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Full Length Article

Comparative study of the differences in shoulder muscle activation according to arm rotation angle

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ABSTRACT

Background: Scapular muscle exercise is important for patients with shoulder disorders. Distal variance leads to changes in shoulder muscle activation. Here, we aimed to determine whether scapular muscle activation is affected by different arm rotation angles.

Methods: Overall, 30 healthy men participated in this study. The subjects were asked to keep their arms at 120 degrees of shoulder flexion while holding a 1.0-kg dumbbell in palms down (pronation) and palms up (supination) positions. Electromyography was used to measure anterior, middle, posterior deltoid, serratus anterior, upper, and lower trapezius muscle activation during the task. The muscle activations of each shoulder were compared between the pronation and supination positions.

Results: Anterior deltoid and serratus anterior activations were significantly higher in supination than in pronation ($p < .05$). Alternatively, posterior deltoid and lower trapezius muscles were significantly more activated in pronation than in supination ($p < .05$).

Conclusion: Scapular muscle activation changed with arm rotation angle. Arm rotation angle should be assessed to estimate scapular muscle activation during exercise and motion analysis in clinical practice.

1. Introduction

The scapulothoracic joint (STJ) plays a key role in shoulder mobility and stability and is important in exercise to increase range of motion (ROM) and strengthen the muscles. The consensus on whether electromyographic activity changes consistently in people with shoulder disorders is far from reached and debate is ongoing, however many researchers have reported the change of muscle activation and scapular movement [McQuade, Borstad, & de Oliveira, 2016; Chester, Smith, Hooper, & Dixon, 2010]. Patients with shoulder disorders perform abnormal scapular movements and show altered muscle activation [Cools, Witvrouw, Declercq, Vanderstraeten, & Cambier, 2004; Lefevre-Colau et al., 2018; Michener, Sharma, Cools, & Timmons, 2016; Voight & Thomson, 2000]. Scapular upward rotation, posterior tilt, and clavicular elevation are increased during shoulder elevation in patients with shoulder impingement [McClure, Michener, & Katsuma, 2006]. Ludewig indicated that the serratus anterior had low activation but the upper trapezius had high activation in patients with frozen shoulder and impingement syndrome [Ludewig & Reynolds, 2009]. A

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combination of interventions for the glenohumeral joint (GHJ) and STJ has been shown to be effective in patients with shoulder joint disorders [Cools et al., 2014; Hotta, Santos, McQuade, & Oliveira, 2018; Saito, Harrold, Cavalheri, & McKenna, 2018; Zhang et al., 2015]. Therefore, it is necessary to assess scapular movements and activation in patients and strengthen weak scapular muscles during shoulder rehabilitation. Researchers have investigated exercises resulting in the highest muscle activation for the serratus anterior and recommended push-up plus exercises [Decker, Hintermeister, Faber, & Hawkins, 1999]. Rhomboid muscle activation has been investigated using electromyography, and researchers reported that Kendall's manual muscle testing was the most effective for rhomboid activation [Smith et al., 2004]. Similar studies have reported that exercises resulted in the highest scapular muscle activity [Ekstrom, Soderberg, & Donatelli, 2005; Moseley Jr, Jobe, Pink, Perry, & Tibone, 1992].

Previous studies evaluated how position is the most effective for achieving high muscle activation [Larsen, Juul-Kristensen, Olsen, Holtermann, & Søgaard, 2014; Nascimento et al., 2017]. It was reported that serratus anterior activation increased significantly when maximal scapular protraction was combined with horizontal shoulder adduction [Jung, Hwang, Kim, Gwak, & Kwon, 2017]. Other author showed the result of investigating the effect of simultaneous recruitment of the lower extremity muscles and trunk muscles on the serratus anterior activation when performing a forward punch plus [Kaur et al., 2014]. In the studies comparing the full can test and the empty can test, one study showed that muscle activation of supraspinatus and subscapularis was greater during the empty can test than during the full can test and one study showed there was no evidence of a difference in rotator cuff muscle activation levels between the empty can test and the full can test [Kai et al., 2015; Boettcher, Ginn, & Cathers, 2009]. A different muscle activation between scapular and coronal plane abduction was also reported [Reed, Cathers, Halaki, & Ginn, 2016]. These studies demonstrated that upper extremity and trunk positions make muscle activation level change and must be considered during exercise for strengthening the scapular muscles. However, the change in the activation of the scapular muscle when the hand is positioned distally, especially during internal and external rotation of the arm, is unknown, and the rotational position of the distal part of the upper extremity is not considered in most exercises. It was hypothesized that a difference in arm rotation angle leads to changes in GHJ and STJ muscle activation. This information would be helpful to judge the rotational position of the distal part of the upper extremity during open kinetic chain exercises such as a serratus anterior punch. Therefore, we must gather fundamental knowledge about the effect of differences in arm rotation angle. This study aimed to clarify the changes in scapular muscle activation that occur in different arm rotation positions. There are many biarticular muscles in the upper extremity and each joint movement is closely coordinated. Furthermore, the activation of the scapular muscle is altered depending on the position of the distal portion of the upper extremity. We hypothesized that scapular muscle activation would change with changes in arm rotation position.

2. Methods

2.1. Subjects

A total of 30 subjects participated in this study. Subjects were excluded if they had upper-limb, neck, or neurological disorders; incurred pain during the study task; or had limited ROM. Hard physical exercise within the previous week was another criterion for exclusion. Patient characteristics (mean ± standard deviation) were as follows: age, 26.2 ± 3.4 years; height, 172.9 ± 5.9 cm; and weight, 65.3 ± 7.6 kg. All subjects were confirmed to have normal ROM of forearm rotation before the measurements, and each provided informed consent to participate in the study. The Juzankai ethics committee approved the study protocol (no. 2017002).

2.2. Experimental protocol

The flexion angle was set to 120 degrees because the patients usually have to elevate approximately 120 degrees in activities of daily living [Namdari et al., 2012; Gates, Walters, Cowley, Wilken, & Resnik, 2016]. Subjects were instructed to perform the motions in the palms down (pronation) and palms up (supination) positions (Fig. 1). For each task, the subjects were asked to turn their palms up/down tightly and hold a 1.0-kg dumbbell. The muscle activation of the dominant arm was measured in all tasks. Shoulder angle was measured using a goniometer, and an adjustable pole was set to a certain height to maintain the angle during each task. The subjects were not allowed to move from their standing position during the measurement to maintain the reach distance. The elbow angle was set to 0 degrees of extension, while the wrist angle was set to 0 degrees of palmar flexion. The order of tasks was randomized. Muscle activation was measured for 5 s, and the subjects were allowed to rest for 1 min after each task.

Surface electromyography (EMG) signals during the tasks were collected with the active electrode (MQ-8 16-bit EMG amplifier; Kissei Comtec, Japan). It recorded data via electrodes (ELECTRODE, Admedic, Japan) at an interelectrode distance of 20 mm. This contact sensor was disposable Ag/AgCl chloride surface electrodes and electrode diameter was 1 *1 cm. The skin at the electrode sites was abraded and cleaned using alcohol. Crosstalk was minimized by careful placement of suitably sized electrodes parallel to the muscle fibers, based on standard anatomical criteria. The EMG signal was recorded at a sampling rate of 1000 Hz. Target muscles included the anterior, middle, and posterior deltoid; upper and lower trapezius; and serratus anterior. The positions of the EMG electrodes were set according to previous studies (Table 1) [Baets, Jaspers, Janssens, & Deun, 2014; Moeller, Bliven, & Valier, 2014; Reinold et al., 2007].

2.3. Data analysis and statistical analysis

EMG data were analyzed by software (BIMTUS-VIDEO; Kissei Comtec). The digital band-pass filter (Finite Impulse Response filter) was set between 5 and 500 Hz. The stable 3 s EMG waves which were located near the center of the task motion was selected

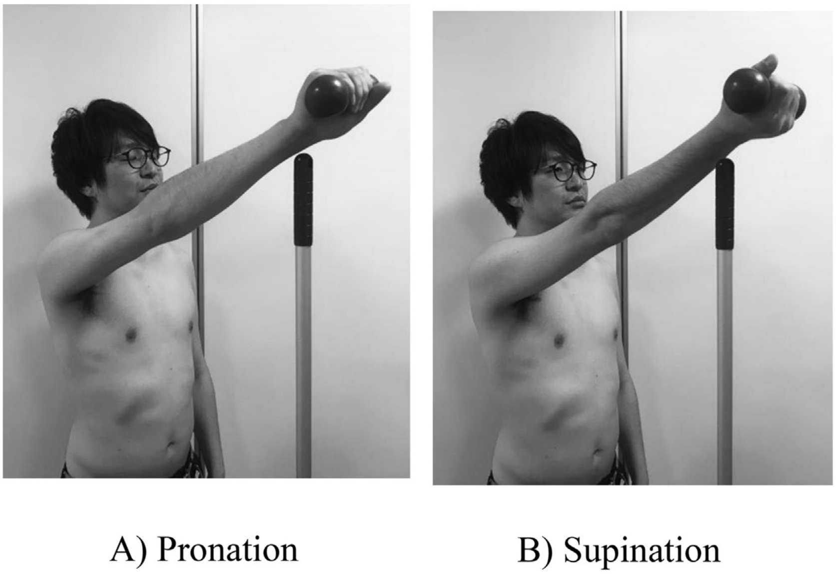


Fig. 1. The positions of the two tasks.
A) Palm down (pronation) position, B) Palm up (supination) position.

Table 1
The positions of the EMG electrodes.

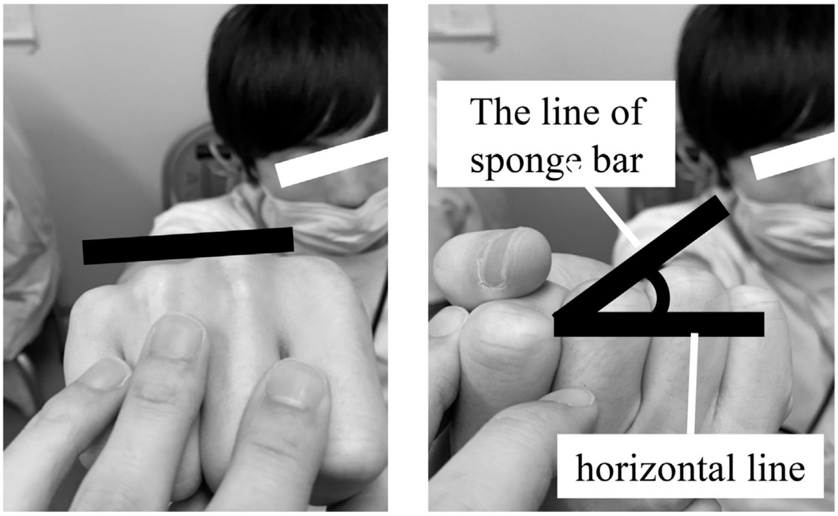
Anterior deltiod	4 cm below the lateral clavicle, parallel to the muscle fibers
Middle deltoid	The muscle belly at a point halfway between the tip of the acromion and the deltoid tubercle
Posterior deltoid	Obliquely 2.5 cm inferior to the posterior margin of the acromion
Upper trapezius	Half the distance between the seventh cervical vertebra and acromion process over the muscle belly
Lower trapezius	Obliquely between the lower thoracic spine (approximately thoracic vertebras of 8–12) and scapular spine approximately 5 to 7 cm inferior to the vertebral border of the scapula
Serratus anterior	Obliquely over the lower fibers of the serratus anterior on the lateral thoracic cage at the level of the inferior scapula and anterior to the latissimus dorsi border just below the axilla

and the integrated EMG (IEMG) was obtained for the 3 s during each task. The IEMG was normalized using the IEMG in static standing and the relative IEMG values were calculated. The normalization by static standing was performed to enable comparison of the results to those in patients with shoulder disease in the future. Normalization for maximum voluntary contraction is common, but the EMG wave of maximum voluntary contraction usually changes between trials. Thus, we used IEMG in the static standing position for the normalization. Relative IEMG values were used for statistical comparison of each task in the same muscle. All statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). More precisely, it is a modified version of R commander designed to add statistical functions frequently used in biostatistics [Kanda, 2013]. We expected to know the difference of muscle activation between in pronation and in supination on the same muscle. The Wilcoxon signed rank test was used to compare the relative IEMG values in pronation to those in supination for each muscle because the data were not normally distributed on the Shapiro-Wilk normality test. The level of statistical significance was set at 0.05.

The difference in humeral rotation angle was measured to determine the contributions of humeral versus forearm rotation to these tasks. The data from six healthy men (age, 22.7 ± 0.8 years; height, 173.8 ± 5.1 cm; weight, 65.5 ± 7.7 kg) were used to evaluate the difference in humeral rotational angle. For the measurement of rotation angle, an original sponge bar (2 × 15 × 2 cm) was set at the middle of the humerus to measure spatial humeral rotational angle and the subject kept their arm at 120° of shoulder flexion in pronation and supination (Fig. 2). The sponge bar was set at a right angle to the line connecting the points of the lateral and medial epicondyles of the humerus. The Measurer took pictures from the axis view of the upper arm. The pictures were taken at the angle when the center of the shoulder joint matched that of the hand to avoid parallax errors caused by misalignment of the camera's optical axis with the axis of the forearm. The difference between the pronation and supination of the joint was calculated by measuring the angles between the line of the sponge bar and the horizontal line at each position using Photoshop (Adobe Systems, San Jose, CA, USA).

3. Results

The relative IEMG value of each muscle is listed in Table 2. At the GHJ, the median relative IEMG value of the anterior deltoid was



A) Pronation B) Supination

Fig. 2. A comparative view of the humeral rotation between the two postures.
A sponge bar was set at the middle of the humerus to measure spatial humeral rotational angle and the subject kept their arm at 120 degrees of shoulder flexion in pronation and supination. The measurer took pictures from the axis the of the upper arm. The angles between the line of the sponge bar and the horizontal line were measured, and the difference between the pronation angle and the supination angle was calculated.

Table 2
The relative IEMG values of each muscle.

	Anterior deltoid	Middle deltoid	Posterior deltoid	Upper trapezius	Lower trapezius	Serratus anterior
Pronation	36.9 (23.4–81.0)	38.2 (15.7–76.9)	38.2 (19.5–68.0)	13.1 (6.9–21.4)	20.6 (10.8–26.2)	16.1 (12.6–21.5)
Supination	51.4 (29.1–87.1)	33.9 (16.4–77.2)	32.3 (17.2–57.1)	13.2 (7.6–31.3)	13.8 (9.5–20.9)	19.5 (15.2–23.1)
p-value	0.007	0.70	0.01	0.06	0.005	0.0008
Effect size (r)	0.49	0.07	0.44	0.35	0.49	0.61

Median (Interquartile range), Unit: fold.

36.9 times in pronation and 51.4 times in supination. The middle deltoid was 38.2 times in pronation and 33.9 times in supination. The posterior deltoid was 38.2 times in pronation and 32.3 times in supination. The relative IEMG value of the anterior deltoid in supination was significantly higher than that in pronation ($p = .007$). There was no difference in the relative IEMG value of the middle deltoid between pronation and supination. In contrast, the relative IEMG value of the posterior deltoid in pronation was significantly higher than that in supination ($p = .01$).

The results of the muscles at the STJ are also listed in Table 2. The median of the upper trapezius was 13.1 times in pronation and 13.2 times in supination, while the lower trapezius was 20.6 times in pronation and 13.8 times in supination. The serratus anterior was 16.1 times in pronation and 19.5 times in supination. There was no difference between pronation and supination for the upper trapezius. Muscle activation of the lower trapezius was significantly higher in pronation than in supination ($p = .005$). The relative IEMG value of the serratus anterior was significantly higher in supination than in pronation ($p = .0008$).

Additionally, a difference in humeral rotational angle between pronation and supination is indicated. The humeral rotation in supination led to greater external rotation than in pronation. Specifically, the humeral rotational angle differed by a median 29.0 (interquartile range: 28.0–31.9) degrees between the pronation and supination positions. There was not a large difference in the dispersion of the measured angles.

4. Discussion

This study aimed to determine differences in shoulder muscle activation according to the arm rotation angle. Our results indicated that activations of the anterior deltoid and the serratus anterior muscle were higher in supination than in pronation. Alternatively, posterior deltoid and lower trapezius muscle activation were higher in pronation than in supination. Many studies have previously reported differences in the activation of the shoulder muscle when the position of upper extremity is changed; these studies suggested that the activities of the muscles at the glenohumeral joint change dependent on the position of the distal part of the upper extremity. However, there weren't enough studies about if the scapular muscles activation changes by rotational difference of distal part of upper extremity as noted in background. The result of this study suggested that activation of the shoulder muscle is affected by the arm rotation during the performance of isometric exercise. The characteristics of scapular muscle activation were reportedly not the same during shoulder isometric contraction; in fact, the time of onset in each scapular muscle during shoulder rotation differed [Ijiri, Takagi, & Suzuki, 2017; Suzuki, 2017]. Based on our previous data and those of this study, various factors affect scapular muscle activation, including movement direction and arm rotation angle. In rehabilitation for patients with shoulder disorders, exercises were usually performed to regain muscle functions and to select effective exercise is important for improvement to shoulder impairment. Because arm rotation angle changes the degree of shoulder muscle activation, it is important to also focus on arm rotation angle during exercise.

In this study, the subjects performed tasks in palm down and palm up positions, and we hypothesized that such arm rotation must lead to a change in forearm rotation angle and humeral rotation angle. Humeral rotational angle was measured in these two positions, and the humeral rotation in supination led to more external rotation than in pronation (28.3°). The total arm rotation angle was about 180° because the palm was changed from down to up, so the rest rotation angle, 180° minus 28.3°, equals 151.7° and must be contributed to by forearm rotation. A previous study reported that shoulder joint angle changed with differences in distal part position [Rowlands, Wertsch, Primack, Spreitzer, & Roberts, 1995]. Differences in the shoulder joint angle were reported between the full can test, thumb up position and the empty can test, thumb down position. In particular, Timmons reported that the full can test led to external rotation of the shoulder joint in contrast to the empty can test [Timmons et al., 2013]. Muscle activation of the posterior deltoid during the empty can test, which is done with the shoulder internally rotated, was higher than that during the full can test [Reinold et al., 2007]. The position of the deltoid shifted and muscle activation of deltoid changed, changing the humeral rotational angle. For that reason, also in our study, muscle activation of the anterior deltoid was higher in supination than in pronation, while the posterior deltoid was higher in pronation than in supination.

The change in humeral alignment led to a change in scapular muscle activation. Researchers have reported that the scapula moves in harmony with the humerus, the so-called scapulohumeral rhythm [Boume, Choo, Regan, Maclntyre, & Oxland, 2007; Gretchen & Wendi, 2015; Inman, Saunders, & Abbott, 1944; Konda, Yanai, & Sakurai, 2015; Ludewig & Cook, 2000; Miyashita, Kobayashi, Koshida, & Urabe, 2010]. The empty can test, in which the shoulder is internally rotated, includes scapular lateral rotation, retraction, and anterior tilt [Lachaine, Allard, Gobout, & Begon, 2015; Thigpen, Padua, Morgan, Kreps, & Karas, 2006]. The full can test, in which the shoulder is externally rotated, includes scapular medial rotation, protraction, and posterior tilt. This movement leads to a change in scapular muscle activation. In our measurement, the serratus anterior showed high activation in the supination position that might be involved in scapular protraction, while the increased activation of the lower trapezius in the pronation position might be involved in scapular retraction. The other possible cause of the change in scapular position was the influence of the biceps brachii. It is known that the biceps brachii is involved with the supination of the forearm. Therefore, the biceps brachii would have worked in the supination task and this activation will influence the scapular position. However, further studies are required to determine the effect of the biceps brachii on the position of the scapula.

This study has several limitations. First, the subjects were asked to keep their arms in a certain position while the muscle activation was being measured. Therefore, our results are only applicable to holding tasks. Previous studies evaluated shoulder muscle activation during exercise, including during a serratus anterior punch, push-up plus, and shoulder horizontal abduction in pronation [Decker et al., 1999]. Our results show that the serratus anterior muscle was highly activated in the supination position. Further research is needed to determine whether supination is recommended for strengthening the serratus anterior during exercise using shoulder motion. Second, how to structure the normalization requires consideration. In this study, the IEMG value of static standing was used to approximate the measurements. However, static standing muscle activation was small and the IEMG value of each subject varied widely. The relative IEMG value also varied widely between subjects. For example, if the IEMG at 90 degrees of shoulder flexion was used for the comparison, the relative IEMG value may have low variability and the data the authors gather will be comparable. Since it caused this problem, the sample size was not perfect in terms of effect size. And finally, the subjects in this study were healthy young men. Future studies should seek to include elderly people and patients with shoulder disorders to apply these results in a clinical situation. Researchers have shown that scapular movements differ in elderly people [Endo et al., 2016] and that some may have asymptomatic rotator cuff tears [Gomide, Carmo, Bergo, Oliveira, & Macedo, 2017]. Angles that lead to changes in muscle activation will be different from those of this study in patients with shoulder disorders because they have limited shoulder and scapular mobility [Kim, Keon, & Kim, 2018; Waszczykowski, Polguj, & Fabis, 2014]. There are different situations among young people, elderly individuals, and patients with disorders, and this information will be useful for clinicians.

5. Conclusion

This study aimed to clarify the changes in shoulder muscle activation that occur in different arm rotation positions. Our results indicated that activations of the anterior deltoid and the serratus anterior muscle were higher in supination than in pronation. Alternatively, posterior deltoid and lower trapezius muscle activation were higher in pronation than in supination. These results suggested that shoulder muscle activation changed with arm rotation angle.

Declaration of Competing Interest

The authors declare no conflicts of interest.

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