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Abstract

Forward head and rounded shoulder posture (FHRSP) is theorized to contribute to alterations in scapular kinematics and muscle activity leading to the development of shoulder pain. However, reported differences in scapular kinematics and muscle activity in those with forward head and rounded shoulder posture are confounded by the presence of shoulder pain. Therefore, the purpose of this study was to compare scapular kinematics and muscle activity in individuals free from shoulder pain, with and without FHRSP. Eighty volunteers were classified as having FHRSP or ideal posture. Scapular kinematics were collected concurrently with muscle activity from the upper and lower trapezius as well as the serratus anterior muscles during a loaded flexion and overhead reaching task using an electromagnetic tracking system and surface electromyography. Separate mixed model analyses of variance were used to compare three-dimensional scapular kinematics and muscle activity during the ascending phases of both tasks. Individuals with FHRSP displayed significantly greater scapular internal rotation with less serratus anterior activity during both tasks as well as greater scapular upward rotation, anterior tilting during the flexion task when compared with the ideal posture group. These results provide support for the clinical hypothesis that FHRSP impacts shoulder mechanics independent of shoulder pain.

Introduction

Shoulder pain is reported to occur in up to 21% of the general population (Urwin et al., 1998) and is thought to be the result of extrinsic risk factors such as repetitive overhead use (> 60° of shoulder elevation), sustained overhead work, and higher loads raised above shoulder height. (NIOSH, 1997) While these may be important they are likely difficult to modify as many occupational and athletic activities require repetitive overhead activity. Intrinsic risk factors such as forward head and rounded shoulder posture (FHRSP) (Szeto et al., 2002) and altered scapular kinematics and muscle activity (Ludewig and Cook, 2000) are reported in patients with shoulder pain. FHRSP is believed to alter scapular kinematics and muscle activity placing increased stress on the shoulder, leading to shoulder pain and dysfunction. (Kendall et al., 1952, Roddey, 2002, Sahrmann, 2001) It is important to understand the effects of FHRSP on scapular kinematics and muscle activity because FHRSP has been shown to be modifiable (Wang et al., 1999, Falla et al., 2007) and may provide a pathway to improve shoulder mechanics and decrease the risk to develop shoulder pain.

Poor posture as defined by increased forward head (Ludewig and Cook, 1996), greater thoracic kyphosis (Finley et al., 2003, Kebaetse, 1999) and an more anterior shoulder position (Borstad and Ludewig, 2005, Wang et al., 1999) have been demonstrated to be associated with altered scapular position, kinematics, and muscle activity. Alterations in scapular kinematics and muscle activity have also been reported in patients with shoulder impingement syndrome and rotator cuff disease. (Ludewig and Cook, 2000, McClure et al., 2004) However, research has not shown a clear relationship between the presence of FHRSP in individuals with shoulder pain. (Greenfield et al., 1995, Lewis et al., 2005, Greigel-Morris, 1992) A major limitation in these studies is the presence of shoulder pain during testing, which makes it difficult to determine if differences in posture, scapular kinematics, or muscle activity are the cause of underlying shoulder pathology or are the result of shoulder pain. Additionally, these studies have tended to use non-functional planar tasks which do not reflect shoulder function in overhead tasks. (Amasay and Karduna, 2009) Therefore, examination of scapula kinematics and muscle activity in individuals with FHRSP and without shoulder pain during a functional task is warranted.

The purpose of this study was to compare scapular kinematics and muscle activity in individuals free from shoulder pain, with and without FHRSP. We hypothesized that individuals with FHRSP would display less scapular upward rotation as well as greater internal rotation and anterior tilting. We also hypothesized that individuals with FHRSP would display less serratus anterior activity, and lower trapezius activity as well as greater upper trapezius activity compared to individuals with ideal head and shoulder posture.

Methods

Postural Analysis

While FHRSP has been described clinically for over 50 years, we were unable to identify objective criteria that have been consistently used to define FHRSP. Therefore, we screened 310 volunteers from the university population to determine ideal (head over shoulders and acromion in line with trunk) and FHRSP. Prior to testing participants completed an informed consent form and underwent a postural screening to identify FHRSP. Posture was assessed using the BioPrint® postural analysis system (Biotonix Inc., Montreal, CA). Reflective markers were placed over the right tragus (ear), acromion, and C_7 spinous process. Next, the participants stood 40 cm in front of a scaled backdrop, bent forward 3 times, reached overhead 3 times, and were instructed to stand looking straight ahead in their natural resting posture. A Canon Powershot 95 (USA) digital camera was placed on a tripod 1 m high and 3.5 m from the wall. High resolution (5.0 mega pixels) digital images were uploaded to a personal computer for processing. Adobe Photoshop® (San Jose, CA, USA) was used to measure forward head angle (FHA) and forward shoulder angle (FSA) based upon the respective angles between the center of the markers (Figure 1). All angles were measured on 3 separate days and the average FHA and FSA were used for subsequent analysis. The assessor was blinded to previous results when measuring subsequent photos.

In order to create distinct groups based on head and shoulder posture, the mean +/- 1 standard deviation of the 310 volunteers was used to establish the postural criteria (Table 1). Based on these measures criteria for the ideal posture group were defined as FHA $\leq 36^\circ$ and FSA $\leq 22^\circ$, while the FHRSP group criteria were defined as FHA $\geq 46^\circ$ and FSA $\geq 52^\circ$. Individuals must have met both FHA & FSA to be assigned to the ideal or FHRSP group. Using these posture criteria represented an attempt to create two distinctly different postural alignment groups.

Of the 310 subjects screened, 92 (29%) met the postural criteria. Forty-seven individuals were assigned to the ideal posture group, and 45 to the FHRSP group (Table 1). Twelve individuals who were selected did not return for further testing, yielding 40 participants in each group. All qualified subjects were scheduled for a 90-minute test session within 2 weeks of the initial screening for assessment of kinematic and muscle activity. Of the 80 individuals who returned for testing 10 with FHRSP and 10 with ideal posture returned for a 2nd postural assessment on the same day. Intra-day reliability for FHA and FSA demonstrated acceptable within day reliability (FHA = Intraclass Correlation Coefficient $(ICC)_{(2,1)}= 0.92$, Standard Error of the Mean (SEM) = 2° and FSA $ICC_{(2,1)}= 0.89$, SEM = 5°) based on this sub-sample. (Portney and Watkins, 2000) FHA and FSA from postural assessment on the initial screening day and on the actual day of testing were used to calculate between day reliability. Inter-day reliability was also acceptable (FHA = $ICC_{(2,k)}$= 0.78, SEM = 4° and FSA $ICC_{(2,k)}$= 0.72, SEM = 7°). All subjects remained in their initial, respective group (ideal vs. FHRSP) classifications.

Subjects

Participants were recruited from the university population who were aged between 18 and 60 and met specific postural alignment criteria as described above. Subjects were excluded if they reported a history of shoulder surgery, current shoulder pain limiting activities, upper extremity injury limiting activities, cervical or thoracic fracture, displayed functional or structural scoliosis, or excessive thoracic kyphosis (>50˚). (Vialle et al., 2005) Thoracic kyphosis was calculated using the BioPrint® software using a validated, optimized estimation technique. (Harrison et al., 2007)

Kinematic and Muscle Activity Measurement

Shoulder kinematics and muscle activity were collected during two overhead tasks, a loaded arm flexion task and a forward overhead reaching task with their dominant arm (arm used to throw a ball). The reaching task was developed through pilot testing to simulate tasks commonly reported to increase the risk of developing shoulder pain. (Chiang et al., 1993, NIOSH, 1997) The flexion task was used as previous work has shown it to be the produce the most reliable scapula movement patterns in subjects without shoulder pain and this is a common task used in other studies examining scapular kinematics (Thigpen et al., 2005). Scapular kinematics were collected using a Flock of Birds® (Ascension Technologies, Inc., Burlington, VT, USA) electromagnetic motion analysis system controlled by the Motion

Monitor® (Innovative Sports Training, Inc. Chicago, IL, USA) software. Three electromagnetic tracking sensors with a sampling rate of 50 Hz were attached using double sided tape to the: 1) thorax over the spinous process of C7/T1, 2) dominant shoulder over the broad flat surface of the scapular acromion and, 3) posterior one third of the upper arm with the sensor over the area of least muscle mass to minimize potential sensor movement and are similar as described by previous studies. (Karduna et al., 2001, Ludewig et al., 1996) In order to measure the shoulder kinematics, reconstruction of the bony segments was performed following the International Society of Biomechanics-Shoulder Group Recommendations. (Wu et al., 2005) The humeral head center was determined as recommended by Stokdjik et al. (2000)

Muscle activity of the serratus anterior (SA), upper trapezius (UT), and lower trapezius (LT) muscles was simultaneously measured during the two tasks. Each participant's skin was shaved if needed, cleaned with alcohol, and then a preamplified/active surface EMG electrode configuration (DelSys, Inc., Boston, MA: interelectrode distance = 10mm; amplification factor = 10,000 (20–450 Hz); CMMR @ 60 Hz > 80 dB; input impedance > 1015//0.2 X//pF) was placed on the midpoint of each muscle belly parallel to the muscle fiber direction and as described below. A carbon reference electrode was placed over the non-involved acromion. Electrodes were placed in the following arrangement: (Michener et al., 2005a)

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 scapular spine approximately at the angle of the neck and shoulder

Lower trapezius: two finger widths medial to the inferior angle of the scapula on a 45° angle towards T10 spinous process.

EMG data were sampled at 1000 Hz using The Motion Monitor motion capture software (Innovative Sports Training, Chicago, IL) then passed via an A/D converter (National Instruments, Austin, TX) and corrected for DC bias.

Maximum Voluntary Isometric Testing

Separate maximal voluntary isometric contractions (MVIC) were performed for the SA (Ekstrom et al., 2003), UT (Ekstrom et al., 2003), and LT (Michener et al., 2005b) muscles based on recommendations of previous literature. EMG activity was recorded for each muscle as subjects performed the MVIC. During MVIC testing, the subjects were instructed to push with a maximal effort for five seconds. There was a 30-second rest period between each MVIC trial and a 1-minute rest period between MVIC testing for each muscle group. Subjects performed practice trials of each test to familiarize them with the testing procedures. All subjects were given standard instructions and encouragement. Subjects were instructed to "push as hard as you can into the pad" then were encouraged by "push, push, push, push" for each MVIC. The average EMG amplitude during the middle 1-second time period was calculated for each trial and then averaged across the three MVIC trials. The average MVIC was used to normalize the EMG values recorded during the two tasks. Thus, EMG data during the loaded flexion and reaching tasks was expressed as a percentage of MVIC (% MVIC).

Flexion and Reaching Tasks

After setup was completed, kinematics and EMG were measured while subjects completed the loaded flexion task and a forward overhead reaching task for 25 repetitions.

Task order was randomized and the subjects rested five minutes between tasks to prevent fatigue. The 2nd through 7th trials were used for this analysis to remove any possible effects of fatigue on our results. The first repetition was not used as the movement pattern may have been different during the initial attempt at a task. The flexion 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 while keeping their elbow straight. The target was placed in the sagittal plane in line with the acromion of their dominant arm. Participants were asked to lift their arms from their side through their full range of motion overhead at a self-selected speed. A non-constrained overhead reaching task also required the participant to lift a weight equal to 3% of their body weight. This task only required the subjects use a standard starting and target position on the shelf but did not control plane of elevation or elbow position. The participant lifted the weight from a position of arms relaxed at their side up to target centered in front of the subject, at a distance the length of the arm (acromion to radial styloid) and equal to their body height plus 15%. Three percent of body weight was selected based on pilot testing in order to load the upper extremity without fatiguing the upper extremity. Three percent of the average body mass is equal to 2.25 kg which would be classified as light work based on the US Dictionary of Occupational Titles: Appendix C: Strength Rating. We believed this to be appropriate given the white collar nature of the subjects in this study.

Data Reduction and Processing

The 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 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: Humeral internal-external rotation about Y' axis, elevation about the X axis, and internal-external rotation about the Y" axis. (An et al., 1991) Scapula motions were calculated as the Euler angles of the scapula relative to the thorax reference frame 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. (Karduna et al., 2000, Wu 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 as determined by residual analysis of the signal.(Winter, 2004)

Scapular upward/downward, external/internal and posterior/anterior tilting angles were measured at selected humeral elevation angles during the ascending and descending phase for each task using custom Matlab (Mathworks, Natick, MA) code. The mean value for each scapular angle for 5 consecutive repetitions were analyzed during the ascending (>29° to >119°) and descending (<120° to >30°) phases of loaded shoulder flexion and during the ascending (>29° to >109°) and descending (<110° to >30°) phases of the loaded reaching task. The peak humeral angle during the reaching task did not reach 120° for all subjects therefore data was only analyzed between 30°-110°. Scapular angles were compared at 60°, 90°, and 120° of humeral elevation for the loaded flexion task. Although the reaching task was standardized, participants did not consistently achieve 120° of humeral elevation so scapular angles were compared at 60°, 90°, and 110° of humeral elevation for the reaching task. Each of the scapular and humeral kinematic variables demonstrated acceptable reliability with $ICC_{(2,1)}$ values ranging from 0.92 to 0.99 and SEM values of 1°-2°

across the averaged trials for each of the scapular angles, (60°, 90°,120°) during the ascending and descending phases. The selected humeral elevation angles were chosen based on epidemiological studies have identified shoulder activity above 60° to increase the risk of shoulder pain (NIOSH, 1997) and in an effort to limit the number of pairwise comparisons for significant interaction effects.

All EMG data were band-pass filtered (10 – 350 Hz) using a Butterworth filter (4^{th} order, recursive, zero-phase lag). The data were further smoothed and rectified by taking the root mean square (RMS) of the EMG signal over a 20 ms time constant. Mean EMG amplitude was calculated during the ascending and descending phase of humeral elevation for the UT, LT, and SA muscles The mean EMG amplitude over the ascending and descending phases of motion was averaged for repetitions 2 to 6 (5 trials) and used for statistical analyses. Each of the EMG variables demonstrated good reliability ($ICC_{(2,1)}$ for UT =0.88, SEM =3%; LT =0.77, SEM =3%; SA =0.90, SEM 3%) across the averaged trials for the ascending and descending phases .

Statistical Analysis

A single one way ANOVA was used to compare subject demographics (age, height, weight) between groups to ensure the groups were similar. Separate mixed model ANOVAs (group x angle x phase) were used to compare scapular upward rotation, internal rotation, and posterior tilting angles (dependent variables) between the ideal and FHRSP groups (independent variable). Each analyses included angles of humeral elevation (loaded flexion task: 60°, 90°, & 120°; loaded reaching task: 60°, 90°, & 110°) as within participant factors. Separate mixed model ANOVAs (group x phase) were used to compare UT, LT, and SA EMG amplitude (dependent variables) between the ideal and FHRSP groups (independent variable). Statistical significance was set a priori at $\alpha < 0.05$ for all analyses. Significant main effects were only considered in the absence of significant interaction effects. Tukey's post hoc analyses were performed to investigate significant main effects and interactions. (Hinkle et al., 1998) Effect sizes were calculated as Cohen's d. (Cohen et al., 2003) SPSS for Windows software (version 13.0, SPSS Inc, Chicago, IL) was used for all statistical analyses.

Results

Subject Demographics

There were no differences between age ($F_{(1,79)} = 0.83$; $p = 0.77$) and thoracic kyphosis angle ($F_{(1,79)} = 1.44$; $p = 0.24$) between groups (Table 1). There was a significant difference between forward head ($F_{(1,79)} = 285$; $p < 0.01$) and shoulder angle between groups ($F_{(1,79)} = 284$; $p < 0.01$) as well as mass ($F_{(1,79)} = 23.5$; $p < 0.01$) with the FHRSP group being heavier (Table 1). Given the difference in mass all analyses were performed with and without mass as a covariate. However, no statistical differences were observed. Therefore, statistical analyses without the covariate are reported.

Scapular Rotation Angles

There was a significant main effect of group for the scapular internal rotation angle during the flexion task ($F_{(1,78)} = 10.55$; $p < 0.01$) and reaching task ($F_{(1,78)} = 14.44$; $p < .01$) (Table 2). On average individuals in the FHRSP group displayed greater scapular internal rotation angles in comparison to the ideal posture group during both tasks (Figure 2). 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) for the reaching task. There were no other significant interaction effects for the flexion task for the group by phase ($F_{(1,78)} = 0.20$; p =

0.65), group by angle ($F_{(1,176)}$ = 0.47; p = 0.62), group by phase by angle ($F_{(1,156)}$ = 0.14; p = 0.87) or reaching task for group by phase ($F_{(1,78)}$ =0.54; p = 0.46), group by angle ($F_{(1,176)}$ = 0.82; p = 0.44), group by phase by angle ($F_{(1,156)}$ = 1.03; p = 0.36) comparisons (Table 2). Average values for the ascending and descending phases as well as group means are provided in Table 2.

There was a significant group by angle interaction ($F_{(1,176)}$ = 10.22; p < .01) regarding the scapular upward/downward rotation angle during the flexion task (Table 2). Post hoc analysis revealed that the FHRSP group displayed greater scapular upward rotation angles at 120° during the ascending and the 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), indicating that the FHRSP group was in 5º greater scapular upward rotation as compared to the ideal posture group at 120° of humeral elevation of the ascending and descending phases (Figure 3). There were no other significant main or interaction effects for the flexion task for the group ($F_{(1,78)}$ = 1.37; p = .25), group by phase ($F_{(1,78)}$ = 0.05; p = .83),group by phase by angle ($F_{(1,156)}$ = 1.21; p = 0.568) or reaching task for group ($F_{(1,78)}$ = 0.001; p = 0.981), group by phase ($F_{(1,78)}$ = 3.78; p = 0.06) , group by angle ($F_{(1,176)}$ = 1.64; p = 0.20)group by phase by angle ($F_{(1,156)}$ = 2.29; p = 0.11) comparisons (Table 2). Average values for the ascending and descending phases as well as group means are provided in Table 2.

There was a significant effect of humeral elevation phase on scapular anterior/posterior tilting angle during the flexion task ($F_{(1,78)}$ = 5.71; p = .019) (Table 2). Post hoc analysis revealed that on average the scapula was more anteriorly tilted for the FHRSP group throughout the ascending and the descending phases of humeral elevation when compared to the ideal posture group. The mean difference between postural groups for scapular anterior/posterior tilting angles was 3° (ES=0.32) for the ascending phase and 4°(ES=0.34) for the descending phase of the flexion task. There were no other significant main or interaction effects for the flexion task for the group ($F_{(1,78)}$ = 0.40; p = 0.53), group by angle ($F_{(1,78)}$ = 0.06; p = 0.94), group by phase by angle ($F_{(1,156)}$ = 1.92; p = 0.15) or reaching task for group ($F_{(1,78)}$ =0.31; p = 0.58), group by phase ($F_{(1,78)}$ = 0.09; p = 0.77) , group by angle ($F_{(1,176)}$ = 0.86; p = 0.42), group by phase by angle ($F_{(1,156)}$ = 0.42; p =0.66) comparisons (Table 2). Average values for the ascending and descending phases as well as group means are provided in Table 2.

Muscle Activity

There was a significant interaction effect between humeral elevation phase by postural group on serratus anterior activity during the flexion task ($F_{(1,78)}$ = 5.64; p = 0.02) and the reaching task ($F_{(1,78)}$ = 4.32; p = 0.04) (Table 3). Post hoc analysis revealed that on average there was less serratus anterior activity for the FHRSP group during the ascending phase of the flexion and the reaching tasks when compared to the ideal posture group. The mean difference between postural groups for serratus anterior activity was 13% (ES=0.38) during the flexion task and 6% (ES=0.33) during the reaching task. There were no other significant main effects for the flexion task for the serratus anterior muscle activity for group ($F_{(1,78)}$ = 2.59; p = 0.11), or reaching task for group ($F_{(1,78)}$ == 0.44; p = 0.51).

There were no other significant main or interaction effects for the flexion task for the upper trapezius muscle activity for group ($F_{(1,78)}$ = 0.20; p = 0.65), group by phase ($F_{(1,78)}$ = 0.76; p = 0.39), or reaching task for group ($F_{(1,78)}$ =0.11; p = 0.74) or group by phase ($F_{(1,78)}$ = 0.42; p = 0.52) comparisons (Table 3). There were no other significant main or interaction effects for the flexion task for the lower trapezius muscle activity for group ($F_{(1,78)}$ = 0.41; p = 0.52) group by phase ($F_{(1,78)}$ = .01; p = 0.5), or reaching task for group ($F_{(1,78)}$ =0.01; p = 0.91) or group by phase ($F_{(1,78)}$ = 0.41; p = 0.53) comparisons (Table 3). Average values for the ascending and descending phases as well as group means are provided in Table 3. These results indicated that there were no significant differences in upper or lower trapezius activity during these tasks when considering postural group.

Discussion

Individuals with FHRSP displayed greater scapular internal rotation as well as anterior tilting throughout the flexion task concurrent with less serratus anterior activity during the ascending phase of the shoulder flexion task. Similarly, greater scapular internal rotation concurrent with less serratus anterior activity were observed during the overhead reaching task. Individuals with FHRSP also displayed greater scapula upward rotation during the upper ranges of shoulder elevation during the flexion task. These results provide evidence that FHRSP contributes to altered scapular kinematics and muscle activity independent of shoulder pain since comparison groups in this study were of similar age, occupational exposure, and free from shoulder pain.

Our results show greater scapular internal rotation and anterior tilting angles observed in individuals with FHRSP are consistent with previous reports examining the effects of posture on three-dimensional scapular kinematics. (Finley and Lee, 2003, Wang et al., 1999, Kebaetse et al., 1999) In this study, subjects with FHRSP displayed greater scapular anterior tilting angles when compared to individuals with ideal posture. The difference of 3° to 4° is similar to changes in scapular anterior tilting attributed to greater thoracic kyphosis, (Finley and Lee, 2003, Borstad and Ludewig, 2005) shorter pectoralis minor length, (Borstad and

Ludewig, 2005) and improvement in thoracic posture after a strengthening and stretching home exercise program. (Wang et al., 1999) In the current study, the FHRSP group demonstrated scapula internal rotation angles that were on average 8º and 10º greater than the ideal posture group during the reaching and flexion tasks, respectively. The greater scapular internal rotation angle is similar to alterations reported in healthy shoulders with short pectoralis minor length (Borstad and Ludewig, 2005), but smaller than increases reported concurrent with increases in thoracic kyphosis (Finley and Lee, 2003, Kebaetse et al., 1999), or after participating in a home exercise program. (Wang et al., 1999) The observed differences in scapular internal rotation and anterior tilting are likely the result of muscular imbalances about the shoulder girdle since this study controlled for the amount of thoracic kyphosis.

Previous studies have reported decreases in scapular upward rotation angles with increased thoracic kyphosis (Finley and Lee, 2003, Kebaetse et al., 1999) or no difference in individuals with short pectoralis minor lengths. (Borstad and Ludewig, 2005) We observed greater scapular upward rotation angle (5°) in individuals with FHRSP as compared to ideal posture. In previous reports of decreased scapular upward rotation, there was a significant increase in thoracic kyphosis, which may account for the decreased upward rotation. (Finley and Lee, 2003, Kebaetse et al., 1999) In this study, there were no significant differences in thoracic kyphosis (mean difference = 6.8°; $p=0.24$) between the posture groups. It is also possible that there are other motions contributing to scapular upward rotation in the upper ranges of humeral elevation that we did not measure such as clavicular elevation. Previous research using bone pins has shown clavicular elevation (translation) to occur concurrent with scapula upward rotation. (Ludewig et al., 2009) Visual observation during testing noted consistent shrugging (or elevation) of the shoulder girdle by the FHRSP group. This observed movement pattern may explain the increases in scapular upward rotation. Considering all observed scapular alterations, it appears that FHRSP has a more global effect on scapular kinematics while pectoralis minor tightness primarily affects scapular tilting and internal rotation although we did not make this direct comparison.

Serratus anterior activity was less during the ascending phase of overhead tasks and may help explain the alterations in scapular upward rotation and posterior tilting. The serratus anterior participates in producing and controlling upward/downward rotation and anterior/posterior tilting of the scapula. Therefore, less serratus anterior activity is thought to contribute to alterations in scapular kinematics. (Ludewig and Cook, 2000) Additionally, our results showed similar amounts of upper & lower trapezius activity between groups suggesting the alteration in kinematics were likely the result of less serratus anterior activity. The observed differences in greater scapular anterior tilt and less serratus anterior activity suggest that the serratus plays an important role in controlling and producing scapular anterior / posterior tilting and upward/downward rotation during overhead tasks. The assumed role of the serratus anterior is as an upward rotator. However when considering the function of the serratus anterior within the upper trapezius/serratus anterior force couple the serratus anterior produces rotation when a sufficient counterforce is produced. Less lower serratus anterior activity with similar upper trapezius activity may have allowed for clavicular elevation. These results support rehabilitative focus on the serratus anterior in individuals who present 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 pattern of scapular upward rotation and posterior tilting.

The absence of differences observed in upper and lower 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 been reported in patients diagnosed with shoulder pain (Ludewig and Cook, 2000) or increased upper trapezius activity with artificially induced increases in forward head posture. (Ludewig and Cook, 1996) It is possible that alterations in trapezii function are related to the presence of shoulder pain or artificially induced changes in head posture. 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. (Bagg and Forrest, 1986, Inman et al., 1944) It is possible that the nature of the tasks in this study in the sagittal plane did not require high levels of recruitment of the trapezius muscles. 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 obscured by analyzing the muscle activity during the ascending phase in total instead of in divisions of humeral elevation. 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.

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. However, given the demonstrated relationship between FHRSP and scapula kinematics across the literature, as well as the strong theoretical framework linking altered posture to changes in movement throughout the kinetic chain it is reasonable to conclude that FHRSP contributes to altered scapula function and not vice versa. Additionally, all subjects reported no current shoulder pain limiting the application of these results to healthy shoulders. We are unable to generalize these findings to individuals with shoulder pain and FHRSP.

There was a female gender bias for the FHRSP group, with 62 % of females, 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 appear to affect these results. Mass was also significantly different between groups, in a similar manner comparisons were reanalyzed using an analysis of covariance on mass and no changes in statistical values were noted.

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°. (Karduna et al., 2001, Thigpen et al., 2005) The sampled ranges of humeral elevation were within these limits, thus we are confident they are an accurate representation of scapular motion.

In conclusion, the results of this study revealed that in individuals free from shoulder pain with FHRSP displayed greater scapular anterior tilting and internal rotation throughout and greater scapular upward rotation at the upper ranges of elevation with concurrent lower levels of serratus anterior muscle activity during the loaded forward flexion task, and greater scapular internal rotation with concurrent lower levels of serratus anterior muscle activity during the loaded forward reaching task. This provides support for the clinical theory that postural alterations associated with FHRSP can alter scapular kinematics and muscle activity during overhead tasks. Future studies should examine scapular kinematics and muscle activity in patients with shoulder pain and FHRSP, and the effects of interventions to improve posture on shoulder pain and disability. Prospective studies should also seek to examine posture, scapular kinematics, and muscle activity as potential risk factors for the development of shoulder pain.

Conflict of Interest:

There are no conflicts of interest.

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