한국전문물리치료학회지 제 17권 제 4호
PTK Vol. 17 No. 4 2010.

Effects of Hand Positions on Electromyographic Activity in Scapulothoracic Muscles During Push-Up Plus

Ji-yeon Yoon, M.Sc., P.T.
Motion Analysis Laboratory, Haeundae Paik Hospital, Inje University
Tae-hoon Kim, M.P.H., O.T.
Dept. of Occupational Therapy, Kaya University
Jae-seop Oh, Ph.D., P.T.
Dept. of Physical Therapy, College of Biomedical Science and Engineering, Inje University

Abstract

This study was designed to investigate the effect of different hand positions on scapulothoracic muscle activities during push-up plus exercises. Fourteen healthy males performed push-up plus exercises under three conditions (neutral, 90° internally rotated, and 90° externally rotated hand positions), during which the activities of the serratus anterior, pectoralis major, and upper trapezius muscles were recorded using surface electromyography. The statistical significance at three different hand positions was tested by repeated one-way ANOVA. The mean activities of the serratus anterior increased and the mean activities of the pectoralis major decreased in the order of neutral hand position, internally rotated hand position, and externally rotated hand position. There was a significant difference during push-up plus between neutral and externally rotated hand positions as well as in the serratus anterior/pectoralis major activity ratio ($p<.05$). However, no significant differences were found in th e activity of the upper trapezius muscle or the serratus anterior/upper trapezius activity ratio. We suggest that the push-up plus exercise performed in the externally rotated hand position could a beneficial strategy for selective strengthening of the serratus anterior muscle, while minimizing the activity of the pectoralis major muscle.

Key Words: Electromyography; Hand position; Push-up plus; Scapular muscle.

Introduction

Pain and stiffness in the shoulder can lead to an inability to work and carry out household and leisure activities due to persistent pain and muscular weakness in the upper extremities, burdening both the patient and society (Szeto et al, 2002). The high prevalence and persistence rates of neck and shoulder complex disorders have given rise to considerable interest in the function of scapular muscles, which play a role in the stability and controlled mobility of the scapula (Larsson et al, 2007).

The scapular muscles are essential for normal upper limbs, including the shoulder girdle (Ebaugh et al, 2005). Neck and shoulder injuries are related to an abnormal activation pattern due to scapular muscle imbalance (Luime et al, 2005). Specifically, increased activities of the upper trapezius (UT) and lower trapezius (LT) muscles, combined with reduced activity of the serratus anterior (SA) muscle, are a general finding among patients with shoulder dysfunction (Ludewig and Cook, 2000; Ludewig et al, 2004). The high activity of the UT represents a compensatory strategy for fatigue or impairment of the SA muscle (Ludewig and Cook, 2000; Szucs et al, 2009).

These activation imbalances may induce scapulothoracic kinematic alterations related to shoulder pathologies (de Morais Faria et al, 2008; Enoka and Duchateau, 2008). When the SA is weak and fatigued from any tasks, scapular motion and scap-

Corresponding author: Jae-seop Oh ysrehab@inje.ac.kr

ulothoracic stability may be compromised (Ludewig and Reynolds, 2009). Abnormal scapular motion, such as excess elevation and increased upward rotation of the scapula during elevation of the arm, is generally thought to be a compensation strategy for a limited glenohumeral motion, and other authors have suggested that abnormal scapular motion may be linked to imbalances in scapulothoracic muscle activity (Ludewig et al, 2004; Sahrmann, 2002).

It is important to strengthen the SA to prevent upper extremity injury and to rehabilitate from disability. However, it is often difficult to selectively activate the SA in a controlled clinical setting (Tucker et al, 2008). Closed kinetic chain exercise is a beneficial strategy for the upper limbs. Clinicians and researchers have extensively investigated activation of the SA during push-ups and modified push-ups. The push-up plus refers to the addition of raised portion by scapular protraction in the starting position of push up (Lehman et al, 2008). In various studies, was the most recommended technique to strengthen the SA (Ellenbecker and Davies, 2001; Ludewig et al, 2004). Many studies have examined exercises for the scapular muscles in various positions and on various surfaces during push-ups (Lehman et al, 2006; 2008; Szucs et al, 2009; Tucker et al, 2008). During the push-up or push-up plus on various unstable surfaces, the electric activation levels of the pectoralis major (PM) did not differ; thus, Lehman et al (2006) reported that the surface stability had no effect on the PM muscle.

Almost all studies on the push-up plus have focused on the amount of activation of the trapezius and SA, although the PM muscle could also be susceptible to tightening, as could the UT. Increased activation of the PM muscle may induce reduced stability of the glenohumeral joint because of increased anterior forces or decreased compression forces (Labriola et al, 2005). A few studies have investigated the effects of activities of the scapular muscles by changing hand positions. Determining the impact of hand position on scapulothoracic muscle activities may play a role in the development of exercises for rehabilitation and training of selective scapulothoracic muscles. Therefore, the aims of this study were to compare the muscle activation of scapular muscles (PM, SA, and UT) during push-up plus exercises depending on hand position (neutral, internally rotated, and externally rotated) and to find the position that minimizes activity of the PM and maximizes activity of the SA. We hypothesized that minimal muscle activity of the PM and maximal muscle activity of the SA would be found in the externally rotated hands position during push-up plus and that muscle activity of the UT would not differ significantly among the three positions.

Methods

Subjects

Fourteen young and healthy males were recruited from Inje University (Table 1). All subjects were right-handed and had normal range of motion (ROM) in the upper limbs. They were free of any neck and shoulder pain for a minimum of 6 months prior to the study and had no congenital deformities of the upper extremities or orthopedic or neurological disorders.

Instrumentation

The activities of the PM, SA, and UT muscles were recorded by an electromyography (EMG) system[1)] and circular surface EMG disposable electrodes with a diameter of 35 ㎜. All EMG signals were amplified, bandpass (30 ㎐ to 500 ㎐) and notch (60 ㎐) filtered, and then sampled at 1000 ㎐ using Acqknowledge 3.9.1 software.

Table 1. General characteristics of subjects (N=14)

Variables	Mean±SD
Age (yrs)	23.0±1.9
Height (㎝)	174.2±4.1
Weight (㎏)	68.0±9.0

1) MP150WSW, Biopac System Inc., Santa Barbara, CA, U.S.A.

The root mean square values of the raw data were calculated, with the amplitude normalized to the maximum voluntary contraction (MVC). For each subject, the mean value of the EMG data was expressed as a percentage relative to MVC.

Electrode placement and MVC testing

Before placing electrodes, the skin was shaved and rubbed with alcohol to reduce electrical impedance. Electrode placement and MVC protocol for the three muscles were as follows: PM electrodes were placed four finger-breadths below the clavicle, medial to the anterior axillary border. The subjects, with the elbow flexed 90° and the shoulder abducted 75°, performed a maximal palm press against the resistance. SA electrodes were placed on the muscle belly in the mid-axillary line of the right side over the fifth rib. The scapula was protracted at 90° of shoulder flexion as resistance was applied over the hand and at the elbow with the subjects in the supine position. UT electrodes were placed on the muscle belly midway between the C7 spinous process and the trapezius' insertion on the right acromioclavicular joint. The shoulder was abducted to 90° with the neck side-bent to the same side, rotated to the opposite side, and then extended as resistance was applied at the head and above the elbow with the subject sitting in an erect posture without back support (Ekstrom et al, 2005; Lehman et al, 2006).

Procedures

Before testing, a primary investigator explained the experimental condition to all subjects, and the subjects practiced for 10 minutes to become familiarized with the positions. The experiment was performed using the push-up plus exercise in three different hand positions: 1) neutral position (forward hand, subject's middle finger under the acromioclavicular joint), 2) 90° internally rotated position, and 3) 90° externally rotated position.

The tasks were administered in randomized order to prevent a learning effect (Figure 1). In the prone position, subjects placed their toes on a 30-㎝-high chair and were asked to maintain a position with hands positioned shoulder-width apart and directly underneath the shoulders, neutral spine curvature, and straight body position from the shoulder to the ankle joint (Figure 2). This position, which elevated feet compared with hands, induced increased SA activation and decreased UT activation (Ludewig et al, 2004; Szucs et al, 2009). The subjects began the push-up plus exercise when instructed to "start," and the eccentric (lowering), concentric, and push-up plus phases each lasted 2 seconds, respectively. Velocity was controlled with a metronome set at 60 beats per minute, and the investigator pushed the switch included in the EMG program to mark the beginning of each phase (Tucker et al, 2008). All tasks were performed with three repetitions, and each trial included a 2-minute rest.

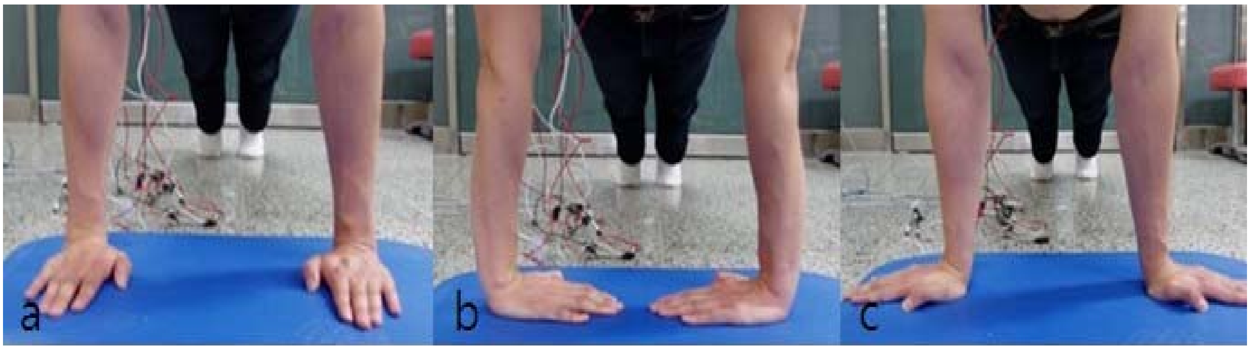

Figure 1. Hand-position (a. neutral; b. internal rotated; c. external rotated position).

Figure 2. Push-up plus starting position.

Statistical analysis

The SPSS statistical package was used for statistical analysis. The significance of three different hand positions on the scapulothoracic muscle activities during the push-up plus was analyzed by repeated one-way ANOVA. Post hoc tests to identify the main mean differences were performed using Bonferroni's correction, and significance was defined as p<.05.

Results

The normalized EMG data of the PM during push-up plus significantly differed in the neutral and 90° internally rotated hand positions compared with the 90° externally rotated hand position (p<.05). The normalized EMG data of the SA and SA/PM ratio differed significantly between the neutral and 90° externally rotated hand positions during push-up plus (p<.05) (Figure 3). No significant differences were found in the UT muscle or SA/UT ratio according to hand positions. The mean SA muscle activities were 45.04%, 47.60%, and 54.04% of MVC, the mean PM muscle activities were 49.87, 46.06, and 40.46%MVC, and the mean UT muscle activities were 25.88%, 26.37%, and 30.21% of MVC during push-up plus at the neutral, 90° internally rotated, and 90° externally rotated hand positions, respectively (Table 2).

The mean SA/PM ratios were 1.04, 1.21, and 1.47, and the mean SA/UT ratios were 1.99, 2.54, and 2.02 during push-up plus in the neutral, 90° internally rotated, and 90° externally rotated hand positions, respectively (Table 2).

Discussion

The scapulothoracic muscles are important for normal function and movement of the upper limbs and contribute to stability and mobility of the glenohumeral joint; however, when the muscles are subject to repeat significantly abnormal postures for a sustained period, they easily become imbalanced, causing neuromusculoskeletal dysfunction in the shoulder girdle (Kamkar et al, 1993; Mottram, 1997). The push-up plus exercise is often performed during rehabilitation and training for individuals with scapular and shoulder pathologies because the SA is con-

Table 2. The mean EMG data of the SA, PM, and UT muscles, and the SA/PM and SA/UT ratio during push-up plus in three hand positions (N=14)

Muscle	Hand position (Mean±SD)			F	p
	Neutral	Internally rotated	Externally rotated		
SA (%MVC)	45.04±13.18	47.60±11.66	54.04±13.35	7.622	.007
PM (%MVC)	49.87±14.90	46.06±15.35	40.46±12.01	7.367	.008
UT (%MVC)	25.88±13.63	26.37±14.29	30.21±17.13	2.644	.112
SA/PM ratio	1.04±.69	1.21±.72	1.47±.63	5.360	.022
SA/UT ratio	1.99±.87	2.54±1.93	2.02±.72	.803	.471

p<.05.

sidered a major stabilizer of the scapula and an upward rotator, along with the trapezius muscles, during arm elevation; it is also a chief protractor, along with the PM and pectoralis minor (Hammer, 1999).

The purposes of this study were to compare the muscle activities of the scapulothoracic muscles (SA, PM, and UT) during the push-up plus exercise depending on hand position (neutral, internally rotated, and externally rotated) and to select the exercise that most facilitates SA activity and prevents compensatory activity in the PM. Changes in hand position during the push-up plus affected the activation level of the scapulothoracic muscles; the activities of the PM significantly decreased, and the activities of the SA significantly increased in the order of neutral, internally rotated, and externally rotated hand positions during the push-up plus; the activities of UT were similar under the three conditions.

The results of this study support the hypothesis that muscle activity of the PM would be lower and that of the SA would be higher during the push-up plus with externally rotated hands compared with neutral hands. This is similar to a previous study qualifying the amplitudes of trunk and chest muscles during various push-up styles. Freeman et al (2006) found that the activities of most trunk muscles, including the chest and arm muscles, were greater when performing push-ups with hands on unstable surfaces and with uneven hand placement. When the muscle activation levels of the PM during various push-ups were ranked, PM muscle activation was lower during push-ups when each hand was externally rotated and placed three inches forward or backward of the shoulder joint compared with a standard push-up. Because triceps brachii and PM muscle are recruited at the same time in the early phase of the push up. de Oliveira et al (2008) reported that, among six exercises, the electrical activation of the SA and PM was the greatest during a push-up on a stable surface, and the second highest electric activation of SA and the lowest activation of PM occurred during a push-up on a medicine ball.

The SA is exaggerated in the final phase, and the triceps and pectoral muscles are activated primarily in the early phase of a push-up exercise. The sternal head of the PM is the largest of the extensors and adductors in the shoulder joint, so the vertical line of force of muscle fibers can increase in greater

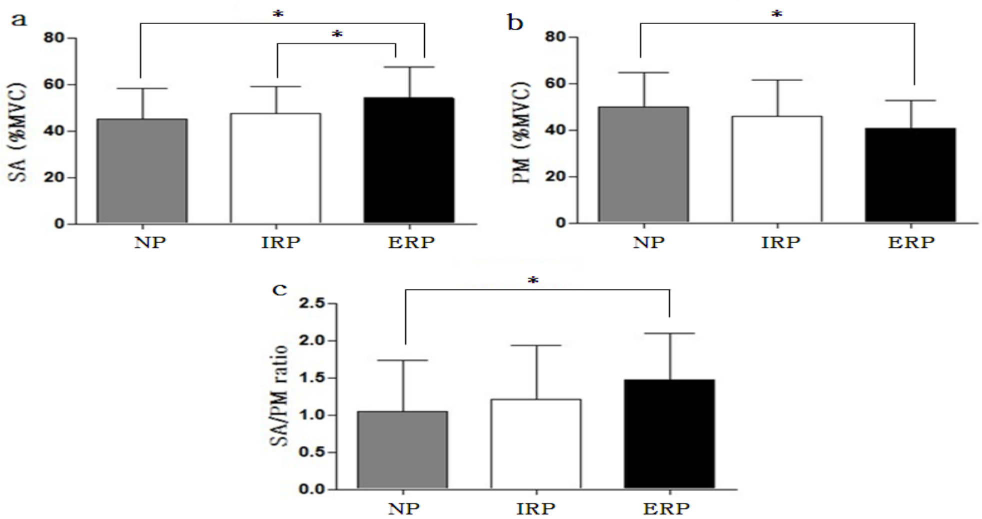

Figure 3. Normalized EMG data. a: SA, b: PM, c: SA/PM ratio. (NP: neutral position, IRP: internally rotated position, ERP: externally rotated position, $^{*}p<.05$)

flexion or adduction of the shoulders (Neumann, 2002). During the push-up plus, especially during the arm-lowering phase of the push-up, the externally rotated hand position may cause the length of the PM to be shortened because it is supporting the adducted shoulder. Accordingly, the PM could not generate its proper force due to insufficient leverage (Kisner and Colby, 2002). The characteristics that most influence muscle function are physiological cross-sectional area and fiber length. The length-tension relationship plays a vital role in skeletal muscle. The magnitude of force that a muscle is able to produce depends on its length and velocity and the stimulation of the muscle fiber. The force is maximal at medium lengths because filament overlap permits the greatest number of cross-bridges to form (Lieber, 2002; Sandercock and Heckman, 2001).

We found that the SA/PM ratios were higher than 1 when performing the push-up plus with internally and externally rotated hand positions and that the ratio was lower than 1 in the neutral hand position. However, the muscle activations of the SA and PM in neutral and internally rotated hand positions were similar to the SA/PM ratios, being approximately 1. Only in the externally rotated hand position was a significant difference observed. Therefore we consider that a reduction in PM activity was compensated by an increase in SA activity.

Townsend et al (1991) reported that the electrical activation of the PM was larger than that of the UT and SA during push-ups on a stable platform. Lehman et al (2006) also found that the activations of the SA and PM were similar but greater than the activation of the UT, and the activation of the triceps increased during push-ups with the hands on a Swiss ball compared with on a stable surface; however, there was no change in electrical activation in the PM.

In this study, we consider that the activity of the UT and the SA/UT ratio did not differ significantly because the SA, UT, and LT muscles play roles as the only scapular upward rotators, and very little scapular upward rotation occurred during the 30°～60° of humeral abduction or flexion (Bagg and Forrest, 1988; Norkin and Levangie, 1992).
The high SA/UT ratio is important because it provides a reduction in the imbalanced couple force in the SA and trapezius, as well as selective strengthening for the SA (Ludewig et al, 2004). Under all three conditions in this study, the muscle activity of the SA was greater than that of the UT, and this is the pattern recommended during shoulder rehabilitation.

There were several limitations in the current study. First, our data cannot be extrapolated to other populations because the sample size was small and all subjects were healthy young males. Second, our data were obtained during a short period of recording at the same speed, so we cannot explain changes related to different speeds and longer durations. Third, we recorded only three muscle activity levels under three conditions. Fourth, the kinetic and kinematic data were lacking in the description of the push-up plus with variously placed hands. Further studies should investigate the activation patterns of various muscles for long-term changes in subjects with shoulder disorders.

Conclusion

This study examined the muscle activations of the SA, PM, and UT when performing the push-up plus in three hand positions. The activation amplitude of the SA increased significantly and the activation of the PM decreased significantly in the order of neutral, 90° internally rotated, and 90° externally rotated hand positions, and the activation amplitude of the UT did not significantly differ. Therefore, we consider that the push-up plus exercise in the externally rotated hand position could be a beneficial strategy for selectively strengthening the SA muscle, while minimizing the activity of the PM muscle. Therefore, hand positions should be considered when applying the push-up plus exercise to people who have an imbalance between the SA and PM muscles.

References

Bagg SD, Forrest WJ. A biomechanical analysis of scapular rotation during arm abduction in the scapular plane. Am J Phys Med Rehabil. 1988;67(6):238-245.

de Morais Faria CD, Teixeira-Salmela LF, de Paula Goulart FR, et al. Scapular muscular activity with shoulder impingement syndrome during lowering of the arms. Clin J Sport Med. 2008;18(2):130-136.

de Oliveira AS, de Morais Carvalho M, de Brum DP. Activation of the shoulder and arm muscles during axial load exercises on a stable base of support and on a medicine ball. J Electromyogr Kinesiol. 2008;18(3):472-479.

Ebaugh DD, McClure PW, Karduna AR. Three-dimensional scapulothoracic motion during active and passive arm elevation. Clin Biomech (Bristol, Avon). 2005;20(7):700-709.

Ekstrom RA, Soderberg GL, Donatelli RA. Normalization procedures using maximum voluntary isometric contractions for the serratus anterior and trapezius muscles during surface EMG analysis. J Electromyogr Kinesiol. 2005;15(4):418-428.

Ellenbecker TS, Davies GJ. Closed Kinetic Chain Exercise: A comprehensive guide to multiple-joint exercises. Champaign, IL, Human Kinetics Pub., 2001.

Enoka RM, Duchateau J. Muscle fatigue: What, why and how it influences muscle function. J Physiol. 2008;586(1):11-23.

Freeman S, Karpowicz A, Gray J, et al. Quantifying muscle patterns and spine load during various forms of the push-up. Med Sci Sports Exerc. 2006;38(3):570-577.

Hammer WI. Functional Soft Tissue Examination and Treatment by Manual Methods. Jones & Bartlett Pub., 1999.

Kamkar A, Irrgang JJ, Whitney SL. Nonoperative management of secondary shoulder impingement syndrome. J Orthop Sports Phys Ther. 1993;17(5):212-224.

Kisner C, Colby LA. Therapeutic Exercise: Foundations and techniques. 4 ed. Philadelphia, F.A. Davis Co., 2002.

Labriola JE, Lee TQ, Debski RE, et al. Stability and instability of the glenohumeral joint: The role of shoulder muscles. J Shoulder Elbow Surg. 2005;14(1):32-38.

Larsson B, Søgaard K, Rosendal L. Work related neck-shoulder pain: A review on magnitude, risk factors, biochemical characteristics, clinical picture and preventive interventions. Best Pract Clin Rheumatol. 2007;21(3):447-463.

Lehman GJ, Gilas D, Patel U. An unstable support surface does not increase scapulothoracic stabilizing muscle activity during push up and push up plus exercises. Man Ther. 2008;13(6):500-506.

Lehman GJ, MacMillan B, MacIntyre I, et al. Shoulder muscle EMG activity during push up variations on and off a Swiss ball. Dyn Med. 2006;5:7.

Lieber RL. Skeletal Muscle Structure, Function and Plasticity. 2nd ed. Philadelphia, PA, Lippincott Williams & Wilkins, 2002.

Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther. 2000;80(3):276-291.

Ludewig PM, Hoff MS, Osowski EE, et al. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. Am J Sports Med. 2004;32(2):484-493.

Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. J Orthop Sports Phys Ther. 2009;39(2):90-104.

Luime JJ, Koes BW, Miedem HS, et al. High incidence and recurrence of shoulder and neck pain in nursing home employees was demonstrated during a 2-year follow-up. J Clin Epidemiol. 2005;58(4):407-413.

Mottram SL. Dynamic stability of the scapula. Man Ther. 1997;2(3):123-131.

Neumann DA. Kinesiology of the Musculoskeletal System: Foundation for physical rehabilitation. St. Louis, Mosby Inc., 2002.

Norkin CC, Levangie PK. Joint Structure and Function: A comprehensive analysis. Philadelphia, F.A. Davis Co., 1992.

Sahrmann SA. Diagnosis Treatment Movement Impairment Syndromes. St. Louis, Mosby Inc., 2002.

Sandercock TG, Heckman CJ. Whole muscle length-tension properties vary with recruitment and rate modulation in areflexive cat soleus. J Neurophysiol. 2001;85(3):1033-1038.

Szeto GP, Straker L, Raine S. A field comparsion of neck and shoulder postures in symptomatic and asymtomatic office workers. Appl Ergon. 2002;33(1):75-84.

Szucs K, Navalgund A, Borstad JD. Scapular muscle activation and co-activation following a fatigue task. Med Biol Eng Comput. 2009;47(5):487-495.

Townsend H, Jobe FW, Pink M, et al. Electromyographic analysis of the glenohumeral muscles during a baseball rehabilitation program. Am J Sports Med. 1991;19(3):264-272.

Tucker WS, Campbell BM, Swartz EE, et al. Electromyography of 3 scapular muscles: A comparative analysis of the cuff link device and a standard push-up. J Athl Train. 2008;43(5):464-469.

This article was received September 29, 2010, and was accepted November 2, 2010.