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The Effect of EMG Biofeedback Training on Muscle Activation in an Impingement Population

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The Effect of EMG Biofeedback Training

on Muscle Activation in an Impingement Population

By

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Accepted in Partial Completion

of the Requirements for the Degree

Master of Science

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Master's Thesis

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The Effect of EMG Biofeedback Training on Muscle Activation in an Impingement Population

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Of the Requirements for the Degree

Master of Science

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Eliot James Mackay

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Abstract

Background: The shoulder is injury prone and subacromial impingement syndrome (SAIS) is one of the most diagnosed causes of pain in the region.

Objective: The purpose of this study was to investigate muscle activity between healthy and SAIS shoulders on the same subject and to understand the effectiveness of EMG biofeedback (EBFB) on bilateral overhead movements.

Design: Ten participants (7 male), that tested positive for 2/3 SAIS clinical tests, volunteered for the study. Bilateral muscle activity was measured via electrodes on the Upper Trapezius (UT), Lower Trapezius (LT), Serratus Anterior (SA), and Lumbar Paraspinals (LP). Kinematic testing involved 3 continuous bilateral scapular plane overhead movements before and after EBFB. EBFB consisted of 10 bilateral repetitions of I, W, Y, and T exercises focused on reducing UT and increasing LT and SA activity.

Results: Prior to EBFB, no significant difference in muscle activity was present between sides. A significant main effect of time indicated that after EBFB both sides exhibited reduced UT activity at 60° ($p = 0.003$) and 90° ($p = 0.036$), LT activity was increased at all measured humeral angles ($p < 0.0005$), and SA muscle activity was increased at 110° ($p = 0.001$).

Conclusion: EBFB in conjunction with scapular based exercise effectively alters muscle activity of healthy and impaired scapular musculature.

Keywords: Scapula, Electromyography, Kinematics, Biofeedback, Impingement

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1. Introduction

The upper extremity is one of the most injured locations in the general population with shoulder injuries making up one-third of primary care visits (Wofford et al., 2005). Moreover, up to two-thirds of individuals may experience some form of shoulder pain over their lifetime (Luime et al., 2004). Research on upper extremity pain and injury rates has been conducted frequently over time and the rate of disorder in this body segment may be increasing (Engebretsen et al., 2015).

The upper extremity is used for a variety of tasks in the workplace, at home, and during leisure activities. In these tasks, there may be a repetitive load placed on the upper extremity while, at times, in mechanically poor positions increasing the risk of a shoulder injury. SAIS is one of the leading diagnosed disorders in this region making up around half of the diagnosed shoulder injuries (Dhillon, 2019; Michener et al., 2003). SAIS is defined as the mechanical compression of the subacromial bursa, long head of biceps tendon, and supraspinatus tendon that may occur with humeral elevation. However, shoulder injuries are complex, and the etiology of SAIS is still not entirely understood (Dhillon, 2019; Karduna et al., 2005; Michener et al., 2003; Ravichandran et al., 2020).

Overhead movement of the upper extremity is accomplished through the coordinated relationship of the scapula and humerus. During overhead movements the scapula dynamically rotates during humeral elevation to prevent compression of tissue as the humerus elevates (Lawrence et al., 2019; Ludewig & Reynolds, 2009; Michener et al., 2003). Changes in scapular kinematics have been reported in many types of shoulder disorders (Keshavarz et al., 2017;

Kijima et al., 2015; Leong et al., 2017; Lopes et al., 2015; Lukasiewicz et al., 1999; Ratcliffe et al., 2014).

During overhead activities in a healthy population, the shoulder movement depends on proper activation of scapular stabilizers to ensure proper scapulohumeral coordination. Alterations to muscle activation patterns of scapular stabilizers have been found in injured general populations (Diederichsen et al., 2009; Lopes et al., 2015; Michener et al., 2016), athletes with a shoulder injury or SAIS (Cools et al., 2004, 2007), and in an occupational population (Ludewig & Cook, 2000). The altered muscular activation patterns indicative of shoulder pathology include increased UT (Chester et al., 2010; Cools et al., 2007; Lopes et al., 2015; Ludewig & Cook, 2000; Michener et al., 2016), decreased LT (Cools et al., 2004), and decreased SA activation (Diederichsen et al., 2009; Ludewig & Cook, 2000).

Rehabilitation from SAIS may be treated best with conservative exercise therapy (Gebremariam et al., 2011). Scapular stabilizer based exercise programs have also proven to be an effective strategy to reduce pain by targeting specific musculature and movement patterns (Ravichandran et al., 2020; Saito et al., 2018) and placing the scapula in a more biomechanically favorable position (Hotta et al., 2018). EMG biofeedback training has successfully demonstrated short term improvements through increased motor control of the trapezius through a reduction in UT activation and increased selective activation of the LT (Du et al., 2020; Larsen et al., 2014), increased external rotation of the scapula (San Juan et al., 2016) and posterior tilt (Huang et al., 2013); however, EMG biofeedback may not have a superior long term benefit on altering kinematics and muscle activity as research has provided contradictory results (Juul-Kristensen et al., 2019; Ma et al., 2011) indicating a need for more longitudinal studies.

To the author's knowledge, there has been no study that has assessed the bilateral effects of EMG biofeedback training on scapular muscle activation of SAIS and healthy shoulders of individuals with shoulder impingement. This area needs attention to understand potential bilateral effects a unilateral upper extremity injury may induce. The primary purpose of this study was to investigate the effectiveness of EMG biofeedback training on altering muscle activation of the scapular stabilizers between healthy and SAIS shoulders. The secondary purpose was to investigate the muscle activation of scapular stabilizers in healthy and SAIS shoulders prior to the intervention.

The first experimental hypothesis (1) is that EMG biofeedback training would significantly decrease the EMG amplitude of the UT, increase SA and LT, and have no effect on the LP of the SAIS shoulder and Healthy shoulder. The second experimental hypothesis (2) is that there would be significantly increased UT activity, decreased SA and LT activity, and no difference in Lumbar Paraspinal activity in the SAIS shoulder compared to the Healthy shoulder.

2. Methods

2.1. Participants

A total of 10 participants were included in this study (7 male and 3 female). The participants had a mean age of 30.60 years ± 15.20 years, mean height 1.72 m ± 0.7 m, and mean mass of 75.65 kg ± 8.69 kg. All the participants were right hand dominant, and 6/10 participants were injured on the right side. A statistical power analysis was conducted using GPower 3.1 (Universitat, Kiel, Germany) to determine the sample size using the data from San Juan et al, (2016). A sample size of 8 participants was needed to detect an effect size (Cohen's f) of 0.5 at a power of 0.8 and alpha of $p < 0.05$. Male and female individuals with a chief complaint of shoulder pain within the prior year between the age of 18-60 years were recruited for participation. Participants were excluded if they had surgical or neurological history that may have affected the upper extremity. Inclusion criteria required a clinical assessment by a certified athletic trainer where the shoulder pain was confirmed through positive tests on two out of three physical examination tests for signs of impingement (Neer's, Hawkins Kennedy, Empty Can). Before data collection, each participant gave written informed consent. The study was approved by the Western Washington University Institutional Review Board.

2.2. Data Collection

All participants completed a single 90-minute testing session. Prior to arrival participants were asked to refrain from high intensity exercise and upper extremity specific exercise 24 hours prior to data collection. All participants were also asked to arrive wearing athletic clothing and females were requested to wear a sports bra. An overview of the study protocol was given, and questions were answered by the researcher. Anthropometric characteristics of body height and mass were collected. Additionally, self-reported age and upper extremity limb dominance were recorded. Limb dominance was determined to be the writing hand of the subject. Participants completed a warm up protocol of 10 clockwise and counterclockwise pendulums with a 2.27 kg weight (San Juan et al., 2016). In preparation for motion analysis digitization and data collection, the skin was cleaned with alcohol wipes and shaved when necessary to ensure sensor adhesion and to reduce noise. The following bony landmarks were then palpated and marked with a permanent pen: C7, T8, T12, jugular notch, xiphoid process, and sternum. Additionally, the following landmarks were palpated and marked on the left and right side: scapular root, acromion angle, inferior angle, lateral epicondyle of the humerus, medial epicondyle of the humerus, deltoid tuberosity of the humerus, and spine of the scapula. A total of 8 (per subject) Noraxon dual EMG disposable, self-adhesive, Ag/AgCl snap electrodes with an interelectrode distance of 2 cm (Noraxon, Scottsdale, AZ, USA) were placed bilaterally and in parallel with the muscle fibers of the UT, LT, SA, and LP. The UT electrode was placed at the midway between the posterior lateral aspect of the acromion process and the spinous process of C7 (Ebaugh & Spinelli, 2010). The LT electrode was placed midway between the spinous process of the seventh thoracic vertebrae and the vertebral border of the scapula at the junction of the scapula spine (Ebaugh & Spinelli, 2010). The SA electrode was placed at the midaxillary line at the level of the seventh rib (Ebaugh & Spinelli, 2010). The LP electrodes were placed at the greatest convexity of the LP muscles at the L4/L5 level (Humphrey et al., 2005). Electromyography data were collected to assess muscle activation using the Noraxon EMG desktop direct transmission system (DTS) (Noraxon, Scottsdale, AZ, USA) and Noraxon MR 3.14 myoMuscle software. Raw EMG data were collected at 1500 Hz and preamplified with a gain of 500, CMRR of 100 dB, and input impedance >100 Mohm. The muscle activation signals in these muscles were verified by the investigator prior to data collection. The protocol for maximal voluntary isometric contraction (MVIC) was adapted from (San Juan et al., 2016) and bilaterally modified for the following muscles UT, LT, SA, and LP (Table 1). MVIC's were performed once for each muscle group and lasted 5 seconds. The middle second of the MVIC was averaged and used for normalization of EMG data. Participants were given time to practice each MVIC and were given adequate rest between muscle groups.

Table 1. Subject positioning for MVIC capture.

Muscle	Subject Position	Subject Motion Resisted
Upper Trapezius	Seated. Bilateral 90º elbow flexion and 90º shoulder abduction	Arm adduction with resistance applied at elbow.
Lower Trapezius	Seated. Bilateral 90º elbow flexion and 90º abduction 90º external rotation of shoulder	Forceful abduction applied at the elbow.
Serratus Anterior	Seated. Bilateral shoulder flexion to 90º. Maximum elbow extension. Hands in a fist.	Scapular retraction applied at the fist.
Lumbar Paraspinals	Prone. Hips over edge of table. Trunk flexed toward the floor.	Forceful trunk flexion. Force applied bilaterally at shoulder.

Humeral elevation was measured using the Polhemus Liberty (Polhemus Inc., Colchester, VT, USA) electromagnetic tracking system collecting at 240 Hz. Data were collected and stored with Motion Monitor (Innovative Sports Training Inc, Chicago, Ill, USA) software (version 9.32). The Liberty is equipped with 8 Sensors, a transmitter, and digitizing stylus. The transmitter was fixed to a custom plastic column 1.23 meters off the ground. The world axis of the transmitter (Global Coordinate System) was set following the right-hand rule with the subject facing +Y, +Z being vertical, and +X orthogonal to those planes. Participants were asked to stand on a taped predetermined location that was within the +X and +Y region. Data collection utilized 5 sensors that were adhered on the right and left deltoid tuberosity, sternum (2.5 cm inferior to the jugular notch), and at the mid portion of the right and left scapular spine using a customized scapular jig (McClure et al., 2001) (Figure 1).

Next, the subject was digitized through a series of steps in Motion Monitor using the marked bony landmarks that are in accordance with the International Society of Biomechanics (ISB) protocol (Wu et al., 2005). The joint center of each glenohumeral joints was found using the rotational method by passive movement in flexion, extension, adduction, abduction, internal rotation, and external rotation. The local coordinate systems of both humerus, trunk, and scapula were defined in line with the recommendations of the ISB (Wu et al., 2005). Electromagnetic systems are reliable with same day trial to trial correlation coefficient values between 0.88 and 0.97 and errors of 1.35º to 1.74º (Thigpen et al., 2005).

After digitization two custom guide poles were placed such that humeral elevation with elbows extended in contact with the pole resulted in the humeral plane of elevation 35º anterior to the frontal plane measured by goniometer. Guide poles were placed in a manner that the subject could maintain contact with them as they elevated their arms (Figure 1). Prior to data collection, participants were asked to practice elevating and lowering their arms in the scapular plane using the guide poles. Participants were asked to keep their elbows straight and thumbs pointed up throughout the movement. Next, the subject was asked to raise their arms until they were close to their ears which were timed at 3 seconds of elevation and then 3 seconds of lowering (San Juan et al., 2016). Once the participant felt comfortable with the movement and pace, data were recorded of the participant completing three humeral elevations where the right and left arms elevated simultaneously in the scapular plane.

After the first set of elevation trials, participants were asked to complete a sequence of shoulder rehabilitation exercises that focused on the scapula stabilizers muscles (San Juan et al., 2016). These exercises were composed of the I, W, T, and Y as described in Table 2. A visualization of the exercises may be seen in Figure 3. A screen was placed in front of the participants that displayed the EMG biofeedback program using the Noraxon MR 3.14 myoMuscle software (Noraxon, Scottsdale, AZ, USA). An explanation of the biofeedback training protocol was given to ensure participants could identify each muscle and how each one was affected by upper extremity movement. During all of the exercises participants were asked to keep the EMG activity of the UT low and for the activity of the LT to be at least twice that of the UT (San Juan et al., 2016). The ‘I’ exercise was completed first and once the subject was comfortable with the exercise and utilizing the correct muscle groups, they then completed 10 repetitions and progressed through to ‘W’, then ‘T’, and culminated with the ‘Y’ exercise (Table 2) (Figure 3). No tactile cueing was used.

After completion of the exercise protocol participants completed another trial of the humeral elevation task. Participants were asked to utilize what they learned about decreasing UT and increasing LT activity from the biofeedback training and transfer that to the elevation trials.

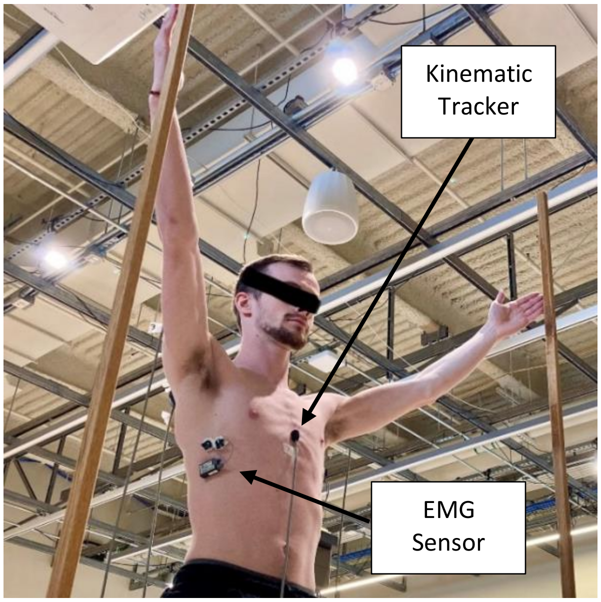

Figure 1. Anterior view of humeral elevation trials with guide poles placed 35° in the scapular plane.

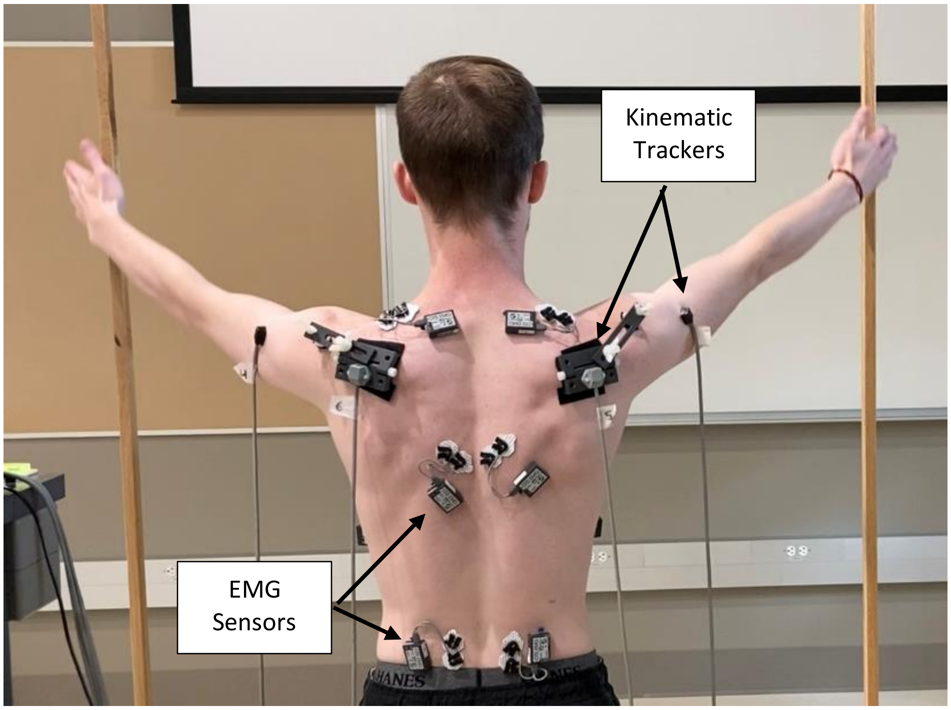

Figure 2. Posterior view of humeral elevation trials with kinematic and EMG sensors attached.

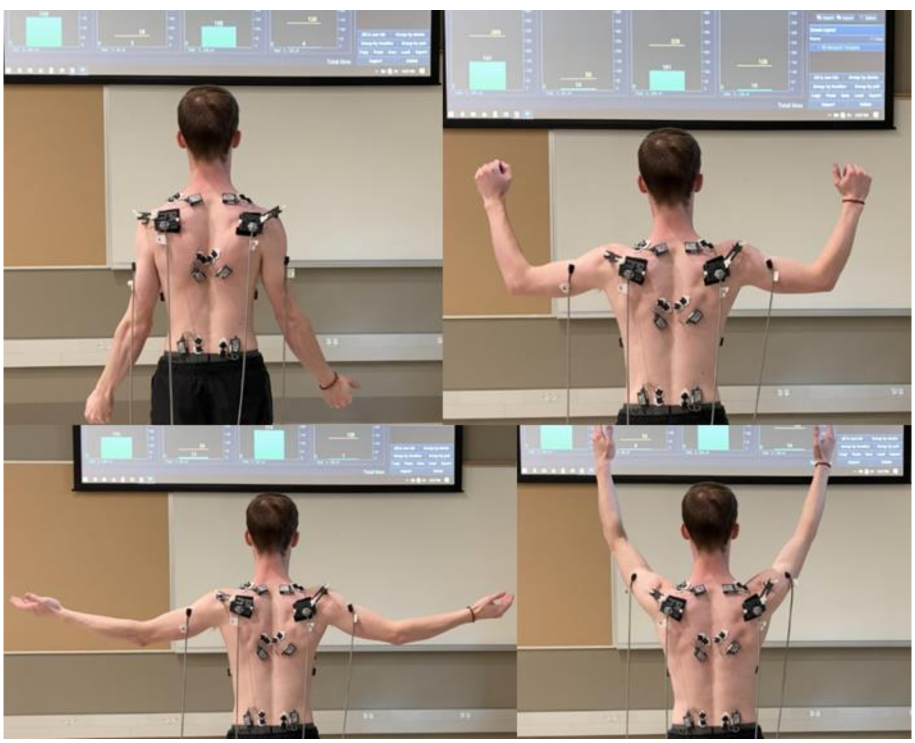

Figure 3. Compilation of EMG biofeedback exercises. Exercises were completed in the following order: Top left is ‘I’, top right is ‘W’, bottom left is ‘T’, and bottom right is ‘Y’.

2.3. Data Analysis

Raw kinematic data were processed in Motion Monitor software. EMG data were smoothed and full wave rectified using root mean square (30 ms window). All EMG data were aligned to kinematic data through innate functions in Motion Monitor. Data were exported and converted to an Excel (Microsoft, Redmond, WA) file format. EMG and kinematic data were run through a custom MatLab script (MATLAB 9.4 and Statistics Toolbox 8.1, The MathWorks, Inc., Natick, Massachusetts, USA) that extracted data at 30º, 60º, 90º and 110º of humeral elevation. The concentric phase of movement was kept for analysis.

Table 2. EMG Biofeedback scapular stabilization exercises (San Juan et al., 2016).

Exercise	Placement of upper extremity	Scapular Motion Performed
I	Arms at sides, fully extended with palms facing forward	Retraction and depression
W	Arms abducted 90°, elbows flexed 90° with palms facing forward	Retraction and depression
T	Arms abducted 90°, forearms extended with palms facing up	Retraction and depression
Y	Hands start crossed in front of body with palms facing back and elbow fully extended. Subject externally rotates arm and elevates arms in the scapular plane to about 135° with forearms completely extended and thumbs pointing back	Retraction and depression

2.4. Statistical Analysis

Statistical analysis was conducted using SPSS (IBM SPSS Statistics 26, Armonk, NY, USA). Descriptive statistics were calculated for all variables (mean and standard deviation). A two-way ANOVA was used to assess pretest differences between sides at each angle interval. A total of four two-way repeated measures ANOVA was used to assess the effect of *side* (SAIS and healthy) *x time* (30º, 60º, 90º, 110º of humeral elevation) of each EMG measure (The alpha was set to 0.05). In total 16 two-way repeated measures were conducted. Levene's test and

Mauchly's test of sphericity were used to assessing homogeneity and differences in variances. The independent variables were the sides (SAIS and healthy), time (before and after EBFB). Dependent variables were muscle activation of the UT, LT, SA, and LP of the SAIS and healthy shoulders.

3. Results

3.1. Pretest Comparison (Pre-EBFB)

Tabulated values of means and standard deviations are located in Table 3.

Upper Trapezius. There was no statistically significant interaction between sides for UT muscle activation at 30º (F [1, 18] = 1.274, p = 0.274, η^2 = 0.066), 60º (F [1, 18] = 0.424, p = 0.523, η^2 = 0.023), 90º (F [1, 18] = 0.022, p = 0.883, partial η^2 = 0.001), and 110º (F [1, 17] = 0.149, p = 0.705, partial η^2 = 0.009).

Lower Trapezius. There was no statistically significant interaction between sides for LT muscle activation at 30º (F [1, 18] = 0.064, p = 0.802, η^2 = 0.004), 60º (F [1, 18] = 0.146, p = 0.706, η^2 = 0.008), 90º (F [1, 18] = 0.005, p = 0.945, partial η^2 < 0.0005), and 110º (F [1, 17] = 0.139, p = 0.714, partial η^2 = 0.008).

Serratus Anterior. There was no statistically significant interaction between sides for SA muscle activation at 30º (F [1, 18] = 0.034, p = 0.856, partial η^2 = 0.002), 60º (F [1, 18] = 0.009, p = 0.927, η^2 < 0.0005), 90º (F [1, 18] = 0.055, p = 0.818, partial η^2 = 0.003), and 110º (F [1, 17] < 0.0005, p = 0.997, partial η^2 < 0.0005).

Lumbar Paraspinals. There was no statistically significant interaction between the side and time on LP muscle activation at 30º (F [1, 18] = 0.027, p = 0.872, partial η^2 = 0.001), 60º (F [1, 18] = 0.011, p = 0.918, η^2 = 0.001), 90º (F [1, 18] = 0.134, p = 0.719, partial η^2 = 0.007), and 110º (F [1, 17] = 0.032, p = 0.860, partial η^2 = 0.002).

3.2. Intervention

Tabulated values of means, standard deviations, and significance values may be seen in Table 3. Additionally, the means for each muscle (UT, LT, SA, and LP) are visualized, respectively, in Figure 4, Figure 5, Figure 6, and Figure 7. There was homogeneity of variances for all muscles studied, as assessed by Levene's test of homogeneity of variance ($p > 0.05$). Mauchly's test of sphericity indicated that the assumption of sphericity was met for the two-way interaction for all muscles measured.

3.2.1. 30 Degrees

Upper Trapezius. There was no statistically significant interaction between the side and time on UT muscle activation (F [1, 18] = 1.218, $p = 0.284$, partial $\eta^2 = 0.063$, Observed power = 0.182). The main effect of time did not show a statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 0.950, $p = 0.343$, partial $\eta^2 = 0.050$, Observed power = 0.152). The main effect of side did not show a statistically significant difference in mean UT muscle activation between intervention sides (F [1, 18] = 49.758, $p = 0.865$, partial $\eta^2 = 0.002$, Observed power = 0.530).

Lower Trapezius. There was no statistically significant interaction between the side and time on LT muscle activation (F [1, 18] = 0.051, $p = 0.824$, partial $\eta^2 = 0.003$. observed power = 0.055). The main effect of time showed a statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 38.636, $p < 0.0005$, partial $\eta^2 = 0.682$, Observed power = 1.000). The EMG activity in LT increased after EBFB compared to prior to it. The main effect of side did not show a statistically significant difference in mean LT muscle activation between intervention sides (F [1, 18] = 0.019, $p = 0.892$, partial $\eta^2 = 0.001$, Observed power = 0.52).

Serratus Anterior. There was no statistically significant interaction between the side and time on SA muscle activation (F [1, 18] = 0.143, p = 0.710, partial η^2 = 0.008. Observed power 0.065). The main effect of time showed no statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 2.495, p = 0.132, partial η^2 = 0.122, Observed power 0.321). The main effect of side did not show a statistically significant difference in mean SA muscle activation between intervention sides (F [1, 18] = 0.156, p = 0.698, partial η^2 = 0.009, Observed power = 0.066).

Lumbar Paraspinals. There was no statistically significant interaction between the side and time on Lumbar Paraspinal muscle activation (F [1, 18] = 0.017, p = 0.896, partial η^2 = 0.001, Observed power = 0.052). The main effect of time showed no statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 0.602, p = 0.448, partial η^2 = 0.032, Observed power = 0.114). The main effect of side did not show a statistically significant difference in mean Lumbar Paraspinal muscle activation between intervention sides (F [1, 18] = 0.003, p = 0 .954, partial η^2 < 0.0005, Observed power = 0.050).

3.2.2. 60 Degrees

Upper Trapezius. There was no statistically significant interaction between the side and time on UT muscle activation (F [1, 18] = 0.088, p = 0.771, partial η^2 = 0.005, Observed power = 0.059). The main effect of time showed a statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 11.457, p = 0.003, partial η^2 = 0.389, Observed power = 0.892). The EMG activity in UT decreased after EBFB compared to prior to it. The main effect of side did not show a statistically significant difference in mean UT muscle activation between intervention sides (F [1, 18] = 0.891, p = 0.358, partial η^2 = 0.047, Observed power = 0.145).

Lower Trapezius. There was no statistically significant interaction between the side and time on LT muscle activation (F [1, 18] = 0.030, p = 0.864, partial η^2 = 0.002, Observed power = 0.053). The main effect of time showed a statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 35.355, $p < 0.0005$, partial η^2 = 0.663, Observed power = 1.000). The EMG activity in LT increased after EBFB compared to prior to it. The main effect of side did not show a statistically significant difference in mean LT muscle activation between intervention sides (F [1, 18] = 0.103, p = 0.752, partial η^2 = 0.006, Observed power = 0.061).

Serratus Anterior. There was no statistically significant interaction between the side and time on SA muscle activation, (F [1, 18] = 0.066, p = 0.800, partial η^2 = 0.004, Observed power = 0.057). The main effect of time did not show a statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 1.602, p = 0.222, partial η^2 = 0.082, observed power 0.224). The main effect of side did not show a statistically significant difference in mean SA muscle activation between intervention sides (F [1, 18] = 0.002, p = 0.967, partial $\eta^2 < 0.0005$, Observed power = 0.050).

Lumbar Paraspinals. There was no statistically significant interaction between the side and time on Lumbar Paraspinal muscle activation (F [1, 18] = 0.065, p = 0.802, partial η^2 = 0.004, Observed power = 0.057). The main effect of time did not show a statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 0.145, p = 0.707, partial η^2 = 0.008, Observed power = 0.065). The main effect of side did not show a statistically significant difference in mean Lumbar Paraspinal muscle activation between intervention sides (F [1, 18] = 0.051, p = 0.824, partial η^2 = 0.003, Observed power = 0.055).

3.2.3. 90 Degrees

Upper Trapezius. There was no statistically significant interaction between the side and time on UT muscle activation (F [1, 18] = 0.596, p = 0.450, partial η^2 = 0.032, Observed power = 0.113). The main effect of time showed a statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 5.136, p = 0.036, partial η^2 = 0.222, Observed power = 0.573). The EMG activity in UT decreased after EBFB compared to prior to it. The main effect of side did not show a statistically significant difference in mean UT muscle activation between intervention sides (F [1, 18] = 0.493, p = 0.492, partial η^2 = 0.027, Observed power = 0.102).

Lower Trapezius. There was no statistically significant interaction between the side and time on LT muscle activation (F [1, 18] = 0.058, p = 0.812, partial η^2 = 0.003, Observed power = 0.056. The main effect of time showed a statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 27.747, p < 0.0005, partial η^2 = 0.607, Observed power = 0.999). The EMG activity in LT increased after EBFB compared to prior to it. The main effect of side did not show a statistically significant difference in mean LT muscle activation between intervention sides (F [1, 18] = .041, p = 0.842, partial η^2 = 0.002, Observed power = 0.054).

Serratus Anterior. There was no statistically significant interaction between the side and time on SA muscle activation (F [1, 18] = 0.109, p = 0.745, partial η^2 = 0.006, Observed power = 0.061). The main effect of time did not show a statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 4.036, p = 0.060, partial η^2 = 0.183, Observed power = 0.477). The main effect of side did not show a statistically significant difference in mean SA muscle activation between intervention sides (F [1, 18] = 0.102, p = 0.754, partial η^2 = 0.006, Observed power = 0.061).

Lumbar Paraspinals. There was no statistically significant interaction between the side and time on Lumbar Paraspinal muscle activation (F [1, 18] = 0.221, p = 0.644, partial η^2 = 0.012, Observed power = 0.073. The main effect of time did not show a statistically significant difference in mean muscle activity at the different time points (F [1, 18] = 0.807, p = 0.381, partial η^2 = 0.043, Observed power = 0.136). The main effect of side did not show a statistically significant difference in mean Lumbar Paraspinal muscle activation between intervention sides (F [1, 18] = 0.279, p = 0.604, partial η^2 = 0.015, Observed power = 0.079).

3.2.4. 110 Degrees

Upper Trapezius. There was no statistically significant interaction between the side and time on UT muscle activation (F [1, 17] = 0.255, p = 0.620, partial η^2 = 0.015, Observed power = 0.076). The main effect of time did not show a statistically significant difference in mean muscle activity at the different time points (F [1, 17] = 3.295, p = 0.087, partial η^2 = 0.162, Observed power = 0.402). The main effect of side did not show a statistically significant difference in mean UT muscle activation between intervention sides (F [1, 17] = 0.027, p = 0.872, partial η^2 = 0.002, Observed power = 0.053).

Lower Trapezius. There was no statistically significant interaction between the side and time on LT muscle activation (F [1, 17] = 0.098, p = 0.758, partial η^2 = 0.006, Observed power = 0.060). The main effect of time showed a statistically significant difference in mean muscle activity at the different time points (F [1, 17] = 46.366, $p < 0.0005$, partial η^2 = 0.732, Observed power = 1.000). The EMG activity in LT increased after EBFB compared to prior to it. The main effect of side did not show a statistically significant difference in mean LT muscle activation between intervention sides (F [1, 17] = 0.025, p = 0.877, partial $\eta^2 = 0.001$, Observed power = 0.053).

Serratus Anterior. There was no statistically significant interaction between the side and time on SA muscle activation (F [1, 17] = 0.005, p = 0.943, partial $\eta^2 < 0.0005$, Observed power = 0.051). The main effect of time showed a statistically significant difference in mean muscle activity at the different time points (F [1, 17] = 15.251, p = 0.001, partial $\eta^2 = 0.432$, Observed power = 0.957). The EMG activity in SA increased after EBFB compared to prior to it. The main effect of side did not show a statistically significant difference in mean SA muscle activation between intervention sides (F [1, 17] = 0.001, p = 0.970, partial $\eta^2 < 0.0005$, Observed power = 0.050).

Lumbar Paraspinals. There was no statistically significant interaction between the side and time on Lumbar Paraspinal muscle activation (F [1, 17] = 0.677, p = 0.422, partial $\eta^2 =$ 0.038, Observed power = 0.122). The main effect of time did not show a statistically significant difference in mean muscle activity at the different time points (F [1, 17] = 1.958, p = 0.180, partial $\eta^2 = 0.103$, Observed power = 0.262). The main effect of side did not show a statistically significant difference in mean Lumbar Paraspinal muscle activation between intervention sides (F [1, 17] = 0.677, p = 0.422, partial $\eta^2 = 0.038$, Observed power = 0.122).

Table 3. Acute effects of EMG biofeedback training on muscle activation

	Humeral Elevation	Impingement Pretest (%)	Impingement Posttest (%)	Healthy Pretest (%)	Healthy Posttest (%)	Interaction *(p)*	Time Main Effect *(p)*	Side Main Effect *(p)*
Upper Trapezius								
	30°	13.76 (5.22)	14.10 (15.09)	17.30 (8.42)	11.95 (11.59)	0.284	0.343	0.865
	60°	35.07 (11.83)	21.30 (14.45	39.42 (17.55)	27.87 (17.11)	0.771	**0.003***	0.358
	90°	38.71 (22.42)	24.39 (14.61)	39.98 (14.84)	32.94 (22.00)	0.450	**0.036***	0.492
	110° ^	44.17 (33.90)	28.75 (15.62)	39.54 (12.61)	30.84 (19.67	0.620	0.087	0.872
Lower Trapezius								
	30°	9.70 (6.44)	65.38 (36.52)	10.47 (7.18)	62.26 (38.99)	0.824	**<0.0005***	0.892
	60°	24.22 (18.32)	87.70 (55.95)	21.10 (18.11)	80.97 (55.29)	0.864	**<0.0005***	0.752
	90°	29.43 (33.93)	76.82 (40.72)	30.20 (24.72)	82.13 (58.45)	0.812	**<0.0005***	0.842
	110° ^	33.93 (7.72)	91.18 (42.56)	39.01 (32.21)	91.23 (52.65)	0.758	**<0.0005***	0.877
Serratus Anterior								
	30°	19.40 (12.01)	25.98 (19.77)	18.48 (10.13)	22.52 (14.12)	0.710	0.132	0.698
	60°	35.41 (18.41)	41.84 (23.05)	36.15 (17.63)	40.41 (22.51)	0.800	0.222	0.967
	90°	62.34 (26.88)	73.18 (40.90)	59.52 (27.04)	67.29 (32.15)	0.745	0.060	0.754
	110° ^	81.85 (31.52)	111.03 (51.60)	81.80 (28.82)	109.91 (28.60)	0.943	**0.001***	0.970
Lumbar Paraspinals								
	30°	7.78 (4.50)	8.63 (5.19)	7.48 (3.61)	8.68 (7.93)	0.896	0.448	0.954
	60°	9.26 (4.99)	10.03 (6.83)	9.05 (4.14)	9.20 (6.86)	0.802	0.707	0.824
	90°	9.56 (5.46)	11.12 (7.37)	8.81 (3.60)	9.30 (6.97)	0.644	0.381	0.604
	110° ^	8.64 (4.03)	11.24 (7.64)	8.33 (3.23)	9.01 (5.67)	0.422	0.180	0.422

Pretest and Posttest table values are presented as Mean (SD); * Statistically significant finding; ^ Statistical analysis was conducted with 9 participants instead of 10.

4. Discussion

The purpose of this study was to investigate the bilateral muscle activation of injured and healthy shoulders within an impingement (SAIS) population. The experimental hypotheses were (1) that prior to EMG biofeedback there would be significantly increased UT, decreased SA, decreased LT, and no difference in lumbar paraspinal muscle activity in the SAIS shoulder compared to the healthy side. The second hypothesis (2) was that EMG biofeedback training would have an effect on both shoulders (SAIS and uninjured side) of the participant thereby significantly decreasing the activity of the UT, increasing the EMG amplitude of the LT and SA, and inducing no change in lumbar paraspinal muscle activity. The results of the study do not support the first hypothesis; however, the data partially support the second hypothesis.

The present study used the right and left shoulders from 10 participants and each individual had one shoulder that was diagnosed with SAIS and the other was healthy. Comparison of the pretest EMG data between the SAIS and healthy shoulder revealed no significant difference in activation level of the scapular stabilizers and Lumbar Paraspinals at any humeral elevation angle ($p > 0.05$). There was no difference between lumbar paraspinal muscle activity in the present study indicating that lumbar specific compensatory movements were not present. In the present study prior to EBFB that the healthy UT, SA, and LT muscle activity was not significantly different than the SAIS side at each humeral angle (ex 90° SAIS: SA had a mean EMG amplitude of 62.34 ± 26.88; 90° Healthy: SA had a mean EMG amplitude of 59.52 ± 27.04). The findings of this study are in contrast with some of the research on the relationship between SAIS and scapula stabilizer muscle activity. Michener and colleagues (2016) indicated a dysfunction in the EMG activity of the scapular stabilizers in the SAIS shoulder. Larsen and colleagues (2014) found that the SAIS shoulders showed motor control deficits. Previous research has reported increased muscle activity amplitude of the UT in the SAIS shoulder of the general population (Lopes et al., 2015; Michener et al., 2016; V. Phadke et al., 2009; Wadsworth & Bullock-Saxton, 1997) and in athletes (Cools et al., 2007). Diederichsen et al. (2009) found decreased SA activity levels in those with SAIS which is in contrast to the present study. Conclusive remarks on the effects SAIS has on muscle activity are ongoing (Chester et al., 2010) and the present study indicates that the EMG profile between SAIS and healthy shoulders are not different thereby calling for additional study in this area. The contrast between the present study and previous research may be related to the sample selected as the present study used the injured and uninjured side of the same individual while the other studies used two sets of participants.

The data demonstrated that the EMG biofeedback training with the scapular-based exercise protocol was effective in eliciting muscle activity amplitude changes in both the healthy and SAIS shoulders of an individual through increases in activity of upward rotators (LT and SA) and a decrease in UT activity. No statistically significant differences were present between lumbar paraspinal activity in the present study after EMG biofeedback training indicating that compensatory movements in order to achieve a greater range of motion were not present. The findings of the present study are in accordance with previous research on the acute effects of biofeedback training (Du et al., 2020; Huang et al., 2013; Larsen et al., 2014). Huang et al. (2013) found increased muscle amplitude changes of increased LT and decreased UT activation after using EMG biofeedback with a different set of exercises than the present study. The present study aligns with another aspect of Larsen and colleagues' (2014) findings as the implementation of EMG biofeedback improved muscle activity amplitude of both SAIS and healthy shoulders. In the present study, the LT muscle activity was significantly increased at all humeral elevation angles reported (30º, 60º, 90º, and 110º). This finding is in accordance with previous research as

Du et al. (2020) found increased LT activation of 4.2% - 18% whereas the present study found a mean difference increase of 6% - 12.5% in the LT of both sides. Comparison of these values is cautioned as protocol and sample population differences are present. EMG biofeedback effectively educated the participants on creating a stable base through increased activation of the LT at humeral angles 60º and lower.

The other upward rotator studied, the SA, had significantly increased muscle activity at 110º of humeral elevation. Ensuring that the SA is active is important as this muscle plays a role in posterior tipping and upward rotation of the scapula (Diederichsen et al., 2009). It is speculated that increasing the recruitment of these muscles will allow for greater subacromial space with humeral elevation. The EMG biofeedback training protocol of the present study was successful in significantly decreasing UT muscle activity at 60º and 90º of humeral elevation. The significant reduction occurred during the painful arc (60º-120º) of humeral elevation where individuals with shoulder pain typically experience pain response and symptoms of SAIS (Kessel & Watson, 1977). As the UT plays a role with anterior tilting of the scapula, this reduction in activity could be beneficial in alleviating symptoms (Camargo & Neumann, 2019). Additionally, in complement, the increased SA activity may induce a corrective posterior tilting thereby also adding to the reduction in symptoms (Ludewig & Reynolds, 2009). The use of EMG biofeedback training is affecting to change the muscle activation amplitude and may be beneficial to those who utilize the UT with overhead movement. Combining the results: the decreased activity of the UT along with increased activity of the upward rotators, may effectively alter the coordinated recruitment patterns allowing for pain-free movement.

Interestingly, prior research has called for implementing exercise programs to correct muscle imbalances (Michener et al., 2016); however, the present study did not show the purported muscular imbalances as a result of SAIS. The intervention used still has merit in reducing the risk of SAIS as a preventative measure to reduce imbalances and to educate on effective recruitment of the scapular stabilizers.

In conclusion, the EMG amplitude profile between SAIS side and uninjured side shoulders of an individual is not significantly different. Additionally, EMG biofeedback training used in conjunction with scapular-based rehabilitation exercises is effective at altering the EMG amplitude of scapular stabilizers in healthy and disordered shoulders. The ability to increase activation of scapular upward rotators (SA and LT) and decrease UT activity may establish a healthy force couple allowing for pain-free movement and reduced injury risk.

5. Limitations

The limitations of this study should be noted. The design of this study did not include a control group which would prevent participants with any relevant background (i.e., shoulder rehabilitation exercise knowledge or use of EMG biofeedback) from inducing bias into the research. Moreover, the findings only demonstrate potential short-term effects. Additionally, data was not analyzed over 110º as a few participants failed to achieve full range of motion making comparisons of EMG difficult with other studies as data is conventionally reported at 30º, 60º, 90º, and 120º. In analyzing the EMG activity this study did not investigate relationships of force couples which may allow for further understanding of upper extremity changes with intervention protocols. Future studies would benefit from including a control group and comparing EMG biofeedback to an exercise only group in order to assess the effectiveness of EMG biofeedback. Additional studies may investigate sex differences in bilateral EMG profiles of healthy and impingement populations.

6. References

Camargo, P.R., Neumann, D.A., 2019. Kinesiologic considerations for targeting activation of scapulothoracic muscles – part 2: trapezius. Brazilian J. Phys. Ther. 23, 467–475. https://doi.org/10.1016/j.bjpt.2019.01.011

Chester, R., Smith, T.O., Hooper, L., Dixon, J., 2010. The impact of subacromial impingement syndrome on muscle activity patterns of the shoulder complex: A systematic review of electromyographic studies. BMC Musculoskelet. Disord. 11, 45. https://doi.org/10.1186/1471-2474-11-45

Cools, A.M., Declercq, G.A., Cambier, D.C., Mahieu, N.N., Witvrouw, E.E., 2007. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. Scand. J. Med. Sci. Sport. 17, 25–33. https://doi.org/10.1111/j.1600-0838.2006.00570.x

Cools, A.M., Witvrouw, E.E., Declercq, G.A., Vanderstraeten, G.G., Cambier, D.C., 2004. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. Br. J. Sports Med. 38, 64–68. https://doi.org/10.1136/bjsm.2003.004952

Dhillon, K.S., 2019. Subacromial impingement syndrome of the shoulder: A musculoskeletal disorder or a medical myth? Malaysian Orthop. J. 13, 1–7. https://doi.org/10.5704/MOJ.1911.001

Diederichsen, L.P., Nørregaard, J., Dyhre-Poulsen, P., Winther, A., Tufekovic, G., Bandholm, T., Rasmussen, L.R., Krogsgaard, M., 2009. The activity pattern of shoulder muscles in subjects with and without subacromial impingement. J. Electromyogr. Kinesiol. 19, 789–799. https://doi.org/10.1016/j.jelekin.2008.08.006

Du, W.Y., Huang, T.S., Chiu, Y.C., Mao, S.J., Hung, L.W., Liu, M.F., Yang, J.L., Lin, J.J., 2020. Single-session video and electromyography feedback in overhead athletes with scapular dyskinesis and impingement syndrome. J. Athl. Train. 55, 265–273. https://doi.org/10.4085/1062-6050-490-18

Ebaugh, D.D., Spinelli, B.A., 2010. Scapulothoracic motion and muscle activity during the raising and lowering phases of an overhead reaching task. J. Electromyogr. Kinesiol. 20, 199–205. https://doi.org/10.1016/j.jelekin.2009.04.001

Engebretsen, K.B., Grotle, M., Natvig, B., 2015. Patterns of shoulder pain during a 14-year follow-up: results from a longitudinal population study in Norway. Shoulder Elb. 7, 49–59. https://doi.org/10.1177/1758573214552007

Gebremariam, L., Hay, E.M., Koes, B.W., Huisstede, B.M., 2011. Effectiveness of surgical and postsurgical interventions for the subacromial impingement syndrome: A systematic review. Arch. Phys. Med. Rehabil. 92, 1900–1913. https://doi.org/10.1016/j.apmr.2011.06.006

Hotta, G.H., Santos, A.L., McQuade, K.J., de Oliveira, A.S., 2018. Scapular-focused exercise treatment protocol for shoulder impingement symptoms: Three-dimensional scapular kinematics analysis. Clin. Biomech. 51, 76–81. https://doi.org/10.1016/j.clinbiomech.2017.12.005

Huang, H.Y., Lin, J.J., Guo, Y.L., Wang, W.T.J., Chen, Y.J., 2013. EMG biofeedback effectiveness to alter muscle activity pattern and scapular kinematics in subjects with and without shoulder impingement. J. Electromyogr. Kinesiol. 23, 267–274. https://doi.org/10.1016/j.jelekin.2012.09.007

Humphrey, A.R., Nargol, A.V.F., Jones, A.P.C., Ratcliffe, A.A., Greenough, C.G., 2005. The value of electromyography of the lumbar paraspinal muscles in discriminating between chronic-low-back-pain sufferers and normal subjects. Eur. Spine J. 14, 175–184. https://doi.org/10.1007/s00586-004-0792-3

Juul-Kristensen, B., Larsen, C.M., Eshoj, H., Clemmensen, T., Hansen, A., Bo Jensen, P., Boyle, E., Søgaard, K., 2019. Positive effects of neuromuscular shoulder exercises with or without EMG-biofeedback, on pain and function in participants with subacromial pain syndrome – A randomised controlled trial. J. Electromyogr. Kinesiol. 48, 161–168. https://doi.org/10.1016/j.jelekin.2019.07.009

Karduna, A.R., Kerner, P.J., Lazarus, M.D., 2005. Contact forces in the subacromial space: Effects of scapular orientation. J. Shoulder Elb. Surg. 14, 393–399. https://doi.org/10.1016/j.jse.2004.09.001

Keshavarz, R., Bashardoust Tajali, S., Mir, S.M., Ashrafi, H., 2017. The role of scapular kinematics in patients with different shoulder musculoskeletal disorders: A systematic review approach. J. Bodyw. Mov. Ther. https://doi.org/10.1016/j.jbmt.2016.09.002

Kessel, L., Watson, M., 1977. The painful arc syndrome. Clinical classification as a guide to management. J. Bone Jt. Surg. - Ser. B 59, 166–172. https://doi.org/10.1302/0301-620x.59b2.873977

Kijima, T., Matsuki, K., Ochiai, N., Yamaguchi, T., Sasaki, Yu, Hashimoto, E., Sasaki, Yasuhito, Yamazaki, H., Kenmoku, T., Yamaguchi, S., Masuda, Y., Umekita, H., Banks, S.A., Takahashi, K., 2015. In vivo 3-dimensional analysis of scapular and glenohumeral kinematics: Comparison of symptomatic or asymptomatic shoulders with rotator cuff tears and healthy shoulders. J. Shoulder Elb. Surg. 24, 1817–1826. https://doi.org/10.1016/j.jse.2015.06.003

Larsen, C.M., Juul-Kristensen, B., Olsen, H.B., Holtermann, A., Søgaard, K., 2014. Selective activation of intra-muscular compartments within the trapezius muscle in subjects with Subacromial Impingement Syndrome. A case-control study. J. Electromyogr. Kinesiol. 24, 58–64. https://doi.org/10.1016/j.jelekin.2013.09.008

Lawrence, R.L., Braman, J.P., Ludewig, P.M., 2019. Shoulder kinematics impact subacromial proximities: a review of the literature. Brazilian J. Phys. Ther. https://doi.org/10.1016/j.bjpt.2019.07.009

Leong, H.T., Ng, G.Y. fat, Chan, S.C., Fu, S.N., 2017. Rotator cuff tendinopathy alters the muscle activity onset and kinematics of scapula. J. Electromyogr. Kinesiol. 35, 40–46. https://doi.org/10.1016/j.jelekin.2017.05.009

Lopes, A.D., Timmons, M.K., Grover, M., Ciconelli, R.M., Michener, L.A., 2015. Visual scapular dyskinesis: Kinematics and muscle activity alterations in patients with subacromial impingement syndrome. Arch. Phys. Med. Rehabil. 96, 298–306. https://doi.org/10.1016/j.apmr.2014.09.029

Ludewig, P.M., Cook, T.M., 2000. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys. Ther. 80, 276–291. https://doi.org/10.1093/ptj/80.3.276

Ludewig, P.M., Reynolds, J.F., 2009. The association of scapular kinematics and glenohumeral joint pathologies. J. Orthop. Sports Phys. Ther. 39, 90–104. https://doi.org/10.2519/jospt.2009.2808

Luime, J.J., Koes, B.W., Hendriksen, I.J.M., Burdorf, A., Verhagen, A.P., Miedema, H.S., Verhaar, J.A.N., 2004. Prevalence and incidence of shoulder pain in the general population; a systematic review. Scand. J. Rheumatol. 33, 73–81. https://doi.org/10.1080/03009740310004667

Lukasiewicz, A.C., McClure, P., Michener, L., Pratt, N., Sennett, B., 1999. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. J. Orthop. Sports Phys. Ther. 29, 574–586. https://doi.org/10.2519/jospt.1999.29.10.574

Ma, C., Szeto, G.P., Yan, T., Wu, S., Lin, C., Li, L., 2011. Comparing biofeedback with active exercise and passive treatment for the management of work-related neck and shoulder pain: A randomized controlled trial. Arch. Phys. Med. Rehabil. 92, 849–858. https://doi.org/10.1016/j.apmr.2010.12.037

McClure, P.W., Michener, L.A., Sennett, B.J., Karduna, A.R., 2001. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. J. Shoulder Elb. Surg. 10, 269–277. https://doi.org/10.1067/mse.2001.112954

Michener, L.A., McClure, P.W., Karduna, A.R., 2003. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. Clin. Biomech. 18, 369–379. https://doi.org/10.1016/S0268-0033(03)00047-0

Michener, L.A., Sharma, S., Cools, A.M., Timmons, M.K., 2016. Relative scapular muscle activity ratios are altered in subacromial pain syndrome. J. Shoulder Elb. Surg. 25, 1861–1867. https://doi.org/10.1016/j.jse.2016.04.010

Phadke, V., Camargo, P.R., Ludewig, P.M., 2009. Scapular and rotator cuff muscle activity during arm elevation: A review of normal function and alterations with shoulder impingement. Rev. Bras. Fisioter. 13, 1–9. https://doi.org/10.1590/S1413-35552009005000012

Ratcliffe, E., Pickering, S., McLean, S., Lewis, J., 2014. Is there a relationship between subacromial impingement syndrome and scapular orientation? A systematic review. Br. J.

Sports Med. https://doi.org/10.1136/bjsports-2013-092389

Ravichandran, H., Janakiraman, B., Gelaw, A.Y., Fisseha, B., Sundaram, S., Sharma, H.R., 2020. Effect of scapular stabilization exercise program in patients with subacromial impingement syndrome: A systematic review. J. Exerc. Rehabil. 16, 216–226. https://doi.org/10.12965/jer.2040256.128

Rundquist, P.J., 2007. Alterations in scapular kinematics in subjects with idiopathic loss of shoulder range of motion. J. Orthop. Sports Phys. Ther. 37, 19–25. https://doi.org/10.2519/jospt.2007.2121

Rundquist, P.J., Anderson, D.D., Guanche, C.A., Ludewig, P.M., 2003. Shoulder kinematics in subjects with frozen shoulder. Arch. Phys. Med. Rehabil. 84, 1473–1479. https://doi.org/10.1016/S0003-9993(03)00359-9

Saito, H., Harrold, M.E., Cavalheri, V., McKenna, L., 2018. Scapular focused interventions to improve shoulder pain and function in adults with subacromial pain: A systematic review and meta-analysis. Physiother. Theory Pract. 34, 653–670. https://doi.org/10.1080/09593985.2018.1423656

San Juan, J.G., Gunderson, S.R., Kane-Ronning, K., Suprak, D.N., 2016. Scapular kinematic is altered after electromyography biofeedback training. J. Biomech. 49, 1881–1886. https://doi.org/10.1016/j.jbiomech.2016.04.036

Thigpen, C.A., Gross, M.T., Karas, S.G., Garrett, W.E., Yu, B., 2005. The repeatability of scapular rotations across three planes of humeral elevation. Res. Sport. Med. 13, 181–198. https://doi.org/10.1080/15438620500222489

Timmons, M.K., Thigpen, C.A., Seitz, A.L., Karduna, A.R., Arnold, B.L., Michener, L.A., 2012. Scapular kinematics and subacromial-impingement syndrome: A meta-analysis. J. Sport

Rehabil. 21, 354–370. https://doi.org/10.1123/jsr.21.4.354

Turgut, E., Duzgun, I., Baltaci, G., 2016. Scapular asymmetry in participants with and without shoulder impingement syndrome; a three-dimensional motion analysis. Clin. Biomech. 39, 1–8. https://doi.org/10.1016/j.clinbiomech.2016.09.001

Wadsworth, D.J.S., Bullock-Saxton, J.E., 1997. Recruitment patterns of the scapular rotator muscles in freestyle swimmers with subacromial impingement. Int. J. Sports Med. 18, 618–624. https://doi.org/10.1055/s-2007-972692

Wofford, J.L., Mansfield, R.J., Watkins, R.S., 2005. Patient characteristics and clinical management of patients with shoulder pain in U.S. primary care settings: Secondary data analysis of the National Ambulatory Medical Care Survey. BMC Musculoskelet. Disord. 6, 1–6. https://doi.org/10.1186/1471-2474-6-4

Wu, G., van der Helm, F.C.T., Veeger, H.E.J.D., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A.R., McQuade, K., Wang, X., Werner, F.W., Buchholz, B., International Society of Biomechanics, 2005. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand. J. Biomech. 38, 981–992. https://doi.org/10.1016/j.jbiomech.2004.05.042

Literature Review

Introduction

This review will broadly explore the mechanisms of shoulder injury, specifically subacromial impingement syndrome (SAIS), in the general population, scapular kinematics in healthy and injured populations, and the complexities of scapula stabilizer muscle activity. The function of scapular kinematics, including scapulohumeral rhythm (SHR), and muscle activation are crucial for identifying injury risk. This review will encompass pertinent background information on injury prevalence and incidence among adults, the role of the scapula, and the effects kinematics and muscle activation have on shoulder pathology in order to support the methodology and procedures used in this study.

General Population Shoulder Pain

The shoulder is one of the most complex joints in the human body because of its large range of motion (ROM) and 6 degrees of freedom that are contingent on both precise scapular rotation and the intricate balance of muscular tension to maintain congruency between the humeral head and glenoid fossa (Hurov, 2009; Michener et al., 2003). The anatomical complexities paired with the individuality of human lives leave an opportunity to use or place the shoulder in weak positions and this may lead to injury. In the United States, injury related shoulder pain was associated with 33.2% of primary care visits while work related shoulder pain made up 21.3% of visits (Wofford et al., 2005). In other parts of the world, males and females have similar chronic shoulder pain rates (17.7% and 22.3% respectively) (Andersson et al., 1993) while other studies present evidence of increased incidence of upper extremity injury rates in females (Bot et al., 2005). Recent analysis indicate that the overall rate of shoulder injury has been increasing (Engebretsen et al., 2015). A lack of consensus is clear as a systematic review confirms a wide range of shoulder injury prevalence rates: a point prevalence rate ranging from 6.9% to 26% while over a lifetime prevalence rate ranges from 6.7% to 66.7% (Luime et al., 2004). Another study purports that SAIS, which is defined as mechanical compression of tissue under the acromion, may account for nearly half or more of all shoulder complaints (Dhillon, 2019; Michener et al., 2003). The reporting of injury definition, regional grouping of injuries (i.e., neck and shoulder vs. shoulder), incidence, and prevalence rates varies throughout the literature therefore providing a conclusive remark is difficult. It is clear that the shoulder is a common source of pain which needs to be investigated.

Etiology of Shoulder Injury

The etiology of overuse or chronic shoulder injuries in the general population is multifactorial. It is known that the coordination of the scapulothoracic and glenohumeral joint is essential to produce healthy movement and to optimize biomechanics (Castelein et al., 2016; Hurov, 2009; Michener et al., 2003). There are 14 muscles that attach to the scapula and influence its movement (Ebaugh & Spinelli, 2010). These muscles can be broken down into groups based on their function with movement (Kibler, 1998). The muscles that act to stabilize and rotate are the Trapezius, Rhomboids, Levator scapulae, and Serratus Anterior. Intrinsic muscles of the rotator cuff are the Subscapularis, Supraspinatus, Infraspinatus, and Teres Minor (Kibler, 1998). Extrinsic muscles are the Deltoid, Biceps Brachii, and Triceps Brachii (Kibler, 1998). The balance of forces between these muscles is crucial to maintain a stable center of rotation in the glenohumeral joint while also allowing the scapula to be mobile as it moves through upward/downward rotation, internal/external rotation, anterior/posterior tilt, depression/elevation, and protraction/retraction (Kibler, 1998). In a healthy population, the three dimensional (3D) pattern of scapular kinematics with humeral elevation is upward rotation, external rotation, and posterior tilt (Ludewig et al., 1996; McClure et al., 2001). These movements of the scapula are important as they allow for the humerus to elevate while maintaining adequate subacromial space (SAS) and reducing the likelihood of compressive forces on tissues under the coracoacromial arch (Karduna et al., 2005). The SAS is of main concern as the underlying Supraspinatus Tendon, Subacromial Bursa, Long Head of the Biceps Brachii Tendon, and shoulder joint capsule (Michener et al., 2003) may be mechanically damaged through contact with the acromion and this decrement in space may lead to SAIS and pain. Studies that have directly measured SAS using magnetic resonance imaging (MRI) have found a decrease in space with protraction compared to retraction (Solem-Bertoft et al., 1993). A study of cadavers (n=8) with SAIS found no change in SAS with scapular external rotation and posterior tilt in the scapular plane but a decrease in SAS with upward rotation of the scapula (Karduna et al., 2005). This surprising finding indicates a potential compensatory mechanism in which those with SAIS create SAS through alternative scapular kinematic patterns. The application of cadaver study to in vivo tissue is difficult as cadaver studies typically are conducted with passive movement; however, understanding compensatory changes as a result of SAIS would be beneficial through more cadaver studies and modelling.

Altered Scapular Kinematics

*Shoulder Injury***.** A plethora of research on the effect of injury on scapular kinematics have been conducted on populations with SAIS (Lopes et al., 2015; Lukasiewicz et al., 1999; Turgut et al., 2016) while some studies have investigated rotator cuff tears (Kijima et al., 2015; Leong et al., 2017), frozen shoulder (Rundquist et al., 2003), idiopathic range of motion loss (Rundquist, 2007), and instability (Matias & Pascoal, 2006). Research on the role the scapula plays in this injury type has been thoroughly examined, however, the relationship of SAIS and scapular orientation is not concrete (Keshavarz et al., 2017; Ratcliffe et al., 2014). A review of scapular kinematics and shoulder injuries indicates, that in the scapular plane, participants with SAIS and glenohumeral instability may have increased protraction, internal rotation, and decreased upward rotation. Those with frozen shoulder may see a decrease in protraction (Keshavarz et al., 2017). In the frontal plane SAIS participants had increases in posterior tilt and external rotation during humeral elevation (Keshavarz et al., 2017). Additional reviews specific to SAIS are conflicting (Ratcliffe et al., 2014; Timmons et al., 2012). Ratcliffe et al. (2014) were unable to draw any conclusive findings because of conflicting findings, heterogeneity of studies, and methodological difference. In contrast, Timmons et al. (2012) found the SAIS population to have decreased scapular upward rotation, external rotation, and no difference in posterior tilt. The plane of motion also affected scapular kinematics as SAIS participants showed greater posterior tilt and external rotation in the frontal plane and less upward rotation and external rotation in the scapular plane (Timmons et al., 2012).

*Sport***.** The general population is filled with athletes of all skill levels therefore it is important to understand the effects an activity may have on upper extremity kinematics. The kinematics of overhead athlete populations such as swimmers (Blache et al., 2018; McLaine et al., 2018), water polo athletes (Turgut et al., 2018), baseball (Myers et al., 2005; Park et al., 2020), and volleyball (Leong et al., 2017) players have been studied using two-dimensional and three-dimensional motion capture. A study of 21 baseball athletes (n=21) compared to age, height, mass, and dominant limb matched controls (n=21) showed a significantly increased degree of upward rotation, internal rotation, and retraction (Myers et al., 2005). In this study, participants were seated, and the dominant limb's scapular motion was assessed using an electromagnetic motion capture device. The scapular motion was measured through 10 continuous overhead humeral elevation/lowering movements in the scapular plane. Participants held a mass that was 25% of their normalized torque determined by an isokinetic dynamometer (Myers et al., 2005). Swimmers may also have kinematic changes as a sample of adult swimmers, when compared to the other groups, had greater internal rotation from 67º to 116º of humeral elevation and while lowering from 81º to 54º (Blache et al., 2018). The swimmers (n=42) were all male and divided evenly into four groups (including the control group) based on age and swimming experience. Bilateral scapular kinematics were recorded via an electromagnetic system with the subject standing. Two repetitions of unilateral elevation and lowering were completed 30º anterior to the frontal plane and the procedure was repeated for the opposite arm (Blache et al., 2018). There were no bilateral differences in upward rotation in the three swimmer groups; however, the control group's scapulae were asymmetrical with the dominant side having more upward rotation through 74 to 104º of elevation (Blache et al., 2018). No difference in posterior tilt was found (Blache et al., 2018). A study that investigated 14-20 year old swimmers' scapular upward rotation in the frontal plane found bilateral symmetry even when shoulder pain was present (n=85) (McLaine et al., 2018). Bilateral scapular upward rotation was measured using a digital inclinometer at 90º and 140º of humeral elevation in the frontal plane while subjects were standing (McLaine et al., 2018). A study on the bilateral scapular kinematics of water polo athletes was measured with a 3D electromagnetic device and tasked participants with elevation and lowering at 40º in the scapular plane for 3 trials while standing (Turgut et al., 2018). Each trial took 6 s total split evenly between elevation and lowering while paced at a tempo of 60 beats per minute (BPM). These data were averaged of across the three repetitions and reported at 30, 60, 90, and 120 (Turgut et al., 2018). Water polo players (n=14) showed no significant bilateral differences as well as no significant differences when compared to age and sex matched healthy controls (n=14) (Turgut et al., 2018).

A couple studies have investigated kinematic changes in sports in conjunction with injury. One investigated the dominant arm of baseball players with upper extremity injury (n=319) that presented significantly greater upward rotation, internal rotation, but less anterior tilt at 150º of sagittal plane flexion (Park et al., 2020). However, group differences were not apparent based on pathology (Park et al., 2020). These findings were measured via 3D computed tomography (CT) scan at rest and 150° of flexion. The participants consisted of mainly middle or high school aged individuals with some collegiate and professional players. Those included in the study had an equally diverse range of injuries thus noted differences may be limited in generalizability due this heterogeneity. A 3D analysis of the dominant or symptomatic shoulder of healthy male volleyball players (n=17) and players with rotator cuff pathology (n=26) was conducted using Vicon motion capture (Leong et al., 2017). Participants were seated and 5 separate arm elevation trials of abduction were paced at 2 s to reach peak elevation and 2 s to lower with data recorded up to 90° of humeral elevation (Leong et al., 2017). There was a significant decrease in upward rotation at an elevation less than 30º in the rotator cuff injury group (Leong et al., 2017). No significant findings were present in posterior tilt or external rotation (Leong et al., 2017).

Scapular kinematics in athletes have been described using various 2D and 3D motion capture technology. There are methodological differences in the plane of motion, pace of elevation, phase of analysis, subject position, as well as a limited number of studies within each sport. More research needs to be conducted in overhead athletes within specific sports to give a better understanding of the demands placed on the upper extremity and if kinematic changes associated with these activities may predispose athletes to shoulder injuries.

Scapulohumeral Rhythm

Normal. Scapulohumeral rhythm (SHR) is defined by the coordinated movement of the scapulothoracic and the glenohumeral joints to move the arm overhead and is reported as a ratio. In classic works, normal rhythm is defined as 2:1 in that for every 2º of humeral elevation the scapula upwardly rotates 1º (Inman et al., 1944; Poppen & Walker, 1976). However, SHR has been reported between 1.25-7.9:1 (Hosseinimehr et al., 2015). Side-to-side scapulohumeral rhythm in healthy populations has reported ratios of 1.8 to 3.4:1 as well as no difference between sides (Lee et al., 2013; Matsuki et al., 2011; Yoshizaki et al., 2009). The large variety of SHR within a general population is varied due to plane of motion studied, sample population, and measurement equipment.

*Injury***.** The repetitive actions associated with overhead activity may lead to shoulder injury. It is important to outline the effects shoulder disorders have on SHR to understand potential changes that may influence injury and rehabilitation. Studies of SHR have been conducted on the rotator cuff, SAIS, and frozen shoulder. In a study of shoulder injuries and scapular changes participants with glenohumeral instability had a significant increase in GH:ST ratio up to 90º of humeral elevation (Paletta et al., 1997). This was due to more movement of the humerus at the glenohumeral joint (Paletta et al., 1997). Another rotator cuff pathology found difficulty in scapular engagement resulting in higher SHR in those with the most limited range of motion while those with more range of motion utilized more scapular movement (Robert-Lachaine et al., 2016). Similarly, full thickness rotator cuff tears showed greater scapular movement with humeral elevation (Mell et al., 2005). A study of athletes with SAIS (n=14) compared to control (n=7) found no significant difference between groups (Lin et al., 2011). Shoulder injuries may result in alterations in an individual's typical shoulder rhythm.

Sex Differences

Anatomical characteristics that distinguish males and females (segment length, mass, etc.) may alter scapular kinematics (Schwartz et al., 2016). There are a few studies that have investigated scapulothoracic motion between sexes. A study of healthy male (n=11) and females (n=11) tested abduction, flexion, and external/internal rotation at 90º arm abduction in the dominant limb. (Schwartz et al., 2016). At rest there was no difference in kinematic orientation; however, differences appeared with active motion where females had greater humerothoracic range of motion as well as a more externally rotated scapula in sagittal and frontal plane movements (Schwartz et al., 2016). Another study in support of kinematic differences between sexes investigated sagittal plane flexion of healthy males (n=58) and females (n=58) and showed that the non-dominant arm of females was found to have more upward rotation and anterior tilt while the female dominant arm had more anterior tilt than their male counterpart (Habechian et al., 2016).

A comprehensive study of scapular kinematics between males and females found the scapula to upwardly rotate, externally rotate, and tilt posteriorly in both groups (Picco et al., 2018). There were sex differences in each plane, elevation angle, and phase of movement with the most pronounced difference between sexes occurring in posterior tilt (Picco et al., 2018). Females (n=14) had a smaller anterior tilt range of motion of 5.7º and 7.3º for raising and lowering, respectively, when compared to males' (n=15) posterior/anterior tilt range of motion of 14.4º during raising and lowering (Picco et al., 2018).

One study investigated a gender effect between sexes using movements of flexion, abduction, and in glenohumeral external/internal rotation with 90º abduction of the arm (Schwartz et al., 2016). No significant differences of scapular positions were reported at rest (Schwartz et al., 2016). Males had significantly more posterior tilt in all three motions while upward rotation was larger in the sagittal plane and 90 degree abduction movements (Schwartz et al., 2016). Females had greater active range of motion for all the movements and increased (6-7 degree) external rotation than their male counterparts (Schwartz et al., 2016).

While these studies may indicate that male and female differences in scapular motion are present through multiple planes and motions the generalizability is difficult due to the use of different measurement techniques (optoelectrical and electromagnetic), phase analysis (eccentric, concentric, and both), and the plane of motion, and small sample sizes. Therefore, more research needs to be conducted on scapular kinematic differences between sexes.

Arm Dominance and Symmetry

Dominance can be defined as the preferential limb to complete particular tasks (Yoshizaki et al., 2009). It is common for researchers and clinicians to compare sides which requires the assumption that there is symmetry between sides. There is not a lot of research on the bilateral scapular function and the conclusion drawn are contradictory (Lee et al., 2013; Matsuki et al., 2011; Schwartz et al., 2014; Turgut et al., 2016; Yoshizaki et al., 2009).

Yoshizaki et al. (2009) investigated healthy individuals' (n=18) 3D scapular kinematics and integrated electromyography (IEMG) muscle activity during a scapular plane elevation and lower task and found no kinematic differences between sides, however, there was a significantly different level of muscle activity in the Lower Trapezius between sides. Lee and colleagues (2013) used an optical tracking system to assess 3D scapular kinematics in three different planes (sagittal, scapular, coronal) in a subject population of healthy men (n=26). Amongst the three planes of motion studied there was no difference in upward rotation or internal rotation only with coronal plane abduction was there a significantly decreased posterior tilting in the non-dominant shoulder (Lee et al., 2013). While some of the results indicate symmetry between sides the change in posterior tilt and SHR inconsistency with the plane of motion is indicative of asymmetrical movement patterns in a population of men. A study by Matsuki et al. (2011) investigated dominant and nondominant scapular motion in men (n=12) during a scapular plane elevation and lowering task using fluoroscopy. The dominant scapulae were downwardly rotated by 10° at rest and during dynamic movement, the scapulae were more upwardly rotated compared to the nondominant side indicative of symmetry (Matsuki et al., 2011). Matsuki's findings of asymmetry at rest are in contrast to Schwartz and colleagues (2014) study that reported the rest position of healthy males and females and found no differences. For abduction the females' dominant arm was more externally rotated than the nondominant arm from 60 degrees to 120° of humeral elevation. In frontal plane movements the male subject's dominant scapula had larger upward rotation. In sagittal plane movement the male's dominant scapula was more upwardly and internally rotated. Frontal plane movement for females resulted in significantly increased externally rotation on the dominant side. Males (n=11) had significantly greater upward rotation in the dominant arm from 40º to 120º of elevation in the frontal plane (Schwartz et al., 2014). In the sagittal plane, the males' dominant side showed significantly greater upward rotation and internal rotation at 120º of elevation and no side-to-side differences were present for the 90º abduction internal/external rotation condition in either sex (Schwartz et al., 2014). Females (n=11), in the frontal plane, presented significantly greater external rotation on the dominant side from 60º to 120º and the sagittal plane revealed significant differences in internal rotation from 20-50º (Schwartz et al., 2014).

Turgut et al. (2016) used 3D electromagnetic tracking and calculated the symmetry angle to assess differences between the dominant arm SAIS and healthy shoulders during an elevation and lowering task with healthy (n=37) and injured SAIS population (n=29). Kinematic differences were present when comparing side-to-side. Those with SAIS had a more anteriorly tilted scapula while the healthy controls scapulae were more internally and downwardly rotated. (Turgut et al., 2016). Using the novel symmetry angle calculation, it was found that more asymmetry existed in those with SAIS indicating that the disorder may exacerbate existing asymmetries (Turgut et al., 2016). Specifically, the SAIS shoulder was more asymmetrical with internal/external rotation and at 60° and 90° and upward rotation were more asymmetrical at 60° and 90° and 120°. No differences were present with the anterior-posterior tilt. (Turgut et al., 2016).

The studies outlined indicate contradictory results in side-to-side differences in kinematics and muscle activity. The differences in kinematic measurement and population groups studied may have an effect on the results seen in the literature. More research with larger sample sizes would benefit the understanding in this area along with a review of the existing literature.

Scapulothoracic Stabilizer Activity

The musculature that surrounds the shoulder girdle is important as it stabilizes the humeral head into the glenoid fossa giving the upper extremity a solid foundation to move, provides the ability for the scapula to rotate, and helps transfer energy (Kibler, 1998). Therefore, proper muscular activation is essential for overhead upper extremity movement and any irregular activity may result in injury. A review of the interaction of SAIS and muscle activity is reveals conflicting findings (Chester et al., 2010). SAIS may result in increased Upper Trapezius activation as a greater magnitude of activation in the Upper Trapezius is found in this population however these conclusions are also contrasted by other studies (Chester et al., 2010). A recent systematic review highlights that trends of decreased Serratus Anterior activity are present in those with SAIS while trapezius muscle changes were not consistent across studies investigated thereby indicating EMG's limitations to capturing the complexities of SAIS (Kinsella & Pizzari, 2017). Additionally, the studies reviewed by both Kinsella and Pizzari (2017) and Chester et al. (2010) were strongly heterogenous thus limiting the conclusions of muscle activity changes due to injury.

Studies that have investigated individual scapular muscle activation magnitudes and latency have been conducted in occupational, healthy, injured, and athletic populations. Overhead workers (N=52) showed an increase in Upper Trapezius activity was present throughout loaded and unloaded scapular elevation. Additionally, the electromyography (EMG) for the Lower Trapezius was increased at humeral angles of 60º-120º of 13% and 17%. Serratus Anterior muscle activity showed a main group effect with a 9% reduction in activation. The data is indicative of muscle alteration with a tendency of increased upper trap activation through increased arm elevation and load. The decreased Serratus Anterior activity may be an important factor as the Lower Trapezius attempts to adjust for its dysfunction (Ludewig & Cook, 2000).

A study by Diederichsen and colleagues (2009) showed changes in the muscle activation pattern during scapular plane abduction and external rotation of eight muscles in a SAIS group (n=21) compared to control (n=20) during an isokinetic task. In an abduction task, the SAIS group's symptomatic side had a greater activity of the latissimus dorsi, supraspinatus, but lower

Serratus Anterior activity compared to the control group's dominant side. No difference was found between the asymptomatic side and nondominant side of the control group. Muscle activity changes were also present during neutral shoulder external rotation (Diederichsen et al., 2009).

A study by Lopes et al. (2015) investigated muscle activity of those with SAIS (n=19) and those with dyskinesis (n=19). This study showed a significant group by arm interaction for the Upper Trapezius activation during elevation. The dyskinesis group had 12% greater Upper Trapezius activation between 30º - 60º. Other muscles and elevation ranges showed no differences (Lopes et al., 2015). Muscle action ratios support the finding of increased Upper Trapezius activity. In a loaded scapular plane movement of a shoulder pain group (n=28) compared to control (n=28) a group main effect of UT/LT ratio and LT/SA ratio occurred that indicated a greater activation of the Upper Trapezius and Lower Trapezius respectively (Michener et al., 2016). The single maximal voluntary isometric contraction (MVIC) method used in this study most likely did not elicit maximal contraction of the muscle measured due to the muscle not being at the optimal length-tension relationship (Michener et al., 2016). In support of muscle activation pattern changes research indicates that a SAIS population induces early activation of the Upper Trapezius when loaded and early Serratus Anterior deactivation when lowering (Vandana Phadke & Ludewig, 2013; Wadsworth & Bullock-Saxton, 1997)**.**

The timing of muscle activation is important as it may indicate central nervous system interruptions. In healthy swimmers, the Upper Trapezius activated first 217 ms before abduction, then 53 ms after arm elevation begins the Serratus Anterior activates and the Lower Trapezius activates last 349 ms after initiation of abduction (Wadsworth & Bullock-Saxton, 1997). In freestyle swimmers with SAIS (n=9), no significant difference was observed in the muscle onset in scapular plane elevation between control (n=9); however, the author notes there may be increased variability (Wadsworth & Bullock-Saxton, 1997). Athletes with SAIS (n=30) showed increased Upper Trapezius activity compared to other healthy controls (n=30) which is similar to other research on SAIS (Cools et al., 2007). There was lower activity in the Lower Trapezius during abduction and the middle trapezius was lower during external rotation (Cools et al., 2007). Leong et al. (2017) found that in volleyball athletes with rotator cuff tendinopathy the Lower Trapezius and Serratus Anterior relative to the Upper Trapezius activated significantly slower (Leong et al., 2017). Another study found that at a higher velocity, a decrement in Lower Trapezius activity in the injured (SAIS) side was present (n=19) during an isokinetic retraction test (Cools et al., 2004).

It is clear that within a population that has shoulder injuries such as SAIS the muscle activation whether it is reported as a ratio, individual muscle activation, or timing there may be an alteration. A systematic review of SAIS compared to control revealed possible increased Upper Trapezius activation in studies of high quality, but the heterogeneity of the research is limiting. The timing of the activation pattern of these muscles may be a more indicative factor as the lower trap was consistently delayed during a scapular plane movement (Chester et al., 2010). Analysis of muscle activation is difficult due to discrepancies in methodology such as the declaration of onset time, EMG normalization procedure, and the movement assessed.

SAIS Clinical Test Efficacy

A clinical physical exam for shoulder injury plays an important role in the treatment process. The structures that surround the shoulder and loads exerted on the area may lead to many injuries so being able to effectively diagnose the issue is important in an individual's return to health. Common tests for SAIS are Hawkins-Kennedy, Neer, Empty Can (Jobe) while some additional tests painful arc, and external rotation also are effective in diagnosis (Du et al., 2020; Michener et al., 2009).

Neer's impingement test was popularized and is conducted by a clinician with one arm inhibiting scapular rotation while the other arm raises the testing arm. This forced mechanical compression of the supraspinatus tendon, bursa, and biceps brachii long tendon elicits a pain response in those with SAIS (Neer, 1983). Neer did acknowledge that this test is not SAIS specific and will induce pain in those with other shoulder disorders. The Hawkins-Kennedy test involves humeral elevation to 90 followed by forced internal rotation induced compression of tissue into the coracoacromial arch (Hawkins & Kennedy, 1980). The authors anecdotally assert this method is less reliable than Neer's test (Hawkins & Kennedy, 1980). Jobe's test also commonly labeled the empty can test or a supraspinatus test (Gismervik et al., 2017) assesses the integrity of the supraspinatus muscle by placing the patient's arm in the scapular plane elevated to 90° with full internal rotation. Weakness or pain with the downward force provided by the clinician indicates a positive test. (Jobe & Moynes, 1982). The painful arc is defined by pain typically present between 60° and 120° of abduction which is indicative of subacromial disorders like SAIS (Kessel & Watson, 1977). Pain from 120° up to 180° of humeral elevation is thought to be associated with acromial clavicular disorders (Kessel & Watson, 1977).

The diagnostic utility of these tests has been thoroughly examined through comparison to imaging technology or arthroscopic assessments. Michener and colleagues (2009) investigated the accuracy of these tests as previous research has found inconsistent results of each test's ability to determine shoulder injury. Furthermore, Michener et al. (2009) sought to determine reliability, accuracy, and which cluster of tests to use specifically for SAIS. The study cohort of 55 participants (47 male and 8 female) were clinically examined and subsequently surgically examined by blinded investigators. The interrater reliability ranged from 69% to 87% for the 5 tests. It is also noteworthy that the Hawkins-Kennedy test alone may not be able to detect SAIS. Combinations of clinical tests may be beneficial as 3 or more positive tests out of 5 can confirm SAIS, whereas less than 3 positive of the 5 tests is helpful in decreasing the likelihood of SAIS (Michener et al., 2009). The use of multiple tests and a thorough physical exam is important in accurately diagnosing shoulder disorder (Hegedus et al., 2012). Another study assessed clinical tests of participants (n=34) and compared results to ultrasound imaging of the shoulder capsule. The results found limited specificity for diagnosing SAIS among all tests however the Hawkins-Kennedy test was the most accurate (Kelly et al., 2010). When clinical tests were compared against MRI, the Hawkins, Neer, and Jobe had a range of accuracy of 44.8% to 65.5% in diagnosing participants (n=30) with SAIS (Silva et al., 2008). Moreover, these tests were found to be more sensitive than specific which is in alignment with much of the literature (Silva et al., 2008).

A number of systematic reviews and meta-analyses have been conducted. Analyses in 2008 indicated that Hawkins-Kennedy and Neer tests have limited diagnostic usefulness (Hegedus et al., 2008). However, the Hawkins-Kennedy and empty can may serve as a screen and confirmation for clinicians (Hegedus et al., 2008). In an update to this study, Hegedus and colleagues (2012) report that the Hawkins-Kennedy test may be beneficial in ruling out SAIS with a negative finding (Hegedus et al., 2012). Alqunaee and colleagues found that all clinical tests (Hawkins-Kennedy, Neer, Empty can, drop arm, and lift-off test) were useful diagnostic tools (Alqunaee et al., 2012). The Hawkins-Kennedy, Neer, and empty can positive tests increase the likelihood of SAIS; A negative Neer's test is useful in ruling out SAIS while the drop arm test is useful in ruling in SAIS (Alqunaee et al., 2012). Gismervik and colleagues' (2017) systematic review concludes that the Hawkins-Kennedy test had the highest likelihood for diagnosing SAIS (Diagnostic odds ratio 2.86; sensitivity 0.58, specificity 0.67) (Gismervik et al., 2017).

The outlook for the effectiveness of these clinical tests as a diagnostic tool is not clear although there have been many systematic reviews and meta-analyses conducted. The multitude of clinical tests available to clinicians indicates a need to further understand elucidate ethe Clinicians and researchers would be prudent to utilize multiple clinical tests are many tests available and clinicians are best to use a combination of tests. Therefore, until technological advances exist to noninvasively image the shoulder capsule use of clinical tests is needed and should continuously be researched with more thorough studies.

Treatment and Rehabilitation of SAIS

Treatment of SAIS can be accomplished through non-operative measures or surgical interventions. Most cases of SAIS are treated conservatively for a period of time, and if necessary, surgical options are available with arthroscopic subacromial decompression having the potential for the most positive results (Dong et al., 2015). In contrast, Gebremariam et al. (2011) found that no surgical option is superior to one another and that there is no evidence for surgical being superior to conservative treatment indicating a need to further evaluate surgical interventions compared to conservative treatment in terms of outcome measures (Gebremariam et al., 2011). Conservative treatment options should revolve around exercise therapy and other modalities may be used in conjunction for optimal results in rehabilitation (Dong et al., 2015).

*Scapula Based Exercise Therapy***.** Teaching proper muscle activation of the scapular stabilizers is a common foundation technique in the rehabilitation process as it provides proximal stability of the upper extremity kinetic chain (Ellenbecker & Cools, 2010; Kibler et al., 2013)

There are a number of scapular focused exercises available however understanding the muscle excitation induced from particular weighted or unweighted movement patterns should be considered (Castelein et al., 2016). There have been a few systematic reviews on scapular based exercise rehabilitation. One of the most recent reviews found a decreased pain index and reduced disability in those with SAIS completing scapular focused exercise training (Ravichandran et al., 2020). This positive finding is shared by a systematic review of scapular based treatment programs in population groups with SAIS that have shown beneficial short term changes in overall shoulder function, abduction ROM, and reduced pain with activities (Saito et al., 2018). A systematic review on rotator cuff shoulder pain found scapular training to be beneficial up to 6-weeks although not clinically significant (Bury et al., 2016). On the contrary, the quality among exercise specific studies is lacking thus making concise exercise recommendations not possible (Shire et al., 2017). Additionally, a study assessed biomechanical changes as a result of scapular based interventions and a control group found that after an 8-week program scapular resting position was more externally rotated and kinematics changes were present in the frontal, sagittal, and scapular plane (Hotta et al., 2018).

Biofeedback Training. EMG Biofeedback training is a conservative treatment method that uses a visual representation of muscle activity to give individuals an additional form of a feedback on how they are using their muscles with motion. Biofeedback in rehabilitation has existed for some time and is one of the most widely used and reported forms of feedback (Giggins et al., 2013). EMG biofeedback training has been successful in training upper extremity muscle activation in an impinged population. A study by Larsen and colleagues (Larsen et al., 2014) investigated motor control effects of SAIS through selective activation of the trapezius musculature. Participants were prone during biofeedback while they completed six three-minute selective activation tasks. A comparison between the healthy (n=15) and SAIS (n=15) groups found that with the aid of EMG biofeedback SAIS participants had better success at selectively activating the Lower Trapezius musculature. Moreover, both groups had higher activation ratios when using EMG biofeedback implicated as a benefit of the training modality to both groups (Larsen et al., 2014).

A study comparing EMG biofeedback (n=20) to video feedback (n=21) in overhead athletes found positive effects in decreasing muscle activation and altering kinematics (Du et al., 2020). The groups were presented with different goals based on their form of feedback with kinematics and muscle activation measured during arm elevation at 30°, 60°, 90°, and 120°. The plane of elevation was not recorded. Each feedback system used in the study had its own benefit. The video feedback allowed for a greater control change in upward rotation (2.3°) while the EMG biofeedback improved Lower Trapezius activation and decreased muscle activation ratios (Du et al., 2020). Both feedback groups produced positive effects in altering kinematics and muscle activity.

Additionally, research has demonstrated an EMG biofeedback training may aid in altering scapular kinematics through scapular based exercises. San Juan and colleagues (2016) found that after completing four scapular based exercises (I, W, T, Y) with EMG biofeedback healthy individuals were able to complete an overhead scapular plane (35°) movement with a 6.5° more externally rotated scapula across elevation angles of 30°, 60°, 90°, and 110°.

Huang et al. (2013) found different kinematic changes compared to San Juan et al. (2016) while also measuring EMG activity during 3 exercises (forward flexion, side-lying external rotation, and a knee push up plus) in healthy adults (n=12) and adults with SAIS (n=13). This study found a significant increase in posterior tilt for those with SAIS (mean difference 1.38°)

(Huang et al., 2013). Muscle activity ratios were analyzed, and positive significant changes were found in the forward flexion and side lying external rotation exercises. This study presents that EMG biofeedback may have an effect on teaching proper muscle activation and positively affecting scapular kinematics (Huang et al., 2013). Side-lying exercises may be the most beneficial to the rehabilitation of SAIS through reduced Upper Trapezius activation (Huang et al., 2013).

The acute effects of EMG biofeedback training are positive however the long-term effects are not as clear. A randomized controlled trial (RCT) investigated 8 weeks of EMG biofeedback on scapular stabilizer muscles (UT, LT, SA) in 49 participants with SAIS (Juul-Kristensen et al., 2019). EMG biofeedback was used with rehabilitative exercises that focused on decreasing Upper Trapezius activation and increasing Lower Trapezius and Serratus Anterior and subsequently compared to control over 8-weeks (Juul-Kristensen et al., 2019). There was no superior benefit in outcome measures of pain and muscle activity amplitude throughout the painful arc (60-120) when using EMG biofeedback compared to no EMG biofeedback (Juul-Kristensen et al., 2019). This is the only longitudinal EMG biofeedback study specific to SAIS and indicates that more research needs to be done to investigate other exercise protocols (Juul-Kristensen et al., 2019).

One 6-week RCT biofeedback intervention found that EMG biofeedback presents more favorable outcomes in terms of pain reduction and EMG activity reduction (Ma et al., 2011). Fifteen participants were split between four groups (biofeedback, active treatment, passive treatment, and control) where EMG amplitude during typing and pain were recorded. After 6-weeks, all three treatments improved patient outcome measures significantly compared to control. This finding persisted at the 6 months follow up even with increased dropout. Ma and colleagues (2011) found that the most effective treatment was the biofeedback training as it allowed for lower pain scores and significantly decreased UT and neck musculature EMG compared to active and passive treatment (Ma et al., 2011).

Ma and colleagues were able to find a reduction in Upper Trapezius activation through educating participants in reducing UT activation in conjunction with EMG biofeedback; however, Juul-Kristensen and colleagues found that their shoulder exercise protocol was effective regardless of using EMG biofeedback. Additional research on scapular focused exercise with longer treatment times will help elicit an understanding of the effects of EMG biofeedback as there may be some benefits but conclusive remarks are limited as there are few randomized controlled trials, systematic reviews, and heterogeneous methodologies (Giggins et al., 2013).

Summary

Shoulder injuries are common in the general population and are affecting an individual's ability to complete activities of daily living. The mobility and stability of the scapula play a critical role in overhead arm movements. Changes in the scapular kinematics, scapulohumeral rhythm, and muscle activation patterns may lead to injury as the subacromial space is decreased with humeral elevation causing mechanical damage to surrounding tissue resulting in pain response. Research does make it clear that injured population groups may show altered kinematics, and this may be associated with muscle activation changes. Those with SAIS may have increased Upper Trapezius activation and decreased Serratus Anterior and Lower Trapezius activation. Furthermore, the timing of muscle activation is more variable in injured shoulders. When deciding the route to regain normal function and decrease pain conservative or operative treatment may be pursued however the positive results of the former may outweigh the comparably poor outcomes of the latter. Biofeedback training in conjunction with scapular based treatment may be a worthwhile treatment as it has effectively trained muscle activation and kinematic changes thus require increased research attention. This review has uncovered gaps in the research of scapular kinematics and muscle activation in those with SAIS and rehabilitation techniques and provided justification for the methodology used in this study.

References

Alqunaee, M., Galvin, R., & Fahey, T. (2012). Diagnostic accuracy of clinical tests for subacromial impingement syndrome: A systematic review and meta-analysis. *Archives of Physical Medicine and Rehabilitation*, *93*(2), 229–236. https://doi.org/10.1016/j.apmr.2011.08.035

Andersson, H. I., Ejlertsson, G., Leden, I., & Rosenberg, C. (1993). Chronic pain in a geographically defined general population: Studies of differences in age, gender, social class, and pain localization. *Clinical Journal of Pain*, *9*(3), 174–182. https://doi.org/10.1097/00002508-199309000-00004

Blache, Y., Gillet, B., Selin, J., Sevrez, V., & Rogowski, I. (2018). Scapular kinematics during scaption in competitive swimmers. *European Journal of Sport Science*, *18*(5), 659–666. https://doi.org/10.1080/17461391.2018.1449893

Bot, S. D. M., Van Der Waal, J. M., Terwee, C. E., Van Der Windt, D. A. W. M., Schellevis, F. G., Bouter, L. M., & Dekker, J. (2005). Incidence and prevalence of complaints of the neck and upper extremity in general practice. *Annals of the Rheumatic Diseases*, *64*(1), 118–123. https://doi.org/10.1136/ard.2003.019349

Bury, J., West, M., Chamorro-Moriana, G., & Littlewood, C. (2016). Effectiveness of scapula-focused approaches in patients with rotator cuff related shoulder pain: A systematic review and meta-analysis. *Manual Therapy*, *25*, 35–42. https://doi.org/10.1016/j.math.2016.05.337

Camargo, P. R., & Neumann, D. A. (2019). Kinesiologic considerations for targeting activation of scapulothoracic muscles – part 2: trapezius. *Brazilian Journal of Physical Therapy*, *23*(6), 467–475. https://doi.org/10.1016/j.bjpt.2019.01.011

Castelein, B., Cagnie, B., Parlevliet, T., & Cools, A. (2016). Superficial and deep scapulothoracic muscle electromyographic activity during elevation exercises in the scapular plane. *Journal of Orthopaedic and Sports Physical Therapy*, *46*(3), 184–193. https://doi.org/10.2519/jospt.2016.5927

Chester, R., Smith, T. O., Hooper, L., & Dixon, J. (2010). The impact of subacromial impingement syndrome on muscle activity patterns of the shoulder complex: A systematic review of electromyographic studies. *BMC Musculoskeletal Disorders*, *11*(1), 45. https://doi.org/10.1186/1471-2474-11-45

Cools, A. M., Declercq, G. A., Cambier, D. C., Mahieu, N. N., & Witvrouw, E. E. (2007). Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. *Scandinavian Journal of Medicine and Science in Sports*, *17*(1), 25–33. https://doi.org/10.1111/j.1600-0838.2006.00570.x

Cools, A. M., Witvrouw, E. E., Declercq, G. A., Vanderstraeten, G. G., & Cambier, D. C. (2004). Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. *British Journal of Sports Medicine*, *38*(1), 64–68. https://doi.org/10.1136/bjsm.2003.004952

Dhillon, K. S. (2019). Subacromial impingement syndrome of the shoulder: A musculoskeletal disorder or a medical myth? *Malaysian Orthopaedic Journal*, *13*(3), 1–7. https://doi.org/10.5704/MOJ.1911.001

Diederichsen, L. P., Nørregaard, J., Dyhre-Poulsen, P., Winther, A., Tufekovic, G., Bandholm, T., Rasmussen, L. R., & Krogsgaard, M. (2009). The activity pattern of shoulder muscles in subjects with and without subacromial impingement. *Journal of Electromyography and Kinesiology*, *19*(5), 789–799. https://doi.org/10.1016/j.jelekin.2008.08.006

Dong, W., Goost, H., Lin, X. B., Burger, C., Paul, C., Wang, Z. L., Zhang, T. Y., Jiang, Z. C., Welle, K., & Kabir, K. (2015). Treatments for shoulder impingement syndrome a prisma systematic review and network meta-analysis. *Medicine (United States)*, *94*(10), 1–17. https://doi.org/10.1097/MD.0000000000000510

Du, W. Y., Huang, T. S., Chiu, Y. C., Mao, S. J., Hung, L. W., Liu, M. F., Yang, J. L., & Lin, J. J. (2020). Single-session video and electromyography feedback in overhead athletes with scapular dyskinesis and impingement syndrome. *Journal of Athletic Training*, *55*(3), 265–273. https://doi.org/10.4085/1062-6050-490-18

Ebaugh, D. D., & Spinelli, B. A. (2010). Scapulothoracic motion and muscle activity during the raising and lowering phases of an overhead reaching task. *Journal of Electromyography and Kinesiology*, *20*(2), 199–205. https://doi.org/10.1016/j.jelekin.2009.04.001

Ellenbecker, T. S., & Cools, A. (2010). Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: An evidence-based review. *British Journal of Sports Medicine*, *44*(5), 319–327. https://doi.org/10.1136/bjsm.2009.058875

Engebretsen, K. B., Grotle, M., & Natvig, B. (2015). Patterns of shoulder pain during a 14-year follow-up: results from a longitudinal population study in Norway. *Shoulder and Elbow*, *7*(1), 49–59. https://doi.org/10.1177/1758573214552007

Gebremariam, L., Hay, E. M., Koes, B. W., & Huisstede, B. M. (2011). Effectiveness of surgical and postsurgical interventions for the subacromial impingement syndrome: A systematic review. *Archives of Physical Medicine and Rehabilitation*, *92*(11), 1900–1913. https://doi.org/10.1016/j.apmr.2011.06.006

Giggins, O. M., Persson, U. M. C., & Caulfield, B. (2013). Biofeedback in rehabilitation. *Journal of NeuroEngineering and Rehabilitation*, *10*(1), 1. https://doi.org/10.1186/1743-

0003-10-60

Gismervik, S., Drogset, J. O., Granviken, F., Rø, M., & Leivseth, G. (2017). Physical examination tests of the shoulder: A systematic review and meta-analysis of diagnostic test performance. *BMC Musculoskeletal Disorders*, *18*(1). https://doi.org/10.1186/s12891-017-1400-0

Habechian, F. A. P., Rosa, D. P., Haik, M. N., & Camargo, P. R. (2016). Sex-related differences in scapular kinematics during elevation of the arm in asymptomatic children and adults. *Journal of Applied Biomechanics*, *32*(5), 513–519. https://doi.org/10.1123/jab.2015-0341

Hawkins, R., & Kennedy, J. (1980). Impingement syndrome in athletes. *The American Journal of Sports Medicine*, *8*(3), 151–158. https://doi.org/10.1016/S0278-5919(05)70265-9

Hegedus, E. J., Goode, A., Campbell, S., Morin, A., Tamaddoni, M., Moorman, C. T., & Cook, C. (2008). Physical examination tests of the shoulder: A systematic review with meta-analysis of individual tests. *British Journal of Sports Medicine*, *42*(2), 80–92. https://doi.org/10.1136/bjsm.2007.038406

Hegedus, E. J., Goode, A. P., Cook, C. E., Michener, L., Myer, C. A., Myer, D. M., & Wright, A. A. (2012). Which physical examination tests provide clinicians with the most value when examining the shoulder? Update of a systematic review with meta-analysis of individual tests. *British Journal of Sports Medicine*, *46*(14), 964–978. https://doi.org/10.1136/bjsports-2012-091066

Hosseinimehr, S. H., Anbarian, M., Norasteh, A. A., Fardmal, J., & Khosravi, M. T. (2015). The comparison of scapular upward rotation and scapulohumeral rhythm between dominant and non-dominant shoulder in male overhead athletes and non-athletes. *Manual Therapy*, *20*(6), 758–762. https://doi.org/10.1016/j.math.2015.02.010

Hotta, G. H., Santos, A. L., McQuade, K. J., & de Oliveira, A. S. (2018). Scapular-focused exercise treatment protocol for shoulder impingement symptoms: Three-dimensional scapular kinematics analysis. *Clinical Biomechanics*, *51*, 76–81. https://doi.org/10.1016/j.clinbiomech.2017.12.005

Huang, H. Y., Lin, J. J., Guo, Y. L., Wang, W. T. J., & Chen, Y. J. (2013). EMG biofeedback effectiveness to alter muscle activity pattern and scapular kinematics in subjects with and without shoulder impingement. *Journal of Electromyography and Kinesiology*, *23*(1), 267–274. https://doi.org/10.1016/j.jelekin.2012.09.007

Humphrey, A. R., Nargol, A. V. F., Jones, A. P. C., Ratcliffe, A. A., & Greenough, C. G. (2005). The value of electromyography of the lumbar paraspinal muscles in discriminating between chronic-low-back-pain sufferers and normal subjects. *European Spine Journal*, *14*(2), 175–184. https://doi.org/10.1007/s00586-004-0792-3

Hurov, J. (2009). Anatomy and mechanics of the shoulder: Review of current concepts. *Journal of Hand Therapy*, *22*(4), 328–343. https://doi.org/10.1016/j.jht.2009.05.002

Inman, V. T., Saunders, J. B., & Abbott, L. C. (1944). Observations on the function of the shoulder joint. *JBJS*, *26*(1), 1–30. https://doi.org/10.1097/00003086-199609000-00002

Jobe, F. W., & Moynes, D. R. (1982). Delineation of diagnostic criteria and a rehabilitation program for rotator cuff injuries. *The American Journal of Sports Medicine*, *10*(6), 336–339. https://doi.org/10.1177/036354658201000602

Juul-Kristensen, B., Larsen, C. M., Eshoj, H., Clemmensen, T., Hansen, A., Bo Jensen, P., Boyle, E., & Søgaard, K. (2019). Positive effects of neuromuscular shoulder exercises with or without EMG-biofeedback, on pain and function in participants with subacromial pain syndrome – A randomised controlled trial. *Journal of Electromyography and Kinesiology*, *48*, 161–168. https://doi.org/10.1016/j.jelekin.2019.07.009

Karduna, A. R., Kerner, P. J., & Lazarus, M. D. (2005). Contact forces in the subacromial space: Effects of scapular orientation. *Journal of Shoulder and Elbow Surgery*, *14*(4), 393–399. https://doi.org/10.1016/j.jse.2004.09.001

Kelly, S. M., Brittle, N., & Allen, G. M. (2010). The value of physical tests for subacromial impingement syndrome: A study of diagnostic accuracy. *Clinical Rehabilitation*, *24*(2), 149–158. https://doi.org/10.1177/0269215509346103

Keshavarz, R., Bashardoust Tajali, S., Mir, S. M., & Ashrafi, H. (2017). The role of scapular kinematics in patients with different shoulder musculoskeletal disorders: A systematic review approach. In *Journal of Bodywork and Movement Therapies* (Vol. 21, Issue 2, pp. 386–400). Churchill Livingstone. https://doi.org/10.1016/j.jbmt.2016.09.002

Kessel, L., & Watson, M. (1977). The painful arc syndrome. Clinical classification as a guide to management. *Journal of Bone and Joint Surgery - Series B*, *59*(2), 166–172. https://doi.org/10.1302/0301-620x.59b2.873977

Kibler, W. Ben. (1998). The role of the scapula in athletic shoulder function. *American Journal of Sports Medicine*, *26*(2), 325–337. https://doi.org/10.1177/03635465980260022801

Kibler, W. Ben, Ludewig, P. M., McClure, P. W., Michener, L. A., Bak, K., & Sciascia, A. D. (2013). Clinical implications of scapular dyskinesis in shoulder injury: The 2013 consensus statement from the "scapular summit." *British Journal of Sports Medicine*, *47*(14), 877–885. https://doi.org/10.1136/bjsports-2013-092425

Kijima, T., Matsuki, K., Ochiai, N., Yamaguchi, T., Sasaki, Y., Hashimoto, E., Sasaki, Y., Yamazaki, H., Kenmoku, T., Yamaguchi, S., Masuda, Y., Umekita, H., Banks, S. A., & Takahashi, K. (2015). In vivo 3-dimensional analysis of scapular and glenohumeral kinematics: Comparison of symptomatic or asymptomatic shoulders with rotator cuff tears and healthy shoulders. *Journal of Shoulder and Elbow Surgery*, *24*(11), 1817–1826. https://doi.org/10.1016/j.jse.2015.06.003

Kinsella, R., & Pizzari, T. (2017). Electromyographic activity of the shoulder muscles during rehabilitation exercises in subjects with and without subacromial pain syndrome: a systematic review. *Shoulder & Elbow*, *9*(2), 112–126. https://doi.org/10.1177/1758573216660038

Larsen, C. M., Juul-Kristensen, B., Olsen, H. B., Holtermann, A., & Søgaard, K. (2014). Selective activation of intra-muscular compartments within the trapezius muscle in subjects with Subacromial Impingement Syndrome. A case-control study. *Journal of Electromyography and Kinesiology*, *24*(1), 58–64. https://doi.org/10.1016/j.jelekin.2013.09.008

Lawrence, R. L., Braman, J. P., & Ludewig, P. M. (2019). Shoulder kinematics impact subacromial proximities: a review of the literature. In *Brazilian Journal of Physical Therapy*. Revista Brasileira de Fisioterapia. https://doi.org/10.1016/j.bjpt.2019.07.009

Lee, S. K., Yang, D. Y., Kim, H. Y., & Choy, W. S. (2013). A comparison of 3D scapular kinematics between dominant and nondominant shoulders during multiplanar arm motion. *Indian Journal of Orthopaedics*, *47*(2), 135–142. https://doi.org/10.4103/0019-5413.108882

Leong, H. T., Ng, G. Y. fat, Chan, S. C., & Fu, S. N. (2017). Rotator cuff tendinopathy alters the muscle activity onset and kinematics of scapula. *Journal of Electromyography and Kinesiology*, *35*, 40–46. https://doi.org/10.1016/j.jelekin.2017.05.009

Lin, J. J., Hsieh, S. C., Cheng, W. C., Chen, W. C., & Lai, Y. (2011). Adaptive patterns of movement during arm elevation test in patients with shoulder impingement syndrome.

Journal of Orthopaedic Research, *29*(5), 653–657. https://doi.org/10.1002/jor.21300

Lopes, A. D., Timmons, M. K., Grover, M., Ciconelli, R. M., & Michener, L. A. (2015). Visual scapular dyskinesis: Kinematics and muscle activity alterations in patients with subacromial impingement syndrome. *Archives of Physical Medicine and Rehabilitation*, *96*(2), 298–306. https://doi.org/10.1016/j.apmr.2014.09.029

Ludewig, P. M., & Cook, T. M. (2000). Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Physical Therapy*, *80*(3), 276–291. https://doi.org/10.1093/ptj/80.3.276

Ludewig, P. M., Cook, T. M., & Nawoczenski, D. A. (1996). Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation. *Journal of Orthopaedic and Sports Physical Therapy*, *24*(2), 57–65. https://doi.org/10.2519/jospt.1996.24.2.57

Ludewig, P. M., & Reynolds, J. F. (2009). The association of scapular kinematics and glenohumeral joint pathologies. *Journal of Orthopaedic and Sports Physical Therapy*, *39*(2), 90–104. https://doi.org/10.2519/jospt.2009.2808

Luime, J. J., Koes, B. W., Hendriksen, I. J. M., Burdorf, A., Verhagen, A. P., Miedema, H. S., & Verhaar, J. A. N. (2004). Prevalence and incidence of shoulder pain in the general population; a systematic review. *Scandinavian Journal of Rheumatology*, *33*(2), 73–81. https://doi.org/10.1080/03009740310004667

Lukasiewicz, A. C., McClure, P., Michener, L., Pratt, N., & Sennett, B. (1999). Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. *Journal of Orthopaedic and Sports Physical Therapy*, *29*(10), 574–586. https://doi.org/10.2519/jospt.1999.29.10.574

Ma, C., Szeto, G. P., Yan, T., Wu, S., Lin, C., & Li, L. (2011). Comparing biofeedback with active exercise and passive treatment for the management of work-related neck and shoulder pain: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, *92*(6), 849–858. https://doi.org/10.1016/j.apmr.2010.12.037

Matias, R., & Pascoal, A. G. (2006). The unstable shoulder in arm elevation: A three-dimensional and electromyographic study in subjects with glenohumeral instability. *Clinical Biomechanics*, *21*(SUPPL. 1). https://doi.org/10.1016/j.clinbiomech.2005.09.014

Matsuki, K., Matsuki, K. O., Mu, S., Yamaguchi, S., Ochiai, N., Sasho, T., Sugaya, H., Toyone, T., Wada, Y., Takahashi, K., & Banks, S. A. (2011). In vivo 3-dimensional analysis of scapular kinematics: Comparison of dominant and nondominant shoulders. *Journal of Shoulder and Elbow Surgery*, *20*(4), 659–665. https://doi.org/10.1016/j.jse.2010.09.012

McClure, P. W., Michener, L. A., Sennett, B. J., & Karduna, A. R. (2001). Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. *Journal of Shoulder and Elbow Surgery*, *10*(3), 269–277. https://doi.org/10.1067/mse.2001.112954

McLaine, S. J., Ginn, K. A., Fell, J. W., & Bird, M. L. (2018). Scapular upward rotation position is symmetrical in swimmers without current shoulder pain. *Physical Therapy in Sport*, *29*, 9–13. https://doi.org/10.1016/j.ptsp.2017.09.003

Mell, A. G., LaScalza, S., Guffey, P., Ray, J., Maciejewski, M., Carpenter, J. E., & Hughes, R. E. (2005). Effect of rotator cuff pathology on shoulder rhythm. *Journal of Shoulder and Elbow Surgery*, *14*(1), S58–S64. https://doi.org/10.1016/j.jse.2004.09.018

Michener, L. A., McClure, P. W., & Karduna, A. R. (2003). Anatomical and biomechanical mechanisms of subacromial impingement syndrome. *Clinical Biomechanics*, *18*(5), 369–379. https://doi.org/10.1016/S0268-0033(03)00047-0

Michener, L. A., Sharma, S., Cools, A. M., & Timmons, M. K. (2016). Relative scapular muscle activity ratios are altered in subacromial pain syndrome. *Journal of Shoulder and Elbow Surgery*, *25*(11), 1861–1867. https://doi.org/10.1016/j.jse.2016.04.010

Michener, L. A., Walsworth, M. K., Doukas, W. C., & Murphy, K. P. (2009). Reliability and diagnostic accuracy of 5 physical examination tests and combination of tests for subacromial impingement. *Archives of Physical Medicine and Rehabilitation*, *90*(11), 1898–1903. https://doi.org/10.1016/j.apmr.2009.05.015

Myers, J. B., Laudner, K. G., Pasquale, M. R., Bradley, J. P., & Lephart, S. M. (2005). Scapular position and orientation in throwing athletes. *American Journal of Sports Medicine*, *33*(2), 263–271. https://doi.org/10.1177/0363546504268138

Neer, C. S. (1983). Impingement lesions. *Classic Papers in Orthopaedics*, 70–77. https://doi.org/10.1007/978-1-4471-5451-8_75

Paletta, G. A., Warner, J. J. P., Warren, R. F., Deutsch, A., & Altchek, D. W. (1997). Shoulder kinematics with two-plane x-ray evaluation in patients with anterior instability or rotator cuff tearing. *Journal of Shoulder and Elbow Surgery*, *6*(6), 516–527. https://doi.org/10.1016/S1058-2746(97)90084-7

Park, J. Y., Kim, J., Seo, B. H., Yu, H. D., Sim, J. H., Lee, J. H., Oh, K. S., & Chung, S. W. (2020). Three-Dimensional analysis of scapular kinematics during arm elevation in baseball players with scapular dyskinesis: Comparison of dominant and nondominant arms. *Journal of Sport Rehabilitation*, *29*(1), 93–101. https://doi.org/10.1123/jsr.2017-0216

Phadke, V., Camargo, P. R., & Ludewig, P. M. (2009). Scapular and rotator cuff muscle activity during arm elevation: A review of normal function and alterations with shoulder impingement. *Revista Brasileira de Fisioterapia*, *13*(1), 1–9. https://doi.org/10.1590/S1413-

35552009005000012

Phadke, Vandana, & Ludewig, P. M. (2013). Study of the scapular muscle latency and deactivation time in people with and without shoulder impingement. *Journal of Electromyography and Kinesiology*, *23*(2), 469–475. https://doi.org/10.1016/j.jelekin.2012.10.004

Picco, B. R., Vidt, M. E., & Dickerson, C. R. (2018). Scapular kinematics by sex across elevation planes. *Journal of Applied Biomechanics*, *34*(2), 141–150. https://doi.org/10.1123/jab.2017-0082

Poppen, N. K., & Walker, P. S. (1976). Normal and abnormal motion of the shoulder. *The Journal of Bone and Joint Surgery*, *58*, 195–201. https://doi.org/10.1007/978-1-4471-5451-8_82

Ratcliffe, E., Pickering, S., McLean, S., & Lewis, J. (2014). Is there a relationship between subacromial impingement syndrome and scapular orientation? A systematic review. In *British Journal of Sports Medicine* (Vol. 48, Issue 16, pp. 1251–1256). BMJ Publishing Group. https://doi.org/10.1136/bjsports-2013-092389

Ravichandran, H., Janakiraman, B., Gelaw, A. Y., Fisseha, B., Sundaram, S., & Sharma, H. R. (2020). Effect of scapular stabilization exercise program in patients with subacromial impingement syndrome: A systematic review. *Journal of Exercise Rehabilitation*, *16*(3), 216–226. https://doi.org/10.12965/jer.2040256.128

Robert-Lachaine, X., Allard, P., Godbout, V., Tétreault, P., & Begon, M. (2016). Scapulohumeral rhythm relative to active range of motion in patients with symptomatic rotator cuff tears. *Journal of Shoulder and Elbow Surgery*, *25*(10), 1616–1622. https://doi.org/10.1016/j.jse.2016.02.031

Rundquist, P. J. (2007). Alterations in scapular kinematics in subjects with idiopathic loss of shoulder range of motion. *Journal of Orthopaedic and Sports Physical Therapy*, *37*(1), 19–25. https://doi.org/10.2519/jospt.2007.2121

Rundquist, P. J., Anderson, D. D., Guanche, C. A., & Ludewig, P. M. (2003). Shoulder kinematics in subjects with frozen shoulder. *Archives of Physical Medicine and Rehabilitation*, *84*(10), 1473–1479. https://doi.org/10.1016/S0003-9993(03)00359-9

Saito, H., Harrold, M. E., Cavalheri, V., & McKenna, L. (2018). Scapular focused interventions to improve shoulder pain and function in adults with subacromial pain: A systematic review and meta-analysis. *Physiotherapy Theory and Practice*, *34*(9), 653–670. https://doi.org/10.1080/09593985.2018.1423656

San Juan, J. G., Gunderson, S. R., Kane-Ronning, K., & Suprak, D. N. (2016). Scapular kinematic is altered after electromyography biofeedback training. *Journal of Biomechanics*, *49*(9), 1881–1886. https://doi.org/10.1016/j.jbiomech.2016.04.036

Schwartz, C., Croisier, J. L., Rigaux, E., Brüls, O., Denoël, V., & Forthomme, B. (2016). Gender effect on the scapular 3D posture and kinematic in healthy subjects. *Clinical Physiology and Functional Imaging*, *36*(3), 188–196. https://doi.org/10.1111/cpf.12212

Schwartz, C., Croisier, J. L., Rigaux, E., Denoël, V., Brüls, O., & Forthomme, B. (2014). Dominance effect on scapula 3-dimensional posture and kinematics in healthy male and female populations. *Journal of Shoulder and Elbow Surgery*, *23*(6), 873–881. https://doi.org/10.1016/j.jse.2013.08.020

Shire, A. R., Stæhr, T. A. B., Overby, J. B., Bastholm Dahl, M., Sandell Jacobsen, J., & Høyrup Christiansen, D. (2017). Specific or general exercise strategy for subacromial impingement syndrome-does it matter? A systematic literature review and meta analysis. *BMC*

Musculoskeletal Disorders, *18*(1). https://doi.org/10.1186/s12891-017-1518-0

Silva, L., Andréu, J. L., Muñoz, P., Pastrana, M., Millán, I., Sanz, J., Barbadillo, C., & Fernández-Castro, M. (2008). Accuracy of physical examination in subacromial impingement syndrome. *Rheumatology*, *47*(5), 679–683. https://doi.org/10.1093/rheumatology/ken101

Solem-Bertoft, E., Thuomas, K. A., & Westerberg, C. E. (1993). The influence of scapular retraction and protraction on the width of the subacromial space: An MRI study. *Clinical Orthopaedics and Related Research*, *296*, 99–103. https://doi.org/10.1097/00003086-199311000-00018

Thigpen, C. A., Gross, M. T., Karas, S. G., Garrett, W. E., & Yu, B. (2005). The repeatability of scapular rotations across three planes of humeral elevation. *Research in Sports Medicine*, *13*(3), 181–198. https://doi.org/10.1080/15438620500222489

Timmons, M. K., Thigpen, C. A., Seitz, A. L., Karduna, A. R., Arnold, B. L., & Michener, L. A. (2012). Scapular kinematics and subacromial-impingement syndrome: A meta-analysis. *Journal of Sport Rehabilitation*, *21*(4), 354–370. https://doi.org/10.1123/jsr.21.4.354

Turgut, E., Duzgun, I., & Baltaci, G. (2016). Scapular asymmetry in participants with and without shoulder impingement syndrome; a three-dimensional motion analysis. *Clinical Biomechanics*, *39*, 1–8. https://doi.org/10.1016/j.clinbiomech.2016.09.001

Turgut, E., Yildiz, T. I., Demirci, S., Eraslan, L., Ulusoy, B., Tok, D., Harput, G., Kara, D., Duzgun, I., Tunay, V. B., & Ergun, N. (2018). Shoulder kinematics and mobility adaptations in water-polo players. *Journal of Sports Medicine and Physical Fitness*, *58*(9), 1264–1268. https://doi.org/10.23736/S0022-4707.17.07674-5

Wadsworth, D. J. S., & Bullock-Saxton, J. E. (1997). Recruitment patterns of the scapular rotator muscles in freestyle swimmers with subacromial impingement. *International Journal of Sports Medicine*, *18*(8), 618–624. https://doi.org/10.1055/s-2007-972692

Wofford, J. L., Mansfield, R. J., & Watkins, R. S. (2005). Patient characteristics and clinical management of patients with shoulder pain in U.S. primary care settings: Secondary data analysis of the National Ambulatory Medical Care Survey. *BMC Musculoskeletal Disorders*, *6*, 1–6. https://doi.org/10.1186/1471-2474-6-4

Wu, G., van der Helm, F. C. T., Veeger, H. E. J. D., Makhsous, M., Van Roy, P., Anglin, C., Nagels, J., Karduna, A. R., McQuade, K., Wang, X., Werner, F. W., Buchholz, B., & International Society of Biomechanics. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion--Part II: shoulder, elbow, wrist and hand. *Journal of Biomechanics*, *38*(5), 981–992. https://doi.org/10.1016/j.jbiomech.2004.05.042

Yoshizaki, K., Hamada, J., Tamai, K., Sahara, R., Fujiwara, T., & Fujimoto, T. (2009). Analysis of the scapulohumeral rhythm and electromyography of the shoulder muscles during elevation and lowering: Comparison of dominant and nondominant shoulders. *Journal of Shoulder and Elbow Surgery*, *18*(5), 756–763. https://doi.org/10.1016/j.jse.2009.02.021

Appendix A: Journal Guide for Authors

Journal of Electromyography and Kinesiology

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Appendix B: WWU IRB

Western Washington University

Consent to Take Part in a Research Study

Acute effects of EMG biofeedback training on muscle activity and scapular kinematics

You are invited to participate in a research study conducted by Jun San Juan, PhD, ATC, from the department of Health and Human Development at the Western Washington University. The purpose of this investigation is to examine the effects of electromyography biofeedback training on how your muscles activate and how your shoulder blades move when you lift your arm.

If you decide to participate, you understand that the following things will be done to you. You will be asked to fill out a brief form to provide basic information such as age, height and weight and which arm is your dominant arm. Non-invasive measurements will be made throughout the experiment. To perform motion measurements, small sensors will be attached by straps or tape to your wrist, elbow, and shoulder. To measure muscle activation, small electrodes will be attached to your skin over several sites surrounding your shoulder. You will be asked to move both arms up and down. In addition, you will be asked to perform 4 shoulder exercises. The entire testing process should take about 90 minutes.

There is no direct benefit to you by participating in this study. However, you understand that information gained in this study may help in understanding the function of the shoulder and may guide decisions made in prescribing strengthening and injury rehabilitation exercise.

Participation in any research study carries with it possible risks. Because multiple trials will be performed, there is a risk of muscle fatigue and muscle soreness from performing the exercises and strength testing. For individuals experiencing shoulder pain, an acute increase of pain may be experience during the first 24-48 hours after the testing. However, precautions will be taken to minimize this risk. You may discontinue participation at any time during testing.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Subject identities will be kept confidential by coding the data with subject numbers, rather than names.

Your participation is voluntary. Your decision whether to participate will not affect your relationship with Western Washington University. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time without penalty.

If you have any questions, please feel free to contact Jun San Juan, (360) 650-2336, Department of Health and Human Development, Western Washington University, Bellingham, WA, 98225. If you have any questions about your rights as a research participant, you can contact the WWU Office of Research and Sponsored Programs (RSP) at 360-650-2146 or by email at compliance@wwu.edu. If you feel that you have been harmed by your participation in this study, please contact the researchers listed above or the RSP.

By signing below, you are saying that you have read this form, understand the tasks involved, and volunteer to take part in this research.

Full Name____ Date____________________

Signature____

Note: Please sign both copies of the form and retain the copy circled "Participant Copy"

Appendix C: Researcher Training Procedures

Prior to involvement with the study, researchers and research assistants were required to provide proof of CITI training to ensure proper handling of human subjects.

Appendix D: Graphs

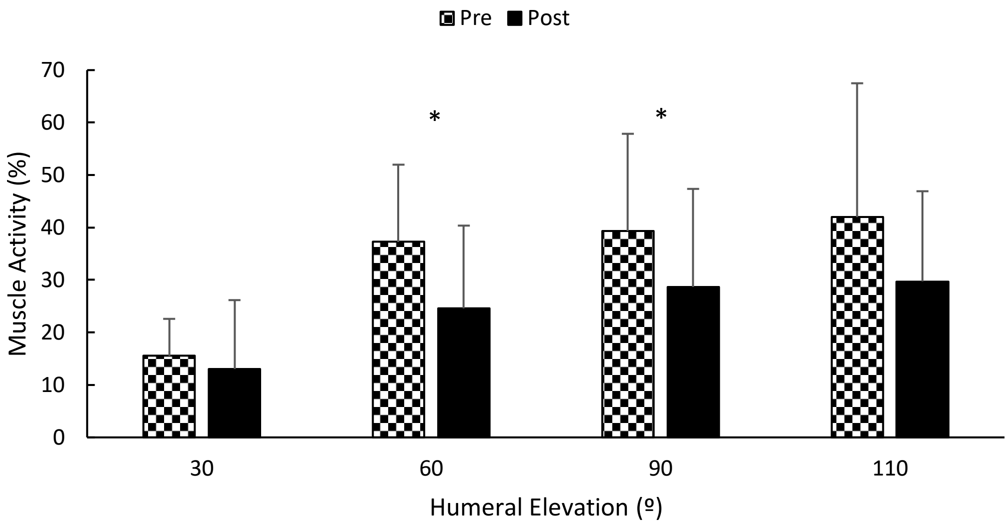
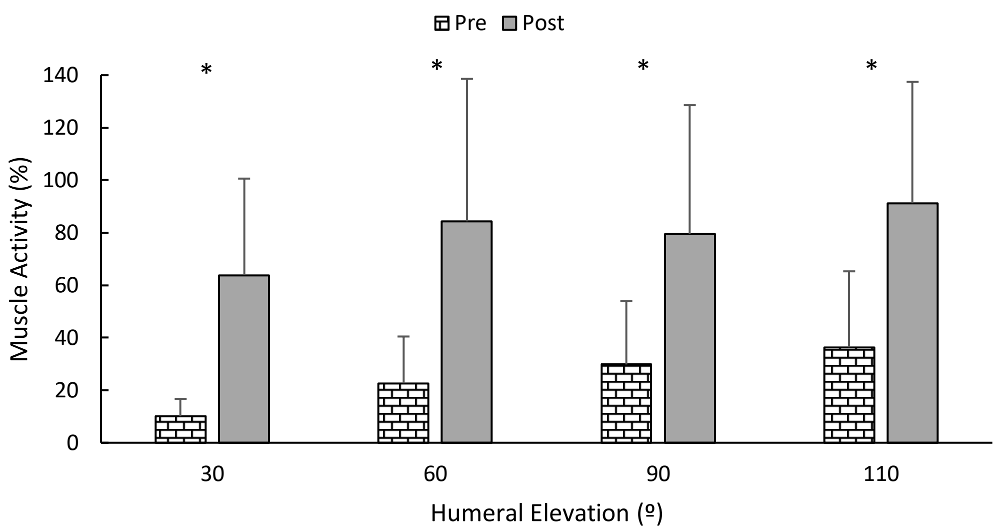


Figure 4. Muscle activity of the Upper Trapezius. * Statistically significant finding.



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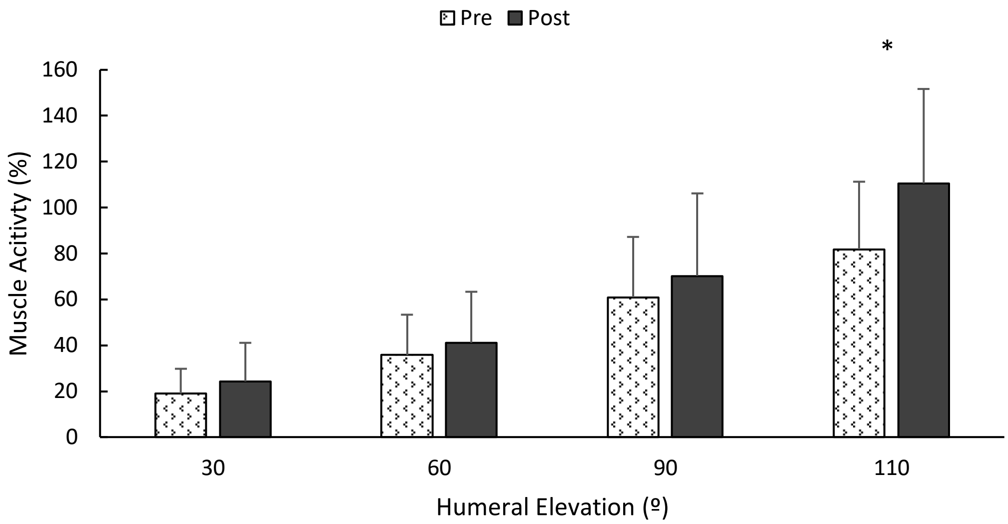

Figure 6. Muscle activity of the Serratus Anterior. * Statistically significant finding.

Figure 7. Muscle activity of the Lumbar Paraspinals. No statistically significant findings.