Title page

Title:

Isometric muscle activation of the serratus anterior and trapezius muscles varies by arm position, a pilot study with healthy volunteers for implications for rehabilitation.

Running Title:

Isometric activation of the periscapular muscles

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Abstract

Background: This study aimed to determine the most appropriate angle and moving direction of the arm for improving coordination of the periscapular muscles, including the serratus anterior (SA) and the upper (UT), middle (MT), and lower trapezius (LT).

Methods: Muscle activation amplitudes were evaluated in the SA, UT, MT, and LT in 11 healthy subjects using surface electromyography. The subjects were asked to maintain the arm position at five elevated positions with maximal effort against applied manual forces, which were directed from upper to lower (Test 1), lower to upper (Test 2), posterior to anterior in the frontal plane and lateral to medial in the sagittal plane (Test 3), and anterior to posterior in the frontal plane and medial to lateral in the sagittal plane (Test 4). The relative activity of the UT with respect to the SA, MT, and LT was calculated, resulting in the UT/SA, UT/MT, and UT/LT ratios.

Results: Test 4 in all positions but 150° of elevation in the frontal plane showed high activity of the SA with a low UT/SA ratio. High MT activity with a low UT/MT ratio was observed during Test 3 at the 90° elevated position, whereas high LT activity without UT hyperactivation was not found.

Discussion: To strengthen the periscapular muscles in the balanced condition, horizontal adduction is recommended for the SA. Horizontal abduction at the 90° elevated position

should be effective for the MT. Since no technique in this study was effective for the LT, further studies are needed.

Level of evidence: Basic science, kinesiology

Key Words: Electromyography; shoulder; exercise; muscle activation; muscle balance; periscapular muscles

Introduction

The scapula plays an important role in achieving effective stability and motion of the normal shoulder. For glenohumeral joint stability, the scapula works as a base for the humerus in the glenohumeral joint as well as a moving component of the scapulothoracic joint. Efficient shoulder motion requires coordination of both the scapula and the humerus, collectively referred to as scapulohumeral rhythm [17].

Altered static scapular position and loss of dynamic control of the scapular motion, termed “scapular dyskinesis,” are associated with a variety of shoulder disorders [2,19]. Alterations in periscapular muscle activation in particular have drawn attention as a major cause of scapular dyskinesis: Specifically, excessive activity of the upper trapezius muscle (UT) combined with reduced activity of other portions of the trapezius muscle and the serratus anterior muscle (SA) contributes to loss of posterior tilt and upward scapular rotation of the scapula [3,5-7,21,23].

Rehabilitation protocols focusing on correcting those abnormal muscle activities have been designed. Some exercises have been proposed to strengthen the SA, middle trapezius muscle (MT), and lower trapezius muscle (LT) [4,8,20]. Others have intended to restore scapular muscle balance by eliciting the greatest amount of SA and LT activity while minimizing UT activation [1,10,14,16,22,25]. To evaluate scapular muscle balance, UT/SA, UT/MT, and UT/LT ratios were recently introduced: Those muscle activities are measured by electromyography (EMG), and lower ratios demonstrate higher activities of the SA, MT, and LT compared with that of the UT [4,22]. According to Cools et al. and Ludewig et al., side-lying forward flexion (subject performing forward flexion to 135°), prone horizontal abduction with external rotation (subject performing horizontal abduction from 90° forward flexion with an additional external rotation of the shoulder at the end of the movement), and push-up plus (subject performing a standard push-up with full shoulder protraction after achieving full-elbow extension) were recommended to promote the MT, LT, and SA [4,22].

These exercises should be performed in an elevated arm position, which may cause subacromial impingement. In addition, the subject should hold dumbbells or support one's own weight while performing these exercises, which may cause overload-related pain in patients with shoulder problems. To identify safe exercises for such patients, details about the ideal shoulder position and direction to move the arm should be obtained. The purpose of the present study was to determine the most appropriate position and moving direction of the arm for strengthening and coordinating the SA, MT, and LT while considering muscle balance ratios. We hypothesized that there were specific arm positions and isometric contractions that highly activate the SA, MT, and

LT with low activity of the UT.

Materials and methods

Subjects

Eleven men (mean age, 23.9 ± 4.3 years; mean height, 171.9 ± 5.8 cm; mean weight, 64.6 ± 6.4 kg) were studied. None of the subjects had a history of shoulder injury requiring activity restriction or demonstrated scapular dyskinesis on clinical examination. All subjects were well informed and fully consented to participate in the study. This study was approved by the Ethical Review Board of Kyoto University Graduate School of Medicine.

EMG recording

Muscle activities of the SA, UT, MT, and LT were recorded using surface EMG. The skin at the electrode placement points was shaved and washed with an alcohol swab to reduce skin impedance (<10 kΩ). Blue sensor bipolar surface electrodes (Ambu A/S, Ballerup, Denmark) were placed at a 2-cm inter-electrode distance on the SA, UT, MT, and LT as described by Cools, Ekstrom, and Kibler [4,13,20]. A reference electrode was placed on the lateral end of the clavicle. The dominant arm was tested in each subject, and all subjects were right-handed. Each set of bipolar recording electrodes was connected to a multi-channel bioamplifier EMG system (BA-1008; Nihonsanteku Co., Ltd., Osaka, Japan). The sampling rate was 2048 Hz. All of the raw myoelectric signals were pre-amplified (overall gain, 1000; common rate rejection ratio, 80 dB; signal-to-noise ratio < 4 μV; peak-to-peak baseline noise filtered to produce a bandwidth of 5–3000 Hz). The BA-1008 was interfaced with the computer via an eight-channel, 16-bit MaP211 A/D card (Nihonsanteku Co., Ltd.). All of the raw EMG signals were converted from analog to digital via the MaP211 A/D card at 2048 Hz. All data were recorded, stored, and analyzed on a personal computer using the EMG multi-analysis program MaP1038 software (Nihonsanteku Co., Ltd.).

Testing procedure

During the testing, the subjects were asked to sit looking straight ahead with their pelvis and trunk fastened to the chair. The examiners held each subject's arm at five elevated positions of 30°, 60°, 90°, 120°, and 150° in the frontal and sagittal planes (Fig. 1). The subjects were asked to maintain the arm position for 3 seconds with maximal effort against the applied manual forces, which were directed from the upper to lower (Test 1), lower to upper (Test 2), posterior to anterior in the frontal plane and lateral to medial in the sagittal plane (Test 3), and anterior to posterior in the frontal plane and medial to lateral in the sagittal plane (Test 4) positions. Arm positions and applied force directions were randomized to avoid systematic influences of fatigue and learning effects. Subjects were allowed to rest for 3 minutes between tests.

Data reduction

All of the raw EMG signals were filtered to a bandwidth of 20–500 Hz. The root mean square of the raw data was determined. To normalize the obtained electrical signal values of the muscle activities during testing protocol, the value at maximal voluntary isometric contraction (MVIC) of each muscle in the recommended posture [15] was recorded. MVIC was sustained for 3 seconds. Each MVIC task was repeated two times and their mean was used as a reference. For normalization, the percentage MVIC (% MVIC) was calculated for the SA, UT, MT, and LT.

To choose the appropriate exertion method as training exercises, we selected pairs of the arm position and test in the SA, MT, and LT that showed EMG activity >60% MVIC. One previous study showed that the >60% MVIC activation level is very high activity sufficient to strengthen muscles [11].

Categorization of muscle activity according to muscle balance ratio

To demonstrate exercises with a highly activated SA, MT, or LT and low UT activity, we calculated the UT/SA, UT/MT, and UT/LT muscle balance ratios using the normalized EMG values [4,22] and classified those extracted pairs into four categories based on the muscle balance ratios: Category 1, <60%; Category 2, 60–80%; Category 3, 80–100%; and Category 4, >100%. According to a previous study, Categories 1, 2, and 3 corresponded to excellent, good, and moderate [4].

Statistical Analysis

To compare the efficiency of each position and test, two-way analysis of variance was calculated. The level of statistical significance was set to .05. A Tukey post hoc analysis with a .05 α level was added to positions or tests that showed statistical significance. All of the statistical analyses were performed using SPSS version 17.0 (SPSS Science, Chicago, IL, USA).

Results

Muscle activation

The % MVIC of the SA, UT, MT, and LT of the four shoulder tests at every arm position are shown in Table I (frontal plane) and Table II (sagittal plane).

The SA was activated at >60% MVIC during Tests 1 and 4 in both planes of all of the elevated positions but 150° of Test 4 in the frontal plane. The UT showed high EMG activity during Test 1 of all of the arm positions in both planes but 30° of Test 1 in the sagittal plane and Test 3 at the 120° and 150° elevated positions in the frontal plane. The MT showed high EMG activity during Test 1 at the 30°, 60°, and 90° elevated positions in the frontal plane and at the 90°, 120°, and 150° elevated positions in the sagittal plane. The MT was also activated at >60% MVIC during Test 3 in both planes of all of the elevated positions but at the 120° and 150° positions in the sagittal plane. The LT showed high EMG activity during Test 1 at the 120° elevated position in the frontal plane and Test 1 at the 120° and 150° elevated positions in the sagittal plane. The LT was also activated at >60% MVIC during Test 3 at the 120° and 150° elevated positions in the frontal plane.

Categories of muscle balance ratio

The muscle balance ratios of UT/SA, UT/MT, and UT/LT of the four shoulder tests at every arm position are shown in Table III (frontal plane) and Table IV (sagittal plane).

Serratus anterior (UT/SA)

On the frontal plane: Category 1 consisted of all situations of Tests 2 and 4; and Category 3 consisted of Test 1 at the 60°, 90°, and 120° elevated positions.

On the sagittal plane: Category 1 consisted of Test 2 at the 60°, 90°, 120°, and 150° elevated positions and Test 4 at the 30°, 60°, 90°, and 120° positions; Category 2 consisted of Test 1 at 30° and Test 4 at 150°; and Category 3 consisted of Test 1 at 60° and 90°and Test 2 at 30°.

The results of other situations were all included in Category 4.

Middle trapezius (UT/MT)

On the frontal plane: Category 1 consisted of all Test 2 positions; Category 2 consisted of Test 3 at the 30°, 60°, and 90° elevated positions; and Category 3 consisted of Test 4 at 30° and 150°.

On the sagittal plane: Category 1 consisted of Test 2 at the 30°, 60°, 90°, and 120° elevated positions and Test 3 at the 90°, 120°, and 150° positions; Category 2 consisted of Test 3 at 30° and 60°; and Category 3 consisted of Test 2 at 150°.

The results of other situations were all included in Category 4.

Lower trapezius (UT/LT)

On the frontal plane: Category 1 consisted of all Test 2 and Test 4 at the 30° and 150° elevated positions; and Category 2 consisted of Test 4 at 60°.

On the sagittal plane: Category 1 consisted of Test 2 at the 60°, 90°, and 120° elevated positions and Test 3 at 150°; Category 2 consisted of Test 2 at 150°; and Category 3 consisted of Test 2 at 30° and Test 3 at 90°.

The results of other situations were all included in Category 4.

Favorably categorized situations with higher muscle activation

The situations categorized 1-3 with muscle activation >60% MVIC were as follows.

Serratus anterior

On the frontal plane: Test 4 at the 30°, 60°, 90°, and 120° elevated positions were classified into Category 1; and Test 1 at the 60°, 90°, and 120° elevated positions were classified into Category 3.

On the sagittal plane: Test 4 at the 30°, 60°, 90°, and 120° elevated positions were in Category 1; Test 1 at 30° and Test 4 at 150° were in Category 2; and Test 1 at the 60° and 90° elevated positions were classified into Category 3.

Middle trapezius

On the frontal plane: No test situation was classified into Category 1; and Test 3 at the 30°, 60°, and 90° elevated positions were classified into Category 2.

On the sagittal plane: Test 3 at 90° of elevation was classified into Category 1; and Test 3 at the 30° and 60° elevated positions were classified into Category 2.

Lower trapezius

No test situation with LT activation >60% MVIC was classified into Categories 1–3.

Statistical comparison

Serratus anterior

There were significant main effects for the tests in both planes. In the frontal plane, the SA was activated to a greater degree during Test 1 than during the other tests ($p < .001$). In addition, the SA was activated to a greater degree during Test 4 than during Tests 2 and 3 ($p = .009$ and $p = .016$, respectively). In the sagittal plane, the SA was activated to a greater degree during Test 1 than during Tests 2 and 3 ($p < .001$) and during Test 4 than during Tests 2 and 3 ($p < .001$).

Upper trapezius

A significant interaction between arm positions and the tests was found in the frontal and sagittal planes ($p < .001$). In both planes, the UT activities were greater during Test

1 than during Tests 2, 3, and 4 ($p < .001$).

Middle trapezius

A significant interaction between arm positions and the tests was found in the frontal and sagittal planes ($p < .001$). In the frontal plane, the MT activities were greater during Test 3 than during the other tests ($p < .001$). In the sagittal plane, the MT was activated to a greater degree during Test 1 than during Tests 2 and 4 ($p < .001$) as well as during Test 3 than during Tests 2 and 4 ($p < .001$).

Lower trapezius

A significant interaction between arm positions and the tests was found in the frontal and sagittal planes ($p < .001$, $p = .009$, respectively). In the frontal plane, the LT was more activated to a greater degree during Test 1 than during Tests 2 and 4 ($p < .001$) as well as during Test 3 than during Tests 2 and 4 ($p < .001$). In the sagittal plane, the LT was activated to a greater degree during Test 1 than during other tests ($p < .001$) as well as during Test 3 than during Tests 2 and 4 ($p < .001$).

Discussion

Muscle activation amplitude

Very high EMG activities (>60% MVIC) of the SA, UT, MT, and LT were simultaneously generated during Test 1 at the 120° and 150° elevated positions in the sagittal plane. In the normal shoulder elevation, the SA, UT, MT, and LT stabilize the scapula to the chest wall and are considered its primary upward rotators [12,26]. In the present study, we did not evaluate scapular movement. However, the scapula would be kept at a constant position with the arm during Test 1 at the 120° and 150° elevated positions against the maximum force applied from the upper side on the arm in the sagittal plane. The activations of the periscapular muscles by isometric contractions as shown in this study are thought to differ from those evoked during isokinetic arm elevation [21,23,24], but all of the periscapular muscles would be elicited to hold the appropriate scapular position. To simply strengthen all of the periscapular muscles, exercises like Test 1 at the 120° and 150° elevated positions would be effective. In daily clinical practice, however, patients with shoulder problems tend to be unable to raise their arms more than 120° due to subacromial impingement.

Prone horizontal abduction at the 90° and 135° elevated positions in the frontal plane and the wide-grip rowing at shoulder level were previously reported to enhance trapezius muscle activation [14, 16, 25, 29]. These exercises have similar motion patterns as Test 3 performed at the 90°, 120°, and 150° elevated positions in the frontal plane. Test 3 at positions >90° in the frontal plane, particularly 120° and 150°, demonstrated higher EMG activities in all of the trapezius muscles. Test 3 in this current study proved the efficacy of well-known exercises for the trapezius muscle. In contrast, it was interesting that high EMG activity of the SA was generated during Test 4 in both planes and was 46.3–123.3% MVIC.

A number of exercises for the SA have been advocated to date, such as the forward punch, military press, push-up plus (push-up with full shoulder protraction), glenohumeral internal and external rotation at 90° abduction, and shoulder flexion, abduction, and scaption >120° [10, 14, 16, 25, 27], but none except the dynamic hug exercise showed the efficacy of horizontal adduction. The dynamic hug exercise begins with the elbows in approximately 45° of flexion and the shoulder abducted 60° and internally rotated 45°. The humerus is then horizontally adducted until full shoulder protraction is reached [10]. Test 4 was isometric contraction that direction was toward horizontal adduction and this direction was similar to dynamic hug exercise. The high EMG activity of the SA during Test 4 showed the importance of the SA during shoulder protraction and elevation as well as horizontal adduction.

Muscle activity categorization according to muscle balance ratio

Serratus anterior

Cools et al. [4] reported that none of the commonly prescribed exercises for the trapezius muscle training showed a low UT/SA ratio. Kibler et al. [20] recommended inferior glide (IG) and low row (LR) exercises for the SA training without UT hyperactivity. However, since the greatest EMG activity of the SA was only 23.4% MVIC during IG and 28.2% MVIC during LR, these activation levels were too low to improve SA strength. Ludewig et al.[22] reported that the push-up plus exercise demonstrated high activation as well as low UT/SA ratios, but the exercise load would be excessive for patients with shoulder pain. Test 4 of this study demonstrated larger SA activation >60% MVIC without UT hyperactivation, even in the low arm positions such as 30° or 60°. In daily clinical situations, Test 4 in the lower position should be easily performed by patients with shoulder problems.

Middle trapezius

Only Test 3 at the 90° elevated position in the sagittal plane was classified into Category 1. Our result indicated that this exercise method would be the most effective for strengthening the MT without hyperactivating the UT. However, in daily practice, there is concern that subacromial impingement might occur at the 90° arm position. Although these tests were classified into Category 2, we recommend Test 3 at the 30° or 60° elevated positions in the sagittal plane in the early phase of rehabilitation.

In the frontal plane, data of Test 3 at the 30°, 60°, and 90° elevated positions were also classified into Category 2 and can be recommended. Test 3 at highly elevated positions such as 120° or 150° elicited MT activities >60% MVIC; these results were consistent with those of previous studies [14, 25]. However, they also activated the UT and were not classified into categories.

Lower trapezius

The LT was highly activated during Tests 1 and 3 in both planes, but all of the tests were classified into Category 4 because of high UT/LT ratios. These results indicated the difficulty of selectively strengthening the LT. Cools et al. [4] reported that the LT showed relatively high EMG activity with a low UT/LT ratio while the subjects in the prone position performed horizontal abduction holding a 1–3 kg dumbbell with external rotation from the 90° elevated position in the frontal plane. This exercise was similar to our Test 3 at the 90° elevated position in the frontal plane, but their LT activity was higher and UT/LT ratio was lower than ours. The difference between Cools's and our method was body position (prone or sitting position) with or without external rotation.

In our Test 3, the UT might be more activated to maintain the elevated position against gravity in sitting position. The role of the UT is to draw the clavicle and scapula backward [18]. Therefore, this UT activity might support horizontal abduction contraction and reduce LT activity. In addition, the external rotation in Cools's method might elicit scapular posterior tilting and effectively activate LT. Considering LT activation, some recent studies focused on multi-joint exercises with hip and trunk extension or diagonal movement in scapular retraction [9, 20]. Further studies of these kinetic chain exercises are needed for LT activation with a low UT/LT ratio.

In some situations classified into favorable categories, the SA, MT, or LT was not sufficiently activated to be strengthened but the UT activation was very low. For example, Test 2 at 30° of humeral elevation in the frontal plane demonstrated no more than 14.4% of the UT/SA ratio (Category 1), but the SA was activated in only 43.6% MVIC. In such situations, the SA, MT, or LT is not strengthened but may be facilitated safely, and they could be reasonable choices in the early phase of rehabilitation.

Statistical examination

Although shoulder elevation is a primary objective for most of the patients, Test 1 more significantly activated the UT than the other tests in both planes. Considering the selective activation of the periscapular muscles, it is better to routinely avoid Test 1. For the SA, Test 4 showed significantly higher activation than Tests 2 and 3 in both planes. Similarly, for the MT, Test 3 demonstrated significantly higher activation than Tests 2 and 4 in both planes. In view of the statistical comparison, Test 4 for the SA and Test 3 for the MT should be reasonable options for strengthening.

This study is a first step in examining the most effective movement for activating the SA, MT, and LT without hyperactivating the UT. We demonstrated that the horizontal adduction exercise might effectively strengthen the SA muscle, even at low arm angles, and that the horizontal abduction exercise at the 90° elevated position might also be effective for the MT. However, we found no appropriate procedure for the LT. The difficulty achieving proper activation of the LT persists, which might suggest the need to reconsider the efficacy of already known LT exercises. Further studies including multi-joint exercises focusing on the kinetic chain are needed for LT exercise. Our results will contribute to rehabilitation programs for improving scapular muscle strength or treating imbalances such as scapular dyskinesis.

Limitation

This study has some limitations. First, the sample size of 11 subjects was small and the data in Tables I–IV included high standard deviation values. We demonstrated the standard deviation in each cell as well as the mean value to prevent readers from overestimating our data. In all tables, however, many situations of extraordinary value were evident in the surveyed muscles, and it seems not to be difficult to avoid non-active exercise patterns.

Second, we researched SA activity as described in previous studies [4,13,20]; in reality, this method recorded only activation of the lower part of the SA instead of the entire SA. This is because our pilot study demonstrated that the recording of the middle and upper SA must be affected by the latissimus dorsi or pectoralis major muscles; this phenomenon is known as cross-talk in surface EMG [30]. Considering that the long thoracic nerve ramifies into more branches in the lower part of the SA [28], activation of the lower SA can represent the entire SA. Third, we studied a sample of young, healthy adults. Clinical patients may have different characteristics than those of our subjects, and we cannot tell whether the muscle activation of the healthy volunteers in this study would be generated in the patients. However, the basic functions of the periscapular muscles such as the upward rotator should be maintained, and we could expect the functional recovery of such patients by applying the accomplishments to our daily practice. To prove the clinical efficiency of our method, further clinical studies are needed.

Conclusion

Here we investigated surface EMG findings of the lower SA, UT, MT, and LT muscles during several shoulder muscle force tests. We found that horizontal adduction should effectively improve SA strength. For the MT, muscle horizontal abduction at 90° of arm elevation should be the most effective. However, we found no ideal exercise for the LT muscle, so future studies are warranted.

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Figure and Table Legends

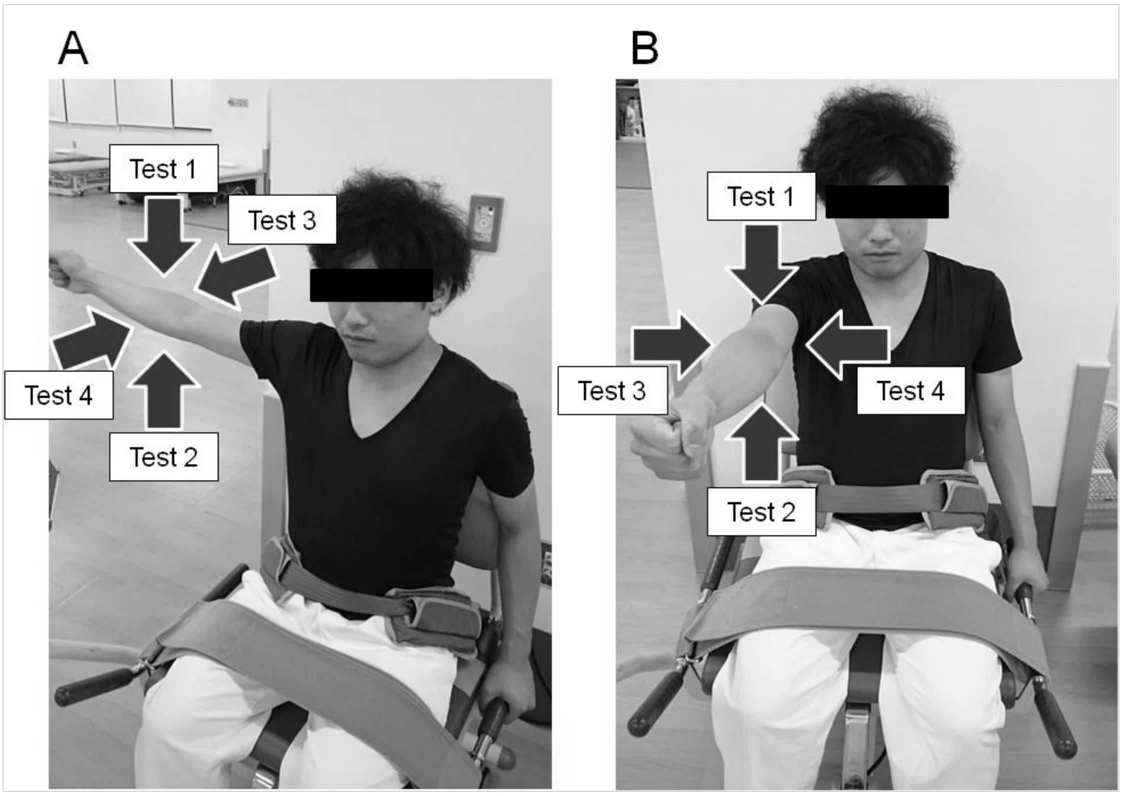

Figure 1. Tests 1–4 performed in the sitting position. Arrows indicate directions of the applied forces. (A) In the frontal plane (at the 90° elevated position). (B) In the sagittal plane (at the 90° elevated position).

	Test 1 (% MVIC) Mean ± SD	Test 2 (% MVIC) Mean ± SD	Test 3 (% MVIC) Mean ± SD	Test 4 (% MVIC) Mean ± SD	Angle effect *P*-value	Test effect *P*-value	Interaction *P*-value
Serratus anterior							
30° humeral elevation	87.0 ± 43.6	43.6 ± 31.7	45.7 ± 55.5	70.5 ± 24.8			
60° humeral elevation	109.7 ± 49.9	48.6 ± 46.4	40.3 ± 51.9	86.1 ± 43.9			
90° humeral elevation	133.1 ± 82.5	38.9 ± 36.7	35.2 ± 55.3	77.9 ± 35.9	.713	<.001	.417
120° humeral elevation	124.1 ± 57.3	34.9 ± 35.3	27.3 ± 41.8	60.0 ± 38.2			
150° humeral elevation	111.4 ± 48.3	32.9 ± 34.0	58.6 ± 56.9	46.3 ± 31.0			
Upper Trapezius							
30° humeral elevation	78.6 ± 25.5	3.7 ± 1.1	34.4 ± 19.0	22.7 ± 18.3			
60° humeral elevation	87.4 ± 13.1	6.8 ± 7.5	51.8 ± 21.8	16.8 ± 17.5			
90° humeral elevation	89.3 ± 18.7	6.2 ± 8.4	55.7 ± 18.1	13.9 ± 15.0	.037	<.001	<.001
120° humeral elevation	82.0 ± 17.3	6.1 ± 10.4	72.9 ± 23.7	13.6 ± 19.4			
150° humeral elevation	82.9 ± 21.2	5.9 ± 9.0	88.8 ± 19.6	5.1 ± 6.3			
Middle Trapezius							
30° humeral elevation	66.8 ± 21.2	15.8 ± 8.7	61.1 ± 18.3	24.4 ± 12.0			
60° humeral elevation	69.2 ± 21.0	17.8 ± 9.4	69.7 ± 20.8	13.6 ± 6.0			
90° humeral elevation	61.0 ± 24.8	13.0 ± 6.0	80.2 ± 29.6	8.2 ± 4.5	.229	<.001	<.001
120° humeral elevation	44.1 ± 23.0	9.8 ± 6.5	78.9 ± 26.7	7.1 ± 5.7			
150° humeral elevation	35.6 ± 22.6	16.1 ± 12.0	93.3 ± 27.7	6.1 ± 3.7			
Lower Trapezius							
30° humeral elevation	52.8 ± 25.3	25.4 ± 17.5	33.4 ± 19.4	43.3 ± 13.3			
60° humeral elevation	59.6 ± 25.4	26.4 ± 22.7	44.1 ± 27.0	24.6 ± 13.9			
90° humeral elevation	53.3 ± 20.7	16.6 ± 11.2	50.4 ± 35.0	13.4 ± 8.0	.743	<.001	<.001
120° humeral elevation	61.9 ± 32.3	17.8 ± 12.1	64.7 ± 33.6	10.5 ± 8.9			
150° humeral elevation	40.2 ± 19.1	20.9 ± 12.2	85.9 ± 40.5	7.6 ± 3.9			

Table I. Electromyographic activities in the frontal plane

Test 1, applied force to the arm from the upper to lower side; *Test 2*, from the lower to upper side; *Test 3*, from the lateral to medial side; *Test 4*, from the medial to lateral side. MVIC, maximal voluntary isometric contraction; SD, standard deviation

	Test 1 (% MVIC) Mean ± SD	Test 2 (% MVIC) Mean ± SD	Test 3 (% MVIC) Mean ± SD	Test 4 (% MVIC) Mean ± SD	Angle effect *P*-value	Test effect *P*-value	Interaction *P*-value
Serratus anterior							
30° humeral elevation	89.1 ± 34.2	47.2 ± 44.8	44.4 ± 56.3	62.5 ± 26.4			
60° humeral elevation	104.7 ± 43.1	45.9 ± 47.3	32.6 ± 34.5	91.8 ± 41.9			
90° humeral elevation	110.0 ± 63.6	27.9 ± 26.6	20.4 ± 17.3	80.8 ± 45.6	.683	<.001	.082
120° humeral elevation	95.1 ± 35.4	24.8 ± 18.6	20.1 ± 17.4	81.9 ± 41.5			
150° humeral elevation	84.2 ± 59.4	23.5 ± 14.9	16.3 ± 12.5	123.3 ± 81.6			
Upper Trapezius							
30° humeral elevation	57.5 ± 10.0	17.1 ± 11.7	57.2 ± 15.5	9.1 ± 8.0			
60° humeral elevation	73.5 ± 15.1	8.5 ± 8.8	53.9 ± 16.5	14.6 ± 18.2			
90° humeral elevation	88.8 ± 16.2	3.4 ± 2.9	39.1 ± 19.1	24.6 ± 24.7	.162	<.001	<.001
120° humeral elevation	93.4 ± 22.0	5.2 ± 4.8	30.8 ± 17.2	37.6 ± 20.0			
150° humeral elevation	93.6 ± 24.6	7.7 ± 10.0	14.3 ± 14.5	57.3 ± 25.7			
Middle Trapezius							
30° humeral elevation	47.2 ± 13.4	39.1 ± 17.8	82.9 ± 23.9	8.4 ± 4.0			
60° humeral elevation	52.1 ± 20.3	26.2 ± 15.0	90.4 ± 27.2	7.9 ± 4.0			
90° humeral elevation	62.3 ± 23.8	17.5 ± 16.6	75.8 ± 27.4	8.9 ± 6.5	.0499	<.001	<.001
120° humeral elevation	76.8 ± 23.2	9.2 ± 6.6	57.0 ± 19.6	8.9 ± 3.7			
150° humeral elevation	81.0 ± 25.5	8.9 ± 8.6	36.4 ± 24.3	12.1 ± 2.9			
Lower Trapezius							
30° humeral elevation	54.2 ± 34.3	29.0 ± 23.8	50.5 ± 37.4	21.1 ± 24.5			
60° humeral elevation	59.2 ± 29.3	16.5 ± 10.9	58.1 ± 45.1	10.4 ± 7.5			
90° humeral elevation	58.0 ± 21.1	15.0 ± 11.8	51.6 ± 29.5	13.8 ± 11.7	.953	<.001	.009
120° humeral elevation	85.5 ± 36.3	9.4 ± 6.0	37.4 ± 18.0	9.2 ± 6.2			
150° humeral elevation	84.7 ± 40.3	10.8 ± 8.4	37.0 ± 24.6	14.3 ± 13.1			

Table II. Electromyographic activities in the sagittal plane

	Test 1			Test 2			Test 3			Test 4		
	Mean		SD	Mean		SD	Mean		SD	Mean		SD
UT/SA												
30° humeral elevation	110.3	±	66.5	14.4	±	9.6	206.2	±	181.1	35.0	±	32.1
60° humeral elevation	89.7	±	30.6	57.6	±	117.1	321.7	±	236.7	20.4	±	22.2
90° humeral elevation	82.6	±	39.3	48.3	±	98.1	450.5	±	383.7	22.1	±	22.5
120° humeral elevation	84.9	±	48.9	56.9	±	140.0	747.9	±	629.4	24.9	±	30.7
150° humeral elevation	102.2	±	82.5	43.4	±	75.5	394.6	±	423.1	18.9	±	32.8
UT/MT												
30° humeral elevation	124.7	±	41.2	28.8	±	15.6	61.3	±	39.6	88.8	±	49.4
60° humeral elevation	135.1	±	36.6	58.5	±	96.5	77.6	±	29.3	104.9	±	72.5
90° humeral elevation	176.3	±	105.1	40.5	±	31.5	79.3	±	39.9	160.6	±	111.5
120° humeral elevation	223.2	±	102.6	50.4	±	37.3	112.7	±	83.2	158.4	±	133.7
150° humeral elevation	305.7	±	199.3	36.7	±	29.8	104.7	±	45.4	85.7	±	52.0
UT/LT												
30° humeral elevation	202.3	±	191.4	22.7	±	19.0	139.4	±	110.5	49.1	±	34.6
60° humeral elevation	180.5	±	97.6	51.3	±	88.6	149.6	±	84.5	67.8	±	55.3
90° humeral elevation	203.2	±	115.5	33.4	±	19.9	145.5	±	71.5	106.7	±	92.7
120° humeral elevation	181.1	±	116.9	32.1	±	27.8	148.8	±	90.8	167.0	±	305.5
150° humeral elevation	357.7	±	457.8	29.2	±	26.1	125.0	±	61.0	59.1	±	29.6

Table III. The balance ratio in the frontal plane

	Test 1			Test 2			Test 3			Test 4		
	Mean		SD	Mean		SD	Mean		SD	Mean		SD
UT/SA												
30° humeral elevation	76.1	±	40.0	83.4	±	94.5	334.0	±	264.9	15.3	±	11.1
60° humeral elevation	80.3	±	34.5	28.9	±	17.9	359.6	±	358.2	15.1	±	15.0
90° humeral elevation	95.4	±	39.5	16.5	±	11.2	338.4	±	278.8	30.6	±	27.5
120° humeral elevation	111.5	±	50.5	25.7	±	26.8	231.6	±	162.9	50.1	±	29.5
150° humeral elevation	141.3	±	65.0	40.1	±	41.4	150.5	±	157.8	72.8	±	51.4
UT/MT												
30° humeral elevation	128.7	±	30.0	54.1	±	55.6	72.1	±	21.2	130.8	±	146.8
60° humeral elevation	155.6	±	51.5	32.9	±	20.1	61.3	±	17.0	199.0	±	230.0
90° humeral elevation	162.9	±	68.5	25.5	±	13.2	58.1	±	38.0	280.5	±	212.2
120° humeral elevation	129.7	±	40.6	55.7	±	30.9	58.9	±	35.7	441.8	±	218.9
150° humeral elevation	125.3	±	46.0	94.0	±	80.1	39.6	±	21.4	472.7	±	202.0
UT/LT												
30° humeral elevation	133.3	±	60.5	89.1	±	79.8	155.9	±	101.6	100.5	±	148.3
60° humeral elevation	165.5	±	103.3	55.2	±	47.6	130.3	±	96.5	141.9	±	147.7
90° humeral elevation	169.6	±	59.4	31.2	±	33.1	89.5	±	59.5	182.3	±	138.4
120° humeral elevation	127.3	±	56.5	54.7	±	37.6	108.6	±	111.0	463.5	±	285.1
150° humeral elevation	127.6	±	49.6	70.5	±	55.2	39.4	±	21.2	603.0	±	353.1

Table IV. The balance ratio in the sagittal plane