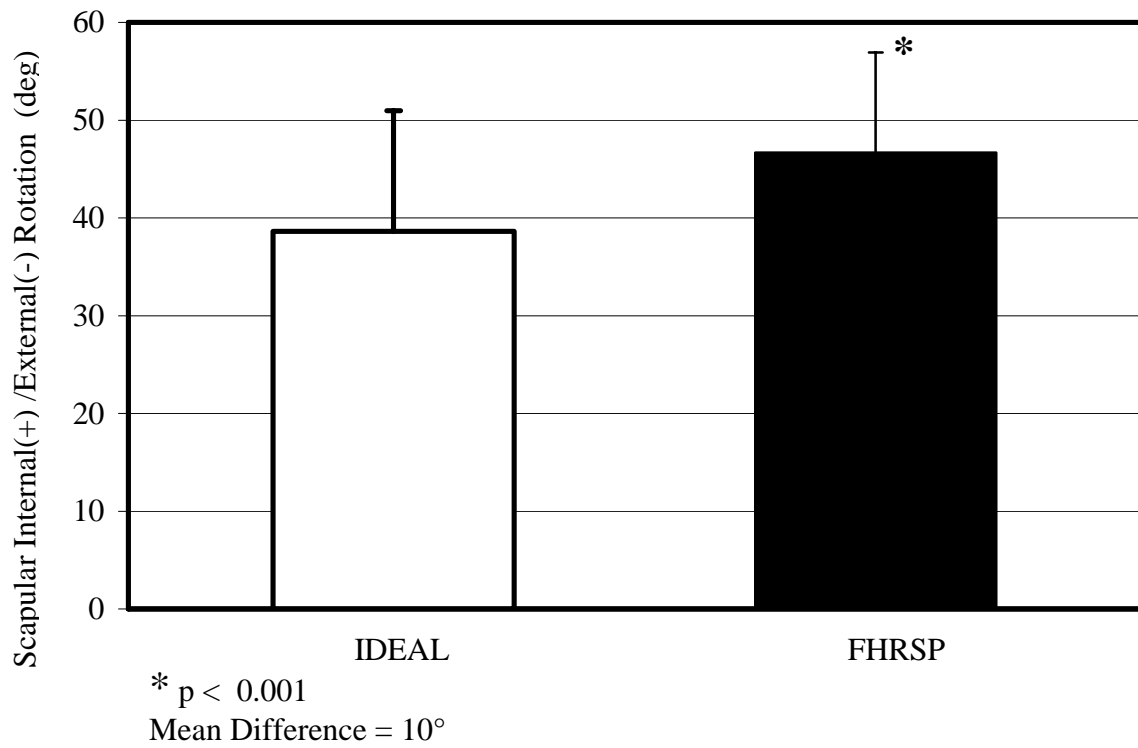* p < 0.001
Mean Difference = 10°

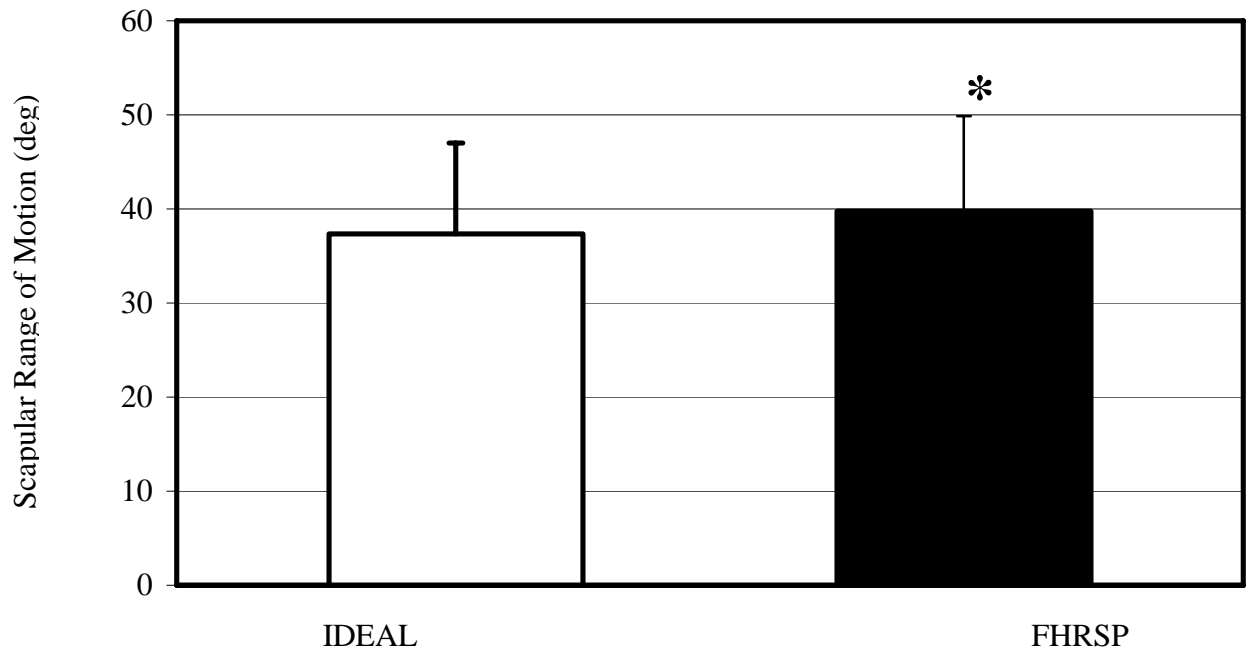Figure 8. Individuals with forward head and rounded shoulder posture (FHRSP) used a greater range of scapular upward rotation during the flexion task.

* p = 0.006
Mean difference = 5°

Figure 9. Individuals with forward head and rounded shoulder posture (FHRSP) displayed a less scapular anterior tipping range of motion during the descending phase of the reaching task.
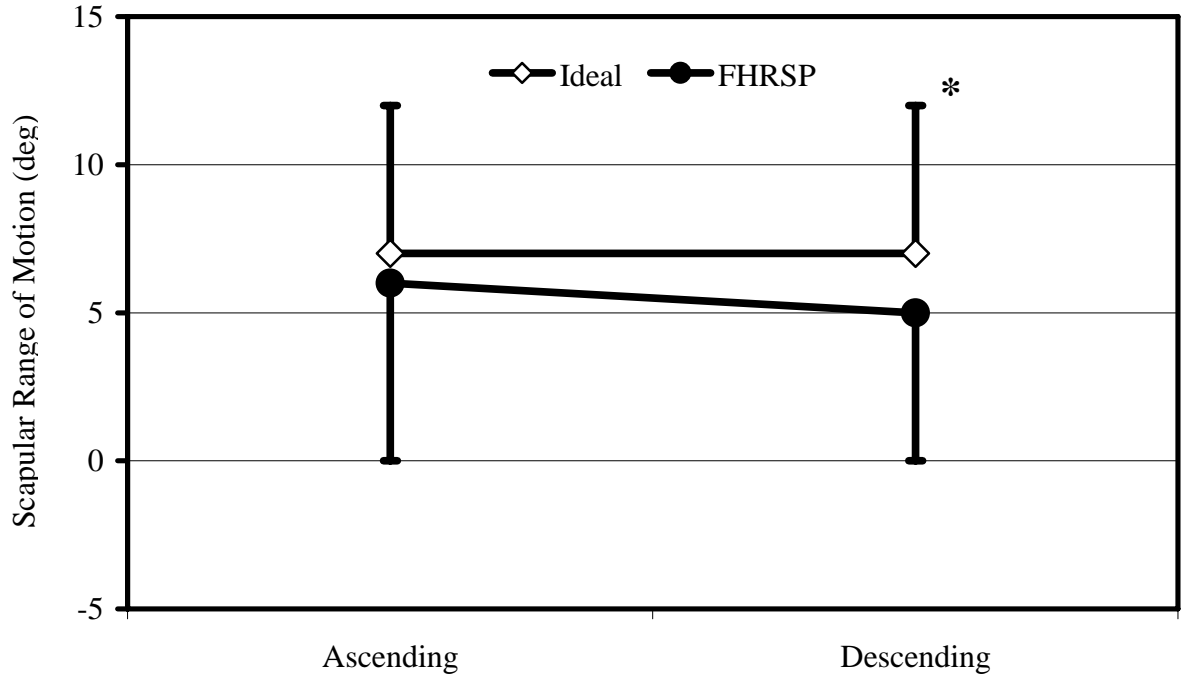
*p = 0.025
MSD = 1°
Mean difference = 2°

Figure 10. Individuals with forward head and rounded shoulder posture (FHRSP) displayed less serratus anterior activity during the ascending phase of the flexion task.

* p = 0.021
MSD = 6%
Mean difference = 12 %

Figure 11. Individuals with forward head and rounded shoulder posture (FHRSP) displayed less serratus anterior activity during the ascending phase of the reaching task.
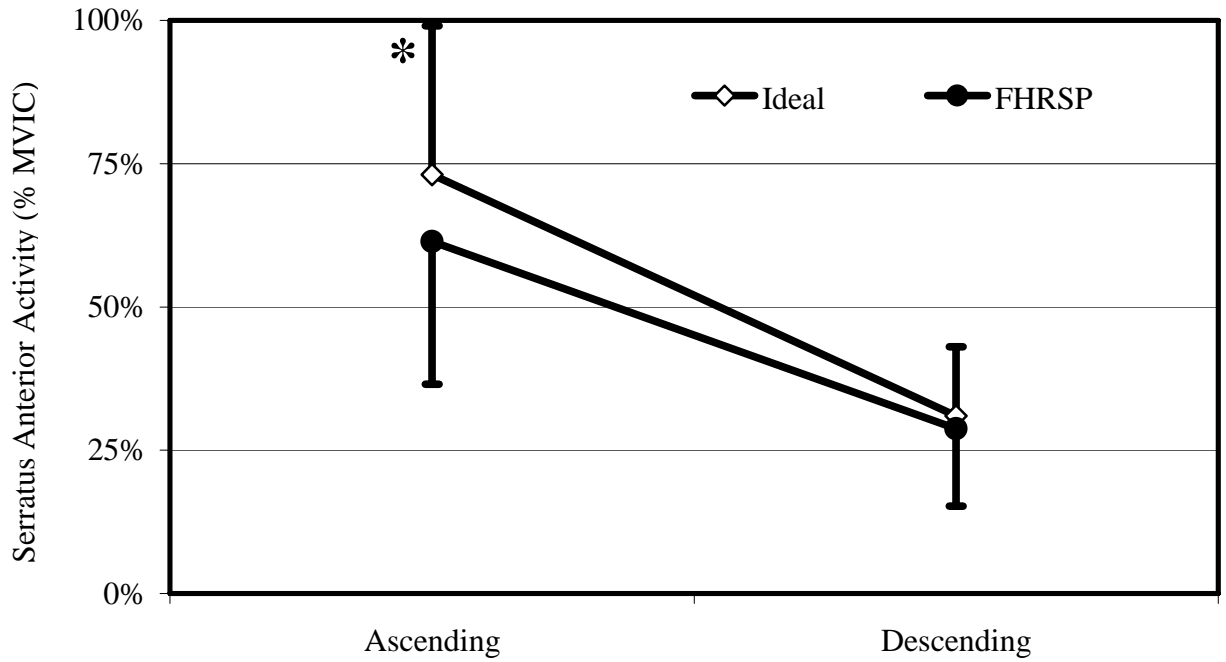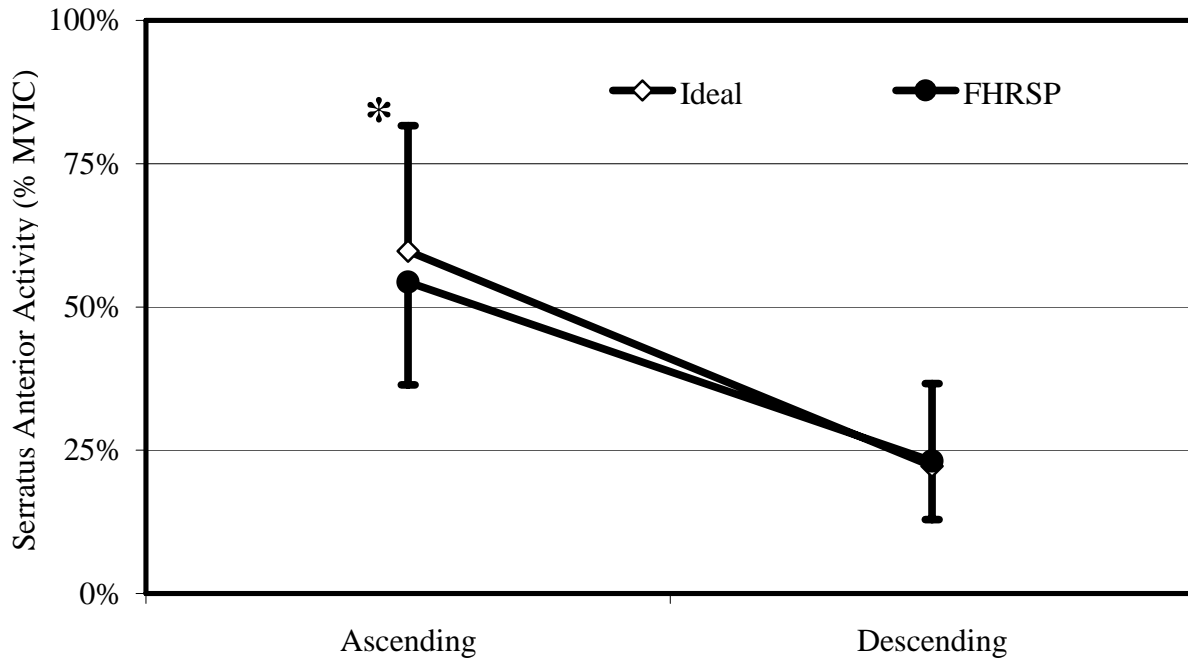

* p = 0.04
MSD = 5%
Mean difference = 6 %

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Appendix D.

Effects of Forward Head and Rounded Shoulder Posture

On Three-Dimensional Scapulohumeral Coordination

Abstract

Background: Forward head and rounded shoulder posture (FHRSP) and deficits in scapular kinematics are associated with the development of shoulder pain. Three-dimensional scapulohumeral coordination may provide valuable insight into shoulder function. Therefore, the purpose of this study was to compare three-dimensional scapulohumeral coordination between individuals with and without FHRSP during repetitive shoulder flexion and a standardized overhead reaching task.

Methods: Eighty volunteers without shoulder pain were classified as having FHRSP or ideal posture. Scapular kinematics was collected using an electromagnetic tracking system during a loaded shoulder flexion and an overhead reaching task. Coordination analysis based on Dynamical System's Theory tenets was used to quantify the coupling and the variability between three-dimensional scapular rotations and humeral elevation. Separate mixed model analyses of variance were used to compare three dimensional scapulohumeral coordination measures between individuals with and without FHRSP during the ascending and descending phases of a loaded flexion and overhead reaching task.

Findings: There were significant changes in the coupling relationships suggesting a more out-of-phase coordination between the humerus and scapular upward/downward rotation during the reaching task and anterior/posterior tipping during the flexion task. The FHRSP group also displayed less variable patterns of scapular internal/external rotation coordination with humeral elevation during the flexion task.

Interpretation: Individuals with FHRSP displayed scapulohumeral coordination patterns that were less coupled for upward/downward rotation and anterior/posterior tipping when

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compared to the ideal posture group. These findings suggest altered scapulohumeral neuromuscular control due to FHRSP.

Relevance: Given the association of FHRSP and repetition with the development of shoulder pain, future studies should examine three-dimensional scapulohumeral coordination as a risk factor for the development of shoulder pain.

Introduction

Shoulder pain is reported to occur in as many as 21% of the general population[1, 2] and cost an estimated $39 billion annually.[3] These costs only reflect the impact on health care resources and do not reflect costs due to time lost, retraining, and long-term disability associated with shoulder pain. Reports also indicate that shoulder injury rates increase to 41% in occupational settings[4-7] and 40% of all shoulder pain persists for at least one year.[8] Due to the high incidence, cost, and long term disability it is necessary to understand potential risk factors for developing shoulder pain.

Identified risk factors for shoulder pain include repetitive overhead use (> 60° of shoulder elevation), prolonged overhead work, and increased loads raised above shoulder height.[9] However, these factors are difficult to modify based on the demands of many occupational settings. Therefore, research investigating the role of modifiable risk factors associated with shoulder pain is needed to develop intervention strategies that may be implemented to reduce the occurrence, cost, and disability associated with shoulder pain.

Forward head and rounded shoulder posture is suggested to be a risk factor for the development of shoulder pain.[6, 10] Forward head and rounded shoulder posture is theorized to alter the length-tension relationships of the shoulder girdle muscles, thereby altering muscle function and disrupting normal shoulder kinematics, muscle activation patterns, and coordination.[11, 12] The associated changes to the neuromuscular system that occur with forward head and rounded shoulder posture are believed to ultimately lead to the development of shoulder pain. However, research has not established a clear link between postural malalignment and the development of shoulder pain.

Scapular kinematics, muscle activity, and shoulder coordination are also potential risk factors for shoulder injury.[13-16] Altered scapular kinematics and muscle activity have been reported in patients with shoulder impingement syndrome and rotator cuff disease.[14-16] The observed alterations in scapular kinematics and scapular muscle activity in those diagnosed with shoulder impingement syndrome suggest that deficits in scapulohumeral coordination may play a role in the development of shoulder pain.[13, 15] However, traditional measures of scapulohumeral rhythm involve only one plane of scapular motion (upward rotation) and therefore provide a very limited insight into scapulohumeral coordination. Recent evidence suggests that individuals with shoulder impingement also have deficits in scapular internal/external rotation and anterior/posterior tipping.[14, 15] Therefore, research examining scapulohumeral coordination should involve all three planes of motion as research involving three-dimensional scapulohumeral coordination measures that can improve our understanding of factors that may influence the development of shoulder pain.

An alternative method for quantifying joint coordination rather than scapulohumeral rhythm is coordination analysis based on the tenets of Dynamical Systems Theory, which evaluates movement patterns as synergistic organizations of sub-systems which represent multiple degrees of freedom. This organization arises based on anatomical (skeletal alignment) and biomechanical factors (length-tension relationships) as well as environmental and task constraints.[17] Specifically, a window into the function of the neuromuscular system is provided by modeling segments as oscillating pendulums. The coupling (in-time) or uncoupling(out-of-time) between the two segments' oscillations during repetitive movements are representative of the coordination between those two segments.[17]

Coordination analyses of the lower extremity has demonstrated uncoupled joint motions in individuals suffering from lower extremity injury as compared to healthy controls.[18-20] The differences in joint coupling were demonstrated between legs of the same individual and between healthy individuals and those with lower extremity pathology. Furthermore, it has been suggested that uncoupling of the segmental movements in pathologic knees may contribute to the development of knee osteoarthritis. It is thought that increased wear and tear on the articular cartilage occurs as a result of decreased neuromuscular control which results in unequal joint loading.

Similar coordination changes may impact shoulder injury given the repetitive nature of activities that are associated with the development of rotator cuff disease, shoulder impingement, and glenohumeral osteoarthritis. Scapulohumeral coordination analyses that investigate the coupling between the scapula and humerus in all three planes of motion may provide important information to fill this void of knowledge. For instance, uncoupled scapular posterior tipping during humeral elevation may be indicative of the inability of the scapula at the appropriate time during humeral elevation. Current analyses only quantify the amount or range of scapular motion not how these motions are altered by pathology. Thus, characterizations of shoulder movement patterns may be valuable in describing the shoulder's response to changes in initial conditions such as FHRSP.

Therefore, the purpose of this study was to compare three-dimensional scapulohumeral coordination between individuals with and without forward head and rounded shoulder posture (FHRSP) during repetitive shoulder flexion and a standardized overhead reaching task. We hypothesized that individuals with FRHSP would display altered scapulohumeral coordination patterns in comparison to individuals with ideal head and shoulder posture.

Methods

<u>Procedures</u>

Participants were recruited from the university population at The University of North Carolina-Chapel Hill through two informational mass emails sent to the university population. Inclusion criteria for the study included being aged between 18 and 60 and meeting the specific postural alignment criteria. Subjects were excluded if they reported a history of shoulder surgery, upper extremity, cervical or thoracic fracture, displayed functional or structural scoliosis, excessive thoracic kyphosis[21], or if they were currently receiving any treatment for shoulder or neck pain which limited use of their dominant upper extremity. The dominant arm (arm used to throw a ball) was used for testing in all subjects.

Prior to testing participants completed an informed consent form and underwent a postural screening using the BioPrint® postural analysis system (Biotonix Inc., Montreal) to ensure that participants met the inclusion criteria for the ideal posture and forward head and shoulder posture groups. Postural screening included measurement of forward head angle (FHA) and forward shoulder angle (FSA). The ideal posture group criteria was defined as FHA $\leq 36°$ and FSA $\leq 22°$ (Figure 1 and 2). The FHRSP group criteria was defined as FHA $\geq 46°$ and FSA $\geq 52°$ (Figure 1 and 3). Subject demographics for the ideal posture group (n=40) and the FHRSP group (n-40) are listed in Table 1.

All participants meeting the inclusion criteria were scheduled for a 90 minute testing session within 1 month of the initial screening. Participants were asked to avoid upper extremity weight lifting and overhead activities on either day of testing.

During the second testing session three dimensional shoulder kinematic analyses were conducted to assess humeral and scapular angles during the ascending (up) and descending

(down) phases of loaded shoulder flexion and reaching tasks. Specifically, humeral

elevation, scapular upward/downward rotation (UR), scapular external/internal rotation (IR),

and scapular posterior/anterior tipping (PT) were evaluated during a loaded arm elevation

flexion task (arm in front of body) and a forward-overhead reaching task. Participants were

asked to perform 25 cycles of both arm elevation and forward reaching task at a self selected

speed during testing. Ratings of perceived exertion based on Borg's modified scale

suggested subject's experienced fatigue during repetitions 15-25. Based on these ratings,

only the first 15 repetitions were used for analysis due to the likely effects of fatigue. The

order in which the elevation and reaching tasks were performed was counterbalanced and

participants rested 5 minutes between each task to reduce the potential effects of fatigue,

learning, and task order.

Postural Alignment Criteria

The postural alignment criteria were based on data collected during a pilot study of 310

individuals. Descriptive characteristics of these individuals appear in Table 2.   Frequency

histograms were plotted and measures of skewness and kurtosis were assessed for forward

head and shoulder angles to confirm normality of these measures. Head and shoulder angles

approximately displayed a normal distribution. Therefore, the mean and standard deviations

were used to represent the data. Cutoffs for each group were determined as the mean ± 1

standard deviation for the head and shoulder angle (Table 1). The FHRSP was 1 standard

deviation above the mean and the ideal posture group was 1 standard deviation below the

mean (Table 2). Thus these groups represent an attempt to create two distinctly different

postural alignment groups.

Excessive kyphosis was defined in a similar manner. The mean thoracic angle plus one standard deviation was 50˚. These data represent a similarly aged sample of 300 subjects.[21] One standard deviation is also similar to the average increase in thoracic kyphosis reported to induce changes in scapular kinematics.[22] Participants were excluded if their postural measures did not fall within the stated group criteria. Ninety-two of the 310 individuals screened met these criteria (29%). Forty-seven individuals were assigned to the ideal posture group and 45 to the forward head and rounded shoulder posture group. Twelve individuals did not schedule a return appointment yielding 40 participants in each group.

Data Collection

Postural Analysis

Reflective markers were placed over the right tragus (ear), chin, labella (between eyes), acromion, C_7, T_7, posterior superior iliac spine, and anterior superior iliac spine. Participants then stood 40 cm in front of the scaled backdrop and were given standard instructions to increase reliability of their normal resting postural alignment. High resolution (5.0 mega pixels) digital images were then uploaded to a personal computer for processing. Adobe Photoshop® was used to measure head and shoulder angles.

Kinematic Assessment

A Flock of Birds® (Ascension Technologies, Inc., Burlington, VT) electromagnetic motion analysis system controlled by the Motion Monitor® (Innovative Sports Training, Inc. Chicago, IL) software was used to assess scapular kinematics at a sampling rate of 50 Hz. The primary component of the electromagnetic tracking system is a standard range DC transmitter containing three orthogonal coils that generates an electromagnetic field. The system incorporates a series of three sensors/receivers that record the electromagnetic flux in

the field generated by the transmitter and conveys the signals to a recording computer via hard wiring.

Three electromagnetic tracking sensors were attached to: 1.) The thorax over the spinous process of T3, 2.) The dominant shoulder over the broad flat surface of the scapular acromion, 3.) The posterior one third of the upper arm with the sensor over the area of least muscle mass to minimize potential sensor movement. In order to assess the shoulder kinematics, reconstruction of the bony segments was performed following the International Society of Biomechanics-Shoulder Group Recommendations.[23] The bony landmarks were: T_{12}, medial and lateral epicondyle of the humerus, T_8, xyphoid process, C_7, sternal notch, spine of the scapula at the medial border, posterior-acromion of the scapula, inferior angle of the scapula, and the glenohumeral joint rotation center. The glenohumeral joint center was defined by the point that moves least with respect to the scapula when the humerus is moved through short arcs ($\leq 45°$) as calculated by a least squares algorithm and has been shown to best represent the glenohumeral joint center.[24]

The electromagnetic transmitter was positioned on a custom stand allowing for the establishment of a global reference system. The global reference system axes were defined such that the Y-axis was designated as positive in the superior direction, the Z-axis was designated as positive to the right, and the X-axis was designated as positive anterior, all relative to the participant. The local axes systems all aligned with the reference axes of the electromagnetic system to simplify data reduction.

Data Reduction and Processing

Kinematic Data

Three-dimensional coordinates of the digitized bony landmarks were calculated using the Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL). Segment reference frames were defined according to the recommendations set forth by the Shoulder Group of the International Society of Biomechanics.[23] Humeral motions were calculated as the Euler angles of the humerus relative to the world reference frame in the following order of rotations: internal-external rotation about Y axis, elevation about the Z' axis, and internal-external rotation about the Y" axis.[25] Scapular motions were calculated as the Euler angles of the scapula relative to the world reference frames in the following order of rotations: internal/external rotation about the Y axis, upward-downward rotation about the X' axis, and posterior-anterior tilting about the Z" axis.[23, 26] Kinematic data were smoothed through a Butterworth a low pass digital-filter (4th order, recursive, zero phase lag) at an estimated optimum cutoff frequency of 3.5 Hz. The estimated optimum cutoff was determined after performing a spectral analysis for each kinematic variable. All humeral and scapular rotation spectral plots were similar.

Coordination Measures

The humeral and scapular kinematic data were analyzed using custom Matlab (Mathworks, Natick, MA) code to calculate the coordination measures. Shoulder kinematic data was smoothed further using a cubic spline routine with of 0.9. The tolerance of the cubic spline routine can be set from 0 to 1 where 0 is a perfect least squares fit between the first and last point of the data sequence, and 1 is the natural spline. The tolerance of the spline routine was set at .7 where 0 is a perfect least squares fit between the first and last point of the data sequence, and 1 is the natural spline.

The mean ensemble curve is the curve generated by averaging all single cycle relative phase curves. This required normalization of all single cycle relative phase curves to a fixed number of points (i.e., 101) for each task. Shoulder kinematic data from each repetition of both elevation and reaching tasks were spline fit to 101 points for 15 repetitions for humeral elevation and each scapular motion. Only 15 repetitions were selected based on the potential effects of fatigue. This was supported by a significant increase in PRE values from 13 at the 15th repetition, to 15 at the 20th repetition, to 17 at the 25th repetition. Angular position and angular velocity was plotted to create phase portraits for humeral elevation, scapular upward rotation, internal rotation, and posterior tipping. The relative phase was calculated between humeral elevation and each scapular motion. Relative phase for a given segment was calculated from the phase angle of each phase portrait. The phase portrait path was transformed from Cartesian (x,y) to polar (r,θ) with a radius r and a phase angle θ. The angle formed by the radius was calculated as: [17]

$$\Theta_i = \tan^{-1}\left(\frac{Yi}{Xi}\right)$$

The angle formed between the horizontal and r for each point i was the phase angle.

The relative phase angle between each of the scapular rotations and humeral elevation was then calculated as the difference between the proximal segment's phase angle and the distal segment's phase angle:[17]

$$\Phi_{i\ \text{relative phase angle}} = \theta_{i\ \text{proximal phase angle}} - \theta_{i\ \text{distal phase angle}}$$

Calculation of mean absolute relative phase (MARP) and deviation phase (DP) allowed for statistical comparison of differences between relative phases. Each continuous relative phase curve was quantified in one term, the mean absolute relative phase (MARP).

This value reflects whether the oscillating segments are in or out of phase during a movement cycle. The MARP value was calculated by averaging the absolute value of all the points of the mean ensemble curve.[17]

$$MARP = \sum_{i=1}^{N} \frac{|\phi relativephase|}{N}$$

Additionally, the deviation phase (DP) was calculated to determine the variation over the entire relative phase curve. This value is reflective of the stability of the neuromuscular system during a movement pattern. DP was calculated by averaging the standard deviations (SD) of all the points over the entire mean ensemble curve.[17]

$$DP = \frac{\sum_{i=1}^{N} SDi}{N}$$

Statistical Analysis

Separate mixed model ANOVA (group x phase) were used to compare for scapular upward/downward rotation-humeral elevation, internal/external rotation-humeral elevation, and posterior/anterior tipping-humeral elevation MARP and DP values (dependent variables) between the ideal and forward head and rounded shoulder groups (independent variable). Each analyses involved phases (ascending and descending) of humeral elevation as within participant factors. Statistical significance was set a priori at $\alpha < .05$ for all analyses. Tukey's post hoc analyses were performed to investigate significant and interactions effects.

Alterations in coordinative patterns were graphically analyzed by plotting the relative phase angles over each movement cycle. Changes in slope, minima, maxima, cusps, and the number of reversals within each continuous relative phase plot were noted.[17] Relative phase values were also qualitatively assessed. Relative phase values closer to 0° suggest a more coupled relationship between two segments while values closer to 180° suggest an uncoupled

relationship. Positive relative phase angles indicate the distal segment is leading the proximal segment and negative angles the converse.

Results

Flexion Task

Mean Absolute Relative Phase

The scapular internal/external rotation and humeral elevation MARP values during the flexion task were not affected by postural group (Table 3). There was not a significant main effect involving group or a group by phase interaction for scapular upward/downward rotation-humeral elevation or scapular internal/external rotation-humeral elevation MARP values during the flexion task (Table 3). These results indicate that on average the FHRSP and ideal posture groups displayed similar coordinative patterns between scapula upward/downward rotation and humeral elevation during the ascending and descending phases of the flexion task.

Scapular anterior/posterior tipping and humeral elevation MARP values were influenced by posture group and phase of humeral elevation. There was a significant main effects for group (p = 0.01, ES = 0.42). However, there was no significant interaction between phase of humeral elevation and postural group on scapular anterior/posterior tipping-humeral elevation MARP values (Table 3). These results indicate that on average individuals in the FHRSP group displayed greater MARP values. This indicates the FHRSP group displayed a more out-of-phase relationship with greater uncoupling between the humerus and scapular anterior/posterior tipping with humeral elevation during the flexion task in comparison to the ideal posture group (Figure 11). The mean difference of scapular anterior/posterior tipping-humeral elevation MARP values between groups was 14°.

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Deviation Phase Values

There were no significant main or interaction effects involving group on scapular upward/downward rotation-humeral elevation or scapular anterior/posterior tipping-humeral elevation DP values (Table 4). These results indicate that on average the stability of scapular upward/downward rotation and anterior/posterior tipping-humeral elevation coordinative patterns were similar when comparing individuals with forward head and rounded shoulder posture and those with ideal posture.

However, there was a significant main effect for group on scapular internal/external rotation-humeral elevation DP values ($p = 0.044$, ES = .56). These results show that on average the FHRSP group displayed smaller DP values indicating a less flexible coordinative pattern for scapular internal/external rotation and humeral elevation (Figure 12).

Reaching Task

Mean Absolute Relative Phase

Postural group had an effect on scapular upward/downward rotation-humeral elevation coupling during the reaching task. There was a significant interaction effect between postural group and phase of humeral elevation ($p = 0.011$) (Table 3). Tukey's post hoc testing revealed significant differences in MARP values between groups during the ascending phase (MSD = 3°). The increase in MARP values during the ascending phase suggests decreased coupling between scapular upward rotation and humeral elevation (Figure 13).

Postural group did not have an effect on scapular internal/external rotation or anterior/posterior tipping-humeral elevation MARP values during the reaching task. There were no significant main or interaction effects for group or group by phase for these scapular

rotations (Table 3). These results indicate that scapular internal/external and anterior posterior tipping displayed similar coordinative patterns with the humerus during the reaching task.

Deviation Phase

Postural group also did not have an effect on scapular upward/downward rotation, internal/external, or anterior/posterior tipping DP values during the reaching task. There was not a significant main or interaction effect involving group on these dependent variables (Table 4). These results indicate that on average the stability of the scapular coordinative patterns between postural groups was similar during an overhead reaching task.

<u>Graphical Analyses</u>

Graphical differences were noted in the shapes of the scapular upward/downward rotation-humeral elevation relative phase plots between postural groups (Figures 5and6). The FHRSP group displayed a more out-of-phase coordinative pattern, since the relative phase curve for this group exhibited values further away from zero. This suggests less coupling between the humerus and scapula during the flexion and reaching tasks for the FHRSP group. This difference was mostly evident in the first and last 25% of both tasks. Comparison of scapular internal/external rotation-humeral elevation relative phase plots revealed differences in the coordinative patterns between the two groups. Specifically, the FHRSP group showed a positive shift in the values of the relative phase (Figures 7and8). This was evident over the entire movement cycle of both tasks. Furthermore, the flexion task showed larger changes in the coordinative coupling between the scapula internal/external rotation and the humeral elevation than the reaching task. This is shown by the larger range of values presented in Figure 8 when compared with Figure 7. This suggests that the

coordinative relationships between the humerus and scapula changed more often during the reaching task.

The FHRSP group displayed a negative shift in the scapular anterior/posterior tipping-humeral elevation phase plot (Figures 9and10). This shift suggests a more out-of-phase coordinative relationship between the scapular anterior/posterior tipping and humeral elevation for the FHRSP group. This was present for both tasks. Specifically, during the reaching task this difference was most apparent during the end of the ascending phase and beginning of the descending phase. It was most apparent for the flexion task during the ascending phase. Furthermore, distinct differences in the overall coordinative patterns between humeral elevation and scapular anterior/posterior were noted between tasks. The reaching task exhibited much larger values indicating a more pronounced out-of-phase coordinative relationship.

Discussion

The purpose of this study was to compare shoulder joint coordination between individuals with and without FHRSP during repetitive overhead tasks. The observed increases in MARP values indicate that individuals with FHRSP display uncoupled or out-of-phase scapulohumeral coordinative patterns for scapular upward/downward rotation during the ascending phase of the reaching task. Individuals with FHRSP also displayed uncoupled or out-of-phase scapular anterior/posterior tipping during the entire flexion task. Decreased DP values for scapular internal/external rotation during the flexion task indicate a less flexible scapulohumeral coordinative pattern for individuals with FHRSP during the flexion task. Together, these differences suggest altered scapular control strategies between individuals with and without FHRSP.

Individuals with FHRSP increased MARP values indicate an uncoupled or out-of-phase coordinative pattern between scapular upward/downward rotation and humeral elevation during the ascending phase of the overhead reaching task. Visual inspection reveals the observed increases in MARP values were the result of a negative shift in the relative phase angles during the first 25% of the overhead reaching task (Figure 3). The negative shift in relative phase angles during the early and late phases of both tasks indicate the larger proximal phase angles during these portions of each tasks. This negative shift by the FHRSP group may reflect a humeral control strategy for scapular upward/downward rotation during the early and late portions of the reaching task.

The out-of-phase humeral control strategy in individuals with FHRSP may represent a loss of dynamic scapular stability during the early and late phases of humeral elevation. The scapula is almost entirely stabilized by peri-scapular musculature. In the upper ranges of humeral elevation muscles and joints moving toward their end range may provide passive scapular stability. The lack of passive stability in the mid-ranges of humeral elevation would require increased dynamic stability and neuromuscular control. This is supported by examining the relative phase curves for scapular upward/downward rotation during the reaching task (Figure 7). Scapular upward rotation-humeral elevation relative phase angles show increased coupling during the middle portion of the reaching task. This is supported by the shift in scapulohumeral rhythm (SHR) from 2:1 in the mid-ranges, to 1:1 in the upper ranges of humeral elevation.[27, 28] The shift in SHR indicates an increase in the rate of scapular upward rotation in the upper ranges of humeral elevation which is similar to the observed increase in coupling (or in-phase relationship) during the middle of the reaching task.

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The decrease in SHR is likely the result of the capsuloligamentous and musculature about the shoulder girdle engaging the scapula at higher ranges of humeral elevation. The increase in passive tension as tissues are pulled taut necessitates humeral elevation and scapular upward rotation becomes more coupled by decreasing the degrees of freedom available to the movement system. The taut tissues also increase the passive stability about the scapula requiring less dynamic stability required to facilitate humeral elevation. The more uncoupled and out-of-phase scapulohumeral coordination for upward/downward rotation suggests a decrease in dynamic scapular stability and control during the early and late phases of the reaching task.

Increased MARP values for the FRHSP group were also observed for scapular anterior/posterior tipping and humeral elevation during the flexion task. The increase in the FHRSP group's MARP values indicates scapular anterior/posterior tipping and humeral elevation were more uncoupled and out-of-phase during the flexion task. The FHRSP also displayed a negative shift in the relative phase curve indicating a humeral control strategy over the entire movement cycle of both tasks (Figure 7). The increase in humeral elevation and more anteriorly tipped resting position are possible explanations for the uncoupled and out-of-phase humeral control strategy by individuals with FHRSP. The plane of humeral elevation influences the contribution of scapular rotations to total shoulder elevation, and sagittal plane humeral elevation elicits a greater contribution of scapular anterior/posterior tipping.[29, 30] Furthermore, as humeral elevation angles increase the rate of scapular posterior tipping increases.[31, 32] Since all individuals used more humeral elevation during the flexion task compared to the reaching task (31°), it is reasonable to conclude that these differences occurred during the upper ranges of humeral elevation. This is supported by the visual

separation of the ideal and FHRSP relative phase curves during the middle portion of the flexion task. Individuals in the FHRSP group also presented with an increase in resting scapular anterior tipping position (9°). This would place the posterior structures in a lengthened position thereby engaging scapular posterior tipping at a lower humeral elevation angle during the reaching task. Similar to scapular upward/downward rotation during the reaching task the altered passive tension may contribute to the altered scapular control strategy.

A decrease in the FHRSP group's DP values for scapular internal/external rotation indicates a less flexible movement pattern during the reaching task. The smaller DP values suggest individuals with FHRSP scapular internal/external rotation pattern used a less variable scapular movement pattern when compared to individuals with ideal posture. The less flexible movement pattern is likely the result of the smaller range of available scapular internal/external rotation to each group. The FHRSP group was in a more internally rotated position at rest (14°). The physiological limits of the scapula to protract and internally rotate around the thorax are limited by the posterior musculature. Since the FHRSP group was much farther into this range there were fewer degrees of freedom available to the movement system resulting in a loss of flexibility of the movement system. Additionally, the flexion task was also standardized to the sagittal plane defined as perpendicular to the 5th metatarsal on the testing side. This task required minimal shoulder girdle horizontal adduction compared to the reaching task. Shoulder girdle horizontal adduction was likely accomplished by combining humeral adduction, scapular protraction, and scapular internal rotation. Since thoracic motion was minimized, the ideal posture group would have more degrees of freedom available compared to the FHRSP group. Considered together, the

results across all three scapular rotations suggest that the demands of each task highlighted scapulohumeral coordination strategy differences between individuals with and without FHRSP.

The observed alterations in shoulder coordination may have important implications on shoulder function. Postural malalignments, such as increased forward head and shoulder angle, are analogous to altering the initial conditions of a mechanical system. Dynamical Systems Theory (DST) hypothesizes that changes in the initial conditions predicate changes in neuromuscular control strategies.[17] Increased MARP values indicate more uncoupled and out-of-phase coordination between the scapula and humerus. Smaller DP values indicate less variable coordination between the scapula and humerus. Scapulohumeral coordination of upward/downward rotation during the early and late phases of shoulder elevation is important to shoulder function. The scapula must be stabilized to allow for optimal force generation by muscles creating shoulder elevation to achieve the goals of the overhead task.

The loss of scapular stability may increase the demands on the shoulder elevators and potentially increase stress to the glenohumeral joint tissues. This is supported by reports of decreased shoulder strength due to alterations in scapular position.[22, 33] Therefore, in order to increase overall force production either more muscles must be used or increased motor units recruited from those muscles to achieve the overhead task. This may lead to fatigue and/or compensatory muscle synergies placing increased stress on muscles such as the long head of the biceps and supraspinatus. Alterations in scapular upward/downward rotation coordination patterns during the early phases of elevation may lead to superior humeral head migration and increased compressive forces on the tissues within the subacromial space [34, 35]. Additionally, the loss of coupling between the humerus and scapular downward rotation

during the descending phase may place greater tensile stress on the rotator cuff, especially in light of recent evidence showing the greatest stress on the rotator cuff occurs as the arm is lowered from an elevated position due to the rotator cuff's length-tension curve.[36] Greater stress may be placed on the rotator cuff due to increased force requirements, increase in subacromial forces, decreased as well as subacromial clearance and overtime may contribute to repetitive overuse injuries associated with neck and shoulder disability such as degenerative rotator cuff disease.

Interestingly, alterations in scapular angles or ranges of motion have not been noted in the lower ranges of humeral elevation when comparing individuals with shoulder impingement.[13-15, 37] Coordination measures used in this study reflect the velocity and angular position interaction of the humerus and scapula. Traditional kinematic analysis of the shoulder controls for velocity of movement and references scapular motion to humeral elevation thereby limiting the amount of information available to detect differences. The more uncoupled and out-of-phase scapula upward/downward rotation-humeral elevation coordinative patterns displayed by individuals with FHRSP may be a risk factor for the development of shoulder pain.

The observed increase in MARP values in those with FHRSP also indicates a more uncoupled and out-of-phase scapular anterior/posterior tipping coordinative pattern. Increases in scapular anterior tipping are the most consistent finding reported in individuals with shoulder pain.[13-15, 37] Research has shown that increases in scapular anterior tipping decrease the subacromial space, which is thought to contribute to mechanical impingement of the rotator cuff based on Neer's model of impingement [38]. The observed uncoupled and out-

of-phase scapular anterior/posterior tipping coordinative patterns may place individuals with FHRSP at risk of extrinsic mechanical rotator cuff impingement.

Smaller DP values suggesting decreased variability in scapular internal/external rotation coordinative patterns may also have important implications for shoulder function. Individuals with FHRSP may be at risk for the development of shoulder pain given the loss of variability during repetitive reaching task. Repetitive arm elevation is a known risk factor for the development of shoulder pain.[6, 9] The loss of variability displayed by scapular internal/external rotation coordination patterns may limit the time available for normal stress adaptations by musculoskeletal tissues. Decreased variability for a given movement pattern also limits the ability of the body to distribute stress efficiently across tissues thereby placing the tissue at risk for injury.[39] This may be particularly harmful for scapular internal/external rotation coordination patterns as increases in scapular internal rotation are associated with increased strain on the anterior-inferior glenohumeral ligament [40] and decreases in shoulder strength.[33] Chronic increases of strain on the anterior-inferior glenohumeral ligament could lead to excessive glenohumeral translation during overhead activities. Additionally, sustained overhead activities in the more internally rotated position may increase stress on the shoulder elevators leading to fatigue and potentially overuse tendonitis. These alterations in neuromuscular control of the shoulder in healthy individuals with FHRSP may capture a potential risk factor for the development of chronic shoulder pain and should be further investigated.

Our results support the clinical observation that individuals with FHRSP display altered shoulder joint coordination.[41, 42] Clinically, this is often termed scapular dyskinesis and described as uneven and uncoordinated scapular movement. Design and implementation

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of a valid and reliable scapular movement classification system has proven difficult.[43] Our results suggest examining shoulder movements using a coordination analyses may provide new and valuable information in the development of clinical assessments aimed at identifying alterations in shoulder joint coordination. Alterations in relative phase dynamics has been shown to be visually perceptible for upper extremity motion.[44] This is important considering that scapular dyskinesis is most often evaluated clinically by visual analysis of the scapula during humeral elevation. Future studies should identify valid and reliable clinical correlates with changes in shoulder coordination.

Three-dimensional scapulohumeral coordination patterns should be examined as a potential risk factor for injury based on reported alterations in lower extremity coordination patterns.[19, 39, 45] Lower extremity coordination patterns indicated by changes in MARP values suggest patients two years post anterior cruciate ligament (ACL) reconstruction displayed altered locomotive strategies during walking and running. [45] Following ACL reconstruction, these patients displayed less coupled coordinative patterns between the foot and shank as well as the shank and thigh. The magnitudes of these differences are similar to those reported in this study (4°-14°).

Decreased variability and lower extremity couplings have also been reported in patients diagnosed with patellofemoral pain syndrome.[19, 46] In contrast to the results of our study, individuals with altered lower extremity posture (Q-angle) did not display altered lower extremity coordination patterns.[47] This may suggest that the underlying neuromuscular control strategies for the upper and lower extremities may respond differently to variations in postural alignment. The discrepancy between our results and the effects of lower extremity postural alignment on coordination may be a reflection on the specific coordination measures

used to compare postural alignment groups. Our results reflect alterations in angular position and velocity while the aforementioned studies only analyzed relative angular position between segments.[19, 46] Altered patterns of lower extremity joint kinetic variability also have been reported in individuals with self-reported history of overuse injury proneness.[39] While a linear combination of ankle, knee, and hip joint kinetics were associated with injury proneness these patterns were not clear. The variability of forces and moments acting on the lower extremity were examined but not the rate of loading or unloading. This may suggest the role of velocity and its derivative in understanding human movement coordination patterns. Considered together, coordination analyses based on Dynamical Systems theory analyzing changes in segment coupling and movement system variability may provide valuable insights into human movement.

Several limitations should be considered in the interpretation and application of these results. The cross sectional-case control design limits direct cause and effect relationships to be drawn between alterations in scapulohumeral coordination and FHRSP. Additionally, all subjects reported no current shoulder pain limiting the application of these results to healthy shoulders. There was also a significant difference in humeral elevation between groups for the flexion task (FHRSP = 138° ± 8, Ideal = 145°± 11, t = 2.9, p =0.004) but not for the reaching task (Reaching: FHRSP = 108° ± 7, Ideal = 111°± 9, t = 1.5, p =0.13). Given the stated importance of humeral elevation as a mechanism facilitating changes in scapulohumeral coordination all comparisons for the flexion task were reanalyzed using humeral elevation angle and humeral elevation range of motion as covariates. These results did not change the conclusions therefore; differences in humeral elevation did not seem to drive the differences between groups. Finally, there were more females in the FHRSP group

compared to the normal posture group. The dependent variables were re-analyzed using gender as a covariate however, the inclusion of gender as a covariate did not influence the statistical findings.

Conclusions

Coordination analyses based on dynamical systems theory seems valuable in describing the shoulder's response to changes in initial conditions such as altered skeletal alignment. The coordination analysis presented is a unique approach to understanding the robust neuromuscular control of the shoulder girdle. This analysis seems to offer unique information concerning shoulder function by embracing movement variability as evidence of the neuromuscular system's flexibility and adaptability to explore new solutions based on a given situation's constraints.[17]

Table 1.   Descriptive statistics for screened volunteers (n=310)

Characteristics		Mean	SD
Male (n= 132)	Age (years)	30.8	17.3
Forward Head Posture		42.4	4.9
Forward Shoulder Posture		32.6	14.3
Female (n= 178)	Age (years)	36.6	16.4
Forward Head Posture		44.6	5.4
Forward Shoulder Posture		40.3	17.7
All (n=310)	Age (years)	34.2	11.9
Forward Head Posture		41.1	5.2
Forward Shoulder Posture		37.4	15.3

Table 2. Descriptive statistics for study participants (n=80)

Group	Characteristics		Mean	SD
Ideal Posture	Male (n= 21)	Age (years)	32.6	13.3
		Height (cm)	178.4	7.6
		Mass (kg)	72.5	11.3
	Female (n= 19)	Age (years)	34.4	12.6
		Height (cm)	165.8	6.9
		Mass (kg)	60.1	11.2
Forward Head and Rounded Shoulder Posture	Male (n= 15)	Age (years)	39.1	12.5
		Height (cm)	177.0	7.3
		Mass (kg)	95.1	19.5
	Female (n= 25)	Age (years)	35.0	11.3
		Height (cm)	161.7	6.7
		Mass (kg)	77.3	15.4

Table 3. Mean Absolute Relative Phase (MARP) values (degrees) for each scapular rotation during ascending and descending phases of the flexion and overhead reaching tasks.

Scapular Rotation	Phase	Ascending Mean (SD)	Descending Mean (SD)	Group Mean (SD)	F-Ratio	P value	9 (L
Shoulder Flexion							
Scapular Upward Rotation	FHRSP	9 (13)	11 (11)	11 (12)	0.008	0.927	
	Ideal	9 (17)	12 (14)	10 (15)			
Scapular Internal Rotation	FHRSP	30 (16)	31 (7)	31 (12)	0.611	0.437	
	Ideal	32 (17)	34 (13)	33 (15)			
Shoulder Posterior Tipping	FHRSP	59 (29)	52 (23)	55 (26)*	6.844	0.011	
	Ideal	43 (24)	39 (21)	41 (22)*			
Reaching Task							
Scapular Upward Rotation	FHRSP	12 (15) †	10 (13)	11 (12)	0.008	0.927	
	Ideal	8 (11) †	10 (11)	10 (15)			
Scapular Internal Rotation	FHRSP	8 (4)	12 (6)	13 (5)	0.983	0.325	
	Ideal	11 (17)	14 (18)	10 (18)			
Shoulder Posterior Tipping	FHRSP	61 (32)	65 (29)	63 (31)	1.824	0.111	
	Ideal	51 (34)	57 (32)	54 (33)			

* MARP values for FHRSP group > ideal posture group
† MARP values for FHRSP group > ideal posture group during the ascending phase of reaching task.
$F_{(1,78)} = 3.99$, $p = 0.049$, MSD = 3, Mean Difference = 4
Ideal CI (4-12) FHRSP CI (8-16)

Table 4. Deviation Phase (DP) values (degrees) for each scapular rotation during ascending and descending phases of the flexion and overhead reaching tasks.

Scapular Rotation	Phase	Ascending Mean (SD)	Descending Mean (SD)	Group Mean (SD)	F-Ratio	P value	95% CIR (LCI – UCI)
Shoulder Flexion							
Scapular Upward Rotation	FHRSP	5 (5)	5 (4)	5 (5)	0.120	0.730	4 – 6
	Ideal	4 (3)	5 (3)	5 (3)			4 – 6
Scapular Internal Rotation	FHRSP	10 (6)	8 (5)	9 (6) *	4.186	0.44	7 – 10
	Ideal	13 (8)	11 (6)	12 (7) *			10 – 14
Shoulder Posterior Tipping	FHRSP	13 (6)	15 (8)	14 (7)	0.007	0.932	13 – 16
	Ideal	15 (8)	14 (8)	14 (8)			13 – 16
Reaching Task							
Scapular Upward Rotation	FHRSP	7 (6)	5 (4)	6 (5)	0.024	0.879	5 – 7
	Ideal	6 (4)	6 (5)	6 (4)			5 – 7
Scapular Internal Rotation	FHRSP	8 (3)	7 (3)	8 (3)	0.000	0.999	6 – 8
	Ideal	8 (3)	7 (3)	8 (3)			6 – 8
Shoulder Posterior Tipping	FHRSP	21 (13)	21 (12)	21 (7)	0.059	0.809	18 – 24
	Ideal	23 (11)	21 (10)	22 (8)			18 – 25

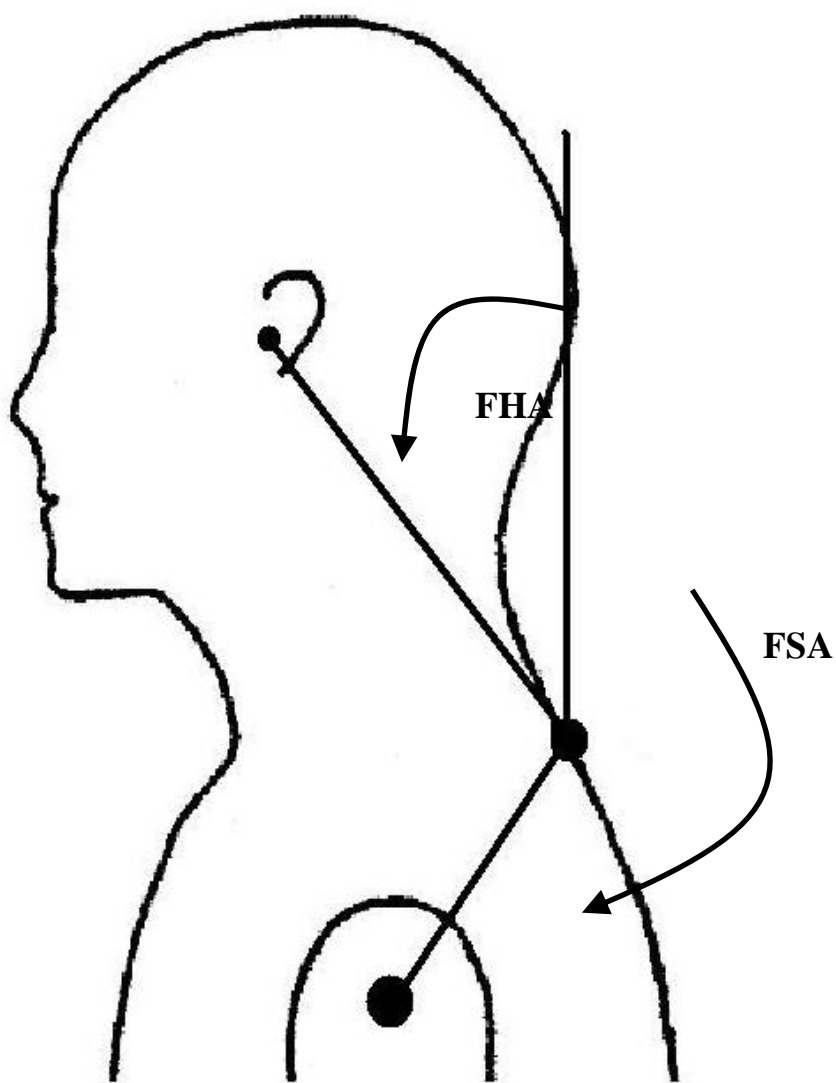* DP values for the FHRSP group < ideal posture group

Figure 1. Forward head angle (FHA) measured from the vertical anteriorly to a line connecting the tragus and the C_7 marker. Forward shoulder angle (FSA) measured from the vertical posteriorly to a line connecting the C_7 marker and the acromial marker.
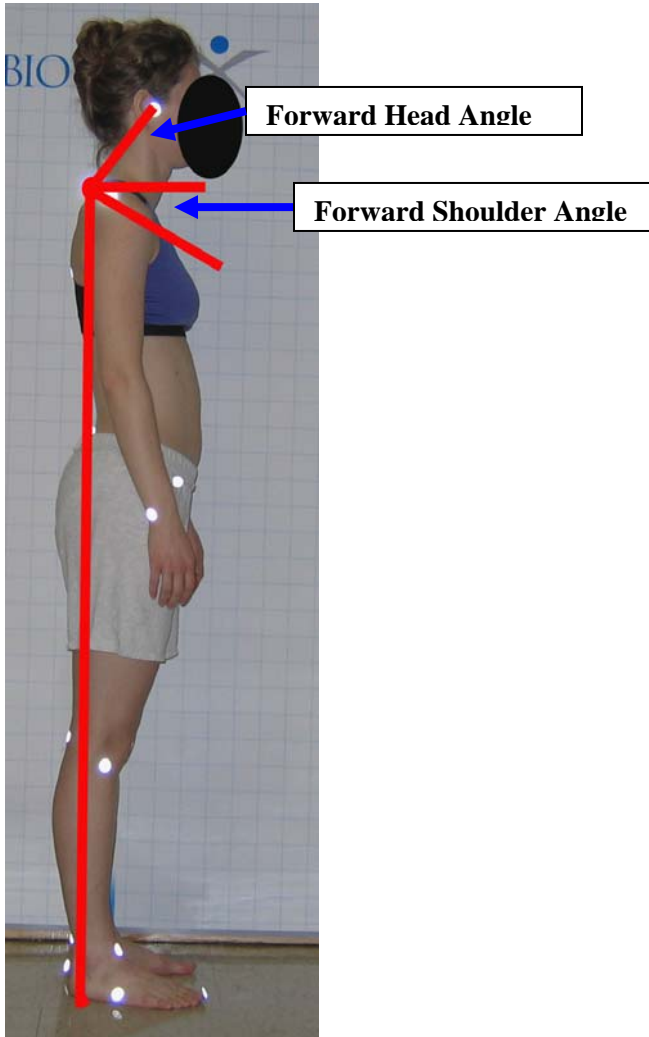
Figure 2. Example of ideal forward
head and shoulder posture
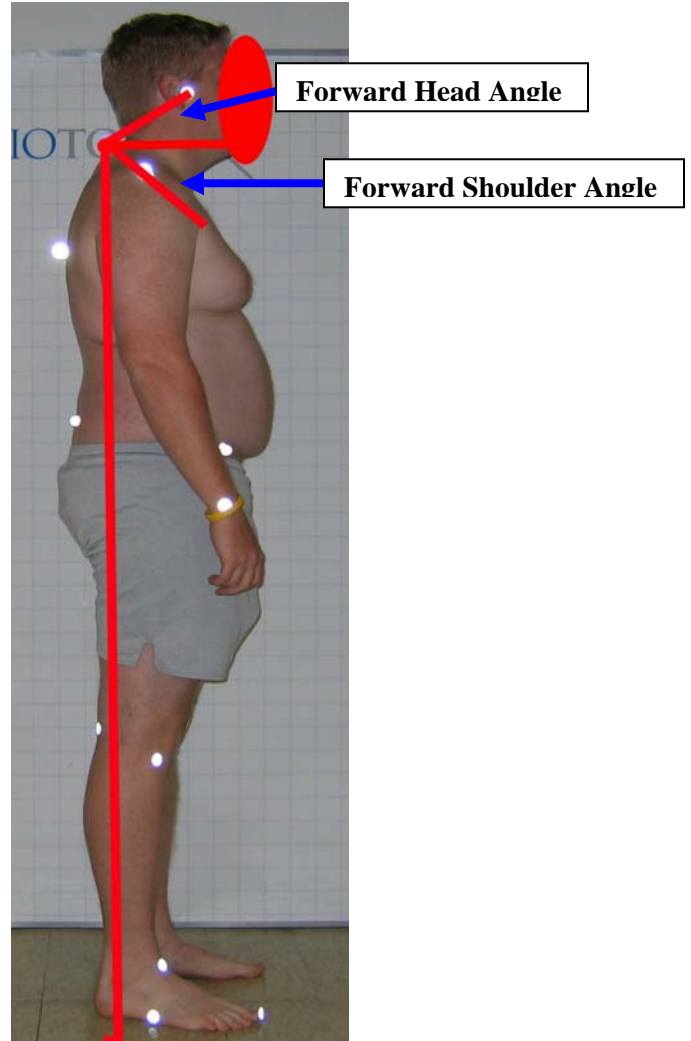Forward Head Angle = 38˚
Forward Shoulder Angle = 22˚

Figure 3. Example of forward head
and shoulder postural posture
Forward Head Angle = 55˚
Forward Shoulder Angle = 60 ˚

Figure 4. Representative phase plot of humeral elevation during the flexion task.
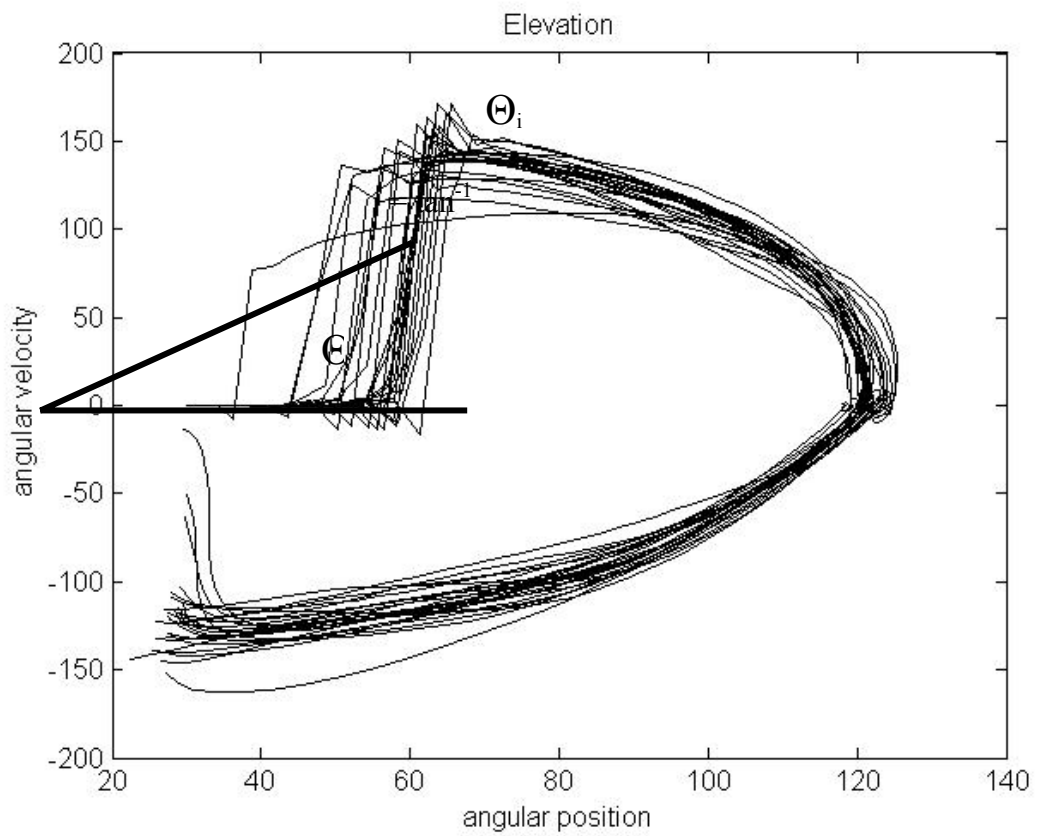
Figure 5. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed similar scapular upward/downward rotation-humeral elevation continuous relative phase curves during the reaching task.
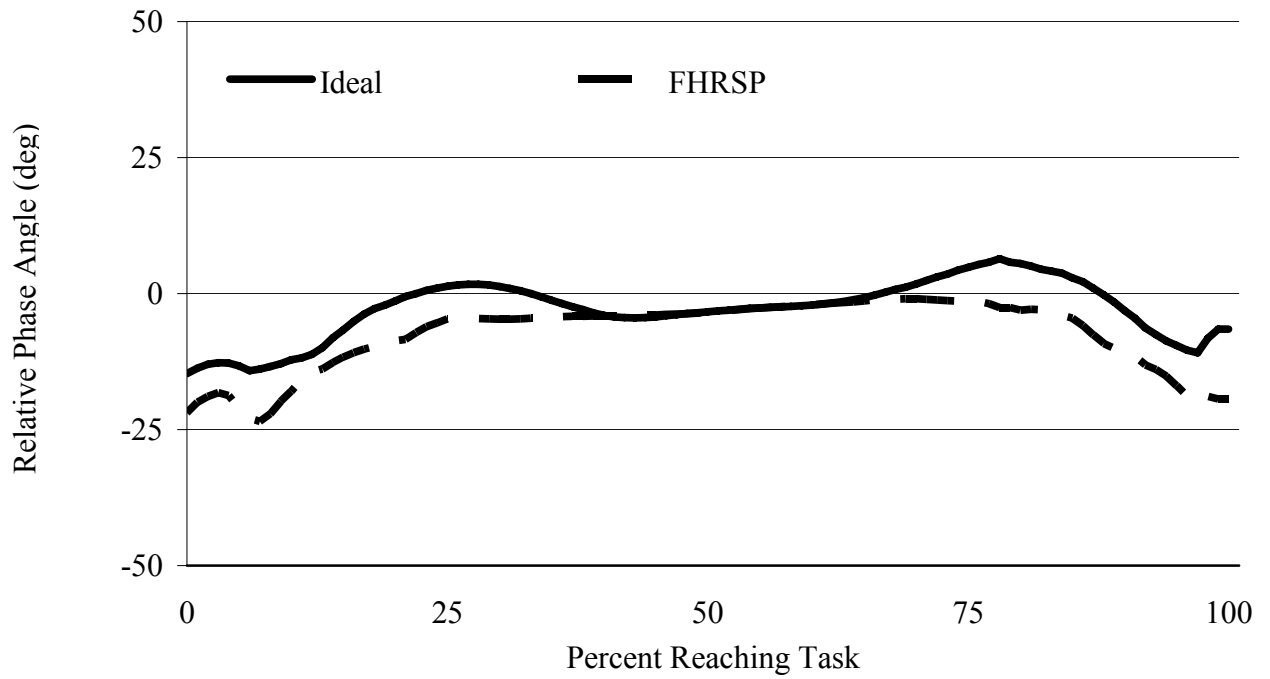
Figure 6. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed similar scapular upward/downward rotation-humeral elevation continuous relative phase curves during the flexion task.
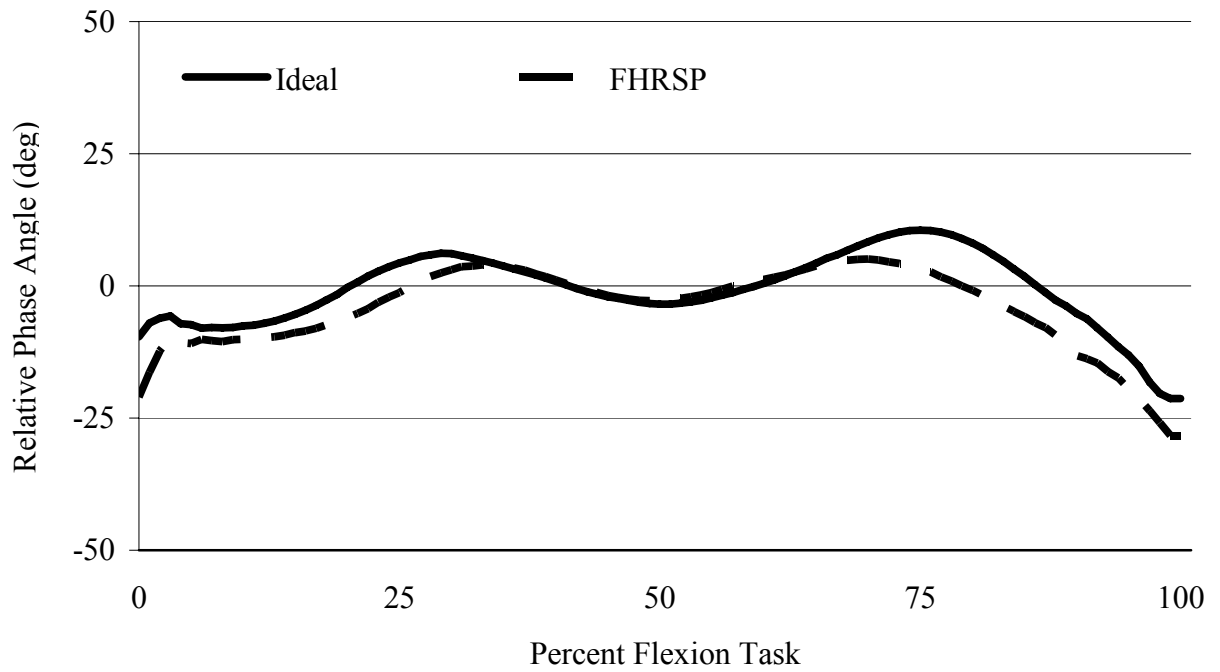
Figure 7. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed similar scapular internal/external rotation-humeral elevation continuous relative phase curves during the reaching task.
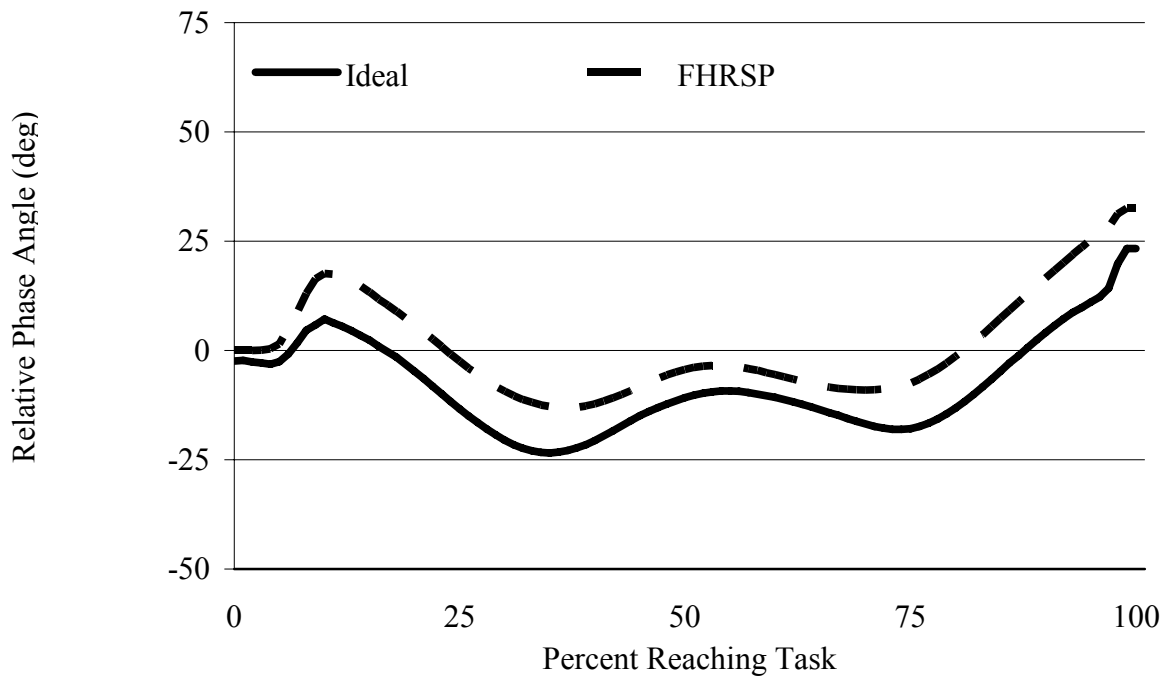
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Figure 8. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed similar scapular internal/external rotation-humeral elevation continuous relative phase curves during the flexion task.
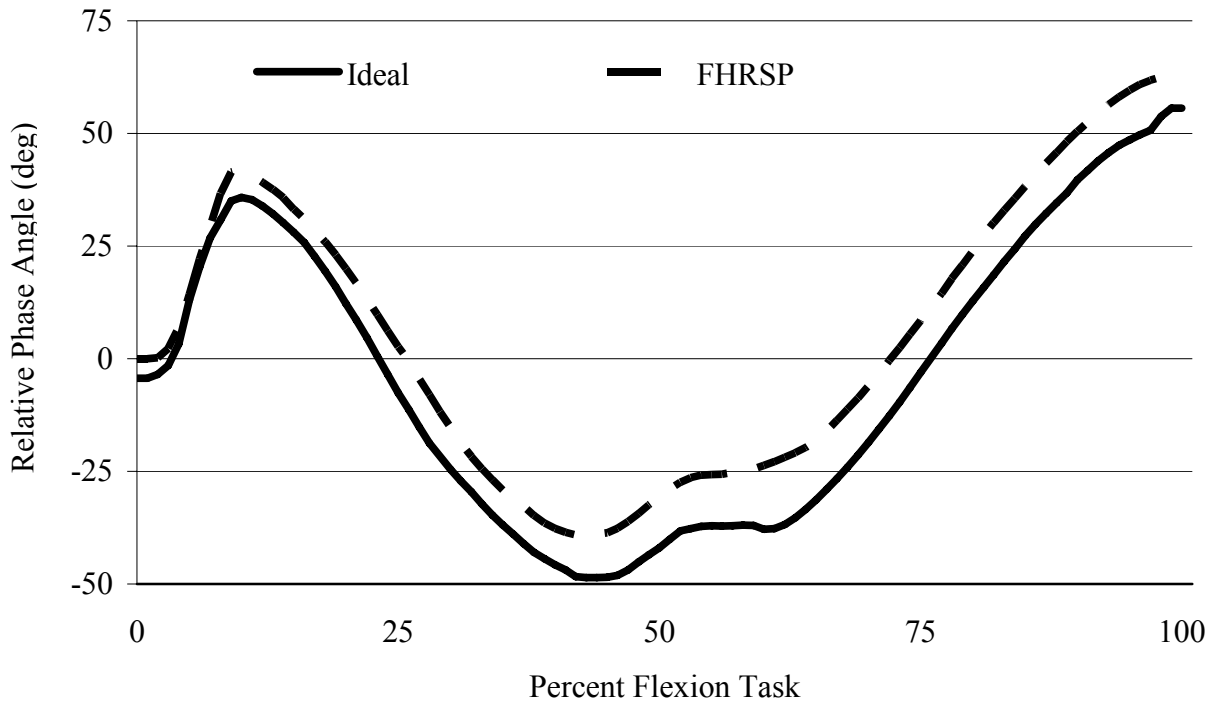
Figure 9. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed similar scapular anterior/posterior tipping-humeral elevation continuous relative phase curves during the reaching task.
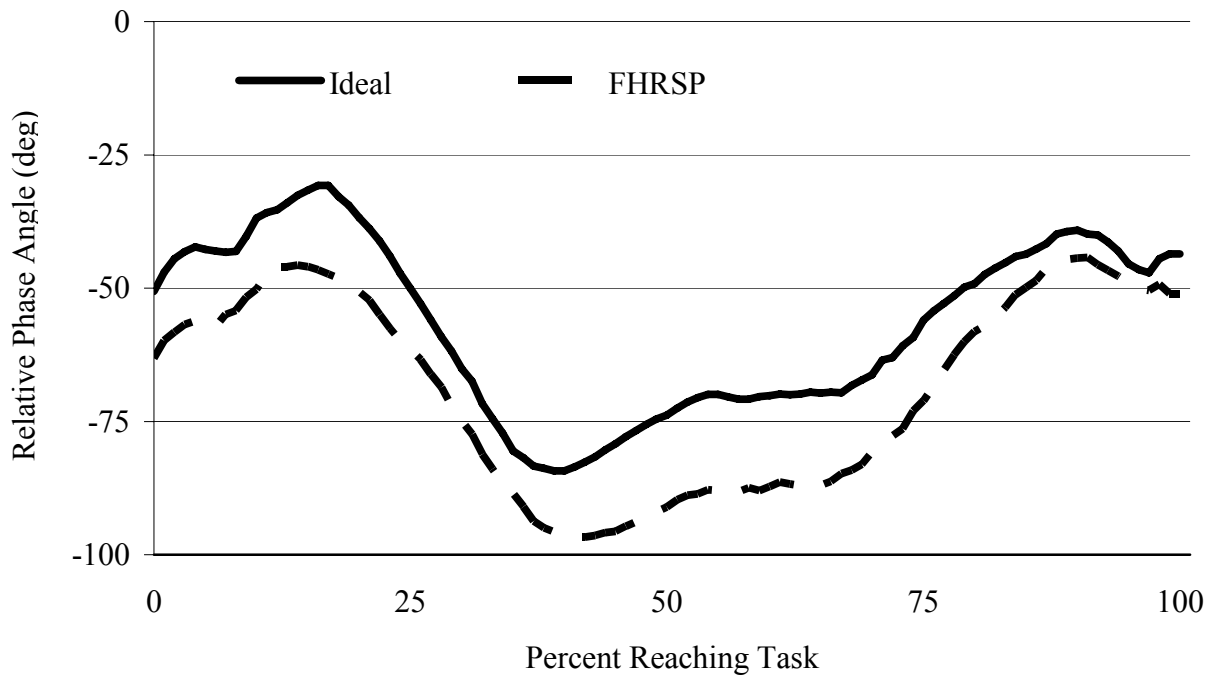
Figure 10. Individuals displaying forward head and rounded shoulder posture (FHRSP) displayed similar scapular anterior/posterior tipping-humeral elevation continuous relative phase curves during the flexion task.
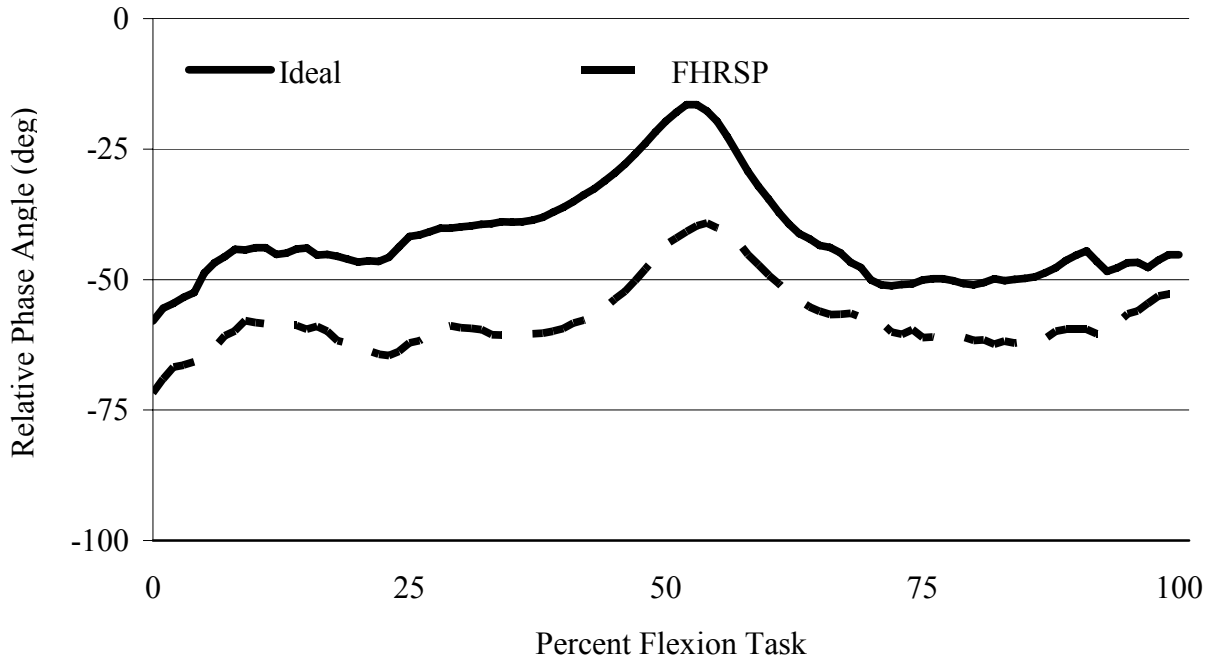
Figure 11 Individuals with forward head and rounded shoulder posture (FHRSP) displayed larger scapular anterior/posterior tipping-humeral elevation mean absolute relative phase values during the flexion task.

* $F_{1,78} = 6.84$, p = 0.01, ES = 0.42

Figure 12. Individuals with forward head and rounded shoulder posture (FHRSP) displayed smaller scapular internal/external rotation-humeral elevation deviation phase values during the flexion task.
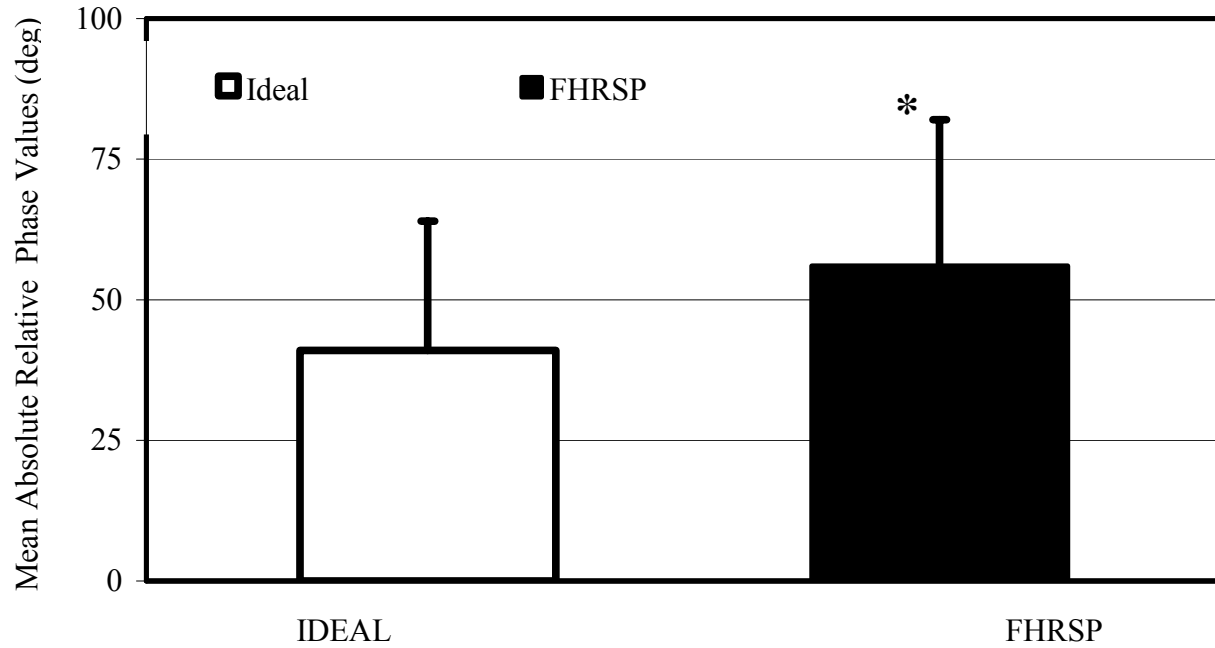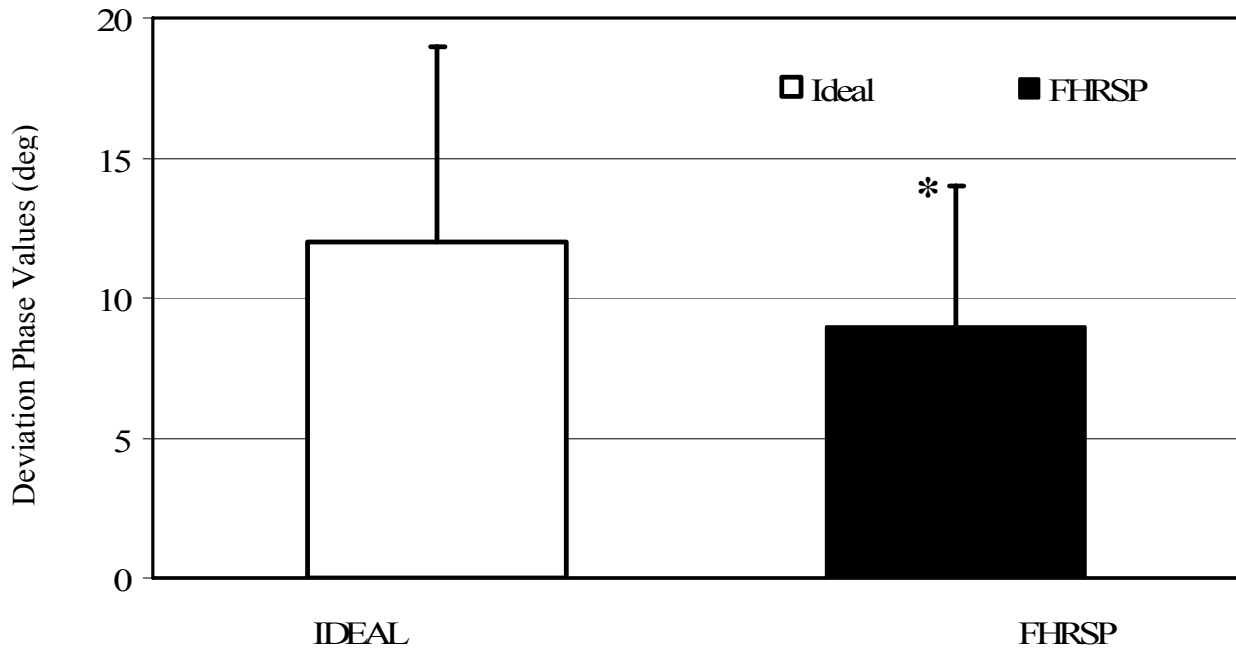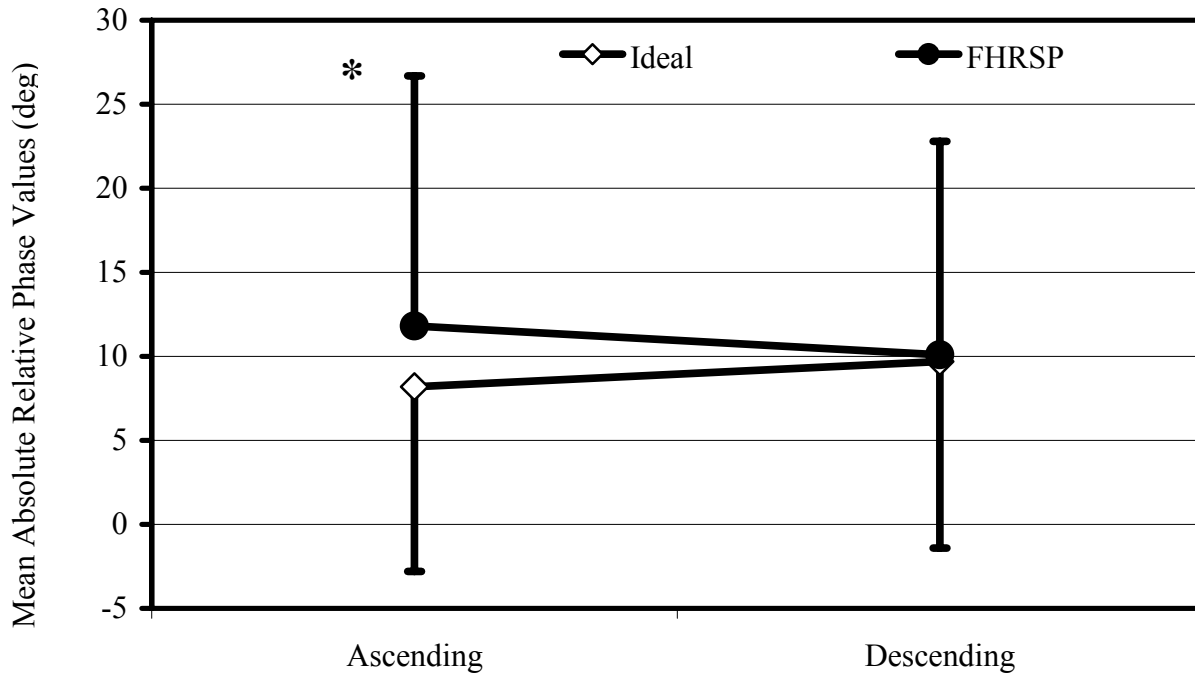
* $F_{1,78} = 4.19$, p = 0.044, ES = 0.46

Figure 13. Individuals with forward head and rounded shoulder posture (FHRSP) displayed larger scapular upward/downward rotation-humeral elevation mean absolute relative phase values during ascending phase of the reaching task.

* $F_{1,78}$ = 3.90, p = 0.05, ES = 0.45; MSD = 2°: Mean Difference 4°

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