



The Effect of Modified Push-up Exercise Using Electromyography Biofeedback on Selection of Scapular Stabilizing Muscles

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Abstract

Background: The serratus anterior (SA) muscle is an important scapular stabilizer and has a profound role in retaining the scapulohumeral rhythm. Therefore, modified push-up plus (MPUP) has been advised to strengthen this muscle as a closed chain workout. However, few previous studies have reported the possibility of a reparative motion from pectoralis major (PM) that could replace and amend SA's function during push-up plus.

Objectives: The current study examined MPUP's effect using biofeedback EMG on some of the selected scapular stabilizers.

Methods: Sixteen healthy young subjects voluntarily participated in this study. Each subject performed push-ups, from the quadruped position, under two conditions (i.e., with or without visual and auditory biofeedback). Surface EMG measured pectoralis major, serratus anterior, and upper trapezius activity. A paired *t*-test was used to determine any statistically significant difference between the two conditions. Additionally, the effect size was calculated to quantify the magnitude of EMG biofeedback in each muscle.

Results: MPUP training using biofeedback significantly increased SA muscle activity and decreased PM muscle activity, but there was no significant change in UT activity.

Conclusions: Excessive PM activity was repressed because of biofeedback, and the workout was done with the enhancement of SA muscular activity. Thus, including biofeedback while doing MPUPs helps limit PM's supplementary action and enhance SA muscle activity.

Keywords: Modified Push-ups, Biofeedback, Surface Electromyography, Scapular Stabilizing Muscles

1. Background

If the shoulder girdle muscles play their role well, they provide a dynamic stable base for the humerus (1). Among the many muscles that influence shoulder stabilization, the serratus anterior (SA) muscle is essential in maintaining the normal scapulohumeral rhythm (2). SA acts together with the rotator cuff muscles to prevent instability of the scapula and shoulder (3). This muscle is essential in stabilizing the scapula, whose primary role, due to several joints, is to stabilize the scapula during the movement of elevation and protraction of the scapula and around the ribcage (4).

SA weakness is common in athletes with overhead movement (5). A weak SA muscle is commonly seen in baseball players with shoulder instability (6). SA dysfunction appears in patients with long-term paralysis of the long thoracic nerve (7). It is believed to be caused by a muscle

imbalance between the rhomboid and trapezius muscles (8). This imbalance in muscle activity can lead to abnormal shoulder position and movement (9).

Shim et al. found that the ratio of muscle activity of the trapezius and SA muscles was significantly different (10).

A low level of SA activity with compensation through UT hyperactivity during upper extremity movement can lead to shoulder scapula movement with excessive upward transfer, reduced rotation upward, and posterior tilt of the scapula, which can lead to shoulder impingement (5, 11). Researchers also suggested that the abnormal movement of the scapula may be related to the weakness of the muscles around the scapula (12, 13). Therefore, the functional motor control of the muscles around the scapula is considered a rehabilitation exercise to recover and eliminate muscle imbalances (14).

It is crucial to choose the appropriate exercise in the

shoulder rehabilitation protocol and stabilize muscles around the shoulder (15).

The effects of various exercises performed to strengthen SA muscles have been identified (16), among which closed kinematic chains have recently been emphasized (9, 17). Closed chain exercise allows coordination of multiple muscles through mechanical pressure on the joint surface (18).

When doctors diagnose the scapular kinematic disorder, their main goal is to train the stabilizing muscles of the scapula, especially SA and LT (19-21). Typically, doctors use push-ups, push-up plus, and variations of this movement to retrain the SA, LT, and UT muscles. As measured by electromyography (EMG), these exercises facilitate movement in the scapular muscles (21-23).

Using push-up variations, researchers showed that SA activity was more significant during push-up plus exercises than during regular push-ups (19, 24).

The lower position of the hands receives more action from the pectoralis major and creates the highest initial joint pressures (25).

Exercise with biofeedback allows accurate training of weakened muscles to stabilize the shoulder (26).

2. Methods

2.1. Subjects

The present study is a quasi-experimental-applied study performed on 16 healthy 20-year-old youths in Tehran. Before the experiment, all subjects agreed with the experiment and signed a consent form to participate in the study after receiving a description of the purpose and method of training. The selection criteria of the subjects were: (1) those with no winged shoulders, (2) those with no shoulder pain during the last six months while participating in the test, (3) those not performing strengthening exercises for the SA muscle in the last six months, (4) those using the pectoralis major muscle during modified push-up training, and (5) those not showing the signs of shoulder impingement syndrome. The exclusion criteria were (1) those with a previous history of clinical evaluation of pain or dysfunction, (2) those whose pain or dysfunction restricted shoulder movement and affected shoulder stability in daily life or during joint laxity testing, (3) those diagnosed with neck pain, sticky capsules, and thoracic outlet syndrome (TOS), (4) those with no abnormal sensations in the upper extremities, and (5) those having a history of surgery or shoulder fractures. The general characteristics of the subjects are presented in Table 1.

Table 1. General Characteristics of the Subjects

Variables	Mean \pm Standard Deviation	Domain
Age	22.7 \pm 2.5	22~30
Height	175 \pm 3.1	171~181
Weight	68.9 \pm 5.7	57~80
BMI	21.7 \pm 1.8	18.8~24.8

2.2. Measurement Tools

2.2.1. Surface Electromyography

A surface EMG instrument was used to measure pectoralis muscle activity, SA, and trapezius muscle activity of the superior upper limb. In order to reduce skin resistance, the hair at the electrode junction was cleaned, the stratum corneum was rubbed 3 - 4 times with suitable sandpaper, and the skin was rubbed with alcohol. The electrodes were connected parallel to the muscle fiber using Ag/AgCl electrodes, keeping the distance of 2 cm between them, and the EMG signal sampling rate was set to 1000 sets, the frequency bandwidth was 80 - 250 Hz, and the notch filter was 60 Hz. The EMG signal was processed using the root mean square (RMS) and converted to ASCII format for analysis.

2.2.2. Biofeedback Device

The biofeedback device has used the biofeedback function provided by the audio-visual biofeedback software. Muscle activity was measured three times during the maximal isometric contraction of the pectoralis major muscle in the supine position, with extended elbows, shoulders bent at 90 degrees, and rotated inward. Ten percent of the mean value was calculated and used as the threshold for the decreased activity of the pectoralis major muscle. In other words, when the pectoralis significant muscle activity increased by 10% or more during maximal isometric contraction, audio-visual biofeedback was provided for the subjects to prevent excessive muscle contraction.

Visual biofeedback was indicated blue if the pectoralis significant muscle activity was less than 10% and red when muscle activity increased by 10% or more through a monitor located between the arms of the subjects. In auditory biofeedback, a "beep" warning sound was given when the pectoralis significant muscle activity crossed the threshold, and the warning sound was removed when it fell below the threshold.

2.3. Methodology

2.3.1. Connection and Normalization of the EMG Electrode

The electrode connection positions of each muscle were determined by referring to the existing studies to

Table 2. Electrode Attachment Position for Each Muscle

Muscle	Electrode Attachment Position
Pectoralis major	Two cm below the clavicle in the diagonal direction to the middle part with a crease
Serratus interior	The inner edge of the scapula to the anterior border of the latissimus dorsi
Upper trapezius	Between the acromion of the scapula in a direction parallel to the muscle fiber and the middle of the spinous process of the seventh cervical vertebra

measure the activities of pectoralis major, trapezius, and SA muscles (27, 28).

The superior upper extremity was determined by verbal questioning and was entirely correct. The electrode attachment position for each muscle is shown in Table 2, and the ground electrode is attached to the center of the acromion of the superior limb. Body position during maximal isometric contraction was performed to normalize the muscle position of the standardized bare hand (2, 29). The pectoralis major muscle was performed in a standing position, with the elbow extended, and the shoulder bent at 90 degrees and internally rotated. Resistance was applied to the arm in the horizontal direction of abduction. The maximum isometric contraction of the SA muscle was measured in the 125-degree abduction position at the scapula level after turning the shoulder inwards while sitting. Resistance was applied to the proximal part of the subject's elbow. Also, the maximum isometric contraction of the upper trapezius muscle was performed in a sitting position, and the resistance of the superior side of the shoulder and occipital bone was used for shoulder elevation, unilateral neck flexion, and rotation to the opposite side. Muscle activity during the maximal isometric contraction of each muscle was measured three times. After processing the RMS of the data values for 5 seconds, the average value of the EMG signal in the middle 3 seconds, excluding the first and last 1 second, was used as 100% MVIC.

2.3.2. Testing Process

All subjects performed modified knee push-up exercises under two conditions. In the first case, biofeedback was not provided, but in the second case, biofeedback was implemented. In order to standardize MKPUP and motor performance in both conditions and eliminate unnecessary movements, starting mode, training performance process, and final position were practically defined. Initially, in the start position, the subjects were placed in the four-limbed pose, shoulder-width apart, and both arms and knees supported their weight (30). In order to maintain the neutral position of the cervical vertebrae, the neck was bent so that the cervical vertebrae and the chest were in a straight line. Subsequently, a marker and both shoulder rods were set on the fourth thoracic spine. In other

words, when performing MKPUP, a marker was installed to help the subject move the shoulder at the same height.

Secondly, to perform the exercise, the researcher's word "start" and the researcher's incremental pressure were created to be performed. The pressure was recorded for 2 seconds in a four-limbed pose, and the push-up mode was maintained for 5 seconds using the metronome. Thirdly, the fourth vertebrae of the subject's chest touched the marker after performing the modified push-up, and both shoulders were maintained in a position where the bar did not fall off. In the end, the position and high pressure were maintained, and the evaluation was successful. Suppose the standard start position, athletic performance, and ending position are not maintained without data collection. In that case, the examiner repeats the measurement three times to ensure that the individuals are in the correct physical position, with 2 minutes of rest for each function. The subject was asked to become acquainted with the transfer from the four-limbed pose to the push-up technique with the body position through verbal instructions and familiarity through demonstration for 10 minutes. All subjects could do push-ups after the introductory period without comfort or difficulty. In the second case, the four-limbed pose technique was changed to push-ups the same way as in the first case, but visual biofeedback and audio biofeedback were provided to prevent excessive chest contraction. During the 5 seconds of maintaining pressure along with the position, pectoralis major muscle activity was displayed in real-time through the monitor screen. In case of muscle activity of more than 10% of the isometric maximum, the provided audio-visual biofeedback showed contraction. The monitor screen was placed between both arms so that when the head was in the neutral position, the screen was immediately visible, and the position of the head did not affect muscle activity.

2.4. Statistical Method

Paired *t*-test was used to compare the differences in the activities of the pectoralis major, SA, and upper trapezius muscles in two conditions according to the presence or absence of biofeedback and the effect size. The significance level of the test was determined to be 0.05, and SPSS version 22 was used for statistical data processing.

Table 3. The Amount of Muscle Activity with and Without Biofeedback in Push-up Plus Movement

	Without Biofeedback		With Biofeedback		P-Value	Effect Size
	Mean \pm Standard Deviation	95% Reliability	Mean \pm Standard Deviation	95% Reliability		
Pectoralis major	19.13 \pm 8.70	12.85~23.24	6.67~1.96	4.63~7.89	0.000	1.52
Serratus anterior	45.04 \pm 15.75	35.63~50.54	54.12~16.21	42.76~61.43	0.001	0.63
Upper trapezius	5.45 \pm 4.01	3.36~8.01	5.61~3.59	3.52~7.74	0.871	0.03

3. Results

According to Table 3, during push-up training, after using audio-visual biofeedback for the pectoralis major muscle, the activity of this muscle decreased significantly by 65% ($P < 0.0001$), and the SA activity significantly increased by 23% ($P = 0.001$). No significant difference was observed in the upper trapezius muscle after using audio-visual biofeedback. The effect size of each muscle was calculated in the pectoralis major muscle at 1.52, in the SA muscle at 0.63, and in the upper trapezius muscle at 0.03.

4. Discussion

The research results showed that modified push-up plus exercises using biofeedback significantly increased SA muscle activity and decreased pectoralis major muscle activity (31). In order to determine the cause of the damage caused by the imbalance of the muscles around the shoulder, the difference or the ratio of the activity of the SA muscle and the trapezius muscle was evaluated (30). It is possible to strengthen the stabilizing muscles of the scapula with different exercises in case of movement damage in the scapula area (winged scapula), and various studies have been conducted in this regard (32). The proper exercise to strengthen the SA muscle is push-up plus movement (18, 30, 33). In general, in comparison of muscle activity in push-up plus and modified push-up plus along with body position (34); muscle activity was observed according to its angle from the support surface during push-up plus (35), and during push-up plus on an unstable surface (36). The above studies are in line with the current research. The effect size measures the degree of difference or association, and when there are small or large numbers of people, it compensates for the distortion of statistical results (31). This study standardized the position and movement of the laboratory, and particularly markers and bars were used to control the movement while doing the push-up plus. It is suggested that biofeedback can be usefully used to suppress overactivity of the pectoralis major muscle during the modified knee push-up plus movement and increase the selective activity of the SA muscle.

Footnotes

Authors' Contribution: Hadi Miri conceived and designed the evaluation and drafted the manuscript. Abbas dostdar participated in designing the evaluation, performed parts of the statistical analysis, and helped draft the manuscript. Mojtaba Rahimi re-evaluated the clinical data, performed the statistical analysis, and revised the manuscript. Mahya Hamidi collected the clinical data, interpreted them, and revised the manuscript. Q. E. re-analyzed the clinical and statistical data and revised the manuscript. All authors read and approved the final manuscript.

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