

Effect of various hand position widths on scapular stabilizing muscles during the push-up plus exercise in healthy people

YANJINSUREN BATBAYAR, RPT¹⁾, DAISUKE UGA, RPT, MS²⁾, RIE NAKAZAWA, RPT, PhD²⁾,
MASAAKI SAKAMOTO, RPT, PhD²⁾*

¹⁾ Mongolian National University of Medical Sciences, Mongolia

²⁾ Graduate School of Health Sciences, Gunma University: 3-39-22 Showa, Maebashi, Gunma 371-8514, Japan

Abstract. [Purpose] The purpose of this study was to determine the effect of various hand position widths during the push-up plus (PUP) exercise on the activity of the scapular stabilizing muscles and other upper-extremity muscles involved in the exercise. [Subjects and Methods] Nine healthy men participated in our study. The PUP exercise was performed on a stable surface in seven different hand positions, namely shoulder width (SW), and narrower SW (NSW) and wider SW (WSW) at 10%, 20%, and 30%. Surface electromyography was used to measure the muscle activities and muscle ratio of the upper trapezius (UT), middle trapezius, lower trapezius (LT), serratus anterior (SA), pectoralis major, deltoid anterior, latissimus dorsi (LD), and triceps muscles. [Results] The SA and LD muscle activities significantly decreased in the 30% NSW and 20% WSW hand positions, respectively. The UT/LT muscle ratio significantly increased in the 30% WSW hand position. [Conclusion] The results of this study suggest that during the PUP exercise, the SW hand position should be used. In the 30% NSW hand position, the SA muscle activity decreased, and the UT/LT ratio increased in the 30% WSW hand position.

Key words: Push-up plus exercise, Hand position, Serratus anterior

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INTRODUCTION

Strengthening of the scapular stabilizing muscles plays a crucial role in the treatment of various shoulder pathologies such as scapular dyskinesia, multidirectional instability, secondary impingement syndrome, and other postoperative conditions¹⁾. The serratus anterior (SA) muscle is one of the most important muscles responsible for scapular stabilization, as it is an important scapular protractor muscle in the scapulothoracic joint owing to its fulcrum being at the axis of the vertical rotation of the acromioclavicular joint²⁾. Weakness in this muscle causes the scapula to rest in a downwardly rotated position, causing scapular winging³⁾.

In particular, excess activation of the upper trapezius (UT) muscle had been proposed as a contributing factor to abnormal scapular motion. In some clinical patients, excess UT muscle activity may compensate for a weak SA muscle, and this is believed to contribute to impingement through the abnormal rotation of the scapula⁴⁾.

The use of a closed kinetic chain exercise with progres-

sive loading and proprioceptive challenges has become an accepted practice in shoulder and scapular rehabilitation programs^{5, 6)}. The standard push-up plus (PUP) exercise provides training for the scapular stabilizing muscles, with the highest average SA activation being demonstrated during the plus phase, as compared with some other rehabilitation exercises⁶⁾. However, the most effective hand position for SA muscle training during PUP exercise remains to be determined.

The purposes of this study were to measure the differences in the activation of the scapular stabilizing muscles and other upper-extremity muscles involved in the PUP exercise, and to study the balance of the scapular stabilizing muscles between the different hand positions during a PUP exercise.

SUBJECTS AND METHODS

Subjects

The subjects were nine healthy men (Table 1). Subjects with a history of upper-extremity injury, surgery, and pain or discomfort within 6 months before study enrollment were excluded from the study. All of the subjects were informed about the protocols of this study, and they provided written consent for participation. This study met the institutional ethical requirements for human experimentation of the Declaration of Helsinki.

*Corresponding author. Masaaki Sakamoto (E-mail: msaka@gunma-u.ac.jp)

Table 1. Subject characteristics

Number of subjects	9
Age (years)	25.0 (2.7)
Height (cm)	173.8 (4.1)
Body weight (kg)	66.3 (4.3)
Body mass index (kg/m ²)	22.3 (1.3)
Data are mean (standard deviation)	

Methods

In preparation, we measured each of the subjects' shoulder width (SW; from the left to the right acromion) and the maximum voluntary contraction (MVC) of each muscle for 5 s. Surface electromyography (EMG; BioLog DL-3100; S&ME, Inc., Tokyo, Japan) was used to collect raw EMG data. The EMG signal was recorded at a 1,000-Hz sampling rate. The EMG electrode (Active Electrode DL-141, S&ME, Inc.) position and MVC technique followed the recommendations from the SENIAM (surface EMG for non-invasive assessment of muscles) project⁷⁾ and previous studies^{1, 8, 9)}. The target muscles were the UT, middle trapezius (MT), lower trapezius (LT), pectoralis major (PM), SA, latissimus dorsi (LD), deltoid anterior (DA), and triceps (TR) on the right side. Before electrode application, the skin was wiped with alcohol and rubbed with skin preparation gel to reduce skin surface impedance.

The subjects performed PUP exercises on the floor in seven different hand position widths (at random) as follows: SW, and narrower SW (NSW) and wider SW (WSW) at 10%, 20%, and 30% (i.e., SW, 10% NSW, 10% WSW, 20% NSW, 20% WSW, 30% NSW, and 30% WSW). The PUP posture was described as both arms straight, the scapula protracted, and the body forming a straight line from the ankles to the head, with the feet pressed against a wall for support. The subjects were allowed to practice once and checked for the appropriate position before EMG signal recording. During the PUP exercise in each hand position, a posture was held for 5 s and repeated three times. The subjects rested for 3 min between exercises to prevent the effects of fatigue.

The EMG recordings were obtained by using biological waveform analysis software (m-Scope, S&ME, Inc.). Raw EMG data were filtered with a digital band-pass filter between 20 and 500 Hz. Root-mean-square (RMS) values were obtained for 3 s in the middle, excluding 1 s each at the beginning and at the end of the EMG recording. The standard statistical method was used to calculate the normalized RMS values by using the percentages of muscle activities of MVC and the mean values for each muscle, during each hand position in the PUP exercise. Moreover, the UT/SA, MT/SA, LT/SA, PM/SA, LD/SA, DA/SA, TR/SA, UT/MT, and UT/LT muscle ratios in the seven hand positions were calculated to obtain the muscle balance during the PUP exercise.

Statistical analysis was performed with SPSS version 17.0 for Windows. Muscle activity and muscle ratio in the SW hand position were compared with those in the other six hand positions by using the Wilcoxon signed-rank test, with a significance level of 5%.

RESULTS

The normalized EMG activity of each muscle and the muscle ratio during the PUP exercise are shown in Tables 2 and 3. The normalized EMG activity of the SA muscle significantly decreased in the 30% NSW hand position ($p = 0.03$). The LD muscle activity significantly decreased in the 20% WSW hand position ($p = 0.04$). The activity of the other muscles showed no significant differences between the hand positions.

The PM/SA ratio significantly increased in the 30% NSW hand position ($p = 0.04$). The LD/SA ratio significantly decreased in the 20% WSW hand position ($p = 0.03$). The TR/SA ratio was significantly increased in the 20% NSW ($p = 0.03$) and 30% NSW ($p = 0.01$) hand positions. The UT/LT muscle ratio significantly increased in the 30% WSW hand position ($p = 0.04$). The other muscle ratios did not significantly differ between the hand positions.

DISCUSSION

In this study, we examined the effects of the different hand position widths on the SA muscle activity required to perform the PUP exercise. During the PUP exercise in the NSW hand position, our results demonstrated that the SA muscle activity decreased in the 30% NSW hand position, and the PM/SA and TR/SA muscle ratios increased in the 20–30% NSW hand positions. This means that the PUP exercise in the 20–30% NSW hand positions is not efficient for the SA muscle strengthening training, and is not a selective training because of PM and TR compensatory activation. Our study supports the past evidence provided by Cogley et al.¹⁰⁾, who reported that the arms are in a neutral to slightly horizontal adducted position, with the PM muscle having the shorter position throughout the PUP exercise. The length-tension relation of the muscle mechanism suggests that muscles generate less tension at shorter muscle lengths than at longer muscle lengths. Therefore, for a given loading condition, a muscle in a shortened position must recruit a greater number of motor units to develop the tension necessary to meet the loading condition. Previous reports observed the highest average SA muscle activity and special strengthening training for SA muscle during the plus phase (full shoulder protraction) of a standard push-up exercise^{11, 12)}. According to our results, performing the PUP in the 20–30% NSW hand positions was less efficient for SA muscle strengthening training.

Meanwhile, during the PUP exercise in the WSW hand position, our results showed that the LD muscle activity and LD/SA muscle ratio decreased in the 20% WSW hand position, and the UT/LT ratio increased significantly in the 30% WSW hand positions. In the WSW hand position, the scapula might be in a more external rotational position on the thorax. This could increase the scapular elevation in the plus phase during the PUP exercise. Therefore, this scapular kinematic change could have an influence on muscle activity. During the shoulder abduction, the UT muscle activity increased and the LT muscle activity decreased in a patient with shoulder injury¹³⁾. Excess UT activity had been proposed as a contributing factor to abnormal scapular motion^{4, 14)}. Thus, in exercises for the scapular stabilizing muscle, the

Table 2. Comparison of muscle activities during the push-up plus exercise according to hand positions

	SW	10% NSW	20% NSW	30% NSW	10% WSW	20% WSW	30% WSW
UT	6.5 (3.3)	5.3 (3.3)	6.7 (3.2)	7.5 (4.1)	7.5 (4.8)	7.5 (5.0)	7.5 (5.1)
MT	7.6 (7.9)	5.6 (3.6)	7.7 (8.6)	8.4 (10.9)	7.1 (7.7)	5.3 (2.1)	6.2 (2.5)
LT	3.5 (1.5)	3.8 (2.6)	5.6 (8.6)	3.2 (1.8)	3.2 (1.4)	3.5 (1.8)	3.3 (1.5)
PM	13.3 (9.8)	11.5 (6.5)	16.9 (8.5)	18.9 (11.0)	12.4 (9.3)	9.0 (6.3)	9.3 (5.7)
SA	90.9 (40.5)	86.3 (42.6)	83.7 (38.8)	80.7 (32.1)*	85.8 (52.5)	87.0 (37.4)	85.6 (40.1)
LD	16.6 (12.1)	15.6 (15.3)	17.3 (13.5)	17.1 (14.1)	14.3 (8.7)	13.0 (7.4)*	15.2 (11.0)
DA	52.0 (21.1)	46.3 (14.0)	49.9 (16.4)	52.4 (22.8)	54.1 (21.0)	51.3 (22.4)	53.1 (22.3)
TR	48.1 (16.2)	47.0 (17.1)	53.3 (18.6)	55.7 (14.8)	48.2 (16.0)	44.7 (13.8)	47.6 (17.8)

Data are mean (standard deviation). * $p < 0.05$, significant difference (SW was compared with other hand positions). MVC: maximum voluntary contraction; SW: shoulder width; NSW: narrow than shoulder width; WSW: wider than shoulder width; UT: upper trapezius; MT: middle trapezius; LT: lower trapezius; PM: pectoralis major; SA: serratus anterior; LD: latissimus dorsi; DA: deltoid anterior; TR: triceps

Table 3. Comparison of the muscle ratios during the push-up plus exercise according to hand positions

	SW	10% NSW	20% NSW	30% NSW	10% WSW	20% WSW	30% WSW
UT/SA	0.09 (0.06)	0.08 (0.06)	0.10 (0.07)	0.12 (0.01)	0.11 (0.09)	0.10 (0.76)	0.10 (0.72)
MT/SA	0.08 (0.06)	0.07 (0.04)	0.10 (0.07)	0.11 (0.12)	0.08 (0.06)	0.07 (0.09)	0.09 (0.47)
LT/SA	0.05 (0.04)	0.06 (0.08)	0.07 (0.07)	0.05 (0.04)	0.04 (0.04)	0.05 (0.04)	0.05 (0.04)
PM/SA	0.16 (0.13)	0.16 (0.12)	0.25 (0.23)	0.28 (0.22)*	0.15 (0.10)	0.13 (0.16)	0.14 (0.16)
LD/SA	0.21 (0.17)	0.21 (0.22)	0.24 (0.18)	0.24 (0.21)	0.19 (0.15)	0.17 (0.11)*	0.20 (0.14)
DA/SA	0.75 (0.62)	0.72 (0.48)	0.81 (0.72)	0.79 (0.57)	0.79 (0.67)	0.74 (0.52)	0.78 (0.54)
TR/SA	0.64 (0.32)	0.69 (0.37)	0.80 (0.51)*	0.81 (0.39)**	0.67 (0.47)	0.63 (0.37)	0.70 (0.46)
UT/MT	1.62 (1.62)	1.37 (1.34)	1.61 (1.56)	1.91 (1.99)	2.01 (2.11)	1.88 (2.03)	1.58 (1.81)
UT/LT	2.37 (2.24)	2.00 (1.60)	2.39 (1.71)	2.75 (1.78)	2.75 (1.78)	2.86 (2.51)	2.81 (2.65)*

Data are mean (standard deviation). * $p < 0.05$, ** $p < 0.01$ significant difference (SW was compared with other hand positions). SW: shoulder width; NSW: narrow than shoulder width; WSW: wider than shoulder width; UT: upper trapezius; MT: middle trapezius; LT: lower trapezius; PM: pectoralis major; SA: serratus anterior; LD: latissimus dorsi; DA: deltoid anterior; TR: triceps

UT muscle activity should be inhibited and the MT, LT, and SA muscles should be more active (i.e. the UT/MT, UT/LT, and UT/SA ratios should be low). This effect reflects imbalance in the scapular force couple necessary for the rotational movements of the scapula during arm elevation. Delayed activation of the LT and MT muscles has been demonstrated in overhead athletes with shoulder impingement and in freestyle swimmers in response to an unexpected drop of the arm from the abducted position¹³). In view of our results, the 30% WSW hand position yielded UT and LT muscle imbalance, making it ineffective for intramuscular balance of the trapezius muscles.

In summary, the 30% NSW hand position had low SA muscle activity and the 20–30% NSW hand positions had high PM and TR activity. Meanwhile, the 30% WSW hand position had a high UT/LT muscle ratio. For patients with shoulder injuries acquired during exercise for the scapular stabilizing muscles, the UT muscle activity should be inhibited and the MT, LT, and SA muscle activities should be high. Therefore, the SW, 10% NSW, and 10% WSW hand positions are more efficient for the PUP exercise.

The limitations of our study include the small number of participants and the great differences in EMG values for the same muscles. In future investigations, researchers may

wish to consider using a different surface and a larger sample size of patients with pathological conditions of the shoulder.

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