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EMG-Biofeedback and Load Sharing Problem in Assistive and Rehabilitation Orthotic Devices

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Abstract— **Biofeedback signals have been frequently used for rehabilitation purposes, and in design and calibration of orthotic and prosthetic devices. Whenever one or a couple of muscles of a joint are chosen for rehabilitation or control of a device, it's assumed that a specific load sharing or activation pattern exists among them for each individual and for each specific joint demand. Indeterminacy or a load sharing problem arises from having more muscles crossing a joint than needed to perform all possible movements. It's proven that muscle activation patterns depend on fatigue, the task (isometric/isokinetic, concentric/eccentric), load type, mental demands, etc. The most used biofeedbacks are electromyogram of one of the muscles or the joint torque signal. An important question is if they can be used interchangeably. This study investigated if the choice of biofeedback can also change the activation pattern in the two main elbow flexors. The results of this experiment on six healthy subjects and seven activation levels, indicated that change in biofeedback type had a significant effect on the activation ratio of these two muscles.**

I. INTRODUCTION

Biofeedback involves measuring some internal physiological events of body and revealing them to the human in real-time [1] to raise awareness of or to control those events. Electromyographic biofeedback technique provides the subject with auditory or visual feedback of the surface electromyogram (EMG) and has been widely used in rehabilitation programs ([2], [3]) or rehabilitative robotic devices ([4], [5], [6], [7], [8]). Also, many assistive devices (either orthotic or prosthetic) utilize EMG signals. These devices need calibration and recalibrations which usually involves a set of maximum voluntary contractions (MVCs) on the related joint whether with or without force/torque as biofeedback ([7], [9]). In [6] and [10], the subjects receive the EMG biofeedback during the calibration .

In general, the number of muscles that cross a joint surpasses its degrees of freedom and the produced torque in each degree of freedom is a result of contribution of multiple muscles. The way the central nervous system distributes the joint torque among the muscles depends on different factors. For example, it is proven that load sharing depends on fatigue [11], type of the motor task (concentric, eccentric,or isometric) [12], load type (controlling force/position) [13], mental demand such as pain or continuing attention [14], and so on. A question of considerable importance is whether having a muscle's EMG signal as biofeedback (receiving real time information about this signal's level) affects the activation pattern or load sharing among the muscles in the related joint. Or, if on the contrary, there is a unique pattern of activation of muscles acting about a joint for a specific situation that does not depend on biofeedback. Place et al. [15] showed that the biofeedback type (EMG or torque), can change the neuromuscular fatigue in isometric submaximal contractions. Palmerud et al. [16] demonstrated that using EMG-biofeedback, subjects are able to voluntarily redistribute some muscles' activities in their shoulder. Howard et al. [17], using EMG biofeedback of two different elbow flexors, showed that in isometric conditions (5-20% MVC), there is not a complete covariation among elbow flexors at various elbow angles (65-170°). So, if recording from one muscle, inferences made regarding other muscle activation levels should be made with caution. They also found that the relative activation of muscles was subject-dependent, muscle-dependent, and angle-dependent. Even at one elbow angle, covariation did not happen.

These aforementioned papers and also interchangeable use of different biofeedbacks ([8], [15], [17], [18]) have motivated this study of load sharing in human elbow flexion. The specific purpose was to investigate any possible change in the relative activation of two main elbow flexors, that are suitable for surface electromyography as well (Biceps Brachii-BIC, and Brachioradialis-BRD), due to choice of the biofeedback type. The investigation was on three types of biofeedback in a wider range of activation (10-70% MVC compared to 5-20% in [17]). This experiment was joint with another study on Parkinsonian patients which used 135° as the constant elbow angle.

II. METHODS

Six healthy male students, mean age 31.7 years (SD 5.8), participated in this study after they were informed of the procedure and gave consent to the experimental procedure, which was approved by Office of Research Ethics at the University of Waterloo. After preparing each subject's skin for surface EMG and attaching electrodes on the related 2 muscles, the subjects were fitted to the experimental apparatus (Fig. 1). The apparatus measured the isometric elbow flexion torque using a reaction torque sensor (OMEGA® TQ301, 45±0.09 N.m).

Each participant was seated upright in a chair facing the device with the shoulder fully adducted, lower arm fully

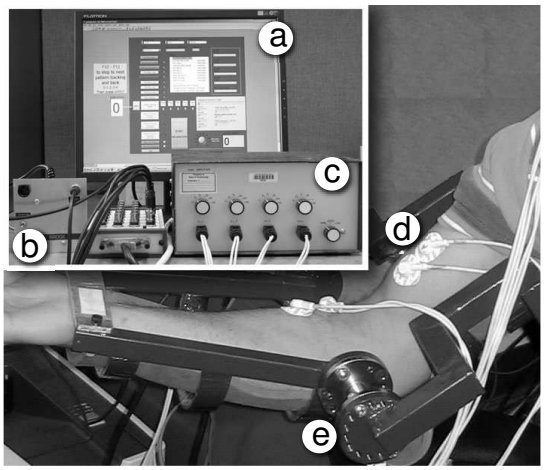

Fig. 1. Subject at experimental apparatus. a) Software interface. b) Torque amplifier. c) EMG amplifier. d) Surface EMG electrodes. e) Torque sensor. Trials of isometric elbow torque were either constant at rest and MVC, or changing stepwise according to random patterns. All trials were performed at an elbow angle of 135°

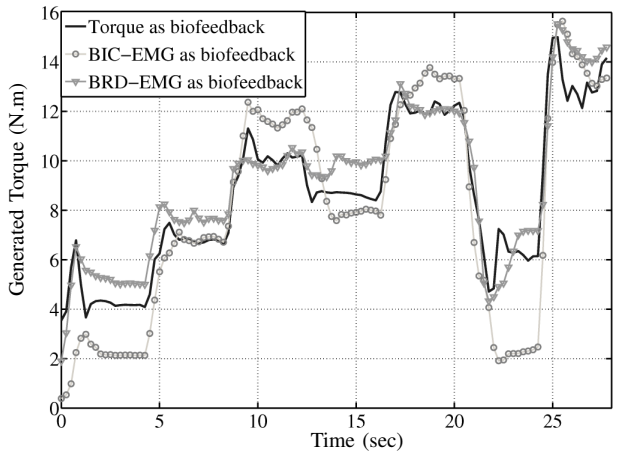

Fig. 2. Generated elbow flexion torque in three trials during which one subject was trying to match biofeedback levels to the same pattern (10-30-50-40-60-20-70%) of activation

supinated, and palm facing up and all the trials were performed at an elbow angle of 135°. Two Maximum Voluntary Contractions (MVCs), of 2 sec duration and with enough rest in between to avoid fatigue, were collected in the flexion direction. Also, rest and shorted-electrode trials (2 sec) were collected to account for the gravitational torque and compare the noise level among sessions. Main data collection was carried out in three sections. In each section, the subjects adjusted their level of elbow flexion effort to match the desired level of one of the provided biofeedbacks (torque, BIC-EMG, or BRD-EMG). Before the main data collection, the subjects were asked to have a couple of trials to become familiar with following the target patterns. In order to offset the learning effect, the sequence of the sections was randomized for each participant. When the torque signal was used as biofeedback, the lowpass filtered torque signal was presented to the subject on the monitor. When the EMG signal was used as biofeedback, its rectified value which was averaged over a window of 250 msec and was updated every 10 msec, was presented to the subject on the monitor. Every section consisted of 5 trials of 28 sec each. In each trial, the subject attempted to match the biofeedback signal level to one of the five patterns displayed on the computer monitor. Each pattern contained seven levels of 10-70% MVC of 4 sec each and the order in which the patterns were displayed was randomized for each participant. Fig. 2 shows the applied torque of a subject in three trials of different sections while he was trying to follow the same pattern using the corresponding biofeedback.

III. Data Acquisition and Processing

Data acquisition throughout the experiment was facilitated by a Labview® (from National Instruments, Inc., Austin, TX) interface (Fig. 1). Subjects elbow flexion torque was collected along with 4 channels of bipolar EMG signals with a 16-bit data acquisition card (only two flexor EMG channels were used in this study) at a sampling frequency of 1 kHz. Ag-AgCl surface EMG electrodes were used to collect the signals. EMG signals were amplified and band-pass filtered (20-500 Hz) before being sampled. The torque signal was also amplified, prior to sampling, using a full bridge amplifier.

The analyses were done off-line using MATLAB® 2007b (MathWorks, Inc., Natick, MA) and STATISTICA^{TM} 7.0 (StatSoft). The gravitational torque due to each subject's lower arm weight, that was found by averaging the torque during the rest trials, was subtracted from all the torque signals. The torque signals were normalized to the average of the two MVC trials' maximum torque. A similar normalization was applied on both EMG signals in which maximum values were acquired after the rectified signal was passed through an averaging window.

To be able to compare torque and EMG signal levels when following different biofeedbacks, averages were calculated for each level. Target levels changed every four seconds and the acquired torque signal and rectified smoothed EMG signals were averaged over the steady part of this period (from 1 sec to 3.5 sec). Therefore, under each biofeedback condition and for each of the seven target levels (10-70% MVC), five average values were found for all three signals (torque, BIC-EMG, and BRD-EMG) for further comparisons.

IV. Results

As can be seen in Fig. 2, trying to match the same target pattern for different biofeedbacks did not result in the same generated torque. For the same subject, results of comparison of the generated torque using the averaged data from all fifteen trials (five trial for each biofeedback), is shown in Fig. 3. The boxplots for each of the seven levels show that, for the subject, this was not only a random difference between the three trials, but rather, the choice of biofeedback systematically affected the generated torque. One interpretation could be (as in [17]) that muscle equivalence was not observed for

this subject.

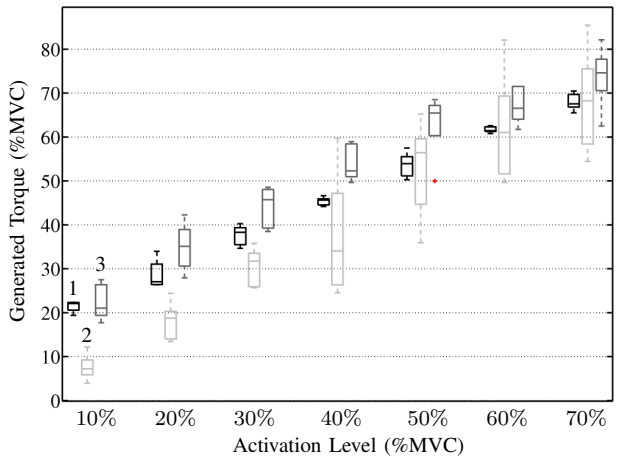

Fig. 3. Comparison of generated flexion torque on one subject's elbow across all the trials while receiving each of the three biofeedbacks: 1- Torque, 2- BIC-EMG, 3- BRD-EMG (three boxplots at each activation level)

In other words, 10% activation in one flexor muscle was not equal to 10% activation in the other muscle and to 10% generated torque. The question is whether or not this difference was just because of dissimilar load sharing patterns for the two muscles (in 10-70% activation). If it was, then the activation ratio in the two muscles should stay almost the same at each level of contraction. Fig. 4 does not concur with this idea and reveals that the choice of biofeedback had a considerable effect on the activation ratio of the two muscles for this subject especially at lower levels of activation.

To investigate the effect of three different biofeedbacks and seven activation levels on the activation ratio across all subjects, a three way analysis of variance (ANOVA), $6\times3\times7$, with one-between and two-within factors was applied to the data. The results indicated that there was a significant effect for the biofeedback factor, $F(2,10) = 5.45,\ \ p = 0.0250$ (Fig. 5-a) and also a significant effect for the the activation level factor, $F(6,30) = 5.39,\ \ p = 0.0007$.

V. Discussion and Conclusions

The activation ratio between two main elbow flexors (BIC, and BRD) was investigated as a measure of load sharing between the two muscles in isometric contractions at a fixed elbow angle (135°). It was found that the choice of biofeedback type significantly changed this ratio, or equivalently the load sharing among the two muscles, across the investigated activation levels (10-70% MVC). Mean BIC/BRD activation

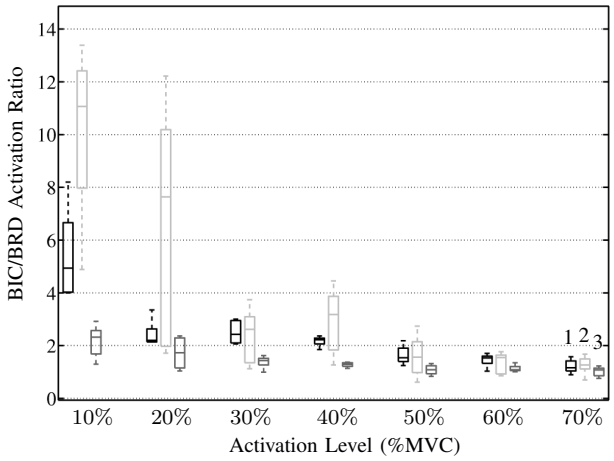

Fig. 4. Comparison of activation ratio in the two elbow flexor muscles of one subject, across all the trials and activation levels (10-70% MVC), while receiving each of the three biofeedbacks: 1- Torque, 2- BIC-EMG, 3- BRD-EMG (three boxplots at each activation level)

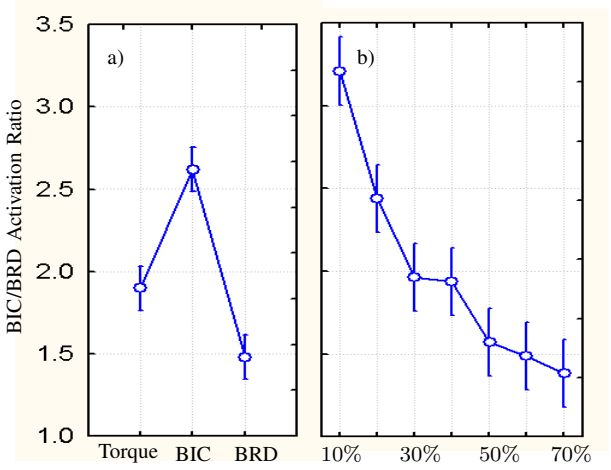

Fig. 5. Effect of a) biofeedback type and b) activation level, on the BIC/BRD activation ratio across all subjects. Vertical lines show the 95% confidence intervals

ratio was higher when BIC-EMG was the choice of biofeedback, and lower when BRD-EMG was the choice (compared to the case in which Torque-biofeedback was chosen) across all subjects and all levels of activation. Therefore, at least among these two muscles, it seems that the central nervous system (CNS) may change the load sharing in favor of the muscle whose EMG is being used as biofeedback.

Another result of this study, which was in line with previous studies, was that activation levels significantly affected the load sharing across all biofeedback types. Mean BIC/BRD activation ratios decreased monotonously as the

activation levels increased from 10% to 70% MVC across all subjects and all biofeedback types. The interpretation might be that for smaller loads, the CNS mainly activates BIC, but for larger loads, the tendency is to use both muscles almost equally.

It seems that not only do these two muscles not consistently co-vary (their activation level cannot be interchangeably used as a measure of joint activation), but also that the muscle activation level (or its ratio between the muscles) should be used in conjunction with the biofeedback type. In other words, the change in load sharing pattern between the two synergist muscles of this joint, in case of biofeedback change, may cause erroneous calibrations in devices or inferences of experiments. Further studies should investigate if the change of biofeedback type would cause similar changes in all of the synergist muscles, and also in different postures of elbow.

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