Sport Sciences and Health Research

University of Tehran
Faculty of
Physical Education and Sport Science

The effect of biofeedback training on electrical activity of trapezius muscles and flexion range of motion in people with shoulder impingement syndrome

Hadi Miri[1], Fariborz Hovanloo[2], Mojtaba Rahimi Bidhandi[3]*

1. Department of Physical Education and Sport Sciences, Amirkabir University of Technology, Tehran, Iran.
2. Department of Health and Sports Rehabilitation, Physical Education and Sport Science Faculty, Shahid Beheshti University, Tehran, Iran.
3. Department of Physical Education and Sport Sciences, Raja University, Qazvin, Iran. ID: JESM-202201-1040 (Corresponding author: Email: mr.mrahimi2015@gmail.com)

Article Info

Original Article

Article history:

Received: 22 January 2020

Revised: 29 January 2020

Accepted: 1 February 2020

Published online: 1 July 2020

Keywords:
biofeedback training,
electrical muscle activity,
range of motion,
shoulder impingement syndrome.

Abstract

Introduction: The aim of present study was to determine the effect of biofeedback training on electrical activity of trapezius muscles and range of motion in people with shoulder impingement syndrome.

Martials and Methods: In this study, 20 patients with shoulder impingement syndrome in age range of 20-40 y were selected as the statistical sample and were divided into experimental (n=10) and control (n=10) groups. The experimental group trained by using EMG biofeedback for 8 weeks and 3 sessions per week. The control group was applied only for pre-test and post-test measurements. For data collection, surface electromyography was used to analyze the muscle activity patterns of trapezius muscles (upper, middle, lower), and a goniometer was executed to evaluate the flexion. Shapiro-Wilk test was used to confirm the normality of the data and covariance analysis test was applied to compare pre-test and post-test. Correlated t-test was used to examine within-group changes.

Results: In this study, after 8 weeks of biofeedback training in the experimental group, a significant improvement in the electrical activity of the middle trapezius (P=0.000) and lower trapezius muscles (P=0.016) was observed. In addition, a significant improvement in the amount of flexion range of motion (P=0.000) was indicated in the experimental group compared to the pretest and also the control group (P=0.05). However, no significant difference was shown in the muscle activity of the upper trapezius muscle (P=0.776).

Conclusion: The present study showed that biofeedback training is effective to improve the electrical activity of trapezius muscle and flexion in people with SIS.

Cite this article: Miri H, Hovanloo F, Rahimi Bidhandi M. “The effect of biofeedback training on electrical activity of trapezius muscles and flexion range of motion in people with shoulder impingement syndrome”. *Sport Sciences and Health Research*. 2020, 12(2): 125-133. doi: 10.32598/JESM.12.2.1.

This is an open access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (CC BY NC), which permits distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

EISSN: 2717-2422 | Web site: https://sshr.ut.ac.ir/ | Email: sshr@ut.ac.ir

© The Author(s). Publisher: University of Tehran, Faculty of Sport Sciences and Health

1. Introduction

Shoulder impingement syndrome is the most frequent and common cause of pain and limitation of movement in the shoulder area, among all the shoulder injuries [1], which is usually resulted by sports exercises or other activities requiring frequent use of hand above head or in other word above the horizontal plane [2]. Anatomical changes in the coracoacromial arch or head of the humerus, weakness or erosion of the rotator cuff tendons, posterior capsule stiffness, kinematic changes of shoulder, scapular muscle weakness or dysfunction, and postural changes are the causes of this syndrome [3, 4]. The middle and lower trapezius muscles are the most important cause of stabilization in the scapulohumeral and shoulder joints. Deficit in the lower and middle trapezius muscles as the important stabilizing muscles results in instability and soft tissue impingement syndrome in the shoulder [5]. Therefore, there is a need for a training method which can increase the activity of the lower and middle trapezius muscles as a rehabilitation program for people with SIS. In particular, the excessive activity of the upper trapezius muscle (UT), along with decreased activity of the lower trapezius (LT) and anterior serratus (SA) have been observed in patients with subacromial impingement syndrome (SAIS). Scapular muscle imbalance may lead to abnormal scapular movement and contribute to progression of impingement. Consequently, scapular muscle training in the treatment of SAIS-related scapular dysfunction should stimulate LT, medial trapezius (MT), and SA, and also reduce activity in UT [6].

Hence, the selection of training is important. In electromyography biofeedback (EMG) training, electronic equipment is used to detect certain physiological events instantly. Subjects can control these involuntary events by manipulating the displayed signals.

It is believed that this technique allows subjects to learn how to control muscle activities, such as their roles as stabilizing or forcing couples during movements.

Biofeedback training allows accurate training of weakened muscles, enabling movement control and muscle activation methods potentially [7]. EMG biofeedback training can identify physiological events in real time which displays on electrical equipment. Through this method, people can learn how to control muscles [8]. Therefore, it was decided to investigate the effect of electromyography biofeedback training on the electrical activity of trapezius muscles and range of motion in people with shoulder impingement syndrome.

2. Materials and Methods

The statistical population of present study was people with shoulder impingement syndrome in Tehran in age range of 20-40 years who were selected through a call to physiotherapy and rehabilitation clinics in Tehran. Gpower software was used to determine the samples for test power of 0.95, effect size of 0.8 and significance level of 0.05 [9]. Twenty people were purposefully selected based on entry and exit criteria and randomly divided into two groups of experimental and control. Initially, all samples signed a (written) consent form for this research. The experimental group trained using EMG biofeedback for 8 weeks and 3 sessions per week. The control group was employed only for pre-test and post-test measurements. For data collection, surface electromyography was used to analyze the muscle activity patterns of the trapezius muscles (upper, middle, lower). A goniometer was applied to evaluate the range of motion of flexion.

2.1. Tools and Measurement methods

The range of motion of shoulder flexion was measured by using a goniometer. In order to measure shoulder flexion, the subject should place the arm sitting in front of the torso. The axis of the articular goniometer is located on the concave head of the humerus on the lateral side of the arm. The fixed bar of goniometer was parallel to the upper body and the person should move the arm to a painless range on sagittal plane. The mobile bar of goniometer was placed parallel to the concussion of the humerus and then the angle of movement of the shoulder joint was measured.

In this study, the surface electromyography equipment (Noraxon Inc.) was used to analyze the muscle activity patterns of the trapezius muscles (upper, middle, lower) and Myo-Research software (Noraxon Inc.) was applied to collect and process data [10].

To minimize skin resistance, the electrode junction was shaved, the skin was cleaned with an alcohol pad and the electrodes was attached. The surface electrode consisted of a pair. The distance between the two poles was maintained at 2 cm and were connected to the muscle fibers in the middle of each muscle in a parallel direction. Upper trapezius electrodes were located at 50% point of the passing line through acromion and the spinous process of the seventh cervical vertebra, on the most prominent part of the muscle. The middle trapezius electrodes were located in the middle of the third cervical vertebra and the middle part of the scapular root. The lower trapezius muscle electrodes were applied on the side of the lower middle edge of the scapula, on the most prominent part of the muscle, 5 cm below the root of the scapula with a diagonal angle of 55 degrees to the horizon [11, 12]. EMG signal sampling speed was set to 1000 Hz, bandwidth was 20-450 Hz and notch filter set to 60 Hz. The measured signal was processed using the root mean square (RMS) method. To standardize muscle activity data, reference voluntary isometric contraction (RVIC) was used. According to the method of Lopes et al. (2015), the subject raised the arm 90° of the sagittal plate while standing. A force was applied and the measuring device puts its hand on the elbow and kept it for 5 sec with downward resistance [13]. However, specific motion-based contractions produce less force than reference voluntary isometric contractions. Muscle activity was measured for 5 sec and the first second was to ensure maximum range, and the 2nd second was to avoid fatigue due to maximal continuous muscle contraction. Hence, the first two seconds was ignored in the study. After a total of three measurements, the mean value was used and a 3-min rest was given between each experiment. Muscle activity was used as a percentage of contraction (RVIC%) based on a specific movement. The upper, middle, and lower trapezius muscles were measured until reaching to 120° (5 sec), keeping at 120° (5 sec), and reaching the first position by lowering the arm again for 5 sec. Data were analyzed again except the first and last seconds [11].

2.3. Training protocol

In this study, SPSS 26 software was used for data analysis and Shapiro-Wilk test was executed to confirm the normality of the data.

Table 1. Training protocol

No.	**Type of training**	**How to run**	**Types of contractions for each training**			**Schedule and number of training sessions**
1	Shoulder flexion in standing position	For anterior flexion, the shoulder is bent up to 90° to the sagittal plane while standing.	Concentric contraction (3 sec)	Isometric contraction (6 sec)	Eccentric contraction (3 sec)	- 3 training sessions per week for 8 weeks - Each training is 3 sets of 10 sec - 3 minutes of rest between each training for a total of 9 min - Dumbbells of 1 to 3 kg only for training one and two
2	External shoulder rotation while lying on lateral side	When lying on lateral side, the elbow joint is bend 90° and the shoulder joint rotates outward.	Concentric contraction (3 sec)	Isometric contraction (6 sec)	Eccentric contraction (3 sec)	
3	Horizontal shoulder abduction in the prone position	In the prone position, the lateral rotation with the elbow joint and then the arm moves upward with horizontal abduction and external rotation of the shoulder joint.	Concentric contraction (3 sec)	Isometric contraction (6 sec)	Eccentric contraction (3 sec)	

Covariance analysis test was applied to compare pre-test and post-test, and correlated t-test was used to examine within-group changes. The minimum significance level in the hypotheses of the present study was considered 0.05.

3. Results

The general characteristics of the subjects including age, height, weight and BMI are shown in Table 2. Also, the mean and standard deviation of measurement variables in experimental and control groups, before and after training, are shown in Table 3.

In order to compare the mean scores of post-test of trapezius muscles and flexion range of motion, covariance analysis test with control of pre-test effect was used (Table 2).

As Table 3, the electrical activity of the middle (*P*=0.000) and lower (*P*=0.016) trapezius muscles, the flexion range of motion (*P*=0.007) had significant changes, but in the case of upper trapezius muscle electrical activity, there is no significant change (*P*=0.776).

Furthermore, according to the results of correlated t-test to examine the intragroup changes (Table 4), biofeedback training in experimental group had a significant effect on the electrical activity of the upper and lower trapezius muscles and the abduction range of motion (flexion).

Table 2. Mean and standard deviation ($\overline{X} \pm SD$) Individual characteristics of the subjects

Group	Number	Age	Height	Weight	BMI
Experimental	10	32.20±5.22	176.50±4.99	77.20±7.20	24.84±2.55
Control	10	29.60±5.73	177.20±5.47	77.40±8.55	24.96±3.27

Table 3. Covariance analysis of comparison of trapezius muscle electrical activity and flexion range of motion in two groups

Variable	**Source of variable**	**Total squares**	**Freedom degree**	**Average squares**	**F**	***P***
Upper trapezius muscle	Pre-test	79.94	1	79.94	10.97	0.004
	Group	0.61	1	0.61	0.084	0.776
	Error	123.88	17	7.28		
Middle trapezius muscle	Pre-test	718.01	1	718.01	275.12	0.000
	Group	76.76	1	76.76	27.49	0.000
	Error	47.47	17	2.79		
Lower trapezius muscle	Pre-test	736.39	1	736.39	69.68	0.000
	Group	75.10	1	75.10	7.10	0.016
	Error	179.65	17	10.56		
Flexion range of motion	Pre-test	295.1	1	295.1	9.30	0.000
	Group	914.03	1	914.03	28.82	0.000
	Error	539.03	17	31.7		

Table 4. Investigation of intragroup changes in trapezius muscle activity and flexion range of motion

Variable	**Group**	**Mean difference**	**t**	**Freedom degree**	***P***
Upper trapezius muscle	Experimental	0.28	0.18	9	0.855
	Control	0.65	0.68	9	0.637
Middle trapezius muscle	Experimental	4.10	4.93	9	0.000
	Control	0.09	0.09	9	0.913
Lower trapezius muscle	Experimental	3.74	2.60	9	0.029
	Control	0.01	0.06	9	0.997
Flexion range of motion	Experimental	5.31	9	0.000	
	Control	0.44	9	0.880	

4. Discussion and Conclusion

In current study, the effect of biofeedback electromyography training on electrical activity of trapezius muscles and flexion range of motion in patients with shoulder impingement syndrome was investigated. The results demonstrated that the electrical activity of the middle trapezius muscle (*P*=0.000) and lower trapezius muscle (*P*=0.016) and the flexion range of motion (*P*=0.000) had significant changes, but the electrical activity of the upper trapezius muscle (*P*=0.776) had no significant change.

The findings of this study are consistent by Son et al. (2015) [14], Huang et al. (2013) [15], Ellen Becker and Cools (2010) [16], and Kibler and McMullen (2003) [17]. However, it wasn’t along with Lin (2006) [18], Ludwig and Cook (2000) [11], and Coles et al. (2007) [19]. In addition, in SEO research (2019), a significant difference was observed in the upper/middle/lower trapezius and anterior serratus muscle activities [20].

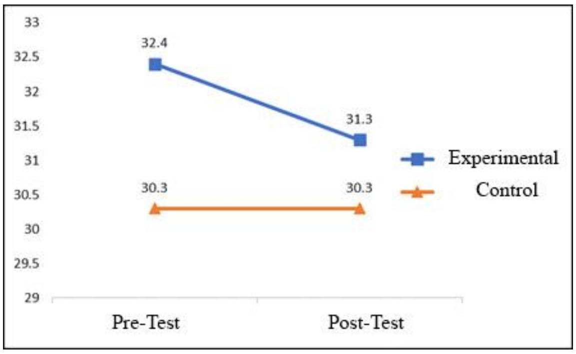

Figure 1. Upper trapezius muscle activity of the two groups in pre-test and post-test

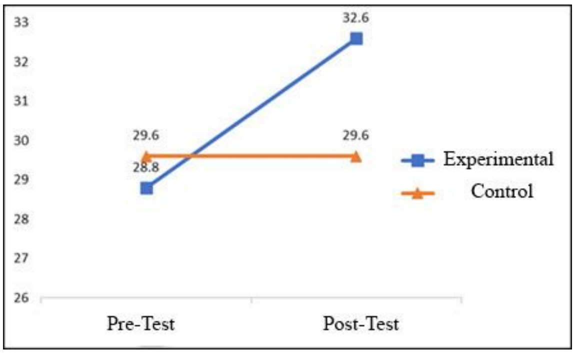

Figure 2. Middle trapezius muscle activity of the two groups in pre-test and post-test

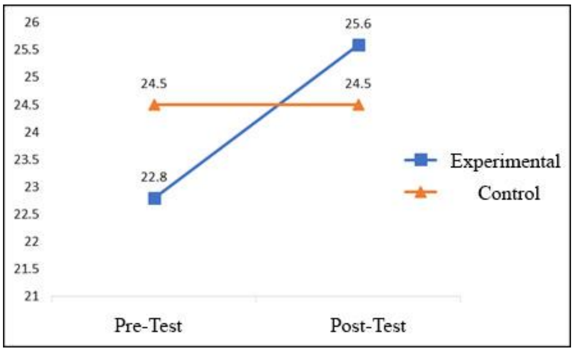

Figure 3. Lower trapezius muscle activity in two groups in pre-test and post-test

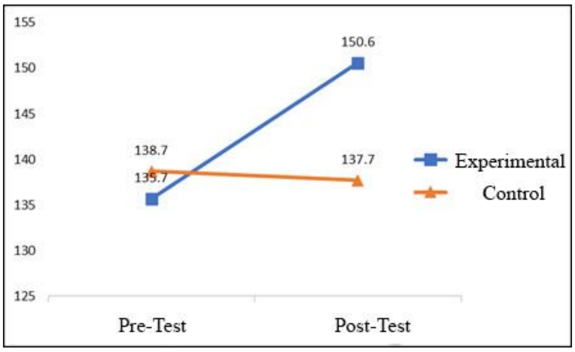

Figure 4. Flexion range of motion of the two groups in pre-test and post-test

In post-hoc analysis, the lower and upper trapezius muscle activities was significantly higher than the upper trapezius and anterior serratus. Moreover, there was a significant difference in each muscle activity of external rotation training in the prone position. External rotation in prone position showed the highest activation of the lower trapezius compared to the activity of the upper trapezius muscle. It seems to be helpful in isolating the lower trapezius muscle in cases where scapular elution is observed.

Consequently, according to the findings in previous studies, it can be found that biofeedback training by using electromyography is effective in balancing muscles. The results of present study indicated that EMG biofeedback training increase the muscle activity of the lower and middle trapezius during the flexion of shoulder joint. In patients with shoulder impingement syndrome, an imbalance of muscle activity among the trapezius muscles was appeared [21]. If the training is performed in real time through biofeedback when examining the trapezius muscle activity, the excessive activity of trapezius muscle can be prevented.

Biofeedback training increases muscle feed forward activity and neuromuscular coordination. As a result, both feed forward and feedback neuromuscular control can increase joint stability by repeatedly stimulating the sensorimotor pathways.

The active and inactive shoulder range of motion are increased by trapezius muscle balance and scapular joint movement, leading to an improvement in shoulder impingement syndrome. The results of present study are consistent by Chilgar et al. (2020) [22], Kim and Song (2020) [23], Peteraitis and Smedes (2020) [24], Senbursa et al. (2007) [25], Shojaoddin (2013) [26], Wang and Cochrane (2001) [27], and Ludewig et al. (2004) [28]. Senbursa et al. compared two treatments in their research which included home training and physiotherapy in people with shoulder impingement syndrome. The findings showed that both methods reduced pain and increased shoulder function, but the range of motion in flexion movement in exercise therapy using physiotherapy modalities had more significant improvement than exercise therapy using home training [25].

This study compared the effects of before and after joint flexion range of motion and electrical activity of the trapezius muscle in patients with shoulder impingement syndrome by EMG biofeedback. After the intervention, the amount of flexion range of motion and the activity of the lower and middle trapezius muscles increased significantly. As a result, it can be concluded that the intervention using EMG biofeedback is an effective training to restore muscle activity among the trapezius muscles and range of motion in people with shoulder impingement syndrome. After training by EMG biofeedback, the shoulder joint range of motion increased considerably. On the other hand, the joint range of motion is related to pain [11], and it seems that the joint range of motion increases due to the reduction of pain. Usual movement of the shoulder joint should be accompanied by the movement of upper arm and shoulder. As the shoulder joint moves, the scapula should rotate upward, inward, and backward [29, 30], and the muscles that function at this time are the lower and middle trapezius [11]. Thus, without the contribution of the scapular joint movement, the range of passive flexion and abduction movement of the shoulder is reduced by at least one third. However, it seems that even the active domain is more affected in these two directions. As a result, the trapezius muscle balance and increase of scapular joint movement, in addition to increasing the overall range of active and inactive motion, improve the cooperation between the scapular and glenohumeral joints and can directly affect normal movement of the glenohumeral joint which leads to the improvement of the impingement syndrome. Consequently, scapular training using EMG biofeedback confirmed the increase of the lower and middle trapezius muscle activity, which is thought affecting the increase of the shoulder joint range of motion.

In current study, performing three types of training using biofeedback electromyography for patients with SIS resulted in increase of the lower and middle trapezius muscle activity significantly during the flexion of the shoulder joint and their range of motion improved.

Further clinical trials should investigate the short and long-term effects of EMG biofeedback in patients with shoulder dysfunction.

Therefore, given to the effect of these training on neuromuscular mechanisms in the shoulder, it is recommended that therapists use biofeedback electromyography training for people with shoulder impingement syndrome.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design.

Ethical considerations

The author has completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc.

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

Acknowledgments

This paper is taken from the MSc thesis in sports injuries and corrective exercises by Mr. Mojtaba Rahimi Bidhendi, under the supervision of Dr. Hadi Miri and the advisor of Dr. Fariborz Hovanloo. We also thank everyone for their help during this study, both academically and formally.

References

[1] Szyluk K, jasinski A, Koczy B, Widuchowski W, Widuchowski J. “Subacromial impingement syndrome —most frequent reason of the painful shoulder syndrome”. *Pol Merkur Lekarski*. 2008; 25(146): 179-83.

[2] Geraets JJ, Goossens ME, de Groot IJ, de Bruijn CP, de Bie RA, Dinant GJ, van der Heijden G, van den Heuvel WJ. “Effectiveness of a graded exercise therapy program for patients with chronic shoulder complaints”. *Australian Journal of Physiotherapy*. 2005; 51(2): 87-94.

[3] Feleus A, Bierma-Zeinstra SM, Miedema HS, Bernsen RM, Verhaar JA, Koes BW. “Incidence of non-traumatic complaints of arm, neck and shoulder in general practice”. *Manual Therapy*. 2008; 13(5): 426-33.

[4] Kooijman M, Swinkels I, van Dijk C, de Bakker D, Veenhof C. “Patients with shoulder syndromes in general and physiotherapy practice: an observational study”. *BMC Musculoskeletal Disorders*. 2013; 14(1): 1-7.

[5] Cools AM, Witvrouw EE, Declercq GA, Danneels LA, Cambier DC. “Scapular muscle recruitment patterns: trapezius muscle latency with and without impingement symptoms”. *The American Journal of Sports Medicine*. 2003; 31(4): 542-9.

[6] Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. “Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises”. *The American Journal of Sports Medicine*. 2004; 32(2): 484-93.

[7] Holtermann, A., Mork, P. J., Andersen, L. L., Olsen, H. B., & Søgaard, K. (2010). The use of EMG biofeedback for learning of selective activation of intra-muscular parts within the serratus anterior muscle: a novel approach for rehabilitation of scapular muscle imbalance. Journal of Electromyography and Kinesiology, 20(2), 359-365.

[8] Giggins OM, Persson UM, Caulfield B. “Biofeedback in rehabilitation”. *Journal of Neuroengineering and Rehabilitation*. 2013; 10(1): 1-11.

[9] Garrido JC, Vas J, Lopez DR. “Acupuncture treatment of shoulder impingement syndrome: a randomized controlled trial”. *Complementary Therapies in Medicine*. 2016; 25: 92-7.

[10] Mehrabian H, Letafatkar A, Barati AH, Abbasi A, Shojaedin SS. “Comparison of Electromyographic Activity of Selected Shoulder Muscles and Scapulohumeral Rhythm in Elite Male Swimmers with and without Shoulder Impingement Syndrome”. *The Scientific Journal of Rehabilitation Medicine*. 2019 Dec 22; 8(4): 132-43. [in Persian]

[11] Ludewig PM, Cook TM. “Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement”. *Physical Therapy*. 2000; 80(3): 276-91.

[12] Çalış M, Akgün K, Birtane M, Karacan I, Çalış H, Tüzün F. “Diagnostic values of clinical diagnostic tests in subacromial impingement syndrome”. *Annals of the Rheumatic Diseases*. 2000; 59(1): 44-7.

[13] Lopes AD, Timmons MK, Grover M, Ciconelli RM, Michener LA. “Visual scapular dyskinesis: kinematics and muscle activity alterations in patients with subacromial impingement

syndrome". *Archives of Physical Medicine and Rehabilitation*. 2015; 96(2): 298-306.

[14] Son JI, Lim OB, Han HR, Cynn HS, Yi CH. "Selective muscle activation with visual electromyographic biofeedback during scapular posterior tilt exercise in subjects with round-shoulder posture". *Physical Therapy Korea*. 2015; 22(4): 17-26.

[15] Huang HY, Lin JJ, Guo YL, Wang WT, Chen YJ. "EMG biofeedback effectiveness to alter muscle activity pattern and scapular kinematics in subjects with and without shoulder impingement". *Journal of Electromyography and Kinesiology*. 2013; 23(1): 267-74.

[16] Ellenbecker TS, Cools A. "Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review". *British Journal of Sports Medicine*. 2010; 44(5): 319-27.

[17] Kibler BW, McMullen J. "Scapular dyskinesis and its relation to shoulder pain". *JAAOS-Journal of the American Academy of Orthopaedic Surgeons*. 2003; 11(2): 142-51.

[18] Lin JJ, Lim HK, Soto-quijano DA, Hanten WP, Olson SL, Roddey TS, Sherwood AM. "Altered patterns of muscle activation during performance of four functional tasks in patients with shoulder disorders: interpretation from voluntary response index". *Journal of Electromyography and Kinesiology*. 2006; 16(5): 458-68.

[19] Cools AM, Dewitte V, Lanszweert F, Notebaert D, Roets A, Soetens B, Cagnie B, Witvrouw EE. "Rehabilitation of scapular muscle balance: which exercises to prescribe?". *The American Journal of Sports Medicine*. 2007; 35(10): 1744-51.

[20] Seo GJ, Park JW, Kwon Y. "Comparison of the electromyographic activity in the lower trapezius muscle according to four different types of exercises in healthy adults". *The Journal of Korean Physical Therapy*. 2019;31(2):134-9.

[21] Borstad JD, Ludewig PM. "The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals". *Journal of Orthopedic & Sports Physical Therapy*. 2005; 35(4): 227-38.

[22] Chilgar LK, Mhatre B, Gandhi H, Mehta A. "Effect of motor control retraining of scapular stabilizers versus mulligan mobilisation with movement in shoulder impingement syndrome. *Imsear journal*. 2020; ID: sea-206188

[23] Kim Y, Song H. "The effects of exercise rehabilitation on shoulder range of motion, ASES score and VAS after rotator cuff repair". *Rehabilitation Science*. 2020; 4(4): 61-6

[24] Peteraitis T, Smedes F. "Scapula motor control training with proprioceptive neuromuscular facilitation in chronic subacromial impingement syndrome: A case report". *Journal of Bodywork and Movement Therapies*. 2020; 24(3): 165-71.

[25] Senbursa G, Baltacı G, Atay A. "Comparison of conservative treatment with and without manual physical therapy for patients with shoulder impingement syndrome: A prospective, randomized clinical trial". *Knee Surgery, Sports Traumatology, Arthroscopy*. 2007; 15(7): 915-21.

[26] Shojaedin SS, Amirii H, Barati AH. "The effect of 6 weeks resistance exercises with Elastic-band on joint pain and range of motion in athlete men with shoulder impingement syndrome." *RJMS*. 2014; 21 (119) :34-41. [in Persian]

[27] Wang HK, Cochrane T. "Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes". *Journal of Sports Medicine and Physical Fitness*. 2001; 41(3): 403.

[28] Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. "Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises". *The American Journal of Sports Medicine*. 2004; 32(2): 484-93.

[29] Lawrence RL, Braman JP, LaPrade RF, Ludewig PM. "Comparison of 3-dimensional shoulder complex kinematics in individuals with and without shoulder pain, part 1: sternoclavicular, acromioclavicular, and scapulothoracic joints". *Journal of Orthopaedic & Sports Physical Therapy*. 2014; 44(9): 636-45.

[30] McClure PW, Michener LA, Sennett BJ, Karduna AR. "Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo". *Journal of Shoulder and Elbow Surgery*. 2001; 10(3): 269-77.