

# Onset of Shoulder Muscle Activation During Internal and External Shoulder Rotation

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## Abstract

**Background:** Scapulae activation and the order of muscle activation tends to be changed in patients with shoulder disorder and abnormal muscle activate pattern is the risk for shoulder disability. However, previous studies have only explored shoulder elevation in regard to the order of shoulder muscle activation. Hence, the order of muscle activation during other shoulder movements is unknown. The purpose of this study was to investigate the order of shoulder muscle activation during internal and external shoulder rotation.

**Methods:** Eighteen healthy subjects participated in this study. The onset of muscle activation was measured by electromyography under two conditions. Initially, the subjects started the movement of internal or external rotation at their own discretion, and then they performed isometric contraction of internal or external rotation against an external load.

**Results:** Following the two test conditions, results of internal rotation task showed that activation of the middle trapezius was significantly later than that of the pectoralis major and the serratus anterior. External rotation indicated that the serratus anterior was recruited after the infraspinatus. The onset of muscle activation of the middle trapezius was the same as that of the infraspinatus.

**Conclusion:** This result showed that the onset among shoulder muscles during internal and external rotation wasn't the same. Especially, there was the difference of onset time among each scapular muscle. From this difference, it is thought that each scapular muscle may have different role in shoulder isometric contraction.

**Keywords:** Scapular muscle; Onset of muscle activation; Shoulder rotation; Shoulder disease

## Introduction

The glenohumeral joint (GHJ) and the scapulothoracic joint (STJ) have important roles in the function of the shoulder complex. It is important to assess not only the GHJ but also the STJ in rehabilitation in patients with shoulder disease. There are numerous studies assessing the STJ, especially regarding scapulohumeral rhythm [1-5] and scapular muscle activation [6-8] during shoulder elevation. Some studies have identified that scapular motion and muscle activation in patients with shoulder disease differs from that in healthy subjects [9]. In particular, the upper trapezius muscle is likely to have higher activation in contrast to the lower trapezius and serratus anterior, which have lower activation during shoulder elevation [10-12]. It is therefore important to attempt to exercise these scapular muscles. Effective exercises for scapular muscle strengthening have been studied [13-15], and examinations have been undertaken to determine which exercise conditions are more likely to result in higher muscle activation [16-18].

Not only scapular motion and muscle activation, but the onset of muscle activation is also changed by shoulder disease [19]. Delay of muscle activation may result in changes in scapulohumeral rhythm, narrowing the subacromial space, changing the length-tension relationship and impairing the optimal positioning of the glenoid beneath the humeral head [20]. This will reduce the stability of GHJ, which would lead to greater mechanical advantages of deltoid and the connection between the humeral head and acromion, increasing the risk of impingement [21,22]. Therefore, therapists have to assess the onset of muscle activation.

There were various studies about shoulder muscle activation, but a number of previous studies had been performed using shoulder elevation [23-25]. Due to the limited number of studies undertaken involving other shoulder movements [26], we do not have a cohesive understanding regarding the muscle activation and the order of muscle activation during other shoulder movements. There are various directions of shoulder movement during sports situation and activity of daily living (ADL). Therapists need to understand knowledge about other than elevation.

Furthermore, the consensus has not yet been formed as how change scapular stability is. In our studies about scapular muscle activation during isometric contraction of shoulder horizontal adduction and

abduction, internal and external rotation, the great difference of muscle activation was found among each scapular muscles [27,28]. Other studies also reported the difference of scapular muscle activation during shoulder motion and exercises [29-32]. It is thought that quite difference of scapular muscle activation may indicate the being of a different role in each scapular muscle. In the studies assessed to relationship about shoulder joint and trunk, these researches indicate muscle activity of the transversus abdominis occurs in advance of shoulder flexion [33,34]. The difference of the role between trunk muscles and shoulder muscles would have made another onset time. The knowledge about onset of muscle activation will be beneficial information to evaluate role of each muscle. However, due to having not enough knowledge, especially other than shoulder flexion, the change in patients with shoulder disease cannot be interpreted [35,36]. Therefore, we have to find knowledge of muscle onset during other than shoulder flexion in healthy people. The purpose of this study was to reveal the order of shoulder muscle activation during shoulder internal and external rotation in healthy subjects. The hypothesis was that the order of muscle activation is different between each scapular muscle.

## Materials and Methods

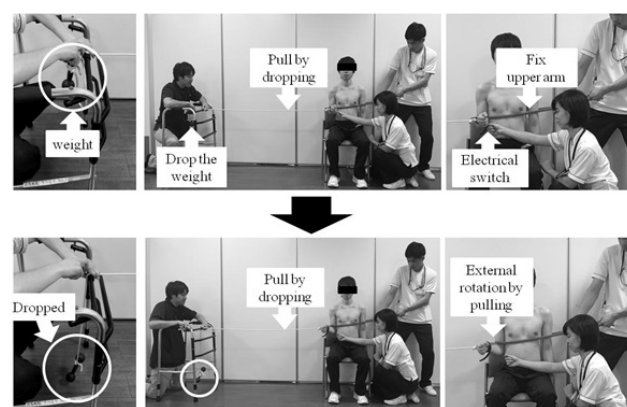
Eighteen healthy men participated in this study. Subjects were excluded from this study if they had experienced upper limb and neck disease, incurred pain during the study task or engaged in hard physical exercise within the previous week. The mean anthropometric characteristics  $\pm$  standard deviation (SD) were age:  $25.2 \pm 2.3$  years, height:  $170.2 \pm 6.0$  cm, and weight:  $63.7 \pm 7.5$  kg. The subjects were provided with consent forms to confirm their agreement to participate in the study. The study protocol was approved by the Ethics Committee (No. 2016003).

Muscle activation was assessed by electromyography during two tasks in shoulder internal and external rotation at 0 degree abduction. The tasks involved a "voluntary task," and an "unpredictable task." Throughout the voluntary task, subjects were measured with sitting as a starting position at 0 degree shoulder abduction, external rotation, and forearm pronation. From this starting position, they started the movement of internal or external rotation at their own timing. A handheld dynamometer was set at the distal part of the subjects' forearm and pushed (Figure 1).



**Figure 1:** Measurement of voluntary task. The subjects started the movement of internal or external rotation at their own timing. The power of the push was aimed at about 50% of maximum muscle strength with some practices being performed before the measurement. The electrical switch was set at the distal part of the forearm to measure the movement starting time.

The power of the resistance by handheld dynamometer was aimed at approximately 50% of maximum muscle strength with some practices being performed before the measurement. Additionally, the electrical switch was set at the distal part of the forearm to measure the movement starting time. Similarly, the unpredictable task involved a sitting position with a 0 degree shoulder abduction, external rotation, and forearm pronation. A cord with a 1.5 kg weight attached to the end was fixed to the distal part of the subjects' forearm. The cord was set on the level by running it on the same height adjusted device placed not in sight of subjects. The external load of the internal or external rotation was given to the subjects by dropping the weight using trochlear fundamental (Figure 2).



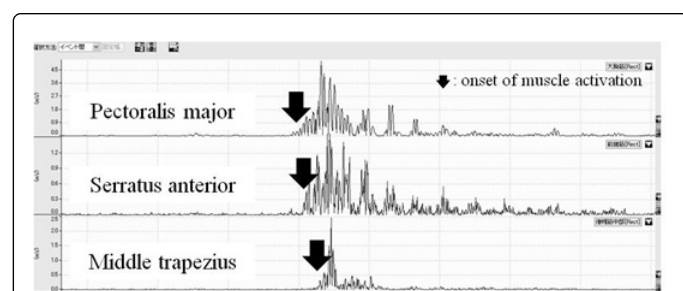
**Figure 2:** Measurement of unpredictable task (ex. internal rotation). A cord with a 1.5 kg weight attached to the end was fixed to the distal part of the subjects' forearm. The external load of the internal or external rotation was given to the subjects by dropping the weight using trochlear fundamental. Subjects were instructed that this cord pull your forearm suddenly but you must keep their starting position against this pulling cord.

The height of the drop was set at 70 cm. The height adjusted device was fixed by the researcher's foot throughout the task. At the beginning of the experiment, a researcher informed the subjects that "Pull your forearm by the cord suddenly but you must keep their starting position against this pulling cord." An electrical switch was set to the subjects' forearm by researcher's hand to measure movement onset. Subjects were instructed to stay relaxed until receiving the external load and to keep the starting position as far as possible after receiving the external load. During the internal rotation task, the distal part of the upper arm was fixed using a resistance tube to avoid shoulder abduction movement by the external load. If the subjects incurred pain during the task, the measurement was quickly suspended. The order of the tasks was random.

Surface electromyography (EMG; MQ-8, Kissei Comtec, Japan) was used to collect raw EMG data. The EMG was recorded at a sampling rate of 1,000 Hz with electrodes (LECTRODE, Admedec, Japan) at an interelectrode distance of 20 mm. Cross-talk was minimized by careful placement of suitably sized electrodes parallel to the muscle fibers, based on standard anatomical criteria. We measured the muscle activation of agonist at GHJ and main scapular stabilizer which had been occurred high activation during isometric contraction of shoulder internal and external rotation by a previous study [28]. The target muscles were the pectoralis major, infraspinatus, serratus

anterior, and middle trapezius on the dominant side. The EMG electrode position was set according to previous studies [37]. The anatomic placement of electrodes was following locations. Pectoralis major electrodes were placed the chest wall over the muscle mass (approximately 2 cm from the axillary fold), and infraspinatus electrodes were placed two fingerbreadths inferior to the center of the spina scapulae. Serratus anterior electrodes were placed 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 middle trapezius electrodes were placed horizontally at half the distance between the spine (approximately T3-5) and vertebral border of the scapula in line with the scapular spine. Raw EMG data was filtered with a digital band-pass filter between 5 and 500 Hz.

From the EMG data, the onset of muscle activation was calculated. Starting motion was judged by the electrical switch. The definition of onset of muscle activation was as follows: the average amplitude of baseline activation was calculated for 500 ms during the starting position. Subsequently, the average amplitude of baseline activity plus three standard deviations was used as a threshold of activity to determine the onset of muscle activation (Figure 3) [38,39].



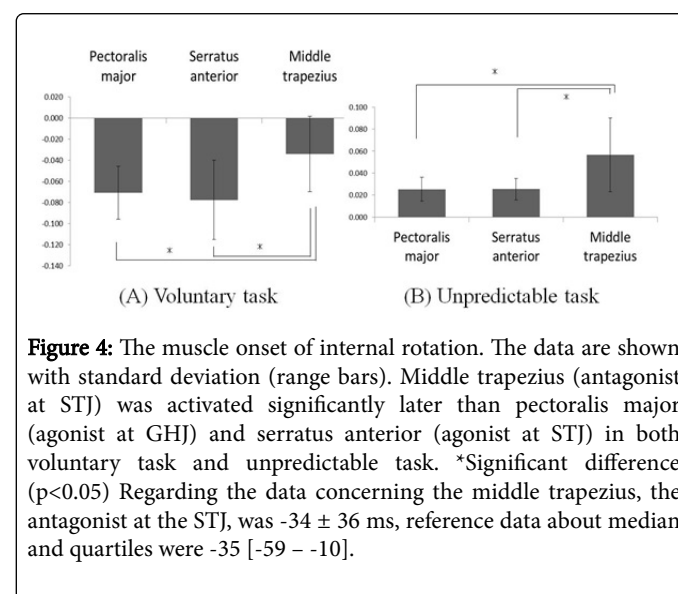
**Figure 3:** The analysis of muscle onset. Voluntary task of internal rotation is shown as example. Onset of muscle activation was indicated by black arrows. Average amplitude of baseline activation was calculated for 500 milliseconds (ms) during starting position. Afterwards average amplitude of baseline activity plus 3 standard deviations was used as a threshold of activity to determine the onset of muscle activation.

The measured muscle was classified as the agonist at the GHJ and the STJ, and the antagonist at the STJ, on each movement direction. It has been revealed that each classified muscle indicated a different activity pattern and the agonist corresponded with high muscle activation and the antagonist with low muscle activation [28,29,40]. The classification to agonist or antagonist muscle followed the rule of scapular movement during shoulder motion. In shoulder internal rotation, the agonist muscle of the GHJ was the pectoralis major. The agonist muscle of the STJ was set at the serratus anterior because scapular internal rotation and protraction is occurred with internal shoulder rotation; scapular internal rotation and protraction is given by activation of serratus anterior. The antagonist muscle of the STJ was defined as the middle trapezius muscle because it has the opposite function of the serratus anterior. The agonist muscle of the GHJ for the external rotation was set as the infraspinatus. The middle trapezius was defined as the agonist muscles of the STJ since scapular external rotation and retraction was achieved by shoulder external rotation. Serratus anterior was defined as the antagonist muscle of the STJ for the external rotation.

In each trial, the onset of muscle activation was compared between the agonist at the GHJ, the agonist at the STJ, and the antagonist at the STJ. One-way repeated measure analysis of the variance test was used to determine if there was a difference between the three muscles: the agonist at the GHJ, at the STJ, and the antagonist at the STJ. The Tukey-Kramer test was used for post-hoc comparison with  $p < 0.05$  being considered significant. Using this result, we examined the order of muscle activation.

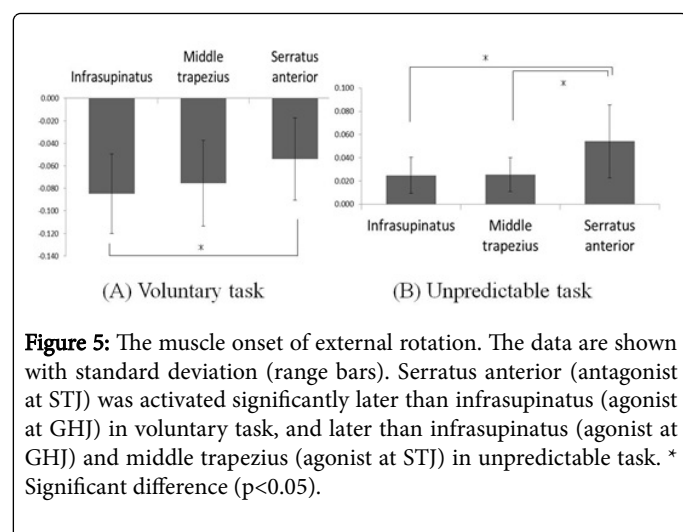
## Results

The results of internal rotation are shown in Figure 4. In the voluntary task of internal rotation, the onset of the pectoralis major, the agonist at the GHJ, was  $-71 \pm 25$  ms; the serratus anterior, the agonist at the STJ, was  $-78 \pm 38$  ms; the middle trapezius, the antagonist at the STJ, was  $-34 \pm 36$  ms. There was no significant difference between the pectoralis major and the serratus anterior. The onset of middle trapezius was significantly later than that of the pectoralis major and the serratus anterior ( $p < 0.05$ ). In the unpredictable task of internal rotation, the onset of the pectoralis major activation was at  $25 \pm 11$  ms, the serratus anterior was at  $25 \pm 10$  ms, and the middle trapezius was at  $57 \pm 34$  ms. There was no significant difference between the pectoralis major and the serratus anterior. The middle trapezius had a significant later onset than the pectoralis major and the serratus anterior muscle ( $p < 0.05$ ).



**Figure 4:** The muscle onset of internal rotation. The data are shown with standard deviation (range bars). Middle trapezius (antagonist at STJ) was activated significantly later than pectoralis major (agonist at GHJ) and serratus anterior (agonist at STJ) in both voluntary task and unpredictable task. \*Significant difference ( $p < 0.05$ ) Regarding the data concerning the middle trapezius, the antagonist at the STJ, was  $-34 \pm 36$  ms, reference data about median and quartiles were  $-35 [-59 - -10]$ .

The results of external rotation are shown in Figure 5. In the voluntary task of external rotation, the onset of infraspinatus activation, the agonist at the GHJ, was  $-85 \pm 36$  ms; at the middle trapezius, the agonist at the STJ, was  $-75 \pm 38$  ms, and at the serratus anterior, the antagonist at the STJ, was  $-54 \pm 36$  ms. The serratus anterior had a significant later onset than the infraspinatus ( $p < 0.05$ ). Under unpredictable tasks, the onset of the infraspinatus activation was  $25 \pm 15$  ms, the middle trapezius was  $26 \pm 15$  ms, and the serratus anterior was  $54 \pm 31$  ms. There was no difference between the infraspinatus and the middle trapezius muscles, but serratus anterior was recruited significantly later than the infraspinatus and the middle trapezius ( $p < 0.05$ ). Overall, the onset of the agonist activation at the GHJ and the agonist at the STJ was the same; however, the antagonist at the STJ was delayed to these two muscles.



## Discussion

It was revealed that there is the difference of muscle onset between the agonist at STJ and the antagonist at STJ. This study identified that the antagonist at STJ started activation after the agonist at the GHJ and the STJ. There are many studies on agonists and antagonists affecting other joints. It had been measured the onset of forearm muscles during movement of the wrist [41,42]. There are also some studies regarding antagonist muscles and the effect on knee and elbow joints [43-45]. From these studies, it was revealed that the antagonist had minimal muscle activation during isometric, isotonic, and isokinetic contraction, and that the function of the antagonist was to control the movement caused from the activation of the agonist and to aid stability by co-contraction with the agonist [46-49]. Additionally, there were some studies about agonist and antagonist at STJ. In the study on scapular muscle activation during isometric contraction of shoulder horizontal adduction and abduction, the agonist at STJ had high activation and the antagonist at STJ had minimal activation [27,31]. Compared to these studies, the results of this study have similar. The characteristic of scapular muscles resembles muscles on other joints, and therefore, the concept as agonist or antagonist might be able to be applied to scapular muscles. Therefore, each scapular muscle have to be assessed individually in clinical situation.

In this study, the experiment was performed under two tasks; voluntary task and unpredictable task. In the voluntary task, the subjects could move their arms at their own timing and onset of muscle activation is faster than the starting time of joint movement, indicating that the onset of muscle activation had a negative value. In the unpredictable task, the muscle activation trigger occurred when subjects were pulled their arms by the external load. The arms were firstly moved by the external load and then the muscle was recruited, consequently, the onset of muscle activation indicated a positive value. We had considered that the activation order of these two conditions might be different, but the results showed that the order of muscle activation was similar. This finding indicates that the activation pattern will not be changed by either the instruction for the subjects to start movement at their own timing and at the reaction of the external load in shoulder joint. And the scapular muscle activation does not commence before the onset at the GHJ muscle. This result indicates that order of exercise for GHJ and STJ was not need to be stucked.

Reaction time differences are influenced by the characteristics of test movement, arthrology, the distance that the neural signal must travel, and motor unit characteristics of the tested joint and muscle. In shoulder joint, muscle latent muscle reaction timing of scapular muscles and rotator cuff muscles was 40-70 ms in response to sudden movement [26,50]. The latency of wrist joint muscle was 20-25 ms [51]. About elbow joint muscle, sudden elbow joint perturbations produced latency of 25-60 ms for biceps brachii and brachialis [52]. Compared to these studies, onset values of the scapular muscles that we report are similar, however a little earlier. In this study, an electrical switch was set to the subject's forearm by researcher's hand to measure movement onset because an electrical switch didn't react in case of setting by mechanical device. This mechanical device couldn't give enough pressure to subject's forearm for making electrical switch react. This manual setting of an electrical switch by researchers might have influenced to whole reaction time value, however this didn't influence to the order of muscle activations.

There were some limitations in this study. First, the subjects were young healthy adults, and hence, the results may not apply to patients with shoulder disease. It had been reported that EMG showed delayed onset of the serratus anterior and earlier onset of the upper trapezius activity in patients with impingement [19,35], resulting in inconclusive data between subjects and patients. This result is useful to compare healthy people; however, we need to conduct a study to understand the characteristics of patients. Furthermore, these results might be changed by age. Teunis reported that overall prevalence of rotator cuff abnormalities increased with age [53], and rotator cuff tear may change muscle activation order. In retrospect, a larger sample size needed to be studied as it would provide more reliable data. Finally, the force of the external load set involved only one pattern in this study; consequently, it would be necessary to confirm the results by incorporating a heavy or light force external load. In daily living activity and sports activities, various levels of muscle activation are observed, and therefore, an examination with several load variations will be useful.

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