Brain activity diagnostics system for exoskeleton control

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***Abstract*—In this work we develop the method of determining the moment of time of the beginning of the act of the imagination of movement by the analysis of the electroencephalograms according to the data that were obtained during experimental research when subjects are performing acts of imaginary movement. In the course of the experiment, we gained the electrical signals of the brain activity. The signals that have undergone preprocessing and filtration were used to test the method of determining the beginning of movement. To demonstrate the abilities of the method, the dependencies of the average power in the alpha band and the topograms were built. The obtained algorithms were used to detect and identify patterns of neural activity that occur in the imaginary movements, as well as their features, that could be used for the exoskeleton control.**

***Index Terms*—EEG; imagination; motor activity; data analysis; exoskeleton**

I. Introduction

The ability to imagine and model new objects, sensations, and concepts in the mind without directly influencing the senses is known as imagination. It is a complex phenomenon that is difficult to study, understand and explain. The study of brain activity to control motor activity is a complex problem at the interface of neurobiology, medicine, nonlinear physics, and engineering. This problem is closely related to the neurorehabilitation of stroke patients suffering from motor and cognitive disorders. Publications in scientific journals devoted to the experimental study of the essence of imagination appeared at the beginning of the 20th century [1]. Since then, thanks to the efforts of cognitive scientists, there has been a rich theoretical base that attempts to explain the nature of imagination. The most important fact obtained by recent studies of imaginative motor activity is the distinction between types of images based on the subject's attempts to reproduce them in his or her mind. Such distinctions exist between imaginary movement and motor activity [2]. Nevertheless, although they all represent important areas of research, the present study focuses mainly on the latter type of imagination. Since motor imagination assessment has a wide range of applications (for the development of brain-computer interfaces [**?**], [3]–[9], rehabilitation tasks [10], [11], prediction and prevention of neurodegenerative disorders [12]–[15], research and diagnosis of psychoses [16], sports [17], [18]), we also consider an important problem related to the study of the possibility of improving the performance of imaginative movement by external influences on the brain in the form of transcranial magnetic stimulation. This leads to a better understanding of the nature of motor imagination, which may help in the future to develop theories of motor imagination and provide a proven description of the physiological processes underlying motor imagination as a reference model for image evaluation in future studies. The aim of this work was to develop a method for determining the moment of initiation of the act of imagining movement from electroencephalogram (EEG) signal recordings that could be used for the limb exoskeleton control.

This work has been supported by the Center for Technologies in Robotics and Mechatronics Components (Innopolis University).

II. Experimental setup

To develop an algorithm for determining the beginning of imaginary movements, a specially developed experiment was designed. During the experiment, signals were recorded during real and imaginary movements. 30 people from among the employees and students of Innopolis University took part in the experiment. The selected participants in the experiment did not have a medical history of lace-brain injuries, strokes or neurological diseases. In the general case, during the experiment, the activity of the brain in the form of EEG was registered [19], [20]. For registration of EEG Activity we used the electroencephalograph "ActiChamp" (Brain Products, Germany). EEG signals were registered for 31 channels, which are located on the skin of the subject in accordance with the "10-10" scheme. The grounding is located at the site of the "FPZ" electrode, and the electrode acting as a referent is placed behind the right ear. For the registration of EEG, active Ag-AgCl electrodes "Acticap" are used, which are placed in the nests of the special cap "Easycap". The scalp of the head was processed by the abrasive gel "NUPREP", which serves to cleanse and degrease the surface of the skin. Then the electrodes are installed using the conducting Supervis gel. These procedures are used to ensure the best conductivity between the skin and electrodes, which leads to an increase in the overall quality of the recorded EEG signals. During the experiment, conductivity values on each of the EEG electrodes

978-1-6654-6174-0/22/$31.00 ©2022 IEEE

were also deployed: less than 25 kOhm values are sufficient for the proper operation of active EEG electrodes and obtaining good quality signals. The frequency of sampling of EEG signals is 1000 Hz.

All volunteers are selected in accordance with the following requirements: right-handed people, non-smokers, not professional athletes, who do not take medications, without neurophysiological diseases and diseases of the motor system. Within 48 hours, before the experiment, volunteers are asked to adhere to a healthy lifestyle: at least 8 hours of sleep, avoid alcohol consumption, exclude or limit the consumption of caffeine, and avoid excessive physical exertion. All experimental work is carried out in the morning in the room with a sufficient level of natural light. Before the experiment, the extensive briefing is carried out, during which they are informed about the goals and methods of the experiment, and about the possible inconveniences related to its conduct. Volunteers have the opportunity to ask all questions of interest and get exhaustive answers to them. Each subject signs a form of informed consent to participate in the experiment. All experimental work is carried out in accordance with the requirements of the Helsinki declaration. The subject is located conveniently in the chair, the hands lie on the armrests. In front of the subject, about 80 cm from the eyes, a monitor is installed, on which, in the course of the experiment, text commands are presented, informing about the current phase of the experiment or the need to make a certain movement. The following types are used: execution of the real/imaginary movement with the left/right hand; rest between two consistent traffic executions; break between two main sessions in the experiment; recording background activity at the beginning and end of the experiment.

The design of the experiment is schematically presented in Fig. 1. Each experiment begins and ends with a recording of the background activity (180 s), during which the subject needs to be in a calm state, try not to make any movements, keep his eyes open. The main phase of the experiment consists of two sessions. During session 1, the subject performed real movements with the left or right hand-in accordance with the text of the team on the monitor. During session 2, the subject imagines the movements with the left or right hand in accordance with the text of the team on the monitor. Imaginary movements are similar to movements that are actually performed in a session 1. Each session consists of 20 movements (trials)-10 real or imaginary movements for each hand. Trials with the movements of the left and right hand are placed randomly inside the session. Between sessions 1 and 2, a short break is made (180 s). Each individual trial consists of a basic level (5 s), a text command indicating the required type of movement (15 s) and rest (15 s), as shown in figure 2. The text command is on the monitor within all 15 s. After this time the subject needs to clearly perform movements of the required type several times. The rest interval lasts from the end of the previous text command to the next. The interval for the basic level is taken from rest after performing the previous movement. During further data analysis, the brain activity during the basic level is subtracted from activity during movement to suppress effects associated with the general state of the subject, and the obtaining of a more clearly pronounced dynamics of activity associated only with the implementation of movement. The performance of movement on each trial (Fig. 1) is a multiple flexion/extension of all five fingers to the center of the palm, reminiscent of compressing/unclenching an imaginary ball in the hand. Flexion/extension of the pallets is performed at a speed comfortable for the subject.

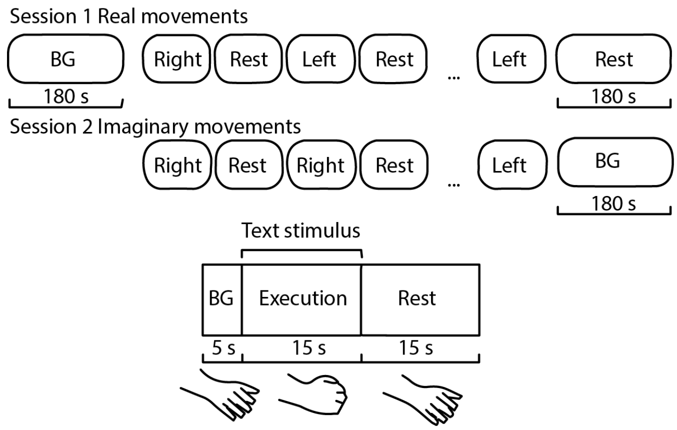

Fig. 1. the developed design of the experimental study in general form and the demonstration of the movement performed on a separate trial. BG denotes background activity

III. Methods and Results

Taking into account experimental setup, the following decision was proposed. The first step is an analysis in an intermediate range between alpha and beta: from 10 to 14 Hz. The analysis is performed using Morle wavelet on the entire affordable temporary range on the EEG channels that are related to the motor zone (FC5 FC1 FC2 FC6 T7 C3 C4 T8 CP5 CP1 CP2 CP2 CP6). Further, from both ends (counting in time), each frequency-temporal surface is excluded at 0.5 s. to eliminate the regional effects caused by the impairing transformation. Part of the data corresponding to the pre-stimulus is averaged, after which it is used for the percentage of data that is related to the post-stimulus. Percentage correction is carried out according to Eq (1):

$$\overline{P_{ij}} = \frac{p_{ij} - b_i}{b_i} \tag{1}$$

where p is the point of the wavelet surface corresponding to the post-stimulus, b is the point corresponding to the time-averaged wavelet surface of the pre-stimulus, i and j are the frequency and time indices, respectively. The obtained data are then averaged over time. To find the moments of desynchronization (the beginning of imaginary motion), a cluster-based permutations on the one-sample t-test is applied. The unit of observation here are trials, each of which corresponds to a matrix of values with dimensions (1000, 13), where 1000 is time (from 5 to 9 s, with a sampling rate of 250

Hz, respectively), and 13 are channels. Before testing, the adjacency matrix for channels and points in time is built, which is then used in clustering. The testing procedure itself is performed as follows: for the original data the t-values are calculated by Eq. (2):

$$\bar{t} = \frac{\overline{X} - \mu}{s} \tag{2}$$

where $\overline{X}$ is the test-averaged value of each matrix point, s is the standard deviation of this value, and μ is the test value of the mean corresponding to zero. A threshold corresponding to the five percent critical level of the t-distribution is then applied to the obtained values. The remaining values are then clustered using the adjacency matrix calculated earlier. Each cluster can contain at least two values, and the so-called cluster statistic (in our case, it is the sum of all t-values in the cluster) is calculated for each cluster, the permutation distribution of which will be compiled next. The distribution itself is compiled as follows: some number of trials is selected, then their values are multiplied by -1, and the cluster statistics in existing clusters is recalculated. Since the number of all possible permutations grows factorially as the number of trials increases, the Monte-Carlo method was chosen to estimate the permutation distribution, in which not all possible permutations are carried out, but only a random part. In the case under consideration, the number 2000 was chosen for each person from the test group. Thus, for each cluster its significance is estimated using constructed distribution. A cluster is considered to be significant if its significance level is higher than 95%. If no significant clusters are found, a new threshold value for t-values is calculated using a list of critical levels (5%, 2.5 %, 1.25 %, 0.1 %). The results obtained are then used to calculate the motor imagination onset time. For this purpose, the earliest significant cluster is chosen, the available t-values in it are averaged over the significant channels, and then the first local minimum is chosen. The time of occurrence of this minimum reflects the greatest desynchronization in a range from 10 to 14 Hz that meets the requirements of motor function activation.

Fig. 1 shows the test results of the developed algorithm for one of the volunteers. Identified clusters are shown on the right, and the topograms of t-values that fell into the cluster, on the left. The dependencies of the power of power in the alpha band with standard deviations are shown in orange and t-values averaged through the channels falling into the cluster in blue. In addition, the dependence indicates the moment of time defined using the algorithm. In the presented drawings, the moment of switching of t-values is clearly visible, for the channels of those who get into the cluster and this characterizes how well the proposed algorithm works.

IV. Conclusion

Thus, in the course of the study, a comprehensive analysis of the process of identifying and identifying patterns of neural activity that arise during the imagination of movements, as well as their features, compared with real moving activity

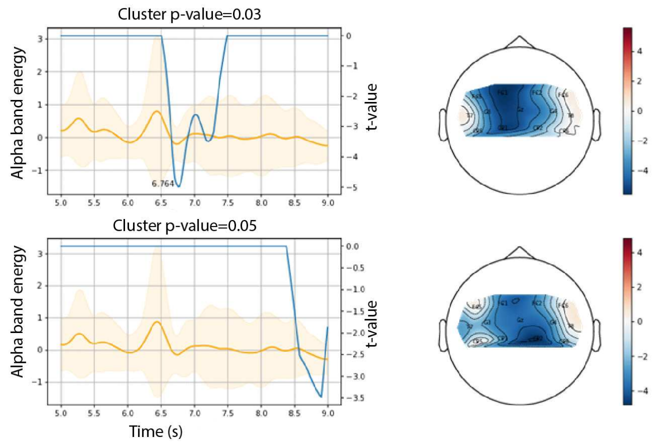

Fig. 2. The dependences of the power of power in the alpha band with a standard deviation (orange) and t-values averaged through the channels that are in the cluster (blue) and the corresponding topograms.

and observation of movements, was carried out. During the algorithm development to determine the moment of movement beginning, which is the main goal in the task of the control of robotics-and-based systems for rehabilitation and training using the interface of the brain-computer and feedback technology, the following idea was taken into account. Since the imagination is linked to motor activity, we must observe the activation of the motor function, which is well characterized by a failure in the alpha band. However, it is important to take into account that, unlike real movements, the processes that occur during motor imagination have great variability. It should also be remembered that the imagination belongs to complex cognitive functions, as a result of which there is a tendency to manifest activity, in a larger step-no one, in the beta-band (from 15 to 30 Hz) than in the alpha band (from the alpha band (from 8 to 12 Hz).

In addition, classification and correlation by brain areas was carried out, activated during various types of movements, to find the most plausible and often observed results on this issue. As a result, the brain topograms were obtained characteristic of the completion of the actual movement. These results can help better understand the nature of the imaginary movement, which is useful for future developments of theories, and provide proven descriptions of physiological processes underlying the motor imagination as a reference model for a future assessment of imagination in a new study. In turn, such a study can be useful for a wide area of application, including sports, music, disease prevention and rehabilitation. An experiment was developed and conducted with the EEG signals during the performance of imaginary movements. The development of the management algorithms for rehabilitation exoskeleton tasks was carried out. The resulting algorithms were used to identify and identify patterns of neural activity that arise during the imagination of movements, as well as their features, compared with real motor activity and monitoring of movements.

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