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Scapular kinematic is altered after electromyography biofeedback training

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ABSTRACT

Electromyography (EMG) biofeedback training affords patients a better sense of the different muscle activation patterns involved in the movement of the shoulder girdle. It is important to address scapular kinematics with labourers who have daily routines involving large amounts of lifting at shoulder level or higher. This population is at a heightened risk of developing subacromial impingement syndrome (SAIS). The purpose of this study was to investigate the acute effects of scapular stabilization exercises with EMG biofeedback training on scapular kinematics. Twenty-three healthy subjects volunteered for the study. Electrodes were placed on the upper and lower trapezius, serratus anterior, and lumbar paraspinals to measure EMG activity. Subjects underwent scapular kinematic testing, which consisted of humeral elevation in the scapular plane, before and after biofeedback training. The latter consisted of 10 repetitions of the I, W, T, and Y scapular stabilization exercises. Subjects were told to actively reduce the muscle activation shown on the screen for the upper trapezius during the exercises. The scapular external rotation had a statistically significant difference at all humeral elevation angles ($p < 0.004$) after biofeedback was administered. After the exercises, the scapula was in a more externally rotated orientation with a mean difference of 6.5°. There were no significant differences found with scapular upward rotation, or posterior tilt at all humeral elevation angles following biofeedback. Scapular kinematics are altered by EMG biofeedback training utilizing scapular stabilization exercises. However, only scapular external rotation was affected by the exercises.

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1. Introduction

Subacromial impingement syndrome (SAIS), or shoulder impingement, is the most common cause of shoulder pain, accounting for 40% of shoulder disorders with an incidence of 19 per 1000 patients (Bot et al., 2005) seen by primary care physicians (Huisstede et al., 2006; Ostor et al., 2005; van der Windt et al., 1995). Impingement syndrome is characterized by a mechanical compression of the soft tissues in the subacromial space (Karduna et al., 2005). SAIS may be the result of a decrease in subacromial space due to altered scapular kinematics, which has been demonstrated in patients with shoulder impingement (Ludewig and Cook, 2000; Warner et al., 1992). Additionally, increased muscle activation of the upper trapezius, in comparison to the lower trapezius and serratus anterior, could lead to changes in normal scapular kinematics (Johnson et al., 1994; Johnson and Pandyan, 2005; Paine and Voight, 2013). These changes can cause shoulder pain as a result of a decreased subacromial space (Karduna et al., 2005; Ludewig and Cook, 2000; Warner et al., 1992).

One of the chief objectives in the rehabilitation of shoulder injuries is re-establishing proper scapular positioning during movement, which is accomplished through retraining the scapular stabilizer muscles (Johnson and Pandyan, 2005; Paine and Voight, 2013). Although, there are clearly underlying biological factors involved, many clinicians feel that abnormal mechanical forces may lead to a pathological progression from impingement syndrome, or tendonitis, to rotator cuff tears.

Education on the correct muscle activation through electromyography (EMG) biofeedback has been shown to be more effective than passive treatment in providing long-term relief from symptoms of impingement (Ma et al., 2011). The technique of EMG biofeedback has been used in clinical settings for rehabilitation of musculoskeletal disorders, and has been employed in rehabilitation programs for patients with shoulder pain (Angoules et al., 2008; Basmajian, 1981; Ehrenborg and Archenholtz, 2010; Flor et al., 1986; Middaugh et al., 2013; Spence et al., 1995). While research interest in this technique has increased in the last few years, still only a handful of studies have been published regarding the use and effectiveness of biofeedback on the improvement of

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muscle balance in the shoulder (Holtermann et al., 2008; Huang et al., 2013; Weon et al., 2011). These studies have reported favorable changes in muscle activation patterns after the use of biofeedback within one session. However, only Huang et al. (2013) examined the effect of biofeedback on scapular motion, as well as muscle activation patterns during a limited number of rehabilitation exercises. The authors recorded EMG activity of four different scapular muscles in both healthy and shoulder impingement subjects and examined their activation ratios with and without EMG biofeedback training. This study found that EMG biofeedback training resulted in an increase in muscle activity of the serratus anterior, middle trapezius and lower trapezius while decreasing the activity of the upper trapezius. They concluded that EMG biofeedback was beneficial for both groups in improving balance ratios of the scapular muscles (Huang et al., 2013).

It is important to address scapular kinematics in a healthy population, because those who have daily routines involving large amounts of lifting at shoulder level or higher, are at a heightened risk of developing SAIS (Lewis et al., 2005). Construction workers, surgeons, dental care workers, mail carriers, daily computer work, and other occupations, or sports, that require consistent elevation of the arm, include those who are at the greatest risk in the general population (Cools et al., 2007a; Milerad and Ekenvall, 1990; Oberg et al., 1995; Sobti et al., 1997; Vedsted et al., 2011; Wells et al., 1983). Biofeedback has been demonstrated as an effective treatment tool in a pathological population, but there is little investigation utilizing it as a preventative means to reduce the possibility of onset subacromial impingement in a healthy population (Holtermann et al., 2010). Currently, there is a paucity in research that examines the acute effects of exercises with EMG biofeedback in prevention of SAIS. The findings of such study in healthy subjects can help to guide the research endeavors into biofeedback measures in the SAIS patients.

The purpose of the study was to investigate the effects of scapular stabilization exercises utilizing EMG biofeedback training on scapular kinematics in healthy individuals. We hypothesized that after undergoing EMG biofeedback training, the subjects would increase scapular upward rotation, external rotation and posterior tilt.

2. Methods

2.1. Participants

There were 23 subjects included in this study (15 males and 8 females) who volunteered. The subjects had a mean age of 23 ± 2.9 y/o, mean height 1.75 ± 0.1 m, and mean mass 73.6 ± 11.1 kg. Sample size calculation was performed using the G*Power 3.1.9 (Universitat, Kiel, Germany) with the effect size calculated from the Huang et al. (2013) data of 0.4, alpha level of 0.05, and desired power of 0.8, the minimum study sample needed was revealed as 10 subjects. Subjects were included only if they had no history of shoulder surgery, or neurological insults to the musculoskeletal system, and were not experiencing bouts of acute or chronic pain in either shoulders. The Institutional Review Board at Western Washington University approved the research protocol involving human subjects. Informed consent was obtained, and the rights of the subjects were protected.

2.2. Electromyography

The Noraxon (Noraxon, Scottsdale, AZ, USA) EMG desktop direct transmission system (DTS) was utilized to collect muscle activation. Data was collected at 1500 Hz, and preamplified with a gain of 500, CMRR of 100 dB, and input impedance > 100 Mohm. Noraxon (Noraxon, Scottsdale, AZ) dual EMG disposable, self-adhesive, Ag/AgCl snap electrodes were placed on the upper and lower trapezius, serratus anterior, and lumbar paraspinals of the dominant arm (Fig. 1A). All muscle locations were determined based on the recommendations by Cram et al. (1998). The inter-electrode distance was 1.75 cm, and all electrodes were placed parallel to the muscle fibers. Signals were verified by the investigator while subject performed an isometric muscle contraction for each of the muscles being measured. Lumbar paraspinal EMG data were collected to ensure that the subjects were not excessively activating their lumbar musculature during the exercises, as a result of a possible compensatory lumbar motion. Before EMG electrode placement, the skin was cleaned with alcohol wipes, abraded, and shaved to reduce any noise.

All EMG data were smoothed and full-wave rectified using root mean square (30 ms window) through a customized LabVIEW program (National Instruments, Austin, TX, USA). The EMG data was displayed on a stationary overhead projector connected to a PC-type of computer using Noraxon MR3.4 myoMuscle software for biofeedback. This software was equipped with a predefine EMG biofeedback setting. This afforded a real time visualization of the muscle activation, while the subjects perform the exercises. EMG amplitude of the upper and lower trapezius, serratus anterior, and lumbar paraspinals were monitored during the scapular stabilization exercises. Further, the amplitudes were normalized using maximum voluntary isometric contraction (MVIC). The MVIC was used for EMG amplitude normalization (San Juan et al., 2015). Each MVIC for the upper trapezius, Lower Trapezius, serratus anterior and lumbar paraspinals were performed once and lasted for 3 s and the middle second was averaged to be used for normalization. All MVIC procedures were performed by the same examiner (Table 1). Each subject was verbally encouraged to provide maximal effort for each test, and was given time to practice the isometric contractions. Further, subjects were given a minute rest in between MVIC testing.

2.3. Scapular kinematics

The Polhemus Fastrak 3D magnetic tracking system (Polhemus Inc., Colchester, VT, USA) was utilized to collect the scapulothoracic and thoracohumeral kinematic data. The sensors were placed at the distal humerus using a customized molded cuff, sternal notch (2.5 cm inferior to the jugular notch), and at the mid portion of the scapular spine using a specialized jig (Karduna et al., 2001) that is made up of plastic (Fig. 1B). The data was collected at 40 Hz. In addition, the fourth sensor was converted to be employed as a Polhemus digitizing stylus. The stylus was utilized to define the scapular, thoracic and humeral 3-dimensional anatomical coordinate system by digitizing the spinous processes of C7, T1, T7, and T8, the sternal notch,

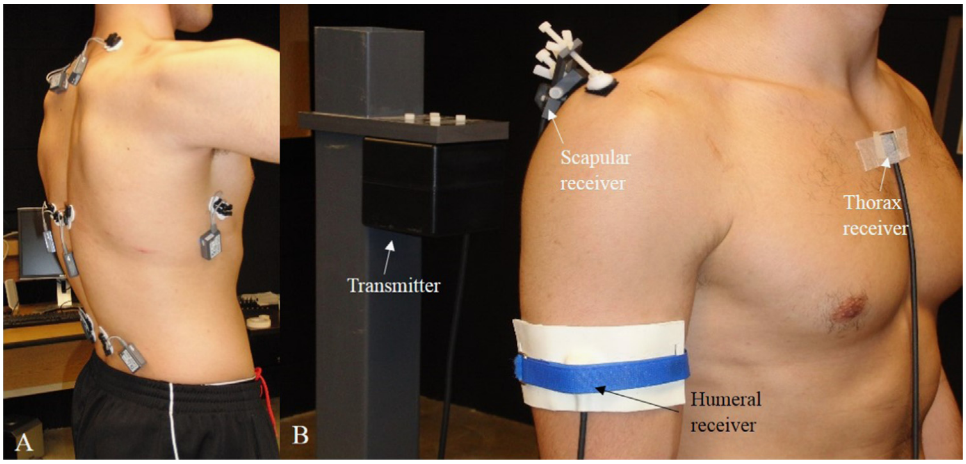

Fig. 1. (A) EMG electrode placement for upper trapezius, lower trapezius, serratus anterior and lumbar paraspinals. (B) The 3D scapular kinematics set-up with Polhemus. Only the electrodes positioned on the dominant side were used in the present experiment.

Table 1
The procedures used to obtain the maximum EMG amplitude necessary for the maximum voluntary isometric contraction normalization. This represents each of the muscles monitored in the EMG biofeedback exercises.

Muscles tested	Subject position	Motion resisted
Upper trapezius	Elbow was flexed at 90°, forearm semi-prone and arm at 90° of abduction	Forceful arm abduction with resistance applied at the elbow
Lower trapezius	Elbow was flexed at 90°, forearm semi-prone and the arm was elevated at 20° in the scapular plane	Combination of adduction and extension of the arm with resistance applied at the elbow
Serratus anterior	Elbow was flexed at 90°, forearm semi-prone, arm was flexed and internally rotated at 90°	Horizontal adduction of the arm with resistance applied on the fist.
Lumbar Paraspinals	Laying prone and trunk extended hanging on a treatment table with feet support	Forceful extension of the trunk with resistance applied on the posterior shoulder

Table 2
The scapular stabilization exercises performed with EMG biofeedback.

Exercise	Placement of arms/forearm	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

the sternoclavicular joint, and lateral and medial epicondyles of the humerus. A customized LabVIEW 2010 (National Instruments, Austin, TX, USA) program was used for data collection and signal processing. The movements performed by each segment were represented as Euler angle sequence-dependent rotations (Suprak et al., 2013). The ISB recommendations were followed to define the anatomical coordinate systems for each segment for the collection of kinematics (Wu et al., 2005). Standard Euler angle sequence were utilized to represent humeral motion where the first rotation defined the plane of elevation, second defined the amount of elevation, and the last rotation represented the amount of internal and external rotation (An et al., 1991). Additionally, scapular rotations were represented by an Euler angle sequence of external rotation (retraction), upward (lateral) rotation and posterior tilting (Karduna et al., 2000). Scapular rotations were then interpolated at 5-deg increments across the humeral elevation range of motion, and averaged across the three elevations within the trial. The upward rotation, posterior tilt, and external rotation values presented and analyzed are, therefore, the average interpolated values across the humeral elevation range of motion.

2.4. Experimental protocol

Before the data collection, subjects performed a standardized shoulder warm-up protocol consisting of 10 pendulum swings in all planes while the subjects were holding a 1.8 kg weight. After warm-up, the subjects were instrumented with the EMG electrodes and Polhemus receivers. Then the subjects were asked to perform a MVIC using previously documented procedures (San Juan et al., 2015).

For the humeral elevation trials, subjects were given time to practice the elevation trials before the start of kinematic data collection. During the data collection, the subjects were asked to elevate the dominant arm in the scapular plane three times. Each elevation trial consisted of three seconds of arm elevation, and three seconds of arm depression (lowering). This task was performed before and after the scapular stabilization exercises. After the first elevation trials, subjects were asked to perform four different exercises designed to target specific scapular stabilizing muscles. The scapular stabilization exercises were composed of the I, W, T, and Y (Table 2). These exercises were recommended to be the best in recruiting the lower trapezius and serratus anterior (Arlotta et al., 2011; Cools et al., 2007b). In order to accommodate for the EMG biofeedback protocol, all of the exercises were performed standing up. Each subject performed all exercises, while looking at the projected EMG biofeedback column graph on the screen in order to see the muscle activation of each muscle while the exercises were being performed. Through this, subjects were able to control and isolate the target muscles, which were the lower trapezius and serratus anterior, during the different exercises. It has been reported in the literature that healthy individuals, and shoulder impingement patients exhibited an upper to lower trapezius ratio of 1.36 and 2.19, respectively during isokinetic abduction (Cools et al., 2007a). In order to achieve a good training effect, all subjects were instructed to actively reduce upper trapezius muscle activation to a level below that of the lower trapezius and serratus anterior as shown on the screen throughout the entire scapular retraction motion. The investigator explained to the subject that the lower trapezius and the serratus anterior should have twice the activity of the upper trapezius during the execution of all the exercises. Each exercise was performed with one set of 10 repetitions and holding each repetition for a second. Subjects were given a minute rest between exercises and between the termination of the biofeedback session and the final humeral elevation trial.

2.5. Statistical analysis

A two-way repeated measures analysis of variance (ANOVA) was conducted to determine the differences in scapular kinematics (i.e. upward/downward rotation, anterior/posterior tilt, and internal external rotation) measured in degrees at pre- and post-biofeedback for each thoracohumeral angle (30°, 60°, 90°, 110°) of interest. SPSS 22 (IBM, Armonk, NY, USA) software was utilized to test statistical significance. The alpha level was set to 0.05. A Greenhouse–Geisser correction was applied if Mauchly's test revealed that the data violated the assumption of sphericity. Simple effects analyses were conducted for significant interaction effects using multivariate ANOVA. Bonferroni post-hoc procedures were conducted in the case of significant main effects.

3. Results

There was a significant interaction found between time (pre and post EMG biofeedback training) and humeral elevation angle on upward rotation of the scapula ($F\,[1.95, 42.83]=5.72$, $p=0.007$, $\eta^2=0.206$, Observed power $=0.833$). However, the simple effects analyses revealed no significant differences between pre- and post-biofeedback at any humeral elevation angles ($p>0.05$ for all levels, Fig. 2A).

There was a significant interaction found between time and humeral elevation angle with posterior tilt of the scapula ($F\,[1.75, 38.57]=5.86$, $p=0.008$, $\eta^2=0.21$, Observed power $=0.813$). However, the simple effects analyses revealed no significant differences between pre- and post-biofeedback at any humeral elevation angles ($p>0.05$ for all levels, Fig. 2B).

No significant interaction effect was found between time (pre and post EMG biofeedback training) and humeral elevation angle with external rotation of the scapula ($F\,[1.262, 27.76]=2.73$, $p=0.103$, $\eta^2=0.11$, Observed power $=0.398$). However, the main effect of time revealed that external rotation of the scapula was significantly increased between pre- and post-biofeedback across all humeral elevation angles ($F\,[1, 22]=17.49$, $p<0.001$, $\eta^2=0.443$, Observed power $=0.979$), with a mean difference of 6.5° (Fig. 2C).

4. Discussion

The current study was aimed at examining the effects of scapular stabilization exercises with EMG biofeedback training in healthy individuals on scapular kinematics. We hypothesized that after undergoing EMG biofeedback training, the subjects would increase scapular upward rotation, external rotation and posterior tilt during scapular plane humeral elevation. The results of the present study exhibited an effect of the EMG biofeedback training,

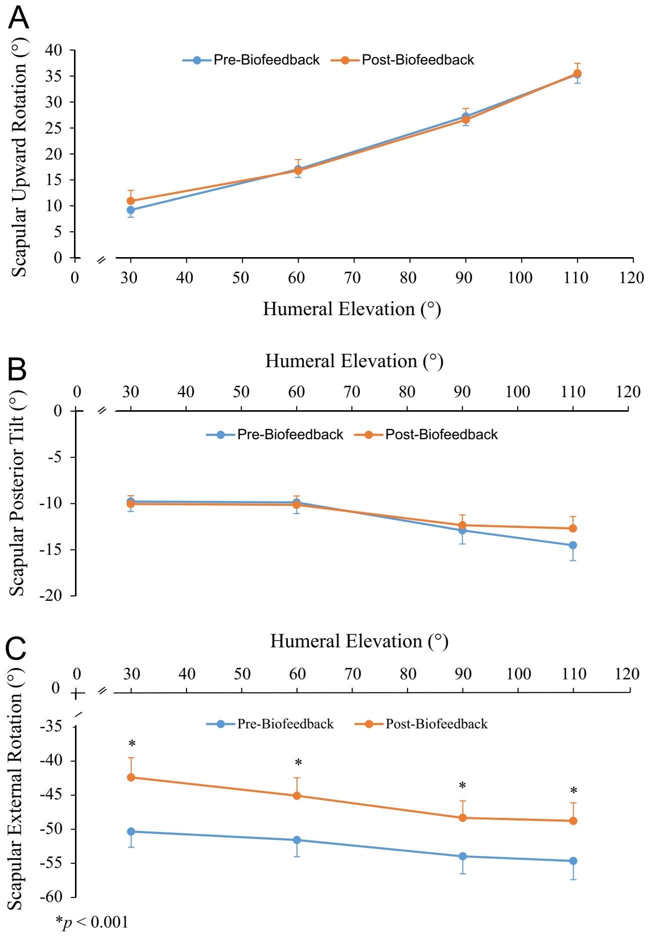

Fig. 2. Scapular motion during humeral elevation A) upward rotation, B) posterior tilt, and C) external rotation before and after scapular stabilization exercises with EMG biofeedback training (mean ± SE). A less negative number represents motion toward scapular posterior tilt and external rotation.

but only with external rotation of the scapula during humeral elevation. The other two rotations, posterior tilt and upward rotation, did not demonstrate any changes pre- and post-biofeedback. This finding suggests that EMG biofeedback training has a direct acute effect on scapular kinematics (i.e. external rotation) in healthy individuals.

EMG biofeedback is a way of instantly and continuously providing electronic displays of internal physiological events that otherwise would go unnoticed, until there is a pathology or injury of some type associated with it. The signals that are being displayed to the person, either in the form of sight or sound, can be altered by the subject themselves (Basmajian, 1981). It has been shown that EMG biofeedback is an effective tool in rehabilitation programs for those who have SAIS (Holtermann et al., 2010; Ma et al., 2011; Vedsted et al., 2011). Shoulder rehabilitation protocols place emphasis on restoring proper resting position of the scapula. This is composed by maintaining a position of external rotation and posterior tilt, which together make up scapular retraction (Kibler et al., 2008). In addition, it has been shown in healthy populations that the scapula is internally rotated relative to the clavicle (Ludewig et al., 2009), which can predispose individuals to a decreased subacromial space. The current study demonstrated that an increase in external rotation was observed after biofeedback training throughout the entire humeral elevation. This result was in accordance with a study by Yamauchi et al. (2015) that showed increased scapular external rotation during scaption after subjects performed shoulder exercises with trunk rotation. Additionally, the results of the current study indicated that scapular stabilization exercises may have had an effect on the serratus anterior activation, which is responsible for preventing excessive internal rotation. Although, the current study did not report muscle activation, this mechanism needs further investigation. Paralysis of the serratus anterior results in an elevated medial border of the scapula from the rib cage which decreases the amount of acromial elevation (Kamkar et al., 1993). This deficiency in acromial elevation has been associated with numerous shoulder injuries (Voight and Thomson, 2000). Further, increase scapular external rotation could increase the subacromial space during humeral elevation, and may decrease the chance of shoulder impingement. The present study demonstrated a mean difference of 6.5° increase in scapular external rotation after EMG biofeedback training. This added motion positions the scapula in a further retracted position throughout the entire humeral elevation range of motion. It has been shown that the anterior opening of the subacromial space decreases as the shoulder moved toward a protracted position (Solem-Bertoft et al., 1993).

The present data exhibited a significant interaction effect of testing time (pre- versus post-EMG biofeedback training) and humeral elevation angle on scapular posterior tilt. This effect suggests that the pattern of scapular posterior tilt across humeral elevation was altered following EMG biofeedback training. Although simple effects analyses were not able to determine where significant pre-test to post-test differences lay across humeral elevation, the current study demonstrated that this difference was most pronounced at 110° of elevation. Posterior tilting of the scapula elevates the anterior acromion, which could be a critical movement in the creation of space for the subacromial tissues, including long head of the biceps brachii, subacromial bursa, and rotator cuff tendons (Lin et al., 2005b). Even if posterior tilt was not significantly altered in the present study, all of the subjects exhibited normal posterior tilt range of motion, when compared to the literature examining scapular kinematics (Lawrence et al., 2014). Further, these results were in agreement with McClure et al. (2004), who found no change in posterior tilt after a six week exercise intervention study.

Scapular upward rotation elevates the lateral acromion, which is necessary in clearing the space for the rotator cuff muscles, and structures, between the acromion and greater tuberosity of the humerus throughout humeral elevation (Lin et al., 2005a). One of the main muscles responsible for scapular upward rotation is the lower trapezius (Fey et al., 2007). The scapular stabilization exercises chosen in the current study focused on increasing lower trapezius activation. The present data demonstrated an interaction effect between humeral elevation angle on scapular upward rotation before and after EMG biofeedback training, indicating changes in the pattern of upward rotation following training. Although simple effects analyses were not able to identify significant pre- to post-testing differences across elevation angles, it can be suggested that this difference was manifested in greater upward rotation at 30° of humeral elevation post-biofeedback training. It has been shown that upper trapezius also contributes to scapular upward rotation and anterior tilting (Johnson et al., 1994). Since an increase in upper trapezius could lead to increase anterior tilting, which is associated with a decreased clearance in the subacromial space (Ludewig and Cook, 2000). This could have minimized the changes seen in the upward rotation of the scapula. This result is in accordance with Huang et al. (2013) who found no significant differences in both upward rotation and posterior tipping in healthy subjects with and without EMG biofeedback exercises. Further, the measured range of the upward rotation during scapular plane humeral elevation in the current study was in accordance with studies that measured humeral elevation in the scapular plane (Lawrence et al., 2014; Matsuki et al., 2011). This finding indicated that scapular upward rotation might not be altered in asymptomatic healthy individuals, even with increasing muscle activation responsible for that specific scapular motion.

The present study had limitations. We only investigated healthy college-aged individuals, and only examined acute effects of EMG biofeedback. Future research should examine the effects of EMG biofeedback exercise intervention in the shoulder impingement population. Secondly, the subacromial space was not measured but extrapolated from scapulothoracic kinematics. Lastly, only the dominant arm scapular kinematics was measured during the elevation trials. Although, the subjects performed EMG biofeedback in both arms. Future research should investigate bilateral scapular kinematics in order to be able to see similarities or differences between the dominant and non-dominant sides after biofeedback training.

5. Conclusion

In healthy population, scapular stabilization exercises combined with EMG biofeedback training caused the scapula to be in a more externally rotated position during the entire range of motion of scapular plane humeral elevation. This places the shoulder in a retracted position and helps decrease the chance of developing shoulder impingement injuries. However, there were no significant changes observed in scapular upward rotation and posterior tilting.

Conflict of interest statement

The authors declare that there is not conflict of interest that could influence the content of the presented work.

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