The Approach to the Detection of the Movement Precursor by Electromyographic Signals

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Abstract: We have developed a technique allowing automatic detection of the precursor of movement beginning based on the analysis of electromyographic signals. Methods for determining the beginning of movement and the moments of movement planning are of urgent need in neuroscience, and a separate problem is the use of muscle electrical activity signals (electromyograms) to accurately determine the beginning of hand movement due to the complexity, short duration and noise of the original signals. This issue is particularly significant for experiments with simultaneous recording of electroencephalograms, when it is necessary to consider the interaction between the structures of the brain. We have found out that in the case when the movement starts on a certain sound signal, the moment of the movement beginning is detected with a some time delay.

1 INTRODUCTION

The development of effective methods for determining the precursor of movement beginning and the moments of movement planning is an urgent problem of neuroscience and neurotechnology. In particular, this task is closely related to the development of human-machine interfaces. A separate problem here is the use of muscle electrical activity signals (electromyograms) for exact detection of the of limb movement precursor. This issue is particularly acute when conducting experiments with simultaneous recording of electroencephalograms, when the relationship between the excitation of certain brain areas and human motor activity is investigated.

Currently, the problem of studying the processes occurring in human body related to the performance of motor activity attracts a large scientific interest (Wood et al., 2014; Hayashibe et al., 2015; Maksimenko et al, 2018; Mondini et al., 2018). The relevance of this research area is connected with the possibility of applying the results in such areas as rehabilitation, prosthetics, robotics and others.

However, the use of additional methods for the analysis of motor activity, basically, involves conducting an experiment according to a previously developed plan, according to which movements are performed on a special sound signal. In this case, there is the problem of accurate determining the moment of the start of movement (Reis, 2014).

To solve this problem, it seems promising to use signals of electrical activity excited directly by muscle fibers – electromyograms (EMG) (Rouillard et al., 2015). The analysis of EMG signals, in turn, is difficult due to the low amplitude of the potentials, the strong nonstationarity, the presence of various artifacts and the poor structuring of the initial data (Basmajian, 1979; De Luka, 2010; Kastalskiy et al., 2018).

Thus, there is now a need to develop new effective methods for EMG signals analysis and for their

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application for a detailed study of human motor activity.

2 METHODS

2.1 Data Preparation

In the course of the experiment, the registration of non-invasive EMG signals from the elbow muscle was carried out. The subject was in an upright position. The subject had no pathologies of the central nervous system.

The duration of the experiment was 150 minutes. During the recording of signals, breathing was arbitrary.

The subject was instructed to perform on the sound signal the following actions: (1) flexion and (2) subsequent extension of the hand with intermediate fixation in the upper position (see Fig. 1a). Registration of EMG signals was carried out using a multichannel electroencephalograph-analyzer "Encephalan-131-03", model 10 (Taganrog, Russian Federation) with a set of standard sensors. Signals were recorded at a sampling frequency of 250 Hz with a 12-bit resolution.

For additional control and registration of motor activity, a copy-type setting device was used, which is a lever construction made of plastic and light alloys, made similar to the human skeletal scheme with the coincidence of the position of the mobility axes and joints (exoskeleton). The lever mechanism was identical to the kinematic scheme of a human hand and contained an analogue of the forearm connected to the shoulder with a rotational pair with one degree of freedom, which allows to obtain data on the flexion of the elbow joint simultaneously with EMG recording.

2.2 Experimental Setup

The structure of the experiment is shown in Fig. 1c. In total, the experiment consisted of six sessions and included pre-registration of background activity without subject performing special instructions (BG, 15 minutes), two half-hour sessions with flexion of the hand on the sound signal (AM), two sessions with arbitrary flexion of the hand (FM), the final registration of the background activity without the subject performing special instructions for 15 minutes. The beginning of each session was preceded by an automatic audiovisual warning of the subject about its occurrence. For sessions with flexion of the hand on the sound signal 50 movement repetitions were planned. Sound stimuli were given at arbitrary moments of time but provided for at least 10 seconds of rest between every two movements. For the session with an arbitrary flexion of the hand, no sound stimuli were given, however, the subject was instructed to be at rest also for at least 10 seconds after each period of motor activity. The experiment was conducted in the first half of the day in a specially equipped laboratory, where the volunteer was in comfortable environment, eliminating the presence of distracting factors, such as background noise and bright light.

2.3 Methods

To detect the precursor of the hand movement, the EMG signal was numerically filtered in the frequency band 1–10 Hz, then smoothed by a sliding window of 2 s in length, after which the derivative of the signal was found along the smoothed series.

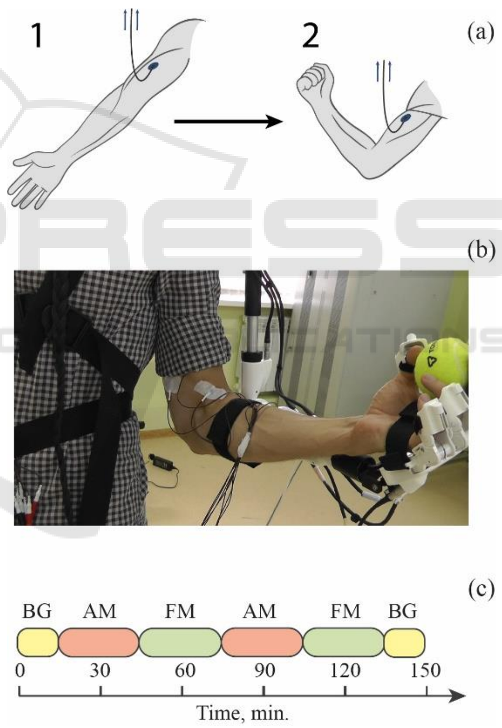

Figure 1: (a) A schematic representation of the movement of the subject's hand with a connected sensor for measuring the EMG signal during the experiment; 1 corresponds to the extension of the hand, and 2 – to the flexion. (b) Photograph of the subject's arm with sensors for measuring EMG signals and exoskeleton. (c) The structure of the experiment that contains the following sessions: BG, AM and FM denote a single period of background activity, audio stimulated movement and free movement, respectively. Each session was preceded by the video message with instructions.

Comparing the original EMG signal and the derived derivative, it was found that at the time points corresponding to the beginning of the movement, value of the derivative exceeds the threshold value.

Thus, comparing the received signal with the threshold value at each moment of time, the moments corresponding to the beginnings of movement (precursors of the movement) were determined. Figure 2 shows a fragment of typical raw EMG signal recorded from an elbow muscle (Fig. 2*a*), smoothed time series of the EMG (Fig. 2*b*), and its derivative (Fig. 2*c*). The grey line corresponds to the threshold value of the derivative used for automatic detection of the moment of movement beginning.

The red risks mark the moments of the sound signals corresponding to the commands. The Fig. 2 shows that a sharp increase in the amplitude of the registered signal corresponds to the moments of the beginning of the movements.

3 RESULTS

On the basis of the conducted research, the optimal threshold value of the derivative of the EMG signal was determined, which ensures the best ratio of the sensitivity and the percentage of false conclusions of the algorithm for determining the moments of the movement beginning. This value is equal to 0.5 of the maximum value of the series derivative.

Fig. 3 shows the dependencies of true positives (TP) and false positives (FP) of the algorithm for determining the movement beginning on the threshold value R. The threshold value varied in the range from zero to the maximum value of the series with a step of 0.05. It is clearly seen from Fig. 3 that the maximum difference between TP and FP (the best accuracy of the algorithm) is observed at the value of

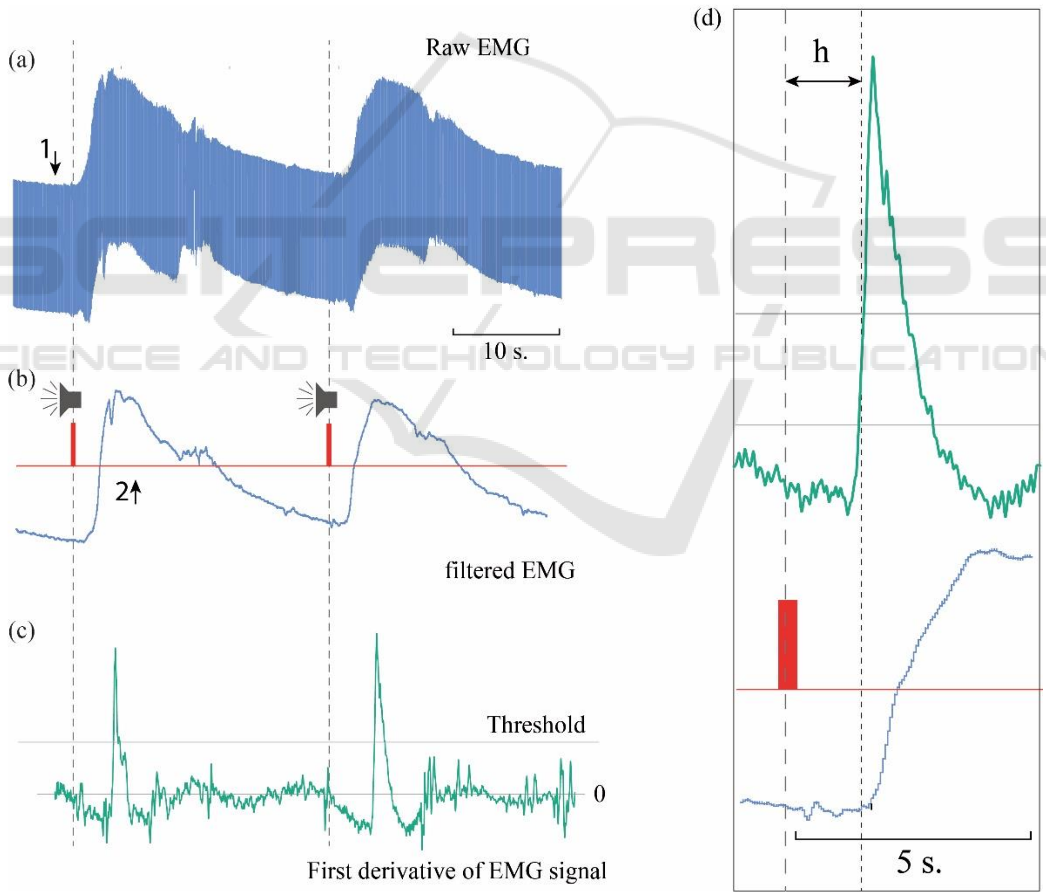

Figure 2: (a) Fragment of the original (raw) experimental EMG signal; (b) smoothed and filtered EMG signal (blue curve); (c) its derivative (green curve). The moments of the sound signals are marked in red, the line of the threshold value used to determine the moments of the beginning of the movements is marked with the grey line (threshold). (d) Enlarged fragment of the filtered signal and its derivative, which demonstrates the delay *h* between the moment of presentation of the sound signal and the moment of beginning of the movement.

R equal to 0.5 of the maximum value of the series. Note, that this value of R was then used to calculate the distribution of delays h between the time of sound signal presentation and the beginning of the movement. The advantage of this approach is its simplicity and speed, compared with more accurate and complex methods that require individual training of subjects.

Indeed, it can be seen from Fig. 2 that there is a time delay h between the moment when the sound signal is presented, and the detected time moment (precursor) of movement beginning. The analysis of the characteristic time delay h is shown in Fig. 4 in the form of the distribution obtained in one typical experimental session. The blue curve in the figure is Gaussian kernel density estimate.

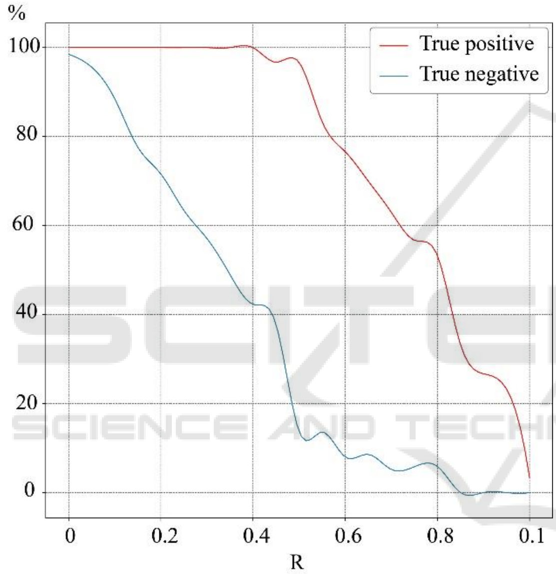

Figure 3: Dependencies of true positives (TP, red curve) and false positives (FP, blue curve) of determining the movement beginning on the threshold value *R*. The dependencies are given in percent.

It can be seen that the mode of the distribution corresponds to the time 1.6–1.8 s. The narrowness of the distribution obtained suggests that the preparation time for movement can be estimated and then considered in the experiment without presenting a sound signal. The causes of the time delay detected in the work may be related to the processes of the stimulus processing and movement planning. In this context, the use of EMG signals provides great potential for identifying the various phases associated with the implementation of human motor activity. The modern concept of the mechanism of conditional connection closure (Hazy et al., 2009) assumes that the association of excitation foci corresponding to the conditioned and unconditioned stimuli can occur both at the level of the cortex and at the level of the subcortex. With continued flowing along specific paths to a certain limited cortical focus of afferent impulses, gradually generalized excitation is concentrated in this focus. Then it gives a significant part of its influence on the construction of movement to the underlying foci of excitation, which have the advantage that afferent proprioceptive impulses continue to flow to them.

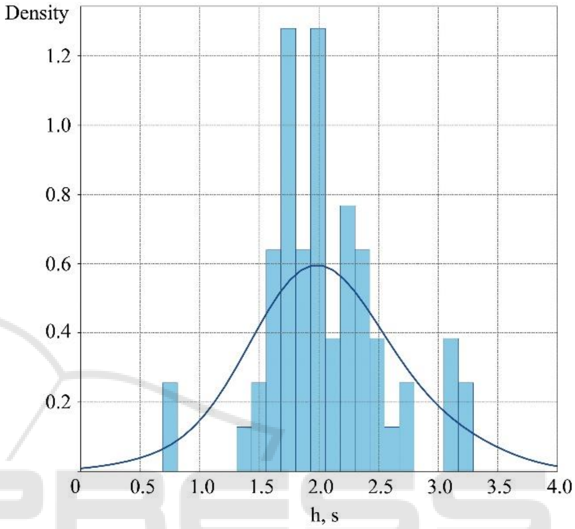

Figure 4: The distribution of time delays between the moment of presentation of the sound signal and the detected time moment (precursor) of movement beginning. The distribution is based on the results of one experimental session consisting of a series of repetitions of the movement. The results were obtained for the optimal threshold value *R* for the derivative of the smoothed EMG signal. The blue curve is Gaussian kernel density estimate.

Recent studies indicate the presence of delays in the activation of sensorimotor processing in the human brain associated with the phases of formation, recognition of the stimulus, categorization of response, decision making and reaction of afferent neurons that have times comparable to those obtained in this work, although they take less values due to the specifics of the experiment (Melnik et al., 2017; Asakawa et al., 2014).

It should be noted, that the distribution in Fig. 4 is rather well approximated by the Gaussian-like distribution. The time it takes for the pulse to travel from the brain to the muscle and the reaction time of the muscle are approximately constant for all repetitions of movement. Consequently, the noise component, which determines the form of distribution of the time delay h (Fig. 4), is a consequence of the processes occurring in the brain, when processing the stimulus and the generating the control signal. Indeed, the effect of “brain noise” was discovered in (Pisarchik et al., 2019; Runnova et al., 2016). Thus, it can be assumed that the initial state of the brain before each act of movement is different and is determined by the processes in the brain at this moment, which determines the noise nature of the distribution.

4 CONCLUSIONS

In the work, a method was proposed that allows to automatically determine the precursor of the movement beginning, based on the analysis of EMG signals. It was found out that in the case when the motion begins on the sound signal, the moment of the start of motion is detected some time after the signal, the distribution of which is approximated fairly well by the Gaussian-like distribution. Possible causes and background of the obtained results are discussed. The obtained results can be used to isolate the phases of “movement planning” and contribute to solving a number of applied problems associated with improving the quality of life of people and with development of human-machine interfaces. The proposed technique has the potential for application in human-machine interfaces.

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