

# Isometric Contraction of Scapular Muscles Activities during Horizontal Abduction and Adduction of the Shoulder

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## Abstract

**Background:** Scapular stability is important for shoulder movement; however, the mechanism of scapular stability remains unknown. In addition, activities of scapular muscles have been only evaluated during shoulder elevation, but not extensively observed those of other shoulder movements. We investigated muscle activity, including scapular muscle activity, during horizontal abduction and adduction of the shoulder joint.

**Methods:** Eighteen healthy men without orthopedic or neurological abnormalities participated in this study. Muscle activity was measured during horizontal isometric abduction and adduction of the shoulder joint in the sitting position. Measurements were conducted in three positions horizontal adduction at 0°, 45° and 90°, and external loads were set at 3, 5 and 10% of each subject's body weight. External load was added to the direction of horizontal abduction on horizontal adduction task and the direction of horizontal adduction on horizontal abduction task. Surface electromyography was used to collect raw data during the task. Based on scapular movements during shoulder motion, the measured muscles were classified as agonist muscles of the glenohumeral joint, and agonist and antagonist muscles of the scapulohumeral joint.

**Results:** The same patterns of muscles activities were identified during horizontal abduction and adduction in all positions. Electromyographic activities of agonist muscles of both the glenohumeral and scapulothoracic joints became higher with greater load; however, activities of antagonist muscles of the scapulohumeral joint did not show statistical significance.

**Conclusion:** Most scapular muscles engage during isometric contraction, and the high activating muscles were changed by the direction of shoulder movement. We have to evaluate the scapular muscle activities individually in consideration of this finding.

**Keywords:** Scapular muscles; Electromyography; Horizontal adduction and abduction; Shoulder joint; Scapular stability

## Introduction

The shoulder complex is made up of several joints. The glenohumeral joint (GHJ) and the scapulothoracic joint (STJ) are thought to be important in the shoulder complex and make up a large portion of shoulder movement. There are numerous studies on scapulo-humeral rhythm and muscle activity, especially during shoulder elevation [1-5]. Therefore, although there is a lot of information on shoulder elevation, there is less information on horizontal abduction and adduction and internal and external rotation of the shoulder joint [6]. Shoulder movement during activities of daily living and sport is diverse and does not just comprise shoulder elevation. Therefore, an investigation of shoulder movements other than elevation will further the understanding of shoulder performance in activities of daily living and athletics.

The scapula supports the humerus, and scapular stability is important for shoulder movement. Scapular muscle activity and

scapular movement are different in patients with shoulder disease compared to healthy subjects [7]. For example, scapular kinematic alterations associated with shoulder impingement, rotator cuff tendinopathy, rotator cuff tears, adhesive capsulitis, and so on, and these patients often reduced serratus anterior and increased upper trapezius activation [8-10]. And it was reported that the combination of standard rehabilitation interventions and scapulothoracic joint control training exercises were an effective treatment of the shoulder joint dysfunction [11,12]. Therefore, research on exercises to change scapular muscle activity [13,14] has led to the recognition of the importance of scapular stability for shoulder movement in normal scapular muscle activity. However, apart from shoulder elevation, the mechanism of scapular stability, especially in isometric contraction and movement of the shoulder joint, remains unknown. Ijiri et al. [15] previously investigated scapular muscle activity during isometric contraction of the shoulder joint during internal and external rotation, and revealed differences in activity among the scapular muscles. This difference is based on the constant rule that muscles with same movement as the scapular movement have higher activity. In addition, the reaction time against external force is also different for each

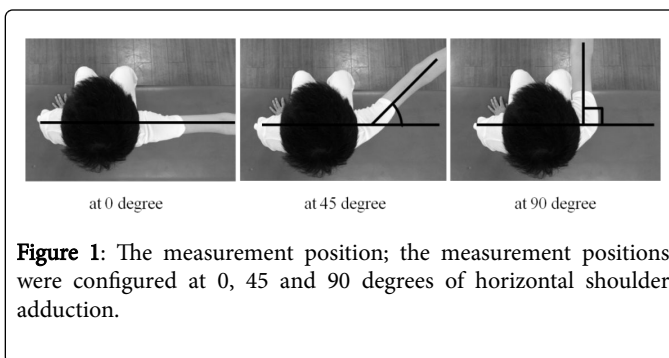
scapular muscle [16]. In the previous study, the muscles with higher activity reacted earlier compared to the other scapular muscles, with similar results for the agonist muscles of GHJ. We considered that the scapular muscles are divided into agonist and the antagonist muscles and that the agonist muscles of STJ have the same function against external force as the agonist muscles of GHJ and contribute to scapular stability.

Therefore, we investigated muscle activity, including scapular muscle activity during horizontal abduction and adduction of the shoulder joint with classification to agonist muscles and antagonist muscles. About the classification to agonist muscles and antagonist muscles, this classification followed the rule of scapular movement during shoulder motion and this classification was the original of us. Previous studies showed that each classified muscle indicated a different activity pattern. In horizontal adduction, the agonist muscle of GHJ was the pectoralis major. The agonist muscle of STJ was set as the serratus anterior because internal rotation and protraction of the scapula is by horizontal adduction [17,18]. The antagonist muscles of STJ were defined as the middle and lower trapezius muscles because they have the opposite function of the serratus anterior. The agonist muscle of GHJ for the horizontal abduction task was set as the posterior deltoid. The middle and lower trapezius muscles were defined as the agonist muscles of STJ because external rotation and retraction of the scapula is achieved by horizontal abduction [17,18]. Serratus anterior was defined as the antagonist muscle of STJ. We classified the measurement muscles and verified changes in the activity of each muscle with increasing load to further understand the mechanism of scapular stability.

## Materials and Methods

Eighteen healthy men without orthopedic or neurological abnormalities participated in this study. Subjects were excluded from this study if they had the experience of shoulder and neck disease or had the pain during the task of this study. And subjects were also excluded if they done hard physical exercise within one week. The mean anthropometric characteristics  $\pm$  standard deviations (SD) were age:  $25.3 \pm 2.3$  years, height:  $168.8 \pm 4.8$  cm, and weight:  $60.7 \pm 6.7$  kg. The subjects were provided with informed consent and agreed to participate in the study.

Muscle activity was measured during isometric horizontal abduction and adduction of the shoulder joint in the sitting position with the trunk fixed to a backrest by a hard, thick rubber band. Because muscle activity changes with angle, measurements were performed at three angles. The external load was set at three weights in order to evaluate change with different loads. The measurement positions were configured at 0°, 45° and 90° of horizontal adduction (Figure 1). A goniometer was used to check the angles. The examiner added the external load to the direction of horizontal abduction on horizontal abduction task and the direction of horizontal adduction on horizontal adduction task. The external load was set at 3, 5 and 10 percent of each subject's body weight (3%, 5% and 10%). These loads were predetermined in a pilot study on maximum muscle strength measurements at low, middle, and heavy weights. The external load was added at the distal humerus with a handheld-dynamometer (MOBIE, SAKAI medical Co, Japan). The angle and weight order was randomly set for each subject. Each angle and weight pattern order was numbered, and the subject selected the number uninformed. The subjects practiced each weight trial before the measurement.



**Figure 1:** The measurement position; the measurement positions were configured at 0, 45 and 90 degrees of horizontal shoulder adduction.

Surface electromyography (EMG; MQ-8, Kissei comtec, Japan) was used to collect raw EMG data during the task. EMG was reported in five seconds and the signal was recorded at a sampling rate of 1,000 Hz. The EMG was recorded with electrodes (LECTRODE, Admedec, Japan) at an interelectrode distance of 20 mm.

		Agonist at GHJ		Agonist at STJ		Antagonist at STJ	
		Pectoralis major	Serratus anterior	Middle trapezius	Lower trapezius		
0 degrees	3%	4.6 ± 1.9	2.0 ± 1.0	0.7 ± 0.3	0.5 ± 0.3		
	5%	7.0 ± 3.5 *	2.7 ± 1.7 *	0.7 ± 0.4	0.5 ± 0.3		
	10%	15.3 ± 8.9	6.2 ± 6.0	1.4 ± 1.9	1.2 ± 1.7		
45 degrees	3%	5.9 ± 3.5	2.2 ± 1.2	0.6 ± 0.2	0.9 ± 0.7		
	5%	8.3 ± 4.9 *	2.9 ± 2.0 *	0.5 ± 0.3	0.9 ± 0.6		
	10%	15.3 ± 9.9	7.5 ± 9.0	1.6 ± 2.6	2.0 ± 2.7		
90 degrees	3%	7.6 ± 4.1	3.5 ± 2.6	0.4 ± 0.2	0.8 ± 0.6		
	5%	10.2 ± 5.6 *	4.4 ± 3.0 *	0.4 ± 0.2	0.8 ± 0.6		
	10%	17.3 ± 10.4	8.6 ± 9.4	0.7 ± 0.5	1.3 ± 1.3		

\*p<0.05

**Figure 2:** Relative IEMG of horizontal adduction.

Muscle activities of pectoralis major and serratus anterior increased with increasing load during horizontal adduction. On the other hand, muscle activities of middle and lower trapezius did not increase significantly. Crosstalk was minimized by careful placement of suitably sized electrodes parallel to the muscle fibers, based on standard anatomical criteria. The target muscles were the pectoralis major and posterior deltoid, as the GHJ muscles, and the middle and lower trapezius and serratus anterior, as the STJ muscles on the dominant side. The EMG electrode position was set according to previous studies by Basmajian et al. [19] and Kibler et al. [20].

The EMG data were analyzed using analysis software (BIMTUS-VIDEO, Kissei comtec, Japan). The integrated EMG (IEMG) was obtained for 3 s in the stable wave during each task and counted per second. The IEMG per second was normalized by the IEMG of the arm at 0° of horizontal adduction. Relative-IEMGs were used for statistical comparison of each load in the same muscle. The Friedman test was used to determine whether a load condition had a statistically

significant effect on relative-IEMG for each muscle. Tukey's post-hoc analysis was then applied for specific comparisons among the three loads and to determine individual effect differences. The level of statistical significance was set at  $P < 0.05$ , unless otherwise noted.

	Agonist at GHJ		Agonist at STJ		Antagonist at STJ
	Posterior deltoid		Middle trapezius	Lower trapezius	Serratus anterior
0 degrees	3%	2.6 ± 0.7	3.5 ± 1.8	3.2 ± 1.1	1.4 ± 1.2
	5%	4.2 ± 1.5 *	5.4 ± 2.2 *	5.0 ± 1.8 *	1.5 ± 1.2
	10%	7.7 ± 3.4	8.2 ± 4.0	7.3 ± 2.6	3.3 ± 7.1
45 degrees	3%	2.0 ± 0.7	2.3 ± 1.4	3.7 ± 2.2	1.8 ± 1.2
	5%	3.2 ± 1.5 *	3.6 ± 2.5 *	4.9 ± 2.8 *	1.9 ± 1.5
	10%	6.3 ± 3.0	6.8 ± 5.3	7.9 ± 4.3	3.7 ± 6.9
90 degrees	3%	1.7 ± 0.9	1.3 ± 0.6	3.0 ± 1.4	2.2 ± 1.5
	5%	3.3 ± 2.2 *	2.2 ± 1.1 *	3.9 ± 2.1 *	2.4 ± 1.9
	10%	6.3 ± 4.8	4.6 ± 3.1	5.9 ± 3.5	4.5 ± 6.8

\* $p < 0.05$

Figure 3: Relative IEMG of horizontal abduction.

Muscle activities of posterior deltoid, middle, and lower trapezius increased with increasing load during horizontal abduction. On the other hand, muscle activities of serratus anterior did not increase significantly.

## Results

First, the horizontal adduction task will be explained (Figure 2). The relative-IEMGs of the pectoralis major, which were classified as the agonist muscle of GHJ, were significantly increased at 10% in all positions, compared to 3% and 5% ( $p < 0.05$ : 5% vs. 10% at 90°,  $p < 0.01$ : the others). The relative-IEMGs of the serratus anterior, which were classified as the agonist muscle of STJ, were significantly increased at 10% compared to 3% and 5% at 0° and 45° ( $p < 0.01$ : 3% vs. 10% at 0°,  $p < 0.01$ : the others), and 3% at 90° ( $p < 0.05$ ). Finally, the middle and lower trapezius muscles, which were classified as the antagonist muscles of STJ, did not show significant changes at all angles.

For horizontal abduction, the result trends were the same as for horizontal adduction (Figure 3). The relative-IEMGs of the posterior deltoid, which were defined as the agonist muscle of GHJ, were significantly higher at 10% in all positions compared to 3% and 5% ( $p < 0.05$ : 5% vs. 10% at 90°,  $p < 0.01$ : the others). The middle trapezius, which was defined as the agonist muscle of STJ, had the same results as the posterior deltoid in all positions ( $p < 0.05$ : 5% vs. 10% at 0° and 45°,  $p < 0.01$ : the others). The relative-IEMGs of the lower trapezius were significantly higher at 5% than 3% ( $p < 0.05$ ) and higher at 10% than 3% and 5% at 0° ( $p < 0.01$ ). And the relative-IEMGs were higher at 10% than 3% and 5% at both 45° and 90° ( $p < 0.05$ : 5% vs. 10% at 45° and 90°,  $p < 0.01$ : 3% vs. 10% at 45° and 90°). By contrast, the relative-IEMGs of the serratus anterior, which were classified as the antagonist muscle of STJ, did not change significantly in all positions.

## Discussion

Strengthening of the scapular muscles is important in rehabilitation. Especially, it is known that serratus anterior and trapezius have central function. Serratus anterior originates on the 1st to 8th ribs at the side of the chest and inserts the medial border of the scapula. The function of serratus anterior is scapular upward rotation, protraction, and internal rotation. Serratus anterior has the crucial role of the movement of scapular lateral direction. Trapezius is existed from scapula and clavicle to thoracic spine, and moves the scapula to retraction and upward rotation. It controls scapular movement of medial direction. The upper extremity moves smoothly by their appropriate activations. Effective exercises for their scapular muscles strengthening have been studied. Decker et al. reported that push-up, dynamic hug, and serratus anterior punch have higher serratus anterior activity and they recommended serratus anterior exercises [21]. Furthermore, Moseley et al. and Ekstrom et al. indicated that horizontal abduction of the shoulder joint with external rotation is good exercise for the middle trapezius muscle [22,23]. In addition, for the lower trapezius, raising the arm above the head in line with the lower trapezius and rowing are effective. Naturally, the effective exercises are not the same for each muscle. In many cases, effective exercises for the serratus anterior include internal rotation and protraction of the scapula, and, for the middle and lower trapezius, include external rotation and retraction of the scapula. Moreover, some of these exercises include isometric contraction. Therefore, not only is the contraction pattern important for scapular muscle activity but also the direction of force. In our previous study on scapular muscles activities during isometric contraction in internal and external rotation of the shoulder joint, the serratus anterior had high activity on internal rotation and the middle trapezius had high activity on external rotation [15]. In this study, serratus anterior had higher activity on horizontal adduction, and the middle and lower trapezius had higher activity on horizontal abduction. From these, there will be the relationship between the movement direction and high activation scapular muscle. And the muscle which has the same function in the direction of scapular movement during shoulder motion may have high activity.

Applied to this study, horizontal adduction of the shoulder joint leads to internal rotation and protraction of the scapula; and horizontal abduction of the shoulder joint leads to external rotation and retraction of the scapula [17,18]. The results validated this idea in that the serratus anterior, in terms of internal rotation and protraction of the scapula, contracted more during horizontal adduction, and the middle trapezius, in terms of external rotation and retraction of the scapula, contracted more during horizontal abduction. This suggests that the mechanism of scapular stability is not to fix the scapula by co-contraction of the scapular muscles but to react to external force through individual scapular muscle activity. Furthermore, the direction of scapular movement should be based on which scapular muscle contracts more, even during isometric contraction.

In this study, similar trends were shown for the agonist muscles of GHJ and STJ but not for the antagonist muscles of STJ. Similar to a previous study on reaction time, the timing of muscle activity in the agonist muscle of STJ was the same as in the agonist muscle of GHJ, but the antagonist muscle of STJ was later [16]. Furthermore, in a previous study on scapular muscle strengthening, serratus anterior strengthening led to increased muscle strength on flexion, abduction, and internal rotation of the shoulder joint and middle trapezius strengthening led to increased muscle strength on external rotation of

the shoulder joint [24,25]. It was evident that the agonist muscles of GHJ and STJ showed the same activity patterns; therefore, these muscles work harmoniously and should have the same function. In particular, because agonist muscles activities of GHJ counteracts external force, agonist muscles activities of STJ will do the same. The amount and timing of antagonist muscles activities of STJ were different from the agonist muscles of GHJ and STJ. This suggests that antagonist muscles of STJ and agonist muscles of GHJ and STJ have different functions. From EMG data, we can consider this way, but we have to verify from various perspectives such as the movement of scapula. This requires further validation.

In this study, the results showed that antagonist muscles activities of STJ were modest with no change on load increase. In a past study on isometric and isotonic contraction, the antagonist muscles at the other joint were shown to have small muscle activity [26-28]. These results were corresponding to my study. For example, there was antagonist muscle activity of only approximately 10 percent maximum voluntary contraction during extension of knee joint in isotonic and isokinetic contraction [28]. Furthermore, in a study on the elbow joint and GHJ, antagonist muscle activity was much smaller than agonist muscle activity [26,27]. The results of this study showed a similar phenomenon in the STJ. The STJ tends to be viewed as part of the shoulder complex; however, in certain respects, it can also be thought of as an isolated joint like the elbow and knee joints, i.e., an “adjacent joint” to the GHJ rather than part of the shoulder joint.

There are some limitations to this study. First, due to the assessment of horizontal adduction and abduction under three loads and at three angles, the number of measurements was comparatively large. The measurement order was random and, therefore, unbiased. However, fatigue was not excluded completely. And the sample size was not perfect. So, we have to investigate again with a lot of subjects. Although the results of muscle activities did not show a statistically significant difference on antagonist muscles of STJ at each load in this study, statistical significance might have been evident with a greater sample size. The numerical value of antagonist muscles activities of STJ tends to increase with increasing load, and, therefore, caution is warranted in interpreting the results. Finally, we have to investigate with more perspectives to find out the scapular stability. In this study, we examined only the activation of scapular muscles, did not analyze the scapular movement. It was not enough to conclude about the function of scapular muscles. So, investigations with more perspectives are necessary for clarification about the mechanism of scapular stability and the function of scapular muscles.

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