

A Study on Human Upper-Limb Muscles Activities during Daily Upper-Limb Motions

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Abstract. Human upper-limb is involved in many daily human activities. The human intention for upper-limb motions can be estimated based on the activation pattern of upper-limb muscles. The upper-limb muscle activities during basic upper-limb motions and the daily upper-limb motions have been studied to enable power-assist robotic exoskeleton systems to estimate human upper-limb motions based on the electromyographic (EMG) signals of related muscles. The relationship between the upper-limb motions and the activity levels of main related muscles concerning the daily upper-limb motions are analyzed in this study. The muscle combinations are identified to separate some basic motions of upper-limb. The EMG signals of identified muscles will be used as input information to design a controller of the upper-limb power-assist robotic exoskeleton systems.

Keywords: Upper-Limb; Motion Estimation; EMG.

1. Introduction

The upper-limb motions are very important for the human daily activities, such as eating, drinking, brushing teeth, combing hair and washing face. It is sometimes difficult for physically weak elderly, disabled, and injured individuals to perform daily upper-limb activities. However, it is important that physically weak individuals are able to take care of themselves in the present society in which the number of physically weak population is increasing and the number of young population is decreasing. Recently, many power-assist robotic systems have been developed to assist daily life motions and/or rehabilitation of physically weak persons [Gopura and Kiguchi, 2008], [Gupta *et al.*, 2006], [Kawamoto and Sankai, 2005], [Kiguchi, 2007], [Perry and Rosen, 2007], [Sasaki *et al.*, 2004]. Some of these power-assist robotic systems are controlled based on electromyography (EMG) signals of the muscles of users since they directly reflect the activity levels of the muscles. The EMG signals provide important information for power-assist robotic systems to understand the motion intention of the user. Therefore, it is important to analyze the relationships between the upper-limb motions and related muscle activities to perform the power-assist of the upper-limb motion. In [Gil Coury *et al.*, 1998], an electromyographic study has been carried out for upper limb adduction force with varying shoulder and elbow postures. Kronberg *et al* [Kronberg *et al.*, 1990] have studied about the muscle activity and coordination in the normal shoulder. In [Micera *et al.*, 2000] small-sized training set of EMG signals data have been used to identify upper-limb movements. In this study, experiments were performed to figure out muscle combinations to identify each basic upper-limb motion. In the experiments, basic motions of upper-limb and six selected daily motions were performed. The selected daily activities are (1) eating by a hand, (2) pouring from a bottle, (3) drinking with a cup, (4) combing hair, (5) picking up a phone on a table and (6) opening a door. The selection was carried out based on the frequencies in the daily activities of majority of individuals to cover all the motions of upper-limb. The angle of each joint was measured by the motion capture system [Vicon MX+, VICON] and the EMG signals of the related muscles were also measured to figure out the relationship between them. In the analysis, muscles were identified to estimate motions of the upper-limb. The analyzed results will be used to design controllers of the upper-limb power-assist robotic systems.

Table 1. Activated muscles for motions

<i>Motion</i>	<i>Activated Muscles</i>
Shoulder vertical flexion (SVF)	Coracobrachialis, Deltoid (anterior), Pectoralis major
Shoulder vertical extension (SVE)	Deltoid (posterior), Teres major, Latissimus dorsi
Shoulder horizontal flexion (SHF)	Pectoralis major (calvicular part)
Shoulder horizontal extension (SHE)	Deltoid (posterior)
Shoulder adduction (SAD)	Coracobrachialis, Latissimus dorsi, Teres major, Pectoralis major
Shoulder abduction (SAB)	Deltoid, Supraspinatus
Shoulder internal rotation (SIR)	Deltoid (anterior), Subscapularis, Latissimus dorsi, Teres major
Shoulder external rotation (SER)	Deltoid (posterior), Infraspinatus, Teres minor
Elbow flexion (EF)	Biceps brachii, Brachioradialis, Brachialis
Elbow extension (EE)	Anconeus, Triceps brachii
Forearm supination (FS)	Supinator, Biceps brachii (long head)
Forearm pronation (FP)	Pronator quadratus, Pronator teres
Wrist flexion (WF)	Flexor carpi radialis, Flexor carpi ulnaris, Palmaris longus
Wrist extension (WE)	Extensor carpi radialis longus, Extensor carpi radialis brevis, Extensor carpi ulnaris
Wrist ulnar deviation (WUD)	Flexor carpi ulnaris, Extensor carpi ulnaris
Wrist radial deviation (WRD)	Extensor carpi radialis longus, Extensor carpi radialis brevis, Flexor carpi radialis

2. Upper-Limb Motions

Human upper-limb consists of several degrees of freedoms (DOF); basically 3DOF in the shoulder joint, 2DOF in the elbow joint and 2DOF in the wrist joint. The basic motions of upper-limb can be categorized into eight individual motions [Rosen *et al.*, 2005]; shoulder vertical flexion/extension, shoulder horizontal flexion/extension, shoulder adduction/abduction, shoulder internal/external rotation, elbow flexion/extension, forearm supination/pronation, wrist flexion/extension, and wrist ulnar/radial deviation. The daily upper-limb motions are the combination of these basic motions. Although fingers also have several DOF, their motions are not considered in this study.

Human upper limb is activated by many kinds of muscles. Some of them are bi-articular muscles and the others are uni-articular. In the upper-limb agonist-antagonist muscles activate shoulder, elbow and wrist. The upper-limb motions and the related muscles for the motions [Martini *et al.*, 1997] are shown in Table 1.

3. Method

In order to obtain the relationships between the human upper-limb motions and activities of related muscles, the experiments were performed with 26 and 28 years old healthy male subjects (A and B, respectively). In the experiment, the basic motions and the selected daily activities of upper-limb were performed three times by each subject. Figure 1 shows the initial position and motion range of each basic motion in the experiments. The daily activities were performed in either standing or sitting posture in accordance with the nature of the daily activity. Except ‘opening a door’ activity, the others were performed in sitting posture. Initial posture of the upper-limb also depends on the nature of the daily activity. Initial and final postures of the daily activities are shown in Fig. 2. The angles of each joint of the upper-limb of the human subject during the daily activities were measured by the motion capture system [Vicon MX+, VICON]. Reflective markers were attached to subjects at key anatomical locations as shown in Fig. 3. Considering the muscle characteristics, sixteen muscles [ch.1: Deltoid (anterior), ch.2: Deltoid (posterior), ch.3: Pectoralis major (calvicular part), ch.4: Teres major ch.5: Pectoralis major, ch.6: Infraspinatus, ch.7: Biceps brachii, ch.8: Triceps brachii, ch.9: Brachialis, ch.10: Supinator, ch.11: Pronator teres, ch.12: Pronator quadratus, ch.13: Extensor carpi radialis brevis, ch.14: Extensor carpi ulnaris, ch.15: Flexor carpi radialis and ch.16: Flexor carpi ulnaris] were selected for the analysis in this study. EMG signals of selected muscles were measured for the selected daily activities. The locations of EMG electrode are shown in Fig. 4. The ch. 17 is grounded and attached to skin of the

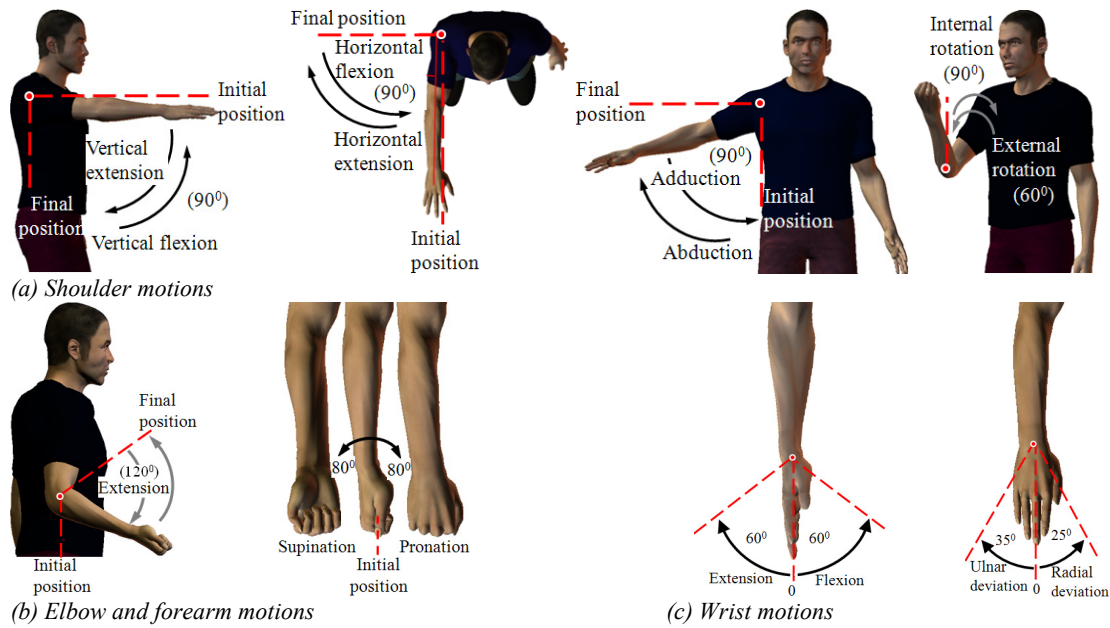


Figure 1. Initial positions and motion ranges of basic motions in the experiments

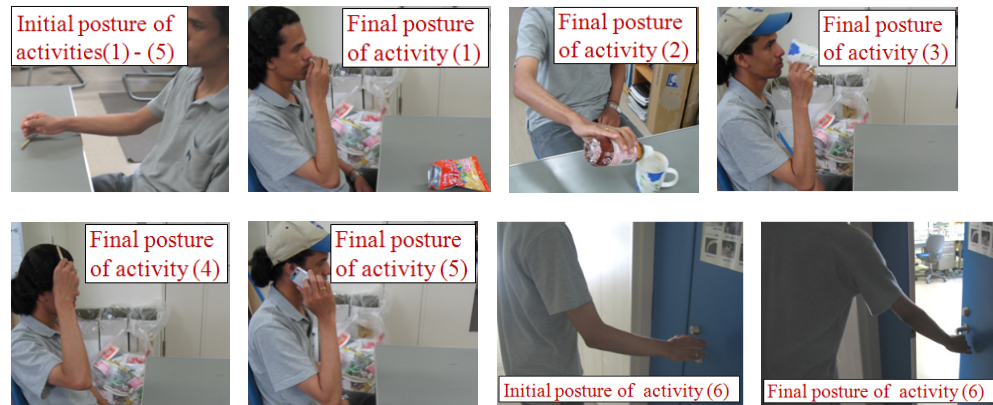


Figure 2. Initial and final postures of selected daily activities

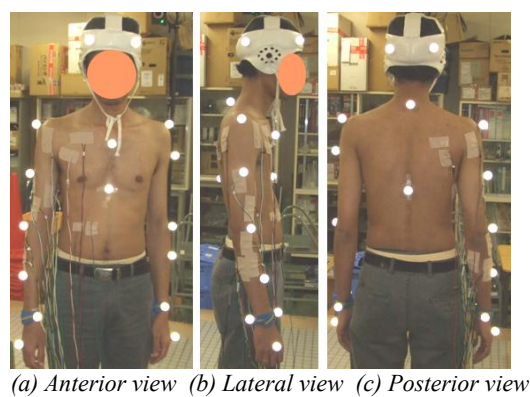


Figure 3. Locations of markers

abdomen which does not have muscles, so that electrically unrelated to the monitored muscles. Muscle of coracobrachialis is neglected since it is small muscle and difficult to attach EMG electrode on the surface of it. Supraspinatus is not taken for analysis since it assists only starting of shoulder abduction. Muscles of subscapularis, teres minor, and anconeus are neglected in this analysis since they are overlapped with other muscles. Since muscle of the palmaris longus is a weak flexor, it is not taken into

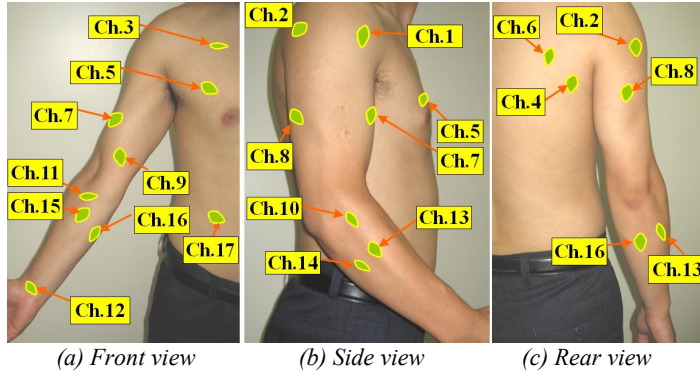


Figure 4. Locations of EMG electrodes

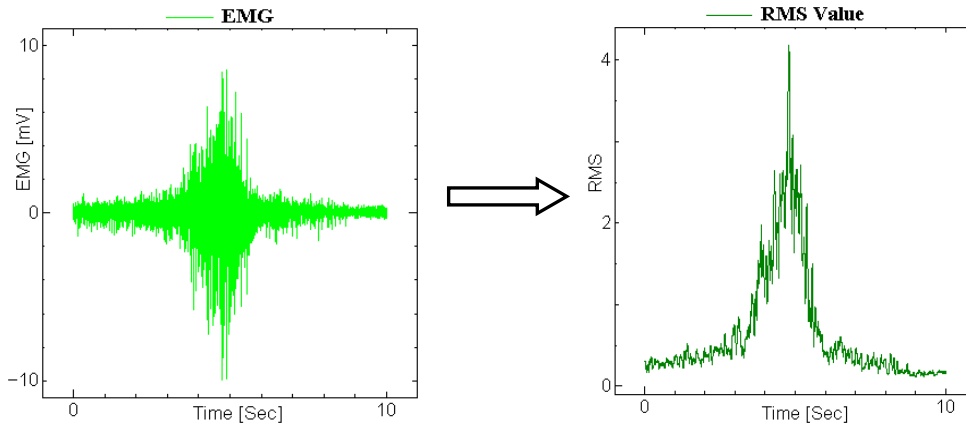


Figure 5. An example of an EMG signal and its RMS value

account. Only extensor carpi radialis brevis is taken for analysis from extensor muscle group. Muscle of brachialis is selected from the muscles of brachialis and brachioradialis since both seem to act for the elbow flexion motion. In order to analyze the EMG signals, features have been extracted from the raw EMG data. Root mean square (RMS) has been applied as a feature extraction method of the EMG signals in this study. An example of an EMG signal and its RMS value is shown in Fig. 5. The equation of RMS is written as:

$$RMS = \sqrt{\frac{1}{N} \sum_{i=1}^N v_i^2} \quad (1)$$

where v_i is the voltage value at i th sampling and N is the number of the samples in a segment. N is set to be 100 and the sampling frequency is set to be 2 kHz in this study.

4. Results

The experimental result of the full range ulnar deviation for different forearm postures is shown in Fig. 6. Figure 7 shows the relationship of activity level of extensor carpi radialis brevis for wrist extension and radial deviation motions. Here the radial deviation was generated from fully ulnar deviated position to fully radial deviated position. Figure 8 shows the relationship between EMG RMS values of muscles and basic wrist motions in natural forearm posture [forearm posture indicated as 'initial posture' in Fig. 1(b)]. Relationship between EMG RMS values of activated muscles and forearm motions is shown in Fig. 9 (here, elbow was maintained about 90 degrees). Figure 10 depicts the relationship of EMG RMS values of activated muscles and elbow and shoulder motions. When performing the basic elbow motions shown in Fig. 10, the shoulder angles was maintained about 0 degrees. Relationships of activity levels of muscles and motion angles of the shoulder vertical flexion and the shoulder adduction for drinking with a cup activity are shown in Fig. 11.

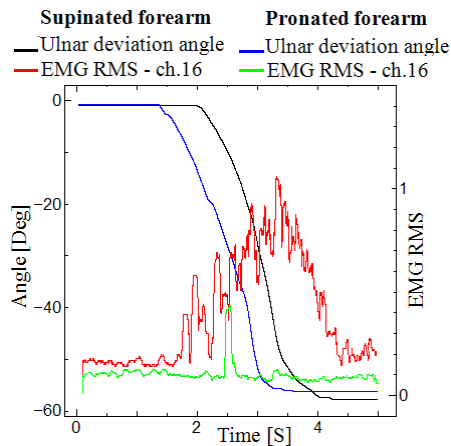


Figure 6. EMG RMS for Ulnar deviation

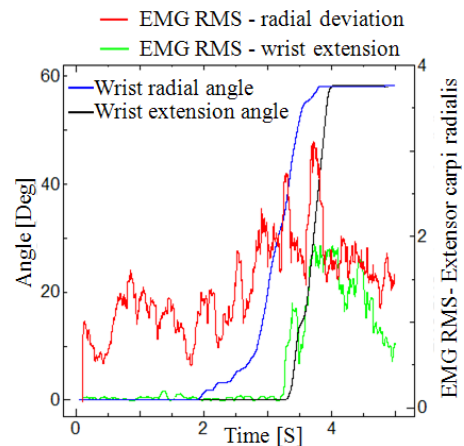


Figure 7. EMG RMS- extensor carpi radialis

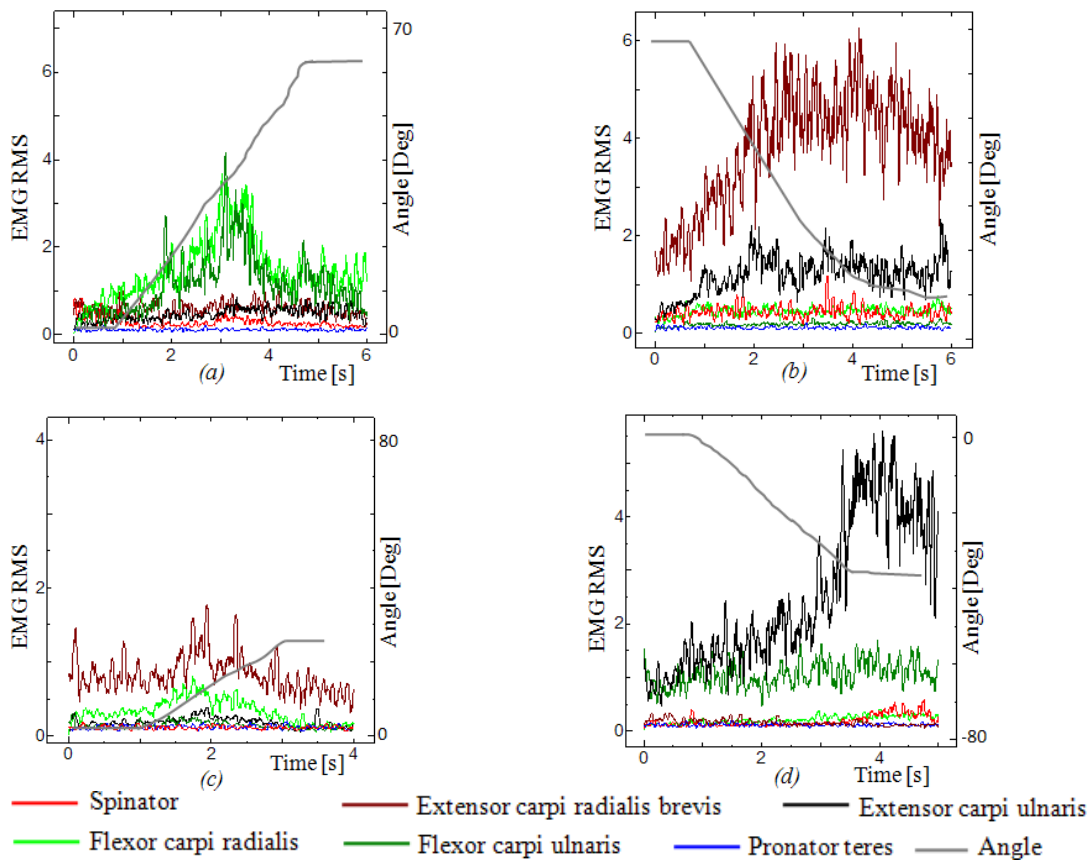


Figure 8. Relationship of EMG RMS and basic wrist motions. (a) Wrist flexion. (b) Wrist extension. (c) Radial deviation. (d) Ulnar deviation.

5. Discussion

It can be identified that the EMG activity levels related to the basic motions (explained in section 2) depend on the joint angles and the upper-limb posture [Gil Coury *et al.*, 1998]. As an example, Fig. 6 shows that the EMG RMS values for ulnar deviation are different in the supinated forearm posture and pronated forearm posture. Although some muscles are not bi-articular muscles, they act for a few motions (see Fig. 7 for an example). From Fig. 7, it can be seen that extensor carpi radialis brevis muscle is activated for both motions of wrist extension and radial deviation. Also muscle of extensor carpi ulnaris is activated for both wrist extension and ulnar deviation (see Fig. 8). Flexor carpi radialis muscle is activated for both wrist flexion and radial motions. Although the muscle of flexor carpi ulnaris is not bi-articular muscle, it is activated for both wrist flexion and ulnar deviation. By analyzing

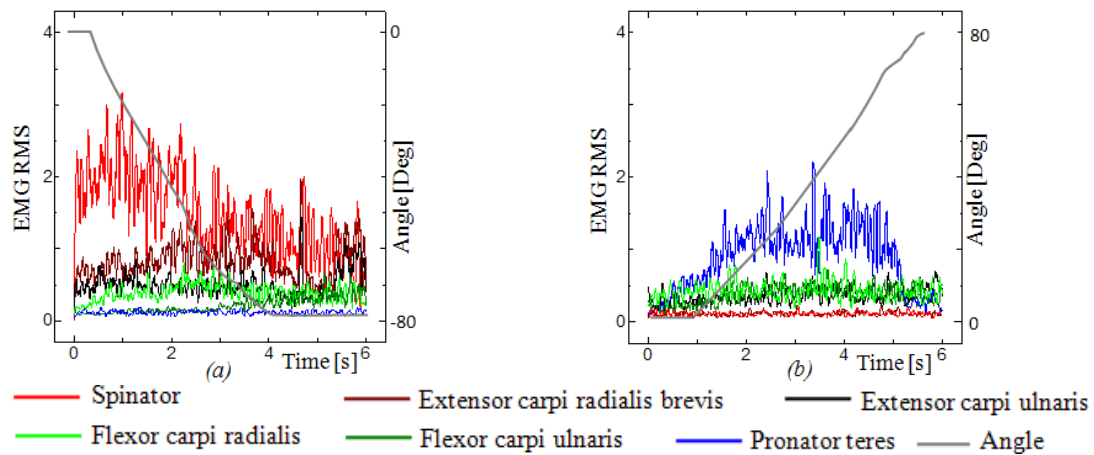


Figure 9. Relationship of EMG RMS and basic forearm motions. (a) Forearm pronation. (b) Forearm supination.

results of the experiments, it can be seen that some basic motions within the motion ranges used in the experiments can be separated by using the combinations of related muscles. Although many muscles are involved in wrist motions, each basic wrist motion can be uniquely identify in any forearm posture by considering simultaneous activation of two of muscles. Although the muscles of extensor carpi radialis longus, extensor carpi radialis brevis and extensor carpi ulnaris generate the wrist extension motion, the muscles of extensor carpi radialis brevis and extensor carpi ulnaris can be used to separate the wrist extension motion [see Fig. 8(b)]. Simultaneous activation of both muscles generates wrist extension motion in any forearm posture even though extensor carpi radialis brevis also activates the wrist radial deviation and extensor carpi ulnaris also activates the wrist ulnar deviation. Similarly, simultaneous activation of flexor carpi radialis and flexor carpi ulnaris generates wrist flexion motion even though they generate wrist radial and ulnar deviations, respectively [see Fig. 8(a)]. Therefore, wrist flexion motion can be separated by considering simultaneous activation of the flexor carpi radialis and flexor carpi ulnaris. Similarly, simultaneous activation of extensor carpi radialis and flexor carpi radialis generates wrist radial deviation [see Fig. 8(c)]. Thus, those muscles can be used to separate wrist radial deviation motion. Simultaneous activation of extensor carpi ulnaris and flexor carpi ulnaris separates the wrist ulnar deviation motion from the other wrist motions [see Fig. 8(d)]. In radial deviation, flexor carpi radialis shows higher muscle activity level than extensor carpi radialis brevis in supinated forearm posture and vice versa in pronated forearm posture. In wrist extension, extensor carpi radialis brevis shows higher muscle activity level than extensor carpi ulnaris in supinated forearm posture and vice vera in pronated forearm posture. Even though supinator and biceps brachii activate the forearm supination motion, biceps brachii works only if elbow flexion angle is about 90 degrees. As shown in Fig. 9 (a), activation of only the supinator muscle can estimate forearm supination motion. The activation of pronator teres or pronator quadratus can be used to identify forearm pronation motion although both activate the motion [see Fig. 9(b)]. The elbow flexion motion is generated by the muscles of biceps brachii, brachialis, and brachioradialis. However, from the analysis it can be identified that only the brachialis muscle also can be used to figure out the motion [see Fig. 10(a)] when shoulder angles maintained 0 degrees.

Although several muscles activates for shoulder motions, activation of one or two muscles can be used to identify each shoulder motion. As shown in Fig. 10(e), activation of the infraspinatus and/or deltoid (posterior) muscle can be used to identify external rotation within the experimented motion ranges. Activation of the whole deltoid muscle (anterior and posterior) can be used to separate the shoulder abduction [see Fig. 10(d)] within the experimented motion ranges. When the shoulder internal rotation is not activated, the muscles of teres major and pectoralis major simultaneously generate shoulder adduction motion in the experimented motion range. When shoulder vertical motion angle is within 0 to 90 degrees, pectoralis major (clavicular part) can be used [see Fig. 10(b)] to identify shoulder horizontal flexion. Muscles of deltoid (anterior) and pectoralis major can be used to identify shoulder vertical motion [see Fig. 10(c)].

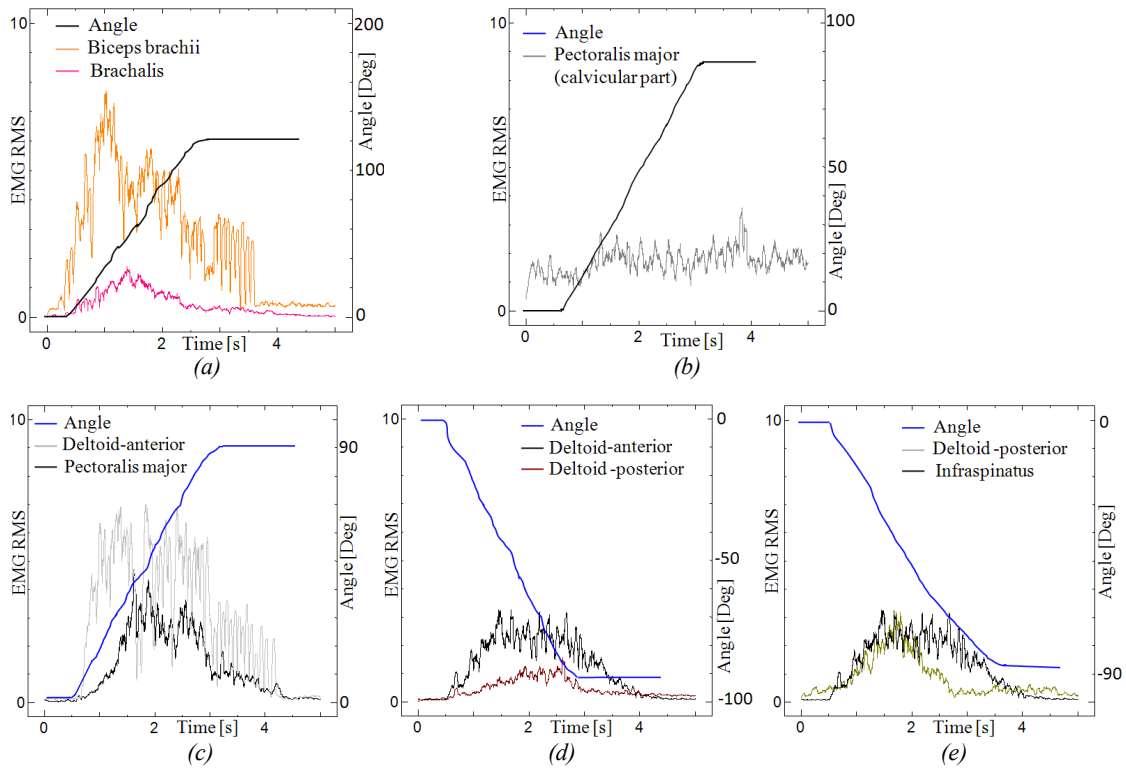


Figure 10. Relationship of EMG RMS and basic elbow and shoulder motions. (a) Elbow flexion. (b) Shoulder horizontal flexion. (c) Shoulder vertical flexion. (d) Shoulder abduction. (e) Shoulder external rotation.

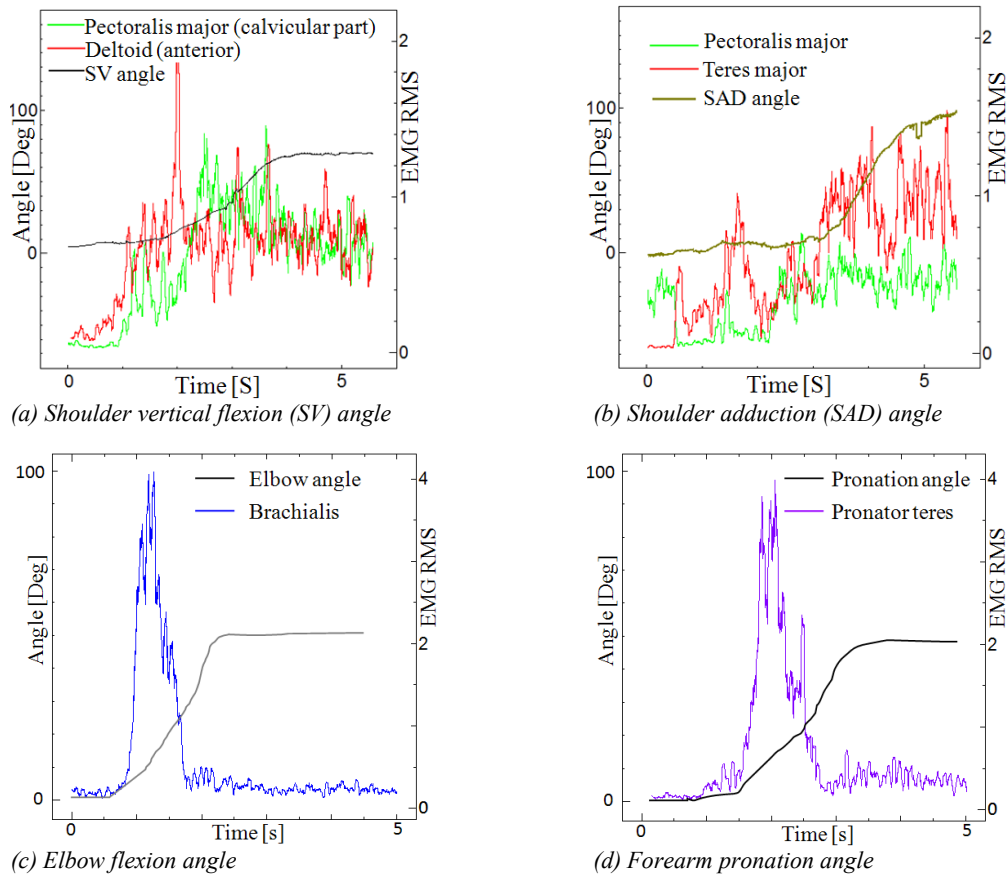


Figure 11. Relationship between muscle activities and shoulder and elbow angles of motion for drinking from cup activity

Every daily activity of upper-limb is a combination of basic motions of upper-limb. Therefore, the relationship between each basic motion angle and the activities of related muscles were analyzed. One daily activity is explained in detail here as an example. In the experiment for the daily activity of drinking with a cup, initially the hand was kept near the cup on the table as shown in Fig. 2 and the final position of hand was near the mouth. The activity was carried out in sitting position. In drinking with a cup activity, each upper-limb joint motion of a human subject (subject-A) are generated as follows. At first elbow flexion and the shoulder internal rotation are carried out at the same time. Then, shoulder is vertically flexed and adducted. When the cup comes near to the mouth, forearm pronation is carried out. Finally, wrist flexion and radial deviation are carried out. However, forearm and wrist motions are little and the activation of each basic motion depends on the person. The relationship of the shoulder vertical flexion motion angle and shoulder adduction motion angle and the EMG RMS levels of related muscles are shown in Fig. 11. As shown in Fig. 11(a), the shoulder vertical flexion motion of drinking from cup activity can be identify from other motions by considering the simultaneous activation of pectoralis major (calvicular part) and deltoid (anterior). The shoulder adduction motion of drinking from cup activity can be identify by considering the activation of pectoralis major and teres major [see Fig. 11(b)]. Figure 11(c) depicts that muscle of brachialis can be used to identify the elbow flexion motion of drinking from cup activity. Similarly, as depicted in Fig. 11(d) pronator teres can be used to identify pronation of forearm in drinking from cup activity.

6. Conclusion

The upper-limb muscle activities during basic upper-limb motion and the daily upper-limb motions have been studied to enable power-assist robotic exoskeleton systems to estimate human upper-limb motions based on electromyographic (EMG) signals of muscles. The relationships between the upper-limb motions and the activity levels of main muscles concerning the daily upper-limb motions were analyzed. Sixteen muscles were identified to estimate each and every motions of upper-limb. The muscle combinations were identified to separate some basic motions of upper-limb. The combinations of the EMG signals of identified muscles will be used as input information to design controllers of upper-limb exoskeleton robot.

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