FEATURES SELECTION FOR ANALYZING THE EFFECT OF PREPARATION INSTRUCTION ON FOREARM MUSCLES DURING PRE-MOTOR ACTIVITY

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ABSTRACT

This paper studies the effect of preparation instruction on pre-motor activity in EMG signals. Two kinds of trials are investigated, the first one uses a warning signal for mental preparation of a contraction while the second one does not use any preparation warning. Time domain analysis has been carried out in order to select Relative Power (RP) and Preparation Duration (PD) as relevant features that characterize the pre-motor stage. Two modes of preparation are defined: small and large. The small one is characterized by short preparation with relatively low power. Large preparation is the opposite case. Statistical analysis for men and women subjects, using MANOVA tests are performed. It shows a diversity of behaviors and discrimination abilities according to the muscle type, to the preparation type and to the gender.

Index Terms— EMG signal, preparation instruction, Preparation Duration (PD), Relative Power (RP), small/large preparation, trials discrimination.

1. INTRODUCTION

Electromyographic (EMG) signals are an indication of the electrical activity of muscles, which arise whenever there is a voluntary or involuntary contraction of a muscle [1]. EMG signal processing has long been used in many fields such as bioengineering and technosciences [2], medicine [3], sports [4]...

Most studies have focused on physical activity during muscle contraction. However, to the best of our knowledge, few have studied the pre-motor activity (the small muscle activity preceding the effective contraction). It generally occurs between the warning signal motivating preparation and the 'go' signal for motion execution.

Previous studies showed that the mental preparation leads to a physical activity change during muscle contraction [5,6]. In this study, we aim to analyze the effect of preparation instruction on pre-motor activity. More precisely, we want answer to the following question: does pre-motor activity change when a preparation warning is given?

To this end, the following methodology is adopted. Firstly, we define features characterizing the pre-motor phase. Secondly, we analyze if there is a difference between the two trials (with and without preparation warning). Thirdly, we define the classification for both trials, and we divide it into two types of preparations ("small" and "large"). Finally, we identify the behavior of features for each of the four classes (defined as all possible combinations of with/without preparation warning and small/large preparation information).

This paper is organized as follows. Section 2 gives the experimental paradigm. Section 3 defines the selected features: Relative Power (RP) and Preparation Duration (PD), the way to calculate them. Section 4 analyzes features behavior during pre-motor activity. In Section 5, we organize the classification of pre-motor activity consistence into small and large preparation modes. Finally, we show the ability of the proposed approach to discriminate between the two trials for both genders.

2. EXPERIMENTAL PARADIGM

2.1. Materials

Surface EMG activity was recorded using bipolar surface electrodes equipped with a preamplifier with an inter-electrode distance of 25 mm (BIOPAC systems, Aero Camino, Goleta, USA). Electrodes were fixed to the skin over the muscle with Elastoplast bands. EMG activity was measured using Acknowledge data hardware (Model MP100A, BIOPAC Systems, USA). EMG signals were amplified and sampled at a frequency of 1kHz.

8 males and 7 females volunteers participated in the experiment. Each volunteer produced 15 maximal isometric contractions during a handgrip exercise. The studied muscles are: the Flexor Digitorum Superficialis (FDS), the First Radial (FR) and the Common Extensor Digitorum (CED). The FDS allows the four medial fingers of the hand to flex. The FR aids in moving the hand. Specifically, it abducts and

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extends the hand at the wrist joint. The EDC extends the medial four digits of the hand.

2.2. Methods

During the handgrip exercise, the EMG signal is composed of three distinct time intervals: a pre-motor activity in which the volunteer can mentally prepare the activity. Then, a motor activity begins and lasts 4.4 seconds (the effective contraction). Finally, a rest period of 44 seconds follows and ends the experiment.
Two trials were carried out. In the first one called commanded (CMD), the subject receives a preparation instruction 6.6 seconds before hearing a statement (bip) asking him to begin the contraction. In the second trial called auto-commanded (ACMD), the volunteer does not receive any preparation warning; he executes the movement when he wants during 4.4 seconds and has the same rest period of 44 seconds.
In this study, we are interested only in the first time interval, which is the pre-motor activity.

3. PRE-MOTOR ACTIVITY FEATURES BEHAVIOR

The first step of this study is to select features that can be used to discriminate between pre-motor activity when a warning signal is given or not. After testing many features in the time domain (duration, power, relative power,...) and in the frequency domain (median frequency and bandwidth), the following ones are retained.

3.1. Selected features

To characterize the preparation stage, two features are extracted in the time domain, namely the Preparation Duration (PD) and the Relative Power (RP). The procedure to calculate them is the following.
First of all, the EMG signal is transformed into a Root Mean Square (RMS) signal by dividing the EMG $x(n)$ into sliding windows and giving it an envelope look:

$$RMS(n) = \sqrt{\frac{1}{N+1}\sum_{k=-N/2}^{N/2} x^2(n+k)}, \qquad (1)$$

where N is the window length. Its duration is chosen equal to 512 (the equivalent duration is 512 ms since the sampling frequency is 1Khz).

The pre-motor (resp. motor) onset, which is the instant of pre-motor (resp. motor) activity beginning, is estimated according to the method described in [7]. The two features are then calculated. The preparation duration is the time interval between pre-motor onset and motor onset (see Fig .1). The relative power RP is the ratio of the pre-motor activity power over the motor activity power.

$$RP(\%) = 100 * \frac{\frac{1}{PD}\sum_{n\in PD} x(n)^2}{\frac{1}{MD}\sum_{n\in MD} x(n)^2}, \qquad (2)$$

where PD (resp. MD) is the pre-motor (resp. motor) activity duration.

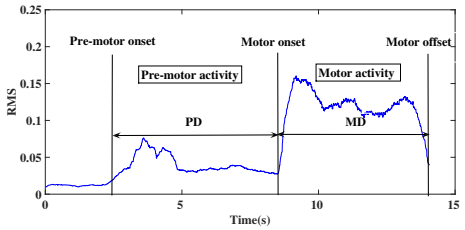

Fig. 1. Illustration of relevant instants and durations in the RMS signal.

3.2. Features behavior according to the trial

In a previous work [8], we have analyzed the preparation duration in both trials (CMD and ACMD). We noticed that: *i)* in both trials, men and women can prepare or not prepare their activity. *ii)* The preparation duration can not discriminate between the two trials for men. *iii)* the preparation duration can discriminate between the two trials for women. This can be explained by the fact that females outperform males in attention, word and face memory, and social cognition tests [9].

In this paper, we aim to improve the study by looking for a method to discriminate between trials for men and women. In order to overcome the limitation of PD, relative power is used and its discrimination ability is analyzed.
Without loss of generality and due to lack of space, only men's results are given for illustration. The boxplots for FDS, FR and EDC muscles in "CMD" and "ACMD" trials are drawn in Fig .2 and the p_values are given in the second line of Tab .1 (the first line is reserved to PD). We recall that p_values help to determine the significance or validity of the discrimination hypothesis when it is less than 0.05, which is a common threshold of weak evidence. From the mentioned figure and table, one can notice that overall behavior for RP feature is quite similar in both trials for FR and EDC muscles, but it is different in the FDS muscle for men. This fact shows the ability of RP to discriminate between trials for the FDS muscle.

The same analysis is carried out now using the dispersion of the couple preparation duration and relative power in the plane (PD, RP). Due to lack of space, only the FDS muscle is illustrated in the case of men (see Fig .3). We can observe a cloud of points. However points of CMD and ACMD trials are mixed in the same region of the plane and are not separated. The results of MANOVA tests, for men, show no differences between both trials (see line 3 of Tab .1). This observation confirms that the preparation warning does not lead systematically to a muscle preparation and *vice versa*. It is then useful to refine the study and to operate differently.
Regarding women, the results are different when PD is used alone and when PD and RP are used together. It means that these features are powerful to discriminate between the two

modes (with and without preparation warning). The RP feature, on the other hand, allows this discrimination for men. Hence, the features seem to behave in an antagonist way when we consider the differences between genders.

Table 1. p_values to describe discrimination ability using one or two features.

	Males			Females		
p_values	FDS	FR	EDC	FDS	FR	EDC
PD	0.575	0.3	0.372	0.009	0.08	0.014
RP	0.028	0.563	0.213	0.71	0.167	0.444
(RP,PD)	0.252	0.467	0.415	0.019	0.09	0.017

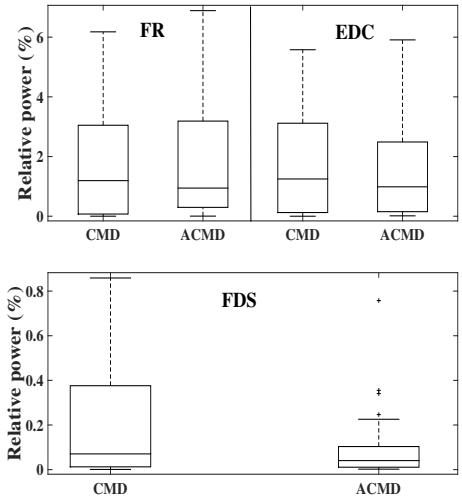

Fig. 2. Boxplots of relative power in "CMD" and "ACMD" modes. (a): FR and EDC muscles, (b): FDS muscle.

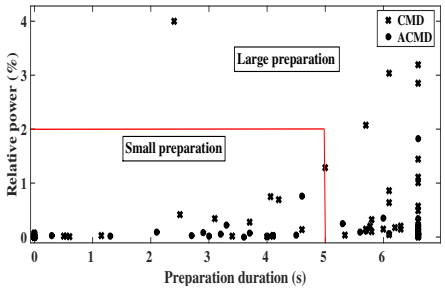

Fig. 3. Distribution of (PD,RP) and identification of short/long preparation for FDS muscle.

4. SMALL/LARGE PREPARATION CLASSIFICATION

Instead of considering the two trials (CMD and ACMD) separately, the data are re-arranged differently according to the pre-motor activity consistence: short or long, and powerful or not. Hence, two new families are defined: pre-motor activity with small or large preparation. The method to obtain them is explained in the following subsection.

4.1. Classification principle

An inspection of the plot of Fig .3 along the whole time interval shows that preparation duration is not spread out all the time: it occurs during the time interval [0s, 4.5s], it stops around 5s and occurs again during [5.2s, 6.6s]. Relative power, on the other hand, varies between 0% and 2% and the between 3% and 4%. Moreover, no matter what the trial is, when preparation duration increases, the relative power increases too. These findings motivate us to classify the pre-motor activity into two classes. The first one is called "small preparation", while the second one is called "large preparation". Small preparation corresponds to short preparation with relative low power, while large preparation is the opposite case.

Small preparation is defined according to this rule: PD is less than τ_{PD} and relative power is less than ρ_{RP}. Large preparation is defined using the opposite rule: PD $\geq \tau_{PD}$ or RP $\geq \rho_{RP}$.

Extensive tests on studied muscles permit to define thresholds. They are given in Tab .2. The distribution to classes is illustrated in Fig .3 for men FDS muscle. It is important to note that women FR muscle give different results. In fact, thresholding is not possible since data for both trials are mixed in the same regions.

Table 2. Thresholding values for small/large preparation classification.

	Males			Females		
	FDS	**FR**	**EDC**	**FDS**	**FR**	**EDC**
τ_D(s)	5	3	5	5	undefined	6.4
ρ_{RP}(%)	2	1	1	0.15	undefined	5

4.2. Novel features distribution: boxplots

According to the new classification, the features repartition to classes are rearranged and boxplots are drawn. Fig .4 (resp. Fig .5) illustrates FDS muscle boxplots of PD (resp. RP) according to the four refined classes: CMD mode characterized by small (resp. large) preparation denoted CMD/small (resp. CMD/large) and ACMD mode characterized by small (resp. large) preparation denoted ACMD/small (resp. ACMD/large). One can see that small preparation is clearly separated from large preparation in both trials. However, separation is not obvious between trials (CMD and ACMD) for small preparation. One can also notice that relative power has a large dynamic in case of CMD/large preparation and it is clearly different from that of ACMD/large.

5. TRIALS DISCRIMINATION USING THE NOVEL CLASSIFICATION

This section aims to discover if the new classification into small/large preparation can help to discriminate between CMD and ACMD modes. The results of ANOVA and MANOVA tests are given in Tab .5. The symbol ($\neq$) (resp. (=)) means that there is (resp. isn't) a significant difference between two trials. When p_value is less (resp. greater) than 0.05, it means that it is (resp. isn't) possible to discriminate between the two trials.

Table 3. p_values and differences between absence and presence of warning using classification.

		Males						Females			
		FDS	**FR**	**EDC**	**FDS**	**FR**	**EDC**	**FDS**	**EDC**	**FDS**	**EDC**
Small preparation	PD	=	$\neq$	$\neq$	0.171	0.012	0.009	=	$\neq$	0.488	0.013
	RP	=	=	=	0.668	0.073	0.615	=	=	0.399	0.827
	RP and PD	=	$\neq$	$\neq$	0.161	0.03	0.033	=	$\neq$	0.458	0.031
Large preparation	PD	=	$\neq$	=	0.365	0.003	0.152	$\neq$	=	0.008	0.171
	RP	$\neq$	=	=	0.046	0.593	0.354	=	=	0.334	0.42
	PD and RP	=	$\neq$	=	0.441	0.001	0.164	$\neq$	=	0.002	0.265

In small preparation:

• Using one or two features (PD or RP), FDS muscle does not react differently when a preparation warning is given for both genders (p_values>0.160).

• Contrary to flexor muscle (FDS), extensor muscle (EDC) is sensitive to preparation warning for both genders (p_values<0.034).

• For FR muscle, females do not react differently when a preparation warning is given. However, males show an opposite behavior.

• In extensor muscle, features giving differences are respectively PD and the couple (PD,RP) for males.

In large preparation:

• EDC muscle does not react differently in the presence or absence of a warning for both genders (p_values>0.151).

• ANOVA tests show a significant difference between both trials in FDS muscle using the feature RP (resp. PD or RP and PD) for males (resp. females). Men and women behavior are different.

• The same results of small preparation in FR muscle are available in large preparation for both genders.

Comparing small and large preparation, ANOVA tests indicate opposite results in FDS and EDC muscles. In fact, the results of FDS during small preparation are similar to those of EDC during large preparation for both genders. On the other hand, the results of FDS muscle during large preparation differs by genders. In fact, males (resp. females) results are opposite (resp. similar) to those of EDC muscle during small preparation.. Physically, the anatomy of muscles shows that the anterior forearm muscles are responsible for hand flexion. The posterior forearm muscles are involved in hand extension. The forearm anterior group muscles are called the agonist muscles while the posteriors are called antagonist [10]. Hence, we confirm that the respective muscle group (FDS/EDC) constitutes agonist/antagonist pairs in pre-motor activity. On the other hand, the muscle responsible for flexion is the FDS muscle. This latter differs by gender during large preparation. It is explained by the fact that males perform better on spatial processing and sensorimotor speed, while females perform better on attention and word. In this case, and especially in "with preparation warning", volunteers must be attentive and concentrated.

6. CONCLUSION

In this work, we proposed features to characterize pre-motor activity in case where there is or there is not a warning of preparation. The discrimination between these two trials is not obvious; that is why we proposed an alternative to classify data according to the importance of preparation. Statistical tests show that effectively, it is possible to discriminate between trials when we consider refined classification based on the small/large preparation concept. However, the muscle responses to the preparation warning are not the same for both genders.

A possible extension of this work is to study the effect of preparation warning and the kind of preparation (small/large) in the transition step which is situated between the pre-motor activity and the effective motor activity. The purpose is to know if it is influenced by the issue of preparation classification.

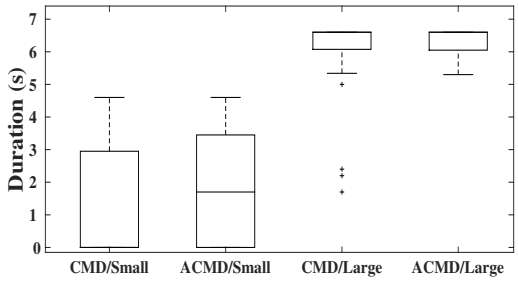

Fig. 4. Four classes boxplots of preparation duration in case of FDS muscle.

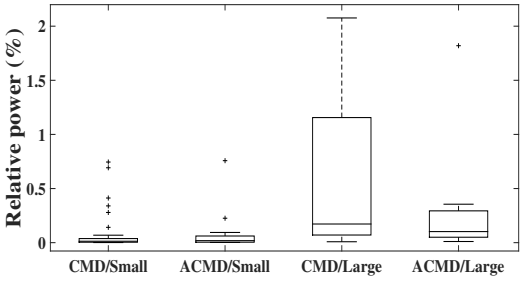

Fig. 5. Four classes boxplots of relative power in case of FDS muscle.

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