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Head & Shoulder Posture Affect Scapular Mechanics & Muscle Activity in Overhead Tasks

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1
2   *Key Words:* shoulder, reaching, three-dimensional kinematics

3
4

1 **Abstract**

2 Forward head and rounded shoulder posture (FHRSP) is theorized to contribute to alterations

3 in scapular kinematics and muscle activity leading to the development of shoulder pain.

4 However, reported differences in scapular kinematics and muscle activity in those with

5 forward head and rounded shoulder posture are confounded by the presence of shoulder pain.

6 Therefore, the purpose of this study was to compare scapular kinematics and muscle activity

7 in individuals free from shoulder pain, with and without FHRSP. Eighty volunteers were

8 classified as having FHRSP or ideal posture. Scapular kinematics were collected

9 concurrently with muscle activity from the upper and lower trapezius as well as the serratus

10 anterior muscles during a loaded flexion and overhead reaching task using an

11 electromagnetic tracking system and surface electromyography. Separate mixed model

12 analyses of variance were used to compare three-dimensional scapular kinematics and

13 muscle activity during the ascending phases of both tasks. Individuals with FHRSP

14 displayed significantly greater scapular internal rotation with less serratus anterior activity

15 during both tasks as well as greater scapular upward rotation, anterior tilting during the

16 flexion task when compared with the ideal posture group. These results provide support for

17 the clinical hypothesis that FHRSP impacts shoulder mechanics independent of shoulder

18 pain.

19

1 **Introduction**

2   Shoulder pain is reported to occur in up to 21% of the general population (Urwin et al.,

3 1998) and is thought to be the result of extrinsic risk factors such as repetitive overhead use

4 ($> 60°$ of shoulder elevation), sustained overhead work, and higher loads raised above

5 shoulder height. (NIOSH, 1997) While these may be important they are likely difficult to

6 modify as many occupational and athletic activities require repetitive overhead activity.

7 Intrinsic risk factors such as forward head and rounded shoulder posture (FHRSP) (Szeto et

8 al., 2002) and altered scapular kinematics and muscle activity (Ludewig and Cook, 2000) are

9 reported in patients with shoulder pain. FHRSP is believed to alter scapular kinematics and

10 muscle activity placing increased stress on the shoulder, leading to shoulder pain and

11 dysfunction. (Kendall et al., 1952, Roddey, 2002, Sahrmann, 2001) It is important to

12 understand the effects of FHRSP on scapular kinematics and muscle activity because FHRSP

13 has been shown to be modifiable (Wang et al., 1999, Falla et al., 2007) and may provide a

14 pathway to improve shoulder mechanics and decrease the risk to develop shoulder pain.

15   Poor posture as defined by increased forward head (Ludewig and Cook, 1996), greater

16 thoracic kyphosis (Finley et al., 2003, Kebaetse, 1999) and an more anterior shoulder

17 position (Borstad and Ludewig, 2005, Wang et al., 1999) have been demonstrated to be

18 associated with altered scapular position, kinematics, and muscle activity. Alterations in

19 scapular kinematics and muscle activity have also been reported in patients with shoulder

20 impingement syndrome and rotator cuff disease. (Ludewig and Cook, 2000, McClure et al.,

21 2004) However, research has not shown a clear relationship between the presence of FHRSP

22 in individuals with shoulder pain. (Greenfield et al., 1995, Lewis et al., 2005, Greigel-Morris,

23 1992) A major limitation in these studies is the presence of shoulder pain during testing,

1   which makes it difficult to determine if differences in posture, scapular kinematics, or muscle

2   activity are the cause of underlying shoulder pathology or are the result of shoulder pain.

3   Additionally, these studies have tended to use non-functional planar tasks which do not

4   reflect shoulder function in overhead tasks. (Amasay and Karduna, 2009) Therefore,

5   examination of scapula kinematics and muscle activity in individuals with FHRSP and

6   without shoulder pain during a functional task is warranted.

7   The purpose of this study was to compare scapular kinematics and muscle activity in

8   individuals free from shoulder pain, with and without FHRSP. We hypothesized that

9   individuals with FHRSP would display less scapular upward rotation as well as greater

10   internal rotation and anterior tilting. We also hypothesized that individuals with FHRSP

11   would display less serratus anterior activity, and lower trapezius activity as well as greater

12   upper trapezius activity compared to individuals with ideal head and shoulder posture.

13   **Methods**

14   *Postural Analysis*

15   While FHRSP has been described clinically for over 50 years, we were unable to identify

16   objective criteria that have been consistently used to define FHRSP. Therefore, we screened

17   310 volunteers from the university population to determine ideal (head over shoulders and

18   acromion in line with trunk) and FHRSP. Prior to testing participants completed an informed

19   consent form and underwent a postural screening to identify FHRSP. Posture was assessed

20   using the BioPrint® postural analysis system (Biotonix Inc., Montreal, CA). Reflective

21   markers were placed over the right tragus (ear), acromion, and C_7 spinous process. Next, the

22   participants stood 40 cm in front of a scaled backdrop, bent forward 3 times, reached

23   overhead 3 times, and were instructed to stand looking straight ahead in their natural resting

1   posture. A Canon Powershot 95 (USA) digital camera was placed on a tripod 1 m high and

2   3.5 m from the wall. High resolution (5.0 mega pixels) digital images were uploaded to a

3   personal computer for processing. Adobe Photoshop® (San Jose, CA, USA) was used to

4   measure forward head angle (FHA) and forward shoulder angle (FSA) based upon the

5   respective angles between the center of the markers (Figure 1).   All angles were measured

6   on 3 separate days and the average FHA and FSA were used for subsequent analysis. The

7   assessor was blinded to previous results when measuring subsequent photos.

8   In order to create distinct groups based on head and shoulder posture, the mean +/- 1

9   standard deviation of the 310 volunteers was used to establish the postural criteria (Table 1).

10   Based on these measures criteria for the ideal posture group were defined as FHA ≤ 36˚ and

11   FSA ≤ 22˚, while the FHRSP group criteria were defined as FHA ≥ 46˚ and FSA ≥ 52˚.

12   Individuals must have met both FHA & FSA to be assigned to the ideal or FHRSP group.

13   Using these posture criteria represented an attempt to create two distinctly different postural

14   alignment groups.

15   Of the 310 subjects screened, 92 (29%) met the postural criteria. Forty-seven individuals

16   were assigned to the ideal posture group, and 45 to the FHRSP group (Table 1). Twelve

17   individuals who were selected did not return for further testing, yielding 40 participants in

18   each group. All qualified subjects were scheduled for a 90-minute test session within 2 weeks

19   of the initial screening for assessment of kinematic and muscle activity. Of the 80

20   individuals who returned for testing 10 with FHRSP and 10 with ideal posture returned for a

21   2nd postural assessment on the same day. Intra-day reliability for FHA and FSA demonstrated

22   acceptable within day reliability (FHA =   Intraclass Correlation Coefficient $(ICC)_{(2,1)}= 0.92$,

23   Standard Error of the Mean (SEM) = 2° and FSA $ICC_{(2,1)}= 0.89$, SEM = 5°) based on this

1 sub-sample. (Portney and Watkins, 2000) FHA and FSA from postural assessment on the

2 initial screening day and on the actual day of testing were used to calculate between day

3 reliability. Inter-day reliability was also acceptable (FHA = $ICC_{(2,k)}$= 0.78, SEM = 4° and

4 FSA $ICC_{(2,k)}$= 0.72, SEM = 7°). All subjects remained in their initial, respective group (ideal

5 vs. FHRSP) classifications.

6 *Subjects*

7   Participants were recruited from the university population who were aged between 18 and

8 60 and met specific postural alignment criteria as described above. Subjects were excluded if

9 they reported a history of shoulder surgery, current shoulder pain limiting activities, upper

10 extremity injury limiting activities, cervical or thoracic fracture, displayed functional or

11 structural scoliosis, or excessive thoracic kyphosis (>50˚). (Vialle et al., 2005) Thoracic

12 kyphosis was calculated using the BioPrint® software using a validated, optimized estimation

13 technique. (Harrison et al., 2007)

14 *Kinematic and Muscle Activity Measurement*

15   Shoulder kinematics and muscle activity were collected during two overhead tasks, a

16 loaded arm flexion task and a forward overhead reaching task with their dominant arm (arm

17 used to throw a ball). The reaching task was developed through pilot testing to simulate tasks

18 commonly reported to increase the risk of developing shoulder pain. (Chiang et al., 1993,

19 NIOSH, 1997) The flexion task was used as previous work has shown it to be the produce

20 the most reliable scapula movement patterns in subjects without shoulder pain and this is a

21 common task used in other studies examining scapular kinematics (Thigpen et al., 2005).

22 Scapular kinematics were collected using a Flock of Birds® (Ascension Technologies, Inc.,

23 Burlington, VT, USA) electromagnetic motion analysis system controlled by the Motion

1   Monitor® (Innovative Sports Training, Inc. Chicago, IL, USA) software. Three

2   electromagnetic tracking sensors with a sampling rate of 50 Hz were attached using double

3   sided tape to the: 1) thorax over the spinous process of C7/T1, 2) dominant shoulder over the

4   broad flat surface of the scapular acromion and, 3) posterior one third of the upper arm with

5   the sensor over the area of least muscle mass to minimize potential sensor movement and are

6   similar as described by previous studies. (Karduna et al., 2001, Ludewig et al., 1996) In

7   order to measure the shoulder kinematics, reconstruction of the bony segments was

8   performed following the International Society of Biomechanics-Shoulder Group

9   Recommendations. (Wu et al., 2005)   The humeral head center was determined as

10   recommended by Stokdjik et al. (2000)

11   Muscle activity of the serratus anterior (SA), upper trapezius (UT), and lower trapezius

12   (LT) muscles was simultaneously measured during the two tasks. Each participant's skin was

13   shaved if needed, cleaned with alcohol, and then a preamplified/active surface EMG

14   electrode configuration (DelSys, Inc., Boston, MA: interelectrode distance = 10mm;

15   amplification factor = 10,000 (20–450 Hz); CMMR @ 60 Hz > 80 dB; input impedance >

16   1015//0.2 X//pF) was placed on the midpoint of each muscle belly parallel to the muscle fiber

17   direction and as described below. A carbon reference electrode was placed over the non-

18   involved acromion. Electrodes were placed in the following arrangement: (Michener et al.,

19   2005a)

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

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

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

23   scapular spine approximately at the angle of the neck and shoulder

1   *Lower trapezius:* two finger widths medial to the inferior angle of the scapula on a

2   45° angle towards T10 spinous process.

3   EMG data were sampled at 1000 Hz using The Motion Monitor motion capture software

4 (Innovative Sports Training, Chicago, IL) then passed via an A/D converter (National

5 Instruments, Austin, TX) and corrected for DC bias.

6 *Maximum Voluntary Isometric Testing*

7   Separate maximal voluntary isometric contractions (MVIC) were performed for the

8 SA (Ekstrom et al., 2003), UT (Ekstrom et al., 2003), and LT (Michener et al., 2005b)

9 muscles based on recommendations of previous literature. EMG activity was recorded for

10 each muscle as subjects performed the MVIC. During MVIC testing, the subjects were

11 instructed to push with a maximal effort for five seconds. There was a 30-second rest period

12 between each MVIC trial and a 1-minute rest period between MVIC testing for each muscle

13 group. Subjects performed practice trials of each test to familiarize them with the testing

14 procedures. All subjects were given standard instructions and encouragement. Subjects were

15 instructed to "push as hard as you can into the pad" then were encouraged by "push, push,

16 push, push" for each MVIC. The average EMG amplitude during the middle 1-second time

17 period was calculated for each trial and then averaged across the three MVIC trials. The

18 average MVIC was used to normalize the EMG values recorded during the two tasks. Thus,

19 EMG data during the loaded flexion and reaching tasks was expressed as a percentage of

20 MVIC (% MVIC).

21 *Flexion and Reaching Tasks*

22   After setup was completed, kinematics and EMG were measured while subjects

23 completed the loaded flexion task and a forward overhead reaching task for 25 repetitions.

1   Task order was randomized and the subjects rested five minutes between tasks to prevent

2   fatigue. The 2nd through 7th trials were used for this analysis to remove any possible effects of

3   fatigue on our results. The first repetition was not used as the movement pattern may have

4   been different during the initial attempt at a task. The flexion task required the participant to

5   lift a weight equal to 3% of their body weight while following a 2-inch target on the wall

6   with their hand while keeping their elbow straight. The target was placed in the sagittal plane

7   in line with the acromion of their dominant arm. Participants were asked to lift their arms

8   from their side through their full range of motion overhead at a self-selected speed. A non-

9   constrained overhead reaching task also required the participant to lift a weight equal to 3%

10 of their body weight. This task only required the subjects use a standard starting and target

11 position on the shelf but did not control plane of elevation or elbow position. The participant

12 lifted the weight from a position of arms relaxed at their side up to target centered in front of

13 the subject, at a distance the length of the arm (acromion to radial styloid) and equal to their

14 body height plus 15%. Three percent of body weight was selected based on pilot testing in

15 order to load the upper extremity without fatiguing the upper extremity. Three percent of the

16 average body mass is equal to 2.25 kg which would be classified as light work based on the

17 US Dictionary of Occupational Titles: Appendix C: Strength Rating. We believed this to be

18 appropriate given the white collar nature of the subjects in this study.

19 *Data Reduction and Processing*

20   The three-dimensional coordinates of the digitized bony landmarks were calculated

21 using the Motion Monitor® software (Innovative Sports Training, Inc. Chicago, IL).

22 Segment reference frames were defined according to the recommendations set forth by the

23 Shoulder Group of the International Society of Biomechanics. (Wu et al., 2005) Humeral

1   motions were calculated as the Euler angles of the humerus relative to the thorax reference

2   frame in the following order of rotations: Humeral internal-external rotation about Y' axis,

3   elevation about the X axis, and internal-external rotation about the Y" axis. (An et al., 1991)

4   Scapula motions were calculated as the Euler angles of the scapula relative to the thorax

5   reference frame in the following order of rotations: internal/external rotation about the Y

6   axis, upward-downward rotation about the X axis, and posterior-anterior tilting about the Z

7   axis. (Karduna et al., 2000, Wu et al., 2005) Kinematic data were smoothed through a

8   Butterworth a low pass digital-filter (4th order, recursive, zero phase lag) at an estimated

9   optimum cutoff frequency of 3.5 Hz as determined by residual analysis of the signal.(Winter,

10 2004)

11   Scapular upward/downward, external/internal and posterior/anterior tilting angles

12 were measured at selected humeral elevation angles during the ascending and descending

13 phase for each task using custom Matlab (Mathworks, Natick, MA) code. The mean value

14 for each scapular angle for 5 consecutive repetitions were analyzed during the ascending

15 (>29° to >119°) and descending (<120° to >30°) phases of loaded shoulder flexion and

16 during the ascending (>29° to >109°) and descending (<110° to >30°) phases of the loaded

17 reaching task. The peak humeral angle during the reaching task did not reach 120° for all

18 subjects therefore data was only analyzed between 30°-110°. Scapular angles were

19 compared at 60°, 90°, and 120° of humeral elevation for the loaded flexion task. Although

20 the reaching task was standardized, participants did not consistently achieve 120° of humeral

21 elevation so scapular angles were compared at 60°, 90°, and 110° of humeral elevation for

22 the reaching task. Each of the scapular and humeral kinematic variables demonstrated

23 acceptable reliability with $ICC_{(2,1)}$ values ranging from 0.92 to 0.99 and SEM values of 1°-2°

1   across the averaged trials for each of the scapular angles, (60°, 90°,120°) during the

2   ascending and descending phases. The selected humeral elevation angles were chosen based

3   on epidemiological studies have identified shoulder activity above 60° to increase the risk of

4   shoulder pain (NIOSH, 1997) and in an effort to limit the number of pairwise comparisons

5   for significant interaction effects.

6   All EMG data were band-pass filtered (10 – 350 Hz) using a Butterworth filter (4th

7   order, recursive, zero-phase lag). The data were further smoothed and rectified by taking the

8   root mean square (RMS) of the EMG signal over a 20 ms time constant. Mean EMG

9   amplitude was calculated during the ascending and descending phase of humeral elevation

10   for the UT, LT, and SA muscles The mean EMG amplitude over the ascending and

11   descending phases of motion was averaged for repetitions 2 to 6 (5 trials) and used for

12   statistical analyses. Each of the EMG variables demonstrated good reliability (ICC$_{(2,1)}$ for

13   UT =0.88, SEM =3%; LT =0.77, SEM =3%; SA =0.90, SEM 3%) across the averaged trials

14   for the ascending and descending phases .

15   *Statistical Analysis*

16   A single one way ANOVA was used to compare subject demographics (age, height,

17   weight) between groups to ensure the groups were similar. Separate mixed model ANOVAs

18   (group x angle x phase) were used to compare scapular upward rotation, internal rotation, and

19   posterior tilting angles (dependent variables) between the ideal and FHRSP groups

20   (independent variable). Each analyses included angles of humeral elevation (loaded flexion

21   task: 60°, 90°, & 120°; loaded reaching task: 60°, 90°, & 110°) as within participant factors.

22   Separate mixed model ANOVAs (group x phase) were used to compare UT, LT, and SA

23   EMG amplitude (dependent variables) between the ideal and FHRSP groups (independent

1   variable). Statistical significance was set a priori at $\alpha < 0.05$ for all analyses. Significant

2   main effects were only considered in the absence of significant interaction effects. Tukey's

3   post hoc analyses were performed to investigate significant main effects and interactions.

4   (Hinkle et al., 1998) Effect sizes were calculated as Cohen's d. (Cohen et al., 2003) SPSS

5   for Windows software (version 13.0, SPSS Inc, Chicago, IL) was used for all statistical

6   analyses.

7
8   **Results**

9   *Subject Demographics*

10   There were no differences between age ($F_{(1,79)} = 0.83$; p =0.77) and thoracic

11   kyphosis angle ($F_{(1,79)} = 1.44$; p =0.24) between groups (Table 1). There was a significant

12   difference between forward head ($F_{(1,79)} = 285$; p < 0.01) and shoulder angle between groups

13   ($F_{(1,79)} = 284$; p < 0.01) as well as mass ($F_{(1,79)} = 23.5$; p <0.01) with the FHRSP group

14   being heavier (Table 1). Given the difference in mass all analyses were performed with and

15   without mass as a covariate. However, no statistical differences were observed. Therefore,

16   statistical analyses without the covariate are reported.

17   *Scapular Rotation Angles*

18   There was a significant main effect of group for the scapular internal rotation angle

19   during the flexion task ($F_{(1,78)} =10.55$; p < 0.01) and reaching task ($F_{(1,78)} =14.44$; p < .01)

20   (Table 2). On average individuals in the FHRSP group displayed greater scapular internal

21   rotation angles in comparison to the ideal posture group during both tasks (Figure 2). The

22   mean difference of scapular internal rotation angles between groups was 8° (Effect Size (ES)

23   = 0.52) for the flexion task and 10° (ES = 0.60) for the reaching task. There were no other

24   significant interaction effects for the flexion task for the group by phase ($F_{(1,78)} = 0.20$; p =

1 0.65), group by angle ($F_{(1,176)} = 0.47$; $p = 0.62$), group by phase by angle ($F_{(1,156)} = 0.14$; $p =$

2 0.87) or reaching task for group by phase ($F_{(1,78)} = 0.54$; $p = 0.46$), group by angle ($F_{(1,176)} =$

3 0.82; $p = 0.44$), group by phase by angle ($F_{(1,156)} = 1.03$; $p = 0.36$) comparisons (Table 2).

4 Average values for the ascending and descending phases as well as group means are provided

5 in Table 2.

6   There was a significant group by angle interaction ($F_{(1,176)} = 10.22$; $p < .01$) regarding

7 the scapular upward/downward rotation angle during the flexion task (Table 2). Post hoc

8 analysis revealed that the FHRSP group displayed greater scapular upward rotation angles at

9 120° during the ascending and the descending phases of humeral elevation in comparison to

10 the ideal posture group. The mean difference between postural groups for scapular

11 upward/downward rotation was 5° (ES = 0.51), indicating that the FHRSP group was in 5°

12 greater scapular upward rotation as compared to the ideal posture group at 120° of humeral

13 elevation of the ascending and descending phases (Figure 3). There were no other significant

14 main or interaction effects for the flexion task for the group ($F_{(1,78)} = 1.37$; $p = .25$), group by

15 phase ($F_{(1,78)} = 0.05$; $p = .83$),group by phase by angle ($F_{(1,156)} = 1.21$; $p = 0.568$) or reaching

16 task for group ($F_{(1,78)} = 0.001$; $p = 0.981$), group by phase ($F_{(1,78)} = 3.78$; $p = 0.06$) , group by

17 angle ($F_{(1,176)} = 1.64$; $p = 0.20$)group by phase by angle ($F_{(1,156)} = 2.29$; $p = 0.11$) comparisons

18 (Table 2). Average values for the ascending and descending phases as well as group means

19 are provided in Table 2.

20   There was a significant effect of humeral elevation phase on scapular

21 anterior/posterior tilting angle during the flexion task ($F_{(1,78)} = 5.71$; $p = .019$) (Table 2). Post

22 hoc analysis revealed that on average the scapula was more anteriorly tilted for the FHRSP

23 group throughout the ascending and the descending phases of humeral elevation when

1 compared to the ideal posture group. The mean difference between postural groups for

2 scapular anterior/posterior tilting angles was 3° (ES=0.32) for the ascending phase and

3 4°(ES=0.34) for the descending phase of the flexion task. There were no other significant

4 main or interaction effects for the flexion task for the group ($F_{(1,78)}$ = 0.40; p = 0.53), group

5 by angle ($F_{(1,78)}$ = 0.06; p = 0.94), group by phase by angle ($F_{(1,156)}$ = 1.92; p = 0.15) or

6 reaching task for group ($F_{(1,78)}$ =0.31; p = 0.58), group by phase ($F_{(1,78)}$ = 0.09; p = 0.77) ,

7 group by angle ($F_{(1,176)}$ = 0.86; p = 0.42), group by phase by angle ($F_{(1,156)}$ = 0.42; p =0.66)

8 comparisons (Table 2). Average values for the ascending and descending phases as well as

9 group means are provided in Table 2.

10 *Muscle Activity*

11 There was a significant interaction effect between humeral elevation phase by

12 postural group on serratus anterior activity during the flexion task ($F_{(1,78)}$ = 5.64; p = 0.02)

13 and the reaching task ($F_{(1,78)}$ = 4.32; p = 0.04) (Table 3). Post hoc analysis revealed that on

14 average there was less serratus anterior activity for the FHRSP group during the ascending

15 phase of the flexion and the reaching tasks when compared to the ideal posture group. The

16 mean difference between postural groups for serratus anterior activity was 13% (ES=0.38)

17 during the flexion task and 6% (ES=0.33) during the reaching task. There were no other

18 significant main effects for the flexion task for the serratus anterior muscle activity for group

19 ($F_{(1,78)}$ = 2.59; p = 0.11), or reaching task for group ($F_{(1,78)}$ == 0.44; p = 0.51).

20 There were no other significant main or interaction effects for the flexion task for the

21 upper trapezius muscle activity for group ($F_{(1,78)}$ = 0.20; p = 0.65), group by phase ($F_{(1,78)}$ =

22 0.76; p = 0.39), or reaching task for group ($F_{(1,78)}$ =0.11; p = 0.74) or group by phase ($F_{(1,78)}$ =

23 0.42; p = 0.52) comparisons (Table 3). There were no other significant main or interaction

1   effects for the flexion task for the lower trapezius muscle activity for group ($F_{(1,78)} = 0.41$; p

2    $= 0.52$) group by phase ($F_{(1,78)} = .01$; $p = 0.5$), or reaching task for group ($F_{(1,78)} = 0.01$; $p =$

3   0.91) or group by phase ($F_{(1,78)} = 0.41$; $p = 0.53$) comparisons (Table 3). Average values for

4   the ascending and descending phases as well as group means are provided in Table 3. These

5   results indicated that there were no significant differences in upper or lower trapezius activity

6   during these tasks when considering postural group.

7   **Discussion**

8   Individuals with FHRSP displayed greater scapular internal rotation as well as

9   anterior tilting throughout the flexion task concurrent with less serratus anterior activity

10   during the ascending phase of the shoulder flexion task. Similarly, greater scapular internal

11   rotation concurrent with less serratus anterior activity were observed during the overhead

12   reaching task. Individuals with FHRSP also displayed greater scapula upward rotation during

13   the upper ranges of shoulder elevation during the flexion task.   These results provide

14   evidence that FHRSP contributes to altered scapular kinematics and muscle activity

15   independent of shoulder pain since comparison groups in this study were of similar age,

16   occupational exposure, and free from shoulder pain.

17   Our results show greater scapular internal rotation and anterior tilting angles observed

18   in individuals with FHRSP are consistent with previous reports examining the effects of

19   posture on three-dimensional scapular kinematics. (Finley and Lee, 2003, Wang et al., 1999,

20   Kebaetse et al., 1999) In this study, subjects with FHRSP displayed greater scapular anterior

21   tilting angles when compared to individuals with ideal posture. The difference of 3° to 4° is

22   similar to changes in scapular anterior tilting attributed to greater thoracic kyphosis, (Finley

23   and Lee, 2003, Borstad and Ludewig, 2005) shorter pectoralis minor length, (Borstad and

1   Ludewig, 2005) and improvement in thoracic posture after a strengthening and stretching

2   home exercise program. (Wang et al., 1999) In the current study, the FHRSP group

3   demonstrated scapula internal rotation angles that were on average 8º and 10º greater than the

4   ideal posture group during the reaching and flexion tasks, respectively. The greater scapular

5   internal rotation angle is similar to alterations reported in healthy shoulders with short

6   pectoralis minor length (Borstad and Ludewig, 2005), but smaller than increases reported

7   concurrent with increases in thoracic kyphosis (Finley and Lee, 2003, Kebaetse et al., 1999),

8   or after participating in a home exercise program. (Wang et al., 1999) The observed

9   differences in scapular internal rotation and anterior tilting are likely the result of muscular

10   imbalances about the shoulder girdle since this study controlled for the amount of thoracic

11   kyphosis.

12   Previous studies have reported decreases in scapular upward rotation angles with

13   increased thoracic kyphosis (Finley and Lee, 2003, Kebaetse et al., 1999) or no difference in

14   individuals with short pectoralis minor lengths. (Borstad and Ludewig, 2005) We observed

15   greater scapular upward rotation angle (5°) in individuals with FHRSP as compared to ideal

16   posture. In previous reports of decreased scapular upward rotation, there was a significant

17   increase in thoracic kyphosis, which may account for the decreased upward rotation. (Finley

18   and Lee, 2003, Kebaetse et al., 1999) In this study, there were no significant differences in

19   thoracic kyphosis (mean difference = 6.8°; p=0.24) between the posture groups. It is also

20   possible that there are other motions contributing to scapular upward rotation in the upper

21   ranges of humeral elevation that we did not measure such as clavicular elevation. Previous

22   research using bone pins has shown clavicular elevation (translation) to occur concurrent

23   with scapula upward rotation. (Ludewig et al., 2009) Visual observation during testing noted

1 consistent shrugging (or elevation) of the shoulder girdle by the FHRSP group. This observed

2 movement pattern may explain the increases in scapular upward rotation. Considering all

3 observed scapular alterations, it appears that FHRSP has a more global effect on scapular

4 kinematics while pectoralis minor tightness primarily affects scapular tilting and internal

5 rotation although we did not make this direct comparison.

6   Serratus anterior activity was less during the ascending phase of overhead tasks and

7 may help explain the alterations in scapular upward rotation and posterior tilting. The

8 serratus anterior participates in producing and controlling upward/downward rotation and

9 anterior/posterior tilting of the scapula. Therefore, less serratus anterior activity is thought to

10 contribute to alterations in scapular kinematics. (Ludewig and Cook, 2000) Additionally, our

11 results showed similar amounts of upper & lower trapezius activity between groups

12 suggesting the alteration in kinematics were likely the result of less serratus anterior activity.

13 The observed differences in greater scapular anterior tilt and less serratus anterior activity

14 suggest that the serratus plays an important role in controlling and producing scapular

15 anterior / posterior tilting and upward/downward rotation during overhead tasks. The

16 assumed role of the serratus anterior is as an upward rotator. However when considering the

17 function of the serratus anterior within the upper trapezius/serratus anterior force couple the

18 serratus anterior produces rotation when a sufficient counterforce is produced. Less lower

19 serratus anterior activity with similar upper trapezius activity may have allowed for

20 clavicular elevation. These results support rehabilitative focus on the serratus anterior in

21 individuals who present with FHRSP, especially in the higher ranges of humeral elevation.

22 Focus on facilitating serratus anterior activity during the higher ranges of humeral elevation

23 may facilitate normal pattern of scapular upward rotation and posterior tilting.

1   The absence of differences observed in upper and lower trapezius activity may be due

2 to the population tested, task performed, or measure of muscle activity selected. The

3 population tested reported healthy shoulders with no positive tests for shoulder pain.

4 Alterations in upper and lower trapezius timing and activity have been reported in patients

5 diagnosed with shoulder pain (Ludewig and Cook, 2000) or increased upper trapezius

6 activity with artificially induced increases in forward head posture. (Ludewig and Cook,

7 1996) It is possible that alterations in trapezii function are related to the presence of shoulder

8 pain or artificially induced changes in head posture.   The observed similarities in trapezius

9 activity also may have been the result of task selection. The trapezius increases its activity as

10 the plane of humeral elevation moves from the sagittal plane to the frontal plane. (Bagg and

11 Forrest, 1986, Inman et al., 1944) It is possible that the nature of the tasks in this study in the

12 sagittal plane did not require high levels of recruitment of the trapezius muscles.

13 Additionally, mean amplitude of each phase of the overhead reaching tasks were used as

14 dependent variables. Given that there was very little activity in both groups during the

15 descending phases, it is possible that any differences were obscured by analyzing the muscle

16 activity during the ascending phase in total instead of in divisions of humeral elevation.

17 Future studies should use multi-planar tasks, examine smaller arcs of motion for differences

18 in muscle activity, and prospectively evaluate trapezius activity between healthy and painful

19 shoulders.

20   Several limitations should be considered in the interpretation and application of these

21 results. The cross sectional-case control design limits a cause and effect relationship to be

22 drawn between alterations in scapular kinematics, muscle activity and FHRSP. However,

23 given the demonstrated relationship between FHRSP and scapula kinematics across the

1 literature, as well as the strong theoretical framework linking altered posture to changes in

2 movement throughout the kinetic chain it is reasonable to conclude that FHRSP contributes

3 to altered scapula function and not vice versa. Additionally, all subjects reported no current

4 shoulder pain limiting the application of these results to healthy shoulders. We are unable to

5 generalize these findings to individuals with shoulder pain and FHRSP.

6   There was a female gender bias for the FHRSP group, with 62 % of females, despite a

7 concerted effort to control for this factor. Comparisons were reanalyzed using an analysis of

8 covariance on gender and no changes in statistical values were noted. Therefore, the gender

9 bias did not appear to affect these results. Mass was also significantly different between

10 groups, in a similar manner comparisons were reanalyzed using an analysis of covariance on

11 mass and no changes in statistical values were noted.

12   The skin-based sensors used in this study only give a representation of scapular and

13 humeral kinematics. However, this method has been validated and shown to be reliable

14 within humeral elevation ranges from 30°-120°. (Karduna et al., 2001, Thigpen et al., 2005)

15 The sampled ranges of humeral elevation were within these limits, thus we are confident they

16 are an accurate representation of scapular motion.

17   In conclusion, the results of this study revealed that in individuals free from shoulder

18 pain with FHRSP displayed greater scapular anterior tilting and internal rotation throughout

19 and greater scapular upward rotation at the upper ranges of elevation with concurrent lower

20 levels of serratus anterior muscle activity during the loaded forward flexion task, and greater

21 scapular internal rotation with concurrent lower levels of serratus anterior muscle activity

22 during the loaded forward reaching task. This provides support for the clinical theory that

23 postural alterations associated with FHRSP can alter scapular kinematics and muscle activity

1   during overhead tasks. Future studies should examine scapular kinematics and muscle

2   activity in patients with shoulder pain and FHRSP, and the effects of interventions to

3   improve posture on shoulder pain and disability. Prospective studies should also seek to

4   examine posture, scapular kinematics, and muscle activity as potential risk factors for the

5   development of shoulder pain.

6   Conflict of Interest:

7   There are no conflicts of interest.

8   Acknowledgments:

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