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The study of human higher mental functions as they relate to neurophysiological processes and personal characteristics

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ABSTRACT

In this paper we study the correlation between the neurophysiological processes and personal characteristics arising in the processes of human higher mental functions. We find that the activity of the brain correlates with the results of psychological tests (according to the Cattell–test). Experimental studies and math processing are described for operation design with the registration of human multi–channel EEG data in two phases (the processes of passive wakefulness (background) and special psychological testing (active phase)).

Keywords: Electroencephalogram, continuous wavelet transform, psychological testing, neuroscience

1. INTRODUCTION

Since ancient times, scientists have been interested in the correlation and the connection between the psychological and neurophysiological description of a person.[1,2] Today studies of same connection are productive and often connective with interdisciplinary works integrated the efforts of researchers of various humanities and natural sciences.[2] In particular, there are many experimental studies that the psychological experiment is integrated with various methods of recording the functional characteristics dynamics of the human brain. In such psychophysiological studies, the method of electroencephalography (EEG) is often used as a noninvasive method for recording brain activity. EEG does not cause any special inconvenience to the subjects and does not impose great restrictions on experimental conditions and simultaneously provides significant spatial and temporal resolution in the records of brain electrical activity.[3] In our work, we register the EEG activity of the subjects brain in the process of testing their ability to concentrate based on a standard psychological test. We have set the goal of this study to identify the correspondence between the intellectual characteristics of a person and the characteristics of the brain activity on the EEG data.

2. EXPERIMENTAL METHODS

Twelve healthy males volunteers between the ages of 35 and 45 participated in the experiments. All of them signed a written consent. The experimental studies were performed in accordance with the Declaration of Helsinki and approved by the local research Ethics Committee of the Yuri Gagarin State Technical University of Saratov. Experimental work with volunteers was conducted independently, before starting subjects did not know about the experiment conditions. The experiments were carried out during the first half of the day at a specially equipped laboratory where the volunteer was siting comfortably and effects of external stimuli, e.g. external noise and bright light, were minimized. We conducted all the measurements with the subjects after a full night's rest and after 1 to 2 hours after the end of breakfast to create the same type of physiological conditions for all volunteers.

The multi-channel EEG was recorded at 250 Hz sampling rate from $N = 63$ electrodes with two reference electrodes used the standard monopolar method of registration.[4] To register EEG data we used adhesive Ag/AgCl electrodes fixed in special prewired headcaps. The ground electrode N was located above the forehead and two

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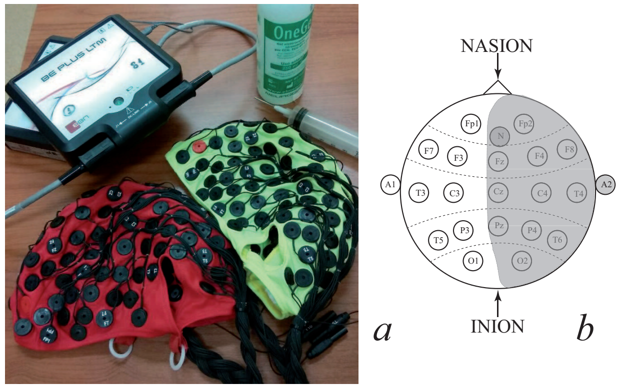

Figure 1. *a* The standard equipment "Be Plus LTM" (EB Neuro S.p.A., Italy), used in experimental study. *b* The scheme of the monopolar registration method. The zone of electrodes, whose signals are recorded relative to electrode A2, is grayed out, signals of the white scalp zone are recorded relative to electrode A1. Only 19 electrodes of classical arrangement "10–20" are shown for reading ease.

reference electrodes $A_{1,2}$ were located on mastoids. The EEG signals were filtered by a band pass filter with cut-off points at 1 Hz (HP) and 300 Hz (LP) and a 50-Hz Notch filter. The electroencephalograph "Be Plus LTM" (EB Neuro S.p.A., Italy) with multiple EEG channels was used for amplification and analog-to-digital conversion of the EEG signals. Standard equipment is shown in Figure 1. Each of twelve participants was subjected to one experiment, lasting approximately $40 - 50$ minutes.

The first part of the experimental work included the psychological block consisted in the psychological test aimed at revealing the static accentuations of the individual and the operational state of the individual at the time of the research. Testing included about 80 questions from a multifactor psychodiagnostic technique on the Cattell–test.[5] In the second part of the experimental work, testing was supplemented with a personal conversation of the subject with a specialist who had experience in composing an individual psychological portrait. During the conversation, human EEG signals were recorded. At the end of the active phase of the experiment, the background signal was recorded in $10 - 15$ minutes, when the subject was in a state of passive wakefulness. If necessary, the data were subjected to filtration procedures similarly as in the works.[6,7]

3. DATA PROCESSING

TREATMENT OF PSYCHOLOGICAL TEST RESULTS

The treatment of the results of psychological testing by the method of Cattell allowed to divide participants into three equal groups (4 subjects each):

1. a pronounced tendency to work alone, low self-control, intolerance to uncertainty and delay in decision-making, which can be expressed in anxiety;
2. high scores on the scales of intellect, emotional maturity, self-control without accentuation of scales;
3. a pronounced tendency to work alone, a high intellect, an analytical mindset and critical thinking, an intolerance of uncertainty and procrastination in decision making.

The first and third groups of subjects demonstrate similar results. However, the third group is distinguished by higher self-control, lack of anxiety, expressed leadership qualities.

MATHEMATICAL PROCESSING OF EEG SIGNALS

We studied the involvement of areas of the cerebral cortex in high-frequency activity. As a basis for creating research methods, continuous wavelet analysis was chosen, which proved to be a powerful tool for cognitive research.[8–11] On the basis of the Morle wavelet, wavelet energy distribution surfaces for the spectrum $(0.1 - 60$

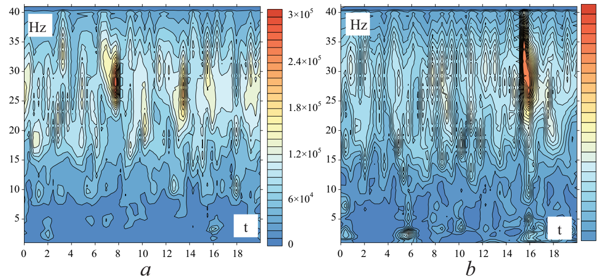

Figure 2. The energy surfaces of the continuous wavelet transform calculated from the fragments of the signal recorded at the electrode F3: *a* and *b* calculated with accumulation over the entire duration of the active and passive phase of the experiment, respectively.

Hz) and signal acquisition time were constructed. We compared two different psycho-physiological states of a person — the phase of passive wakefulness and the phase of a personal interview with a specialist. Figure 2 shows typical examples of surfaces for channel F3. Evaluation of time dynamics by duration, even in 10 minutes of background recording and about 20 minutes of the active phase, is a very difficult task, which reduces to the situation of manual analysis. To illustrate the difference between the active and passive phases in the experiment, the averaged surfaces of wavelet energy with a floating time interval were constructed for the entire period of active interview and passive wakefulness (see Figure 2 *a*, *b*). Despite the visual difference between the wave dynamics in different phases, a specific analysis of the identified features is difficult, both from the volume of data for even 12 subjects, and because of the complexity of their presentation. To reduce the amount of data and for the subsequent automation of the processing process, an approach based on the detection of prevalent frequencies in the wave dynamics of each channel was used. A method based on the study of skeletons of wavelet transform was developed. The dynamics of skeletons of a continuous wavelet transformation proves to be more informative (an example for channel F3 is shown in Fig. 3 *a*, *b*). However, the EEG signals analyzed are highly non–stationary, and in the analysis of skeleton characteristics, one can observe rapid "switching" of even the three older skeletons between each other, which reduces the possibilities of signal analysis. In order to avoid such situations, a method was created based on the introduction of energy characteristics estimating the percentage of oscillation energy per each of the traditionally allocated EEG bands (alpha, beta, delta, etc., whose dynamics for channel F3 is shown in Figure 3 *c*).

4. RESULTS

After carrying out calculations in the single-channel mode of energy characteristics, an spatial distribution, averaged over the time of the active and passive phase of the experimental work for each of the subjects, was evaluated for each EEG signal. All spatial distribution of the scalp wavelet characteristics was further divided into registration zones (Frontal lobe, Temporal lobe, Parietal lobe, Occipital lobe). The calculation of the energy characteristic was carried out in relative units relative to the energy in the considered range for the entire scalp. Then, two zones of neurophysiological activity were considered - oscillations at high frequencies (from 20 to 60 Hz) and low frequencies (1 - 20 Hz). Methods based on the evaluation of the energy characteristics of the observed wave dynamics are now actively used in neuroscience.[12–16] The distribution results for the subjects are shown in Table 1. In addition, for each subject in Table 1, the group number is given, which includes the results of his psychological testing.

Note that the results of analyzes of all subjects on high and low-frequency wave activity are divided into three groups. For the first group, the ratio $\frac{HR}{LR}$ varies from 4 to 5, in the second — 1 – 2, and in the third — 8 – 9. Thus, the analysis of EEG data allows us to classify a group of Dobrovtsi into three subgroups, and these subgroups, as can be clearly seen from Table 1, coincide with the results of psychological typing.

In the work we found a correlation between the characteristics of a person revealed in classical psychological testing and its neurophysiological features of the functioning of the brain on the EEG.

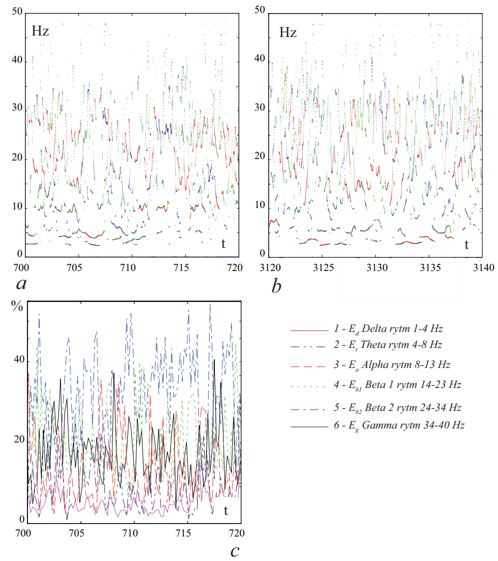

Figure 3. *a*, *b* — dependencies of skeletons of the continuous wavelet transform for the active phase of the experiment and passive wakefulness, respectively. *c* — the calculated value of the energy of the wavelet transformation in the active phase pertaining to different energy ranges (from delta to gamma bands, colors are shown in the legend in the figure)

N	HR	LR	HR/LR	G_{test}
1	17	4	4,25	1
2	19	4	4,75	1
3	5	5	1	2
4	25	3	8,33	3
5	10	8	1,25	2
6	30	3,3	9,09	3
7	28	3,5	8	3
8	22	4,4	5	1
9	7	4	1,75	2
10	27	6,59	4,1	1
11	7	6	1,17	2
12	33	3,9	8,46	3

Table 1. Summary results of data processing of a psychophysiological experiment. The first column (*left*) is the serial number of the subject, which has a random character for the anonymization of the research. The second and third columns are the fractions of the high- and low-frequency oscillations energy in the Frontal and Temporal lobes. The last column (*right*) is the result of passing the psychological Cattell–test of in terms of ranking in one of the groups described above.

We believe that the obtained results are of interest for fundamental science and applied works of psychological testing and diagnostics. The study of such forming strategies on EEG data can be automated and do not require the work of highly skilled psychologists. The results obtained are interesting from the point of view of the choice of training strategies for a particular individual. In addition, similar testing programs are objective and highly protected from "deception" to the subjects.

5. ACKNOWLEDGMENTS

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