Post-stroke rehabilitation with the help of brain-computer interface

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***Abstract*— We considered a group of 50 patients with lateral paresis in the acute period after the first stroke. The EEG recordings in the group of post-stroke patients displayed fundamentally different brain dynamics during real movements of a conventionally healthy hand and a hand with decreased muscle strength. While for the conventionally healthy hand the brain activity in the sensory zone is quite close to the dynamics observed in the control group, for the paretic hand there is pathological activity associated with increased activity in low frequency ranges (up to 12 Hz). Meanwhile, the brain activity during imaginary motion is similar for both hands and hence to the dynamics in the control group of conditionally healthy subjects. The obtained results can be used in rehabilitation techniques based on imaginary motor activity with the help of brain-computer interface.**

Keywords—brain-computer interface, post-stroke rehabilitation, EEG, motor imagery

I. Introduction

The rehabilitation of patients with neurological symptoms is very important for their adaptation to ordinary life. The success of neurosurgical practice and pharmacology allowed a large number of patients to return to normal conditions, that became amatter of social and medical rehabilitation services. However, no more than 20% of post-stroke patients are able to recover their mobility functions. The rest remain disabled with varying degrees of severity and need medical and social support [1–4]. The most frequent consequences of strokes are motor disorders in the form of different paresis, occurring in 80% of patients after a cerebrovascular catastrophe, in half of them the pathology persists for life [5].

In this paper, we consider the issues of primary rehabilitation in the tasks of returning the patient's motor activity and suggest the brain-computer interface for neurorehabilitation.

II. Materials and Methods

A. Participants

Eighty subjects were involved in the experimental study and formed two groups. The 57 control group (group I) contained 30 practically healthy voluntaries selected on the base 58 of their medical records and anamnestic data. The test group consisted of 50 patients 59 with motor disorders with the first established diagnosis of "cerebral infarction, acute 60 phase" confirmed by neuroimaging data. The patients included in the test group had a 61 diagnosis of atherothrombotic cerebral infarction in the pool of the left or right middle cerebral arteries. The main neurological deficit was represented by hemiparesis on the left or right side. These patients were referred, respectively, to subgroup II and subgroup III. The time from the onset of the disease to the study was 5 ± 2 days. Motor abnormalities were assessed according to the British scale for assessing muscle strength (average score 2 ± 1). The main criterion for inclusion in the test group was the stabilityachieved by the patient in a post-stroke condition. The average age of the patients under study was 63.7 years in the range of 59–72 years. In the control group, the 69 average age of the participants was 48 years within the range between 39 and 68 years.

B. Experimental setup

The experiments were carried out with each subject independently. The electrical brain activity was recorded using a monopolar registration method based on an extended arrangement of EEG electrodes according to the "10–10" scheme which allows the evaluation of the activity of the cerebral cortex from projections of all main zones. The cup adhesive Ag/AgCl electrodes were placed on the "Ten20" paste. Before the experiment started, we performed all necessary procedures for increasing the skin conductivity and reducing its resistance using abrasive a "NuPrep" gel. The impedances were monitored after the electrodes were installed, and measured during the experiments. Usually, the impedance values varied within the 2–5 kΩ interval. The ground electrode N was located in front of the head at the Fpz electrode location. The EEG signals were filtered by a 50-Hz Notch filter and a band-pass filter with cut-off points at 1 Hz (HP) and 100 Hz (LP). The amplifier "Encephalan-EEGR-19/26" (Medicom MTD company, Taganrog, Russian Federation) was used to record bioelectric signals. This EEG recorder possesses the registration certificate of the Federal Service for Supervision in Health Care No. FCP 2007/00124

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of 07.11.2014 and the European Certificate CE 538571 of the British Standards Institute (BSI).

During the experiment, each subject was sitting in a comfortable position. The experiment began with the registration of the state of passive wakefulness (rest state), 3 minutes with open eyes and 3 minutes with closed eyes. During further (active) experimental stages, the subjects were required do not close their eyes for a long time and follow instructions on the screen. The subjects were instructed to perform either real or imaginary movement of one of the hands according to the command written on the screen when they heard a beep.

C. *Methods of the data analysis*

Firstly, we have used empirical mode decomposition method for mitigation of artefacts on registered EEG [6,7]. Second, we have used the continuous wavelet analysis for estimation of time-frequency structure of EEG signals [8].

Standard tests were used for statistical analysis of medical data to calculate mean, median, and the range of variation for obtained assessments for the groups of subjects. The separation of the obtained classes of patients was additionally using the Wilcoxon nonparametric criterion.

III. Results and Discussion

In contrast to earlier studies, in this work we consider the overall EEG activity in a wide frequency range, but not only track changes in the dynamics of a sensorimotor rhythm reflected electrical brain activity in the alpha band [9]. The analysis of the brain activity in all frequency ranges allows us to distinguish differences not only between post-stroke patients, but also in the group of healthy subjects, as well as to reveal 381 differences between EEG responses to motor imagery of the left and right paretic and healthy hands

A debatable issue is the situation in which the imagined motor activity of a paretic hand in the most acute period exhibits dynamics in the sensory region similar to healthy subjects. We considered the spatial distribution of changes in the beta and gamma ($f > 12$ Hz) and low frequency ($f < 12$ Hz) range activity, which will allow us to assess changes in the sensorimotor zone and compare them with the activity of the remaining brain areas.

The qualitative analysis of the results for real movements of the post-stroke patients allows us to treat the observed patterns as a local change in the activity characteristics during real movements, mostly the right and left hemispheres are involved near the boundaries with the sensorimotor region, close to the lesion zone visible in the MRI. This results can be correlated with the results of the assessment of the smallest fractal dimension in the lesions [10].

At the same time, the localisation of changes in motor imagery of post-stroke patients is much more complicated. These changes occur in the central, occipital and temporal areas. Whereas, in the control group of practically healthy subjects, the changes are mainly localised in the central zone, similar to real motor activity. Such qualitatively different dynamics of motor imagery of the right and left hands is possibly associated with the activation of a compensatory mechanism for circumventing the post–stroke disturbances of conductive paths.

Thus, early rehabilitation on the basis of imaginary motor activity allows recuperating conditionally normal activation of the sensorimotor brain area as for a hand with preserving muscle strength, as for a paretic hand. Significant improvement of the rehabilitation quality, especially in clinical conditions, was obtained by using biological feedback systems.

We have suggested the brain-computer interface (BCI) developed in our group and tested during the rehabilitation activity. Fig. 1 represents a block diagram of the BCI.

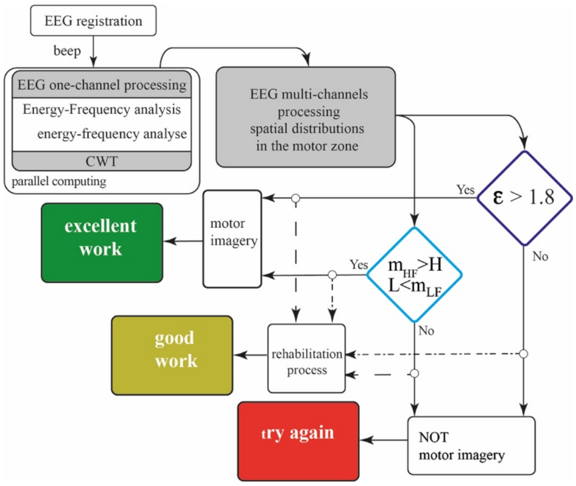

Fig. 1. Diagram of patient's work cycle during motor imagery using the brain-computer interface.

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