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Electromyograph Analysis during Isokinetic Testing of Shoulder Joint in Elderly People*

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Abstract

This study aimed to analyze the muscular activity associated with the proper function, stability, and mobility of the shoulder joint. In the field of orthopedics, the shoulder joint is recognized as having extensive mobility. Using an electromyograph (sEMG), the muscular activity in 10 elderly male subjects was analyzed during joint movements while performing isokinetic exercises. The muscular activity of an agonist was analyzed using both the percent maximum voluntary contraction (%MVC) and the EMG (μV) value before normalization. The %MVC quantified four motions (flexion, extension, abduction, and adduction) for the 10 upper limb muscles whereas the latter did not. The results showed that the pectoralis major (clavicular insertion) activated as an agonist during abduction and adduction. A comparison of when the muscles activated based on each motion revealed that the middle deltoid muscle activated the fastest during abduction. This research is expected to facilitate measurement of the shoulder function for both rehabilitation equipment and their associated programs.

Key words: Shoulder Joint, Surface Electromyograph (sEMG), Isokinetic Test, Muscle Activity, Upper Limb

1. Introduction

In the field of orthopedics, the shoulder joint is recognized as having extensive mobility. Studies have shown that the stability of this joint is maintained by the surrounding muscles and soft connective tissues(1). Furthermore, the cooperation between the agonist and the antagonist muscles of the shoulder joint has been found to play an important during exercise(2). To prevent injury to the shoulder joint and for its rehabilitation, an objective measurement related to the functional activity of the shoulder muscles is required. Toward this end, previous studies used an electromyograph (EMG) to measure the electrical signals generated in the muscles during contraction as an objective way of measuring the muscle activity related to body movements. A surface electromyograph (sEMG) has also been used widely to analyze body movements owing to its availability and simplicity. Most previous studies have focused on younger people in their 20s; however, few studies have focused on other age groups, especially elderly people. Considering the aging of the global population, more studies focusing on elderly people are required in order to analyze the shoulder joint agonist muscle and the muscle activity. This study examined the muscle activity in elderly subjects under four motions (flexion, extension, abduction, and adduction) during isokinetic exercise(3)~(8). The aim of this study is to obtain basic information that could be useful in the

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future for the development of rehabilitation programs and upper-limb rehabilitation equipment.

2. Methods

2.1 Subjects

Ten elderly male subjects with standard body[9] in their mid-50s and late 60s participated in the study. The study was conducted after explaining the entire experiment to them. The subjects had no history of shoulder joint or upper limb surgeries, and they did not have any injuries or pain on both sides of the shoulder joint. Professional athletes were excluded from the study. The subjects' age was 60.7 (±5.1) years; height, 168.4 (±6.0) cm; weight, 70.2 (±10.5) kg; body mass index (BMI), 23.3 (±1.9) kg/m^2; body fat percentage, 23.8% (±3.9); dominant side weight, 2.9 (±0.5) kg; and non-dominant side weight, 2.8 (±0.4) kg (the segment weight was measured by Direct Segmental Multi-frequency - Bioelectrical Impedance Analysis (Inbody, Biospace Inc., Korea)) (Table 1).

Table 1 Parameters of Subjects (mean ± SD)

Subject		Age (years)	Height (cm)	Weight (kg)	Body mass index (BMI)	Body fat percentage (%)	Dominant side weight (kg)	Non-dominant side weight (kg)
Elderly	n = 10	60.7 (±5.1)	168.4 (±6.0)	70.2 (±10.5)	23.3 (±1.9)	23.8 (±3.9)	2.9 (±0.5)	2.8 (±0.4)

2.2 Measurements and data acquisition

First, information about individual subjects was measured, following which a specific measurement sequence was followed. The subjects were instructed to participate in an upper limb stretching program for 10 min to prevent possible injuries from occurring during the measurements[10]. A researcher instructed the subjects on the correct posture, direction, and experimental methods. The subjects underwent a pretest three times on both sides of the shoulder while performing the four motions. The same researcher carried out all measurements. The Multi-Joint System 4 Pro (Biodex Medical Systems Corp., N.Y., USA; Fig. 1(A)), which can be used to measure the muscular strength isokinetically, was synchronized with a Myosystem 2400A (16 channels, Noraxon Inc., USA; Fig. 1(B)) EMG. An sEMG is widely used in many studies because it is completely noninvasive. The system used in the present study allowed 10 shoulder-related muscles to be measured using 10 channels (Table 2)[11]. Preamplified EMG lead (gain: 500, passband: 10–1000 Hz, Noraxon Inc., USA) wires were used as round disposable electrodes. To decrease the electric impedance of the skin, the area where the electrode was to be attached was first cleaned with alcohol. Elastic bandages were used for supporting the electrodes, and the experiment was only performed when the impedance values were under 50 mA. In the experiment, flexion-extension and abduction-adduction movements were carried out for both the dominant and the non-dominant sides. A concentric EMG was measured by maintaining an angular velocity of 120°/s. The muscular strength can refer to either the isometric or the dynamic strength; the latter can be further subdivided into concentric or eccentric movements, which respectively generate power by shortening and lengthening the muscle. The participants were seated on measurement chairs with the unmeasured upper limb and pelvis fixed. The experiment was conducted three consecutive times within the range of motion of the subject. To minimize muscular fatigue during the measurement, the subjects took 90-s breaks between the measurements and 5-min breaks between the motions[12]. They were required to use their full strength during the muscular strength tests.

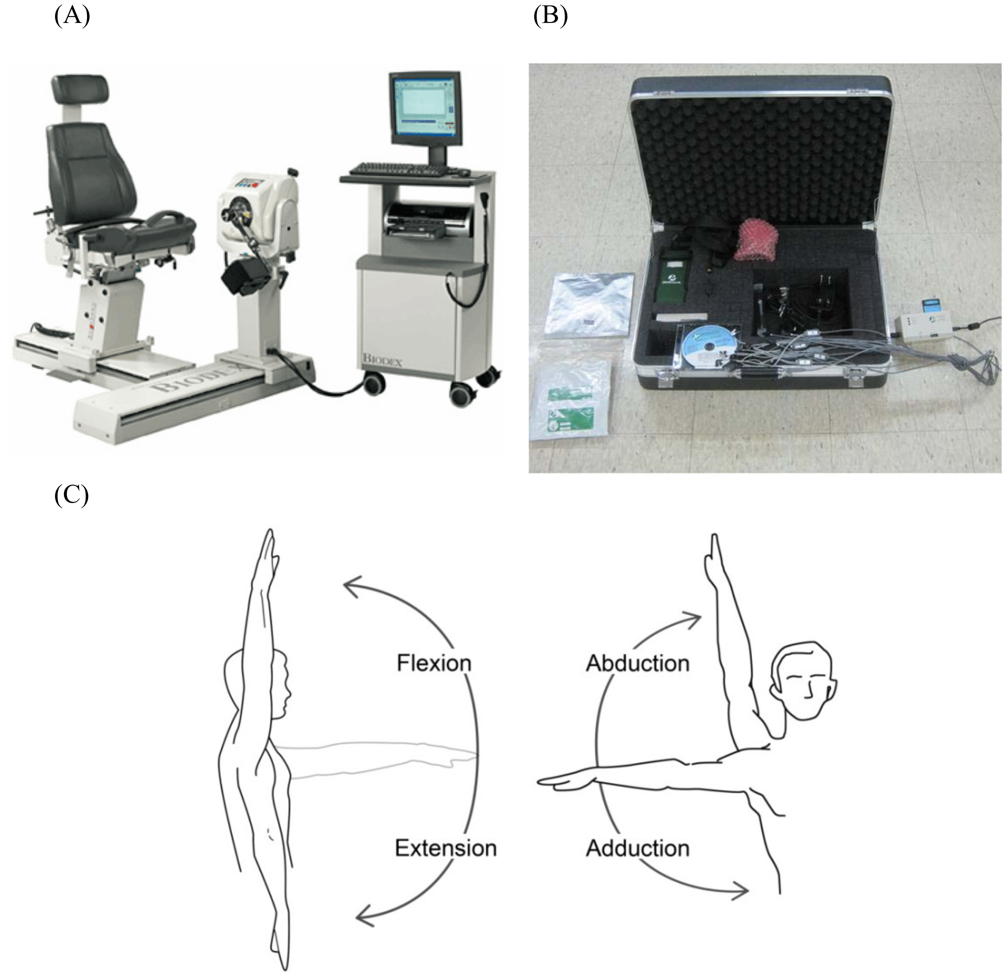
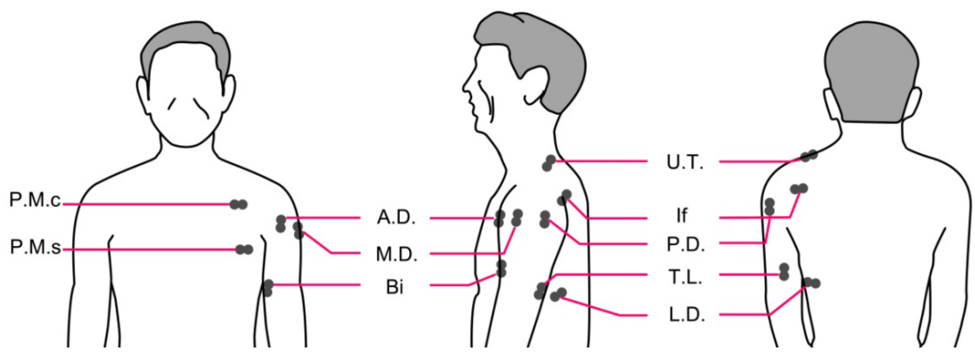


Fig. 1 Equipment for measurements. (A): Myosystem 2400A (16 channels, Noraxon Inc., USA), (B): Multi-Joint System 4 Pro (Biodex Medical Systems Corp., USA), (C): Experiment composition (flexion-extension, abduction-adduction).

Table 2 Position of Muscles and sEMG Electrodes[13]



Muscle	EMG Position
Upper trapezius (U.T.)	Parallel to muscle fiber, halfway between seventh cervical vertebra and acromion
Anterior deltoid (A.D.)	4 cm below the clavicle parallel to muscle fiber on the anterior aspect of the arm
Middle deltoid (M.D.)	On the lateral aspect of the arm, 3 cm below the acromion

Posterior deltoid (P.D.)	2 cm below the scapula spine
Biceps (Bi)	Center of the muscle belly
Triceps long (T.L.)	2 cm medial to arm midline
Pectoralis major, clavicular insertion (P.M.c)	2 cm below the clavicle, medial to axillary fold and at an oblique angle towards the clavicle
Pectoralis major, sternal insertion (P.M.s)	Approximately 2 cm medial from axillary fold, horizontal
Infraspinatus (If)	Parallel to scapular spine, approximately 4 cm below and on the lateral aspect
Latissimus dorsi (L.D.)	4 cm below inferior scapular tip, halfway between spine and later torso edge

The EMG data were normalized as the percent maximum voluntary contraction (%MVC). Thus, before the experiment, the MVCs of the 10 types of muscles were measured. Specific positions for measuring the MVC of the forearm/shoulder muscles (Table 3) were used for choosing a posture and method for measuring MVC[12]. The measurement sequence was as follows: 1) biceps, 2) triceps long, 3) latissimus dorsi, 4) infraspinatus, 5) deltoid (anterior, middle, posterior), 7) upper trapezius, and 8) pectoralis major (clavicular insertion). Three consecutive sets of measurements were performed.

To minimize the influence of muscular fatigue, subjects took 30-min breaks between MVC measurements to allow them to regain their strength before the test.

Table 3 Proposals for Upper Body MVC Test Arrangement[13]~[15]

Muscle	Posture	Method for measuring MVC
Biceps		A valid biceps b. MVC needs a very stable elbow and trunk fixation. This can best be arranged in a seated or kneeling position (in front of a bench). Consider using the latissimus d. MVC test as a control exercise.
Triceps long		Same instructions as for biceps b. Consider using the pectoralis major MVC test as a control exercise.
Latissimus dorsi		The simulation of a pull-up addresses the highest latissimus innervation. Consider/check a frontal and a lateral arm position at 90° elbow flexion. You can also find MVCs for the biceps and the lower trapezius.
Infraspinatus		Being the most important outward rotator of the shoulder cuff, any related outward rotation may work. Good results are achieved with uni- or bilateral manual resistance against the forearm.
Anterior deltoid		Select a seated position, with a fixated back if possible. Fixate the arms near the 90° position. The bilateral contractions guarantee a balanced force distribution for the trunk. The abduction works best
Middle deltoid		

Posterior deltoid		for the pars acromialis of the deltoid muscle. Consider a flexion/extension position for the pars clavicularis.
Upper trapezius		The MVC test can be performed with one side only. A static resistance can be obtained by manually fixating the arm or by arranging for a sufficiently heavy load to press the shoulder down (difficult).
Pectoralis major, clavicular insertion		Numerous test positions can be used. However, all of them require a very good shoulder/back resistance. The prone lying position would best be performed with a (fixated) long bar. The push up may work as an easy-to-arrange alternative. Both positions should be performed with 90° elbow position.
Pectoralis major, sternal insertion		

2.3 Data analysis

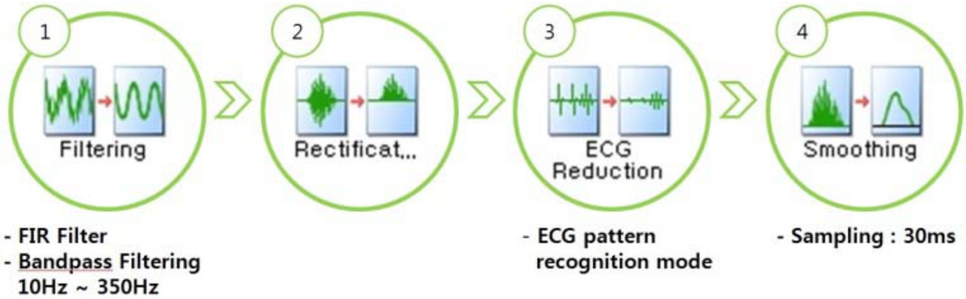


Fig. 2 Post-processing of raw EMG data (Normalization process was omitted in Fig. 2).

EMG data were analyzed using MyoResearch XP Master 1.06 (Noraxon Inc., USA). The post-processing of EMG data was carried out as follows: (1) A bandpass (10–350 Hz) FIR filter was used for filtering. (2) Full-wave rectification was performed to obtain the average, maximum, and width values of the amplitude. A rectifier is an electrical device that performs rectification by converting a negative amplitude to a positive one (the raw EMG before rectification is not so readily interpretable that its average value is zero). (3) EMG artifacts are usually present in the EMG of the upper limb muscle. One of them, the ECG artifact, was eliminated using an ECG pattern-recognition mode (recording EMG for 5 s). (4) Data was smoothed at a 30-ms sampling rate, and the root mean square value was obtained. Finally, the %MVC values were used to derive the normalized ones, and the MVC was calculated at the 300-ms peak value.

When measuring an EMG, the onset time obtained by timing analysis at a point where the SD value became three times (two times SD, 0.3 s) that at 0–1 s was used to determine the activation point of the 10 muscles.

3. Results and Discussion

3.1 Results of agonist analysis

An agonist was determined from the EMG (μV) value before the normalization process for two main reasons. First, agonist analysis is not a process for comparing the subjects' results necessary for normalization, due to different muscles and muscular power. The analysis compared the subjects' muscular activity for a pair of two motions (flexion-extension or abduction-adduction). Second, the %MVC values tended to show higher values even though the absolute muscle activity (μV) was small owing to relatively small muscles with low MVC values. Therefore, this study was conducted based on EMG (μV) data by using a normalization process. Flexion-extension and abduction-adduction showed identical motions with two pairs of four motions in different directions. Thus, an agonist was recognized easily by showing a pair of two motions in one graph (Fig. 3).

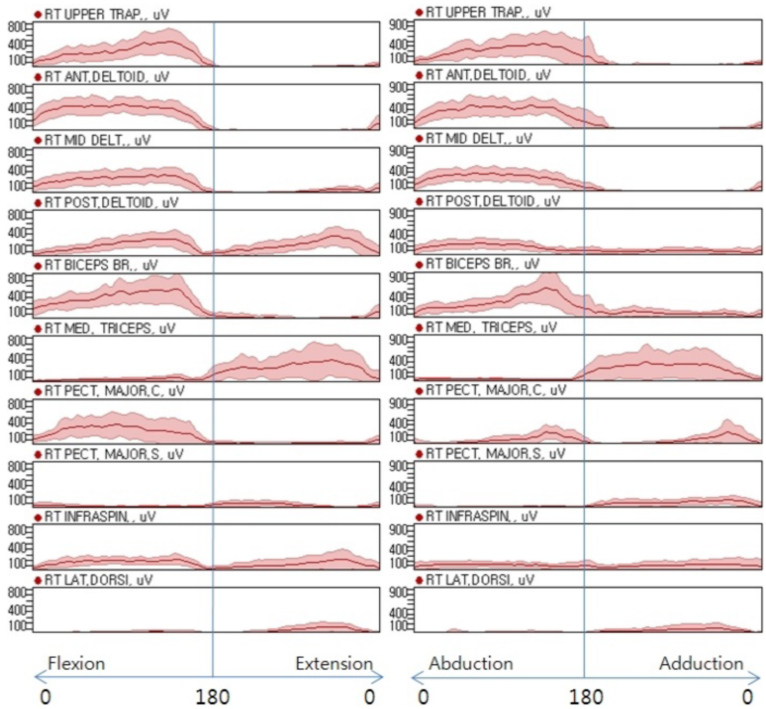


Fig. 3 Results of muscle activation (unit: μV) (concentric, dominant, 120°/s, flexion-extension, abduction-adduction).

The results were as follows. During flexion, the major agonists were the upper trapezius, anterior deltoid, middle deltoid, biceps, and pectoralis major (clavicular insertion). During extension, the major agonists were the posterior deltoid and triceps long, and the assistant agonists were the infraspinatus and latissimus dorsi. During abduction, the results of the agonist analysis appeared similar to those seen during flexion; the major agonists were the upper trapezius, anterior deltoid, and middle deltoid, and the biceps and pectoralis major (clavicular insertion) were used at a certain angle. During adduction, the major agonists were the triceps long, pectoralis major (sternal insertion), and latissimus dorsi, and the assistant agonist was the pectoralis major (clavicular insertion). Notably, through agonist analysis, it was found that the abduction-adduction motion used the pectoralis major (clavicular insertion) as an agonist at a certain angle (Fig. 3).

3.2 Results of agonist normalization

Agonist analysis was useful in analyzing the %MVC values for each motion. During flexion, %MVC resulted in the following order: 1) anterior deltoid, 2) upper trapezius, 3) middle deltoid, 4) pectoralis major (clavicular insertion), and 5) biceps. During extension, %MVC resulted in the following order: 1) triceps long, 2) latissimus dorsi, 3) infraspinatus, and 4) posterior deltoid. During abduction, %MVC resulted in the following order: 1) anterior deltoid, 2) upper trapezius, 3) middle deltoid, 4) biceps, and 5) pectoralis major (clavicular insertion). During adduction, %MVC resulted in the following order: 1) pectoralis major (sternal insertion), 2) triceps long, 3) latissimus dorsi, and 4) pectoralis major (clavicular insertion)

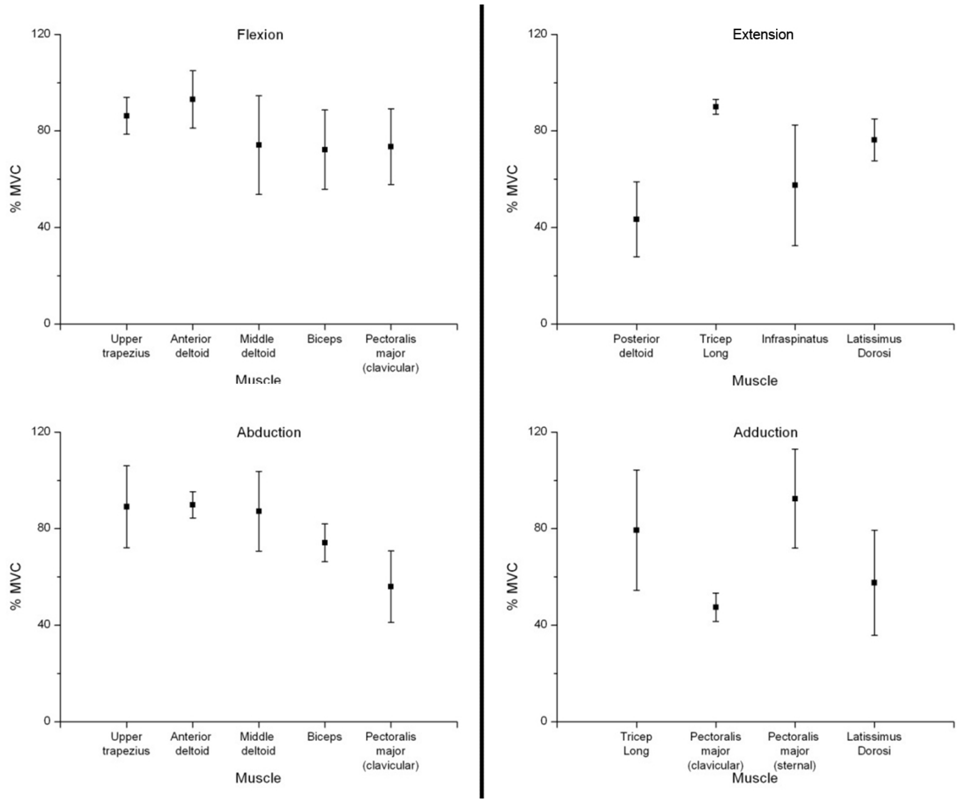


Fig. 4 Muscle activity (%MVC) of agonists in flexion-extension and abduction-adduction (concentric, dominant, 120°/s).

3.3 Results of timing analysis

According to the timing analysis results, both the flexion-extension and the abduction-adduction motions occurred sequentially. Thus, the firing order was analyzed based on the average of the onset time from the subjects during flexion and abduction.

During flexion, the firing order and onset time were found to be as follows: 1) upper trapezius (–0.072, ±0.024), 2) infraspinatus (–0.064, ±0.038), 3) pectoralis major, clavicular insertion (–0.061, ±0.056), 4) middle deltoid (–0.061, ±0.018), 5) anterior deltoid (–0.035, ±0.020), 6) latissimus dorsi (–0.034, ±0.075), 7) posterior deltoid (–0.01, ±0.169), 8) triceps long (0.005, ±0.106), 9) pectoralis major, sternal insertion (0.088, ±0.244), and 10) biceps (0.459, ±0.938).

During abduction, the firing order and onset time were found to be as follows: 1) middle deltoid (–0.079, ±0.033), 2) posterior deltoid (–0.058, ±0.022), 3) anterior deltoid (–0.057, ±0.020), 4) latissimus dorsi (–0.042, ±0.091), 5) triceps long (–0.038, ±0.052), 6) infraspinatus (–0.035, ±0.063), 7) biceps (–0.034, ±0.051), 8) pectoralis major, clavicular insertion (–0.025, ±0.082), 9) upper trapezius (0.007, ±0.169), and 10) pectoralis major, sternal insertion (0.192, ±0.293). According to the firing order, the selected agonists tended to activate faster than the other muscles (Fig. 5).

According to an angular analysis based on when an agonist reached peak torque, during flexion, muscles except for the upper trapezius, biceps, and infraspinatus showed a similar tendency. Extension showed a tendency in the following order: triceps long, latissimus dorsi, and pectoralis. During abduction, only the posterior deltoid showed a tendency.

Adduction showed a tendency in the following order: pectoralis major, sternal insertion, latissimus dorsi, and triceps long (Fig. 5).

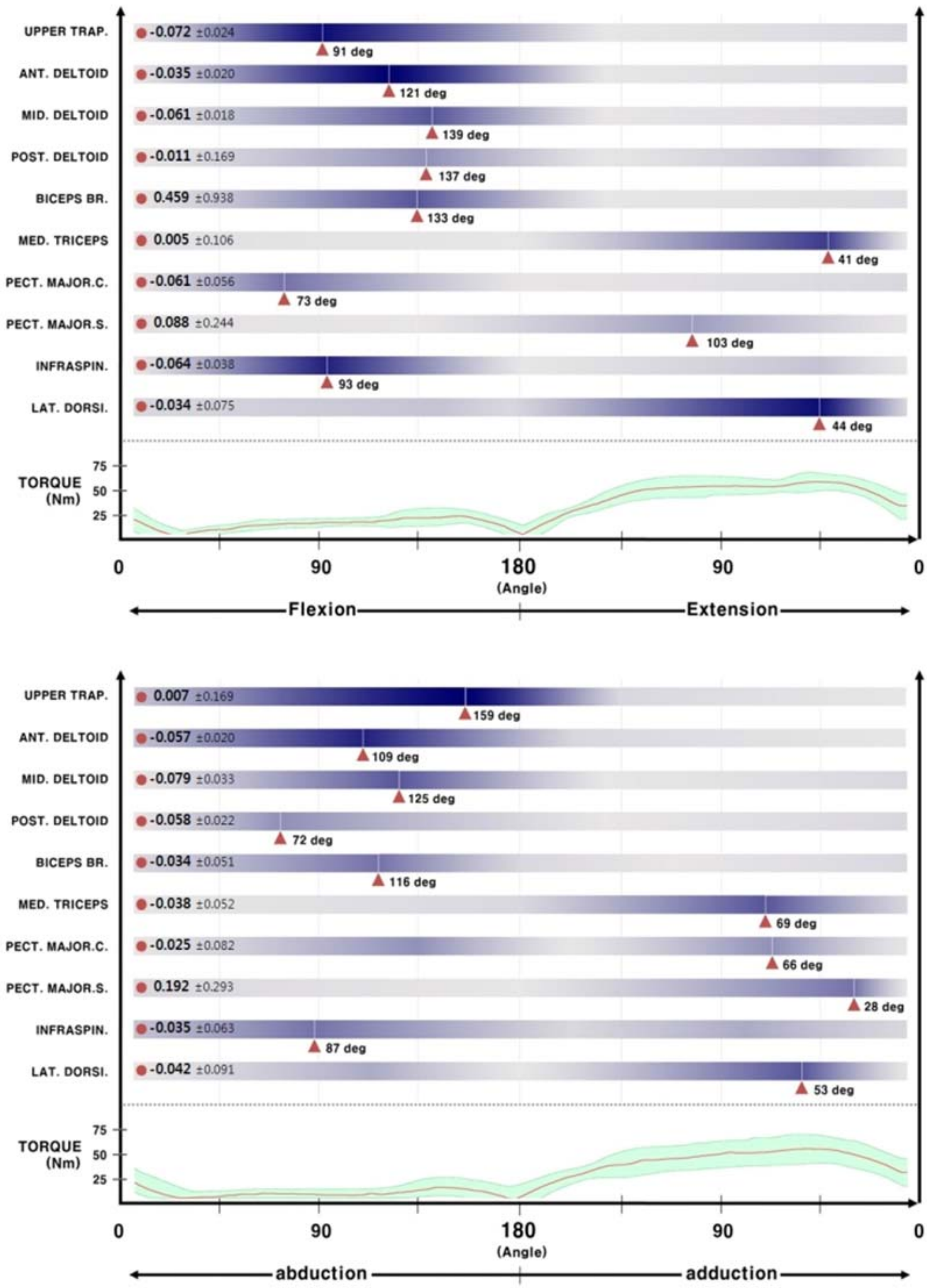


Fig. 5 Results of timing analysis for flexion-extension and abduction-adduction (concentric, dominant, 120°/s).

4. Conclusion

Agonists were defined based on higher muscle activity (µV) results during flexion-extension and abduction-adduction motions. Agonist normalization was subsequently used to analyze %MVC values based on the agonist analysis results. During flexion, the major agonists were the upper trapezius, anterior deltoid, middle deltoid, biceps, and pectoralis major (clavicular insertion). During extension, the major agonists were the posterior deltoid and triceps long. During abduction, the agonists were similar to those seen during flexion, and the biceps and pectoralis major (clavicular insertion) were widely used at a certain angle. During adduction, the major agonists were the triceps long, pectoralis major (sternal insertion), and latissimus dorsi. Notably, it was found that the abduction-adduction motion used the pectoralis major (clavicular insertion) as an agonist at a certain angle. The onset time (second) analysis showed that abduction has the fastest onset time. This study analyzed sEMG signals in elderly subjects during isokinetic movements of the shoulder joint. The results are expected to be used as an available database for diagnosing and measuring the muscle status and exercise condition.

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