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EFFECT OF JOINT ANGLE AND FOREARM POSTURE ON THE ELBOW FLEXOR AND EXTENSOR MUSCLES DURING ISOMETRIC CONTRACTION

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ABSTRACT

The effects of elbow joint angle, forearm posture and different force levels on the activation level of the long head and short head of biceps brachii, the brachioradialis, and the triceps brachii during isometric contractions were investigated. The muscle activation levels are simultaneously acquired by linear surface electrode arrays placed on the muscles. The results suggest that each muscle's contribution to elbow joint torque is affected by changing joint angle and forearm posture, which are muscle, and even subject dependent. At least one of the biceps brachii muscles is sensitive to changes in joint angle, from 60° to 90°, in supination. In the neutral posture, the sensitivity of the biceps muscles and the brachioradialis to joint angle was subject dependent. The short head of biceps brachii is sensitive to forearm posture at 60° but not at 90° joint angle. At 90°, the brachioradialis was significantly affected by forearm posture.

INTRODUCTION

It is important to understand how muscles work together to generate joint torque, for purposes, such as kinesiology, control of prostheses, medical rehabilitation, and human–robot interaction [1-3]. The surface electromyogram (SEMG) is a non-invasive signal which has been extensively studied to acquire information about muscle activation levels and muscle coordination during specific tasks. Joint angle, type of contraction, and generated force level are some important factors that affect the contribution of muscles and their relative activation levels during a contraction, which can also differ across individuals. Also, it is reported that during maximum voluntary contraction (MVC) for concentric and eccentric muscle contractions, different strategies are used and different activation levels are required [4], where lower activation levels are reported during eccentric versus concentric MVC [4], due to the lower motor unit discharge frequencies [5,6].

During muscle contraction, the muscle is not homogeneously activated along its length [4]. Therefore, an electrode array can be used to provide a better representation of muscle activity by measuring activation from a larger proportion of the muscle and reducing the potential effects of altered electrode-muscle geometry [4].

In this study, surface electrode arrays are used to investigate effects of joint angle, forearm posture, and force level on activation level of elbow flexor and extensor muscles to obtain insight into how the net elbow joint torque is distributed among the involved muscles during flexion, under isometric conditions. To this end, the relative contribution of these muscles under two different forearm postures, neutral and supination, at different joint angles, during isometric flexion contraction was determined.

METHODS

Four healthy subjects (2 female and 2 male; age 28±2 years) participated in the experiment. Subjects provided informed consent prior to their participation.

The experiments were conducted using the QARM2, a single degree-of-freedom (1-DOF) exoskeleton testbed [7], which holds the shoulder and wrist in a fixed position to limit the contribution of shoulder and forearm muscles to force generation at wrist, and constrains elbow flexion and extension of the right arm to the horizontal plane. The elbow's axis of rotation is aligned with a pivoting aluminum bar, which is locked at desired joint angles.

SEMG data were collected using four semi-disposal monopolar linear 8 electrode arrays (5 mm spacing) placed on the long head and short head of the biceps brachii, the brachioradialis, and the triceps brachii. The fourth electrode of each patch was placed on the SENIAM sensor location recommendation for the biceps and triceps muscles. For the brachioradialis, the fourth electrode was placed at one third the length of the forearm measured from the elbow. The Bioelecttronica EMG-USB2 high density (HD) amplifier, with a sampling frequency of 2048 Hz, was used to collect signal data. Each signal is band-pass filtered with cut-off frequencies of 10 and 500 Hz prior to sampling.

The experiment was conducted for three elbow joint angles of 60, 90 and 120 degrees at three force levels, 20, 35 and 50% MVC, where MVC was measured for each joint angle. The duration of each contraction was 5 seconds. For each subject, there were two trials in one session, for every joint angle-force level combination. Appropriate rest periods were provided to avoid muscle fatigue.

PROCESSING

Bipolar signals were obtained from the monopolar signals, for 5 mm inter-electrode distance (IED), by subtracting the monopolar signals of neighboring channels to produce seven bipolar signals. Each bipolar channel was band-pass filtered from 10 to 500 Hz using a 4th-order Butterworth filter. Then, the mean absolute value (MAV) of the EMG signals of each channel, which indicates the activation level of muscle, was obtained by full-wave rectification and smoothing.

RESULTS

In order to investigate the effect of elbow joint angle on the muscle activation levels during flexion, the average MAVs over the 7 bipolar channels were calculated for the data recorded from four subjects at the three joint angles and two forearm postures.

As joint angle increased, the relative contribution of the flexor muscles changed but in all cases, the triceps brachii activation level did not change, which was expected since it is an extensor muscle. The average MAVs across subjects are shown in Figure 1. It is clear that the brachioradialis has the highest level of activation, and is sensitive to joint angle and forearm posture. The other flexor muscles, are influenced by joint angle and palm posture, where the muscle activation levels at 90° and 120° joint angle are higher at neutral posture compared to supinated posture.

It is hypothesized that the effects of joint angle and forearm posture are subject and muscle specific because individuals will use different muscles strategies to do the same task. To investigate this hypothesis, the contribution of the flexor muscles was studied individually. In Figure 2, the contribution of the elbow flexor muscles during isometric contraction for different joint angles and postures, for 50%MVC, for each subject is shown. In Figure 2 (a), when forearm posture is neutral, the brachioradialis contribution decreases from 62% to 42% as joint angle increases, while the contribution of the long head (22% to 30%) and the short head of the biceps brachii (16% to 28%) increased. While there is a little increase in the brachioradialis contribution with increasing elbow joint angle, in Figure 2(c, d). It is clear in Figure 2, as the elbow joint angle changes, the contribution of the elbow flexor muscles to generate the desired force level varies. There is no general trend in a muscle’s contribution among all subjects, since different people seem to use different muscle strategies to perform the same task.

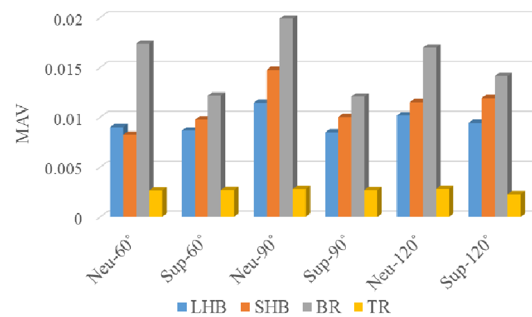

Figure 1: The comparison of average MAVs across subjects during isometric flexion, for one subject, at two postures, as joint angle changes (50%MVC).

The results were investigated statistically. Firstly, in order to investigate the effect of joint angle and forearm posture separately, the data from all subjects were grouped together. Data from each muscle and joint angle were grouped to investigate the effect of joint angle for both postures, and a single factor ANOVA applied. For all muscles, there was no effect of joint angle on muscle activation level. Then, the effect of posture was investigated. It was found that there was no effect of posture on muscle activation level as well except for the brachioradialis at angles of 60º and 90º. Then, according to hypothesis that different subjects use different strategies to perform a task (which is apparent in Figure 2), it is better to group acquired data for each subject separately and apply a single factor ANOVA. Table 1, shows the effect of joint angle on muscle activation level for supination (S) and neutral (N) postures, at 50% MVC. For each subject, data from each muscle at the same joint angle were grouped, to determine if there is a significant difference for changing elbow joint angle from 60° to 90°, and for 90° to 120°. The same process was done for both postures separately. In Table 2 the data from each muscle, at specific joint angle were grouped for each subject and analyzed to see if there is a significant difference between muscle activation with forearm posture, which is apparent for some cases in Figure 2.

DISCUSSION

The purpose of this paper, was to investigate the effect of joint angle, and forearm posture on activation level of the elbow flexor muscles and the triceps brachii during isometric elbow flexion. The results suggest that the activation level of short head of biceps brachii, the long head of biceps brachii, and brachioradialis are influenced differently as joint angle changed during flexion. The triceps brachii activation level is not affected by joint angle or forearm posture during flexion. The results in this study, were in agreement with other papers [4, 8, and 9] where it has been suggested that the activation of the biceps brachii and the brachioradialis are sensitive to joint angle during isometric contraction [8].

In this study, the two heads of the biceps are investigated separately and it found that they are affected differently. For example, in Figure 2 (c), from angle 60º to 90º, activation level of the short head of the biceps brachii increased, while activation level of the long head of the biceps brachii did not change. In addition, it is observed that the elbow flexor muscles are sensitive to forearm posture which affects and the upper arm muscle geometry. It has been reported that during flexion with supinated forearm posture, the biceps muscles show higher level of activation compared to the neutral posture, which was also seen in this study [9]. In all cases, the contribution of the biceps muscles (the short head and the long head) is higher in the supination posture, and is also higher than the brachioradialis at all joint angles.

Also, it is observed that there is a correlation between desired force level and the amplitude of EMG signal, so that as force goes up, the MAV of EMG increases for all cases. In most cases in this study (except F1), as the force level increases from 20%MVC to 50%MVC, the brachioradialis contribution increases, such that at 50% MVC, the brachioradialis was the dominant contributor. The biceps muscle (one or both heads) has higher levels of contribution at lower force levels (20% and 35% MVC), where the contribution of the brachioradialis is low.

HD EMG recording used in this study, provides an opportunity to determine the effects of recording configuration on SEMG signal, since some of signal characteristics such as mean and median frequencies change as IED changes [10]. Therefore, the data can be investigated to assess how the contribution of muscles during a task might be affected with changing IED. Processing for this is underway to investigate if this is an effect of IED on muscle contribution during a specific task.

Table 1: Significant difference of muscle activation levels for different postures, at 50% MVC

Muscle-Subject	60˚&90˚-N *P-value*	90˚&120˚-N *P-value*	60˚&90˚-S *P-value*	90˚&120˚-S *P-value*
LHB-M2	**0.005**	0.568	0.194	0.45
SHB-M2	**0.003**	0.055	**0.042**	0.34
BR-M2	0.163	0.832	0.62	0.78
LHB-F2	0.441	0.519	0.178	0.422
SHB-F2	0.408	0.508	**0.0015**	0.42
BR-F2	0.451	0.471	0.17	0.42
LHB-M1	**0.002**	**0.01**	**0.007**	**0.018**
SHB-M1	**0.031**	0.1	**0.004**	**0.021**
BR-M1	**0.035**	**0.01**	**0.002**	0.143
LHB-F1	0.317	0.076	**0.009**	0.691
SHB-F1	0.691	0.24	**0.022**	**0.032**
BR-F1	0.07	0.4	0.134	0.55

Table 2: P-values for muscles activation levels for individual subjects and changing joint angles, at 50% MVC

Muscle-Subject	60˚ *P-value*	90˚ *P-value*	120˚ *P-value*
LHB-M2	0.65	**0.021**	0.105
SHB-M2	**0.0064**	0.606	0.095
BR-M2	0.25	**0.0101**	0.169
LHB-F2	0.476	0.338	**0.0489**
SHB-F2	**0.006**	0.49	0.581
BR-F2	0.091	**0.0266**	0.8
LHB-M1	**0.02**	**0.046**	**0.035**
SHB-M1	**0.0177**	0.921	**0.03**
BR-M1	**0.002**	**0.006**	0.8
LHB-F1	0.86	**0.039**	0.97
SHB-F1	0.174	0.97	0.131
BR-F1	0.734	**0.048**	0.58

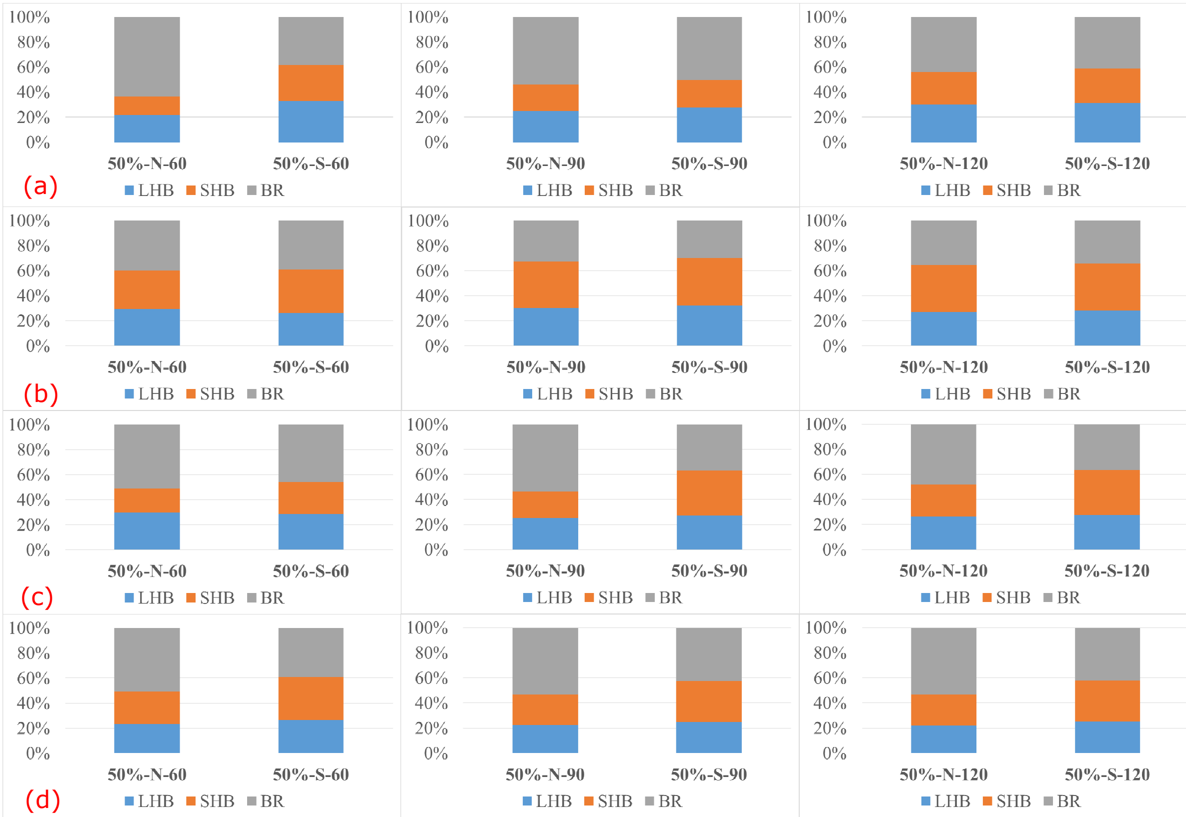

Figure 2: The contribution of the flexor muscles during isometric flexion, for four subjects, at two postures (50%MVC). N and S indicate neutral and supination respectively. The graphs belong to these subjects, a:M1, b:F1, c:F2, and d:M2.

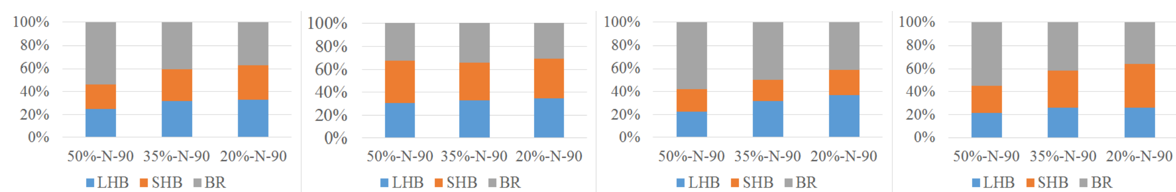

Figure 3: The comparison of the flexor muscles contribution during 90º flexion, neutral posture, at different force levels.

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