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Analysis of psycho-physiological features of a subject in simple tests with the registration of electroencephalograms

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ABSTRACT

In this paper we found a correlation between the characteristics of a person revealed in classical psychological testing on the basis of Schulte tables, and its neurophysiological features of the functioning of the brain obtained from the time-frequency analysis of EEG. The results obtained are interesting from the point of view of the choice of training strategies for a particular individual. 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.

Keywords: Electroencephalogram, continuous wavelet transform, learning process, teaching

1. INTRODUCTION

Since ancient times, scientists have been interested in the correlation and causality of a person's personality traits and in his features of the functioning of the brain or, in other words, 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. 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.

The multi-channel EEG was recorded at 250 Hz sampling rate from $P = 19$ electrodes with two reference electrodes placed at the standard positions of the 10–20 international system[4] (see Fig. 1, *a*). To register EEG data we used cup adhesive Ag/AgCl electrodes. The ground electrode N was located above the forehead and two reference electrodes $A_{1,2}$ were located on mastoids. The EEG signals were filtered by a band pass filter with

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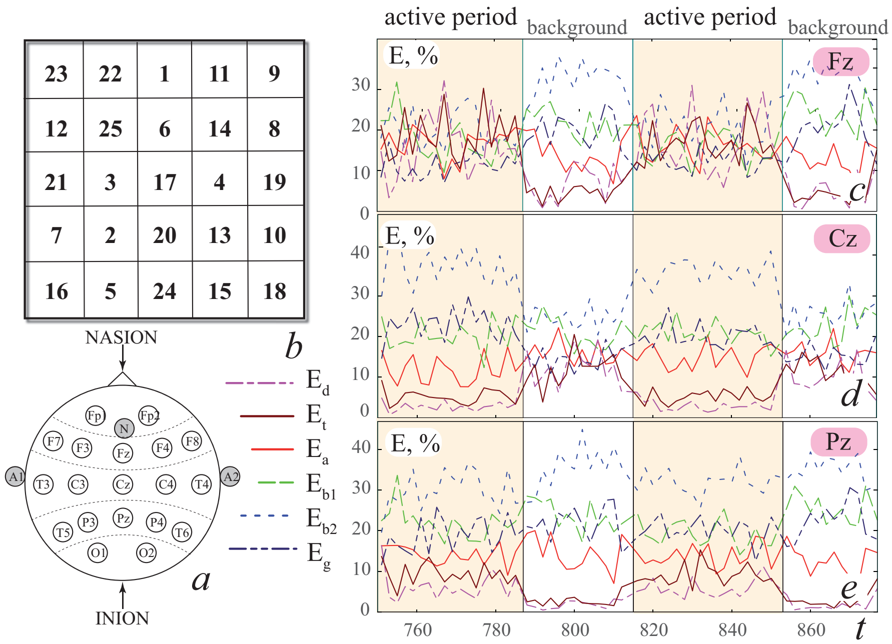

Figure 1. (a) International EEG electrode placement scheme "10–20". (b) The example of the Schulte table. (c) The time dependencies of wavelet energy, averaging on the frequency ranges δ, θ, α, β_1, β_2, γ.

cut-off points at 1 Hz (HP) and 100 Hz (LP) and a 50-Hz Notch filter. The electroencephalograph"Encephalan–EEGR–19/26" (Taganrog, Russian Federation) with multiple EEG channels was used for amplification and analog-to-digital conversion of the EEG signals. Each of twelve participants was subjected to one experiment, lasting approximately 30 minutes.

The psychological block of the experiment consisted of evaluating the cognitive functions of an individual using the methods of Schulte tables.[3,5–7] Note that the Schulte tables are a classic psychodiagnostic test for studying the properties of the individual's attention and it is one of the most objective methods of determining the work effectiveness and ability and the resistance to external interference. The Schulte table represents a square matrix with 5 columns and 5 rows, in which random numbers are placed numbers from 1 to 25. The Schulte table example is demonstrated in the Fig. 1, b. The volunteer task is to find the table all numbers in the reverse order. During experiment each person worked on 5 tables. Between the decisions of different tables, the volunteer had small time intervals of passive relaxation – short background phases of experiment. The time of each table passing is recorded and used to evaluate standard test person criteria: (1) the work efficiency **WE** (the arithmetic mean of the work table time), (2) the indicator of the work warming-up **WU**(the ratio of the work first table time to the WE), (3) the psychological stability **PS** (the ability to sustain the operational activity for a long time). Other words, these criteria can be describe by the following formulas:

$$WE = \frac{T_1 + T_2 + \cdots + T_n}{n}, \tag{1}$$

where T_i – completion time of table i;

$$WU = \frac{T_1}{WE}, \tag{2}$$

$$PS = T_n - \frac{1}{WE}. \tag{3}$$

The work efficiency illustrates the stability of attention and performance in dynamics. The result WU of 1 and lower shows good warming-up, while 1 and more means that one needs more time to prepare for the main work (warm-up). The PS result of 1 and less shown good psychological stability.

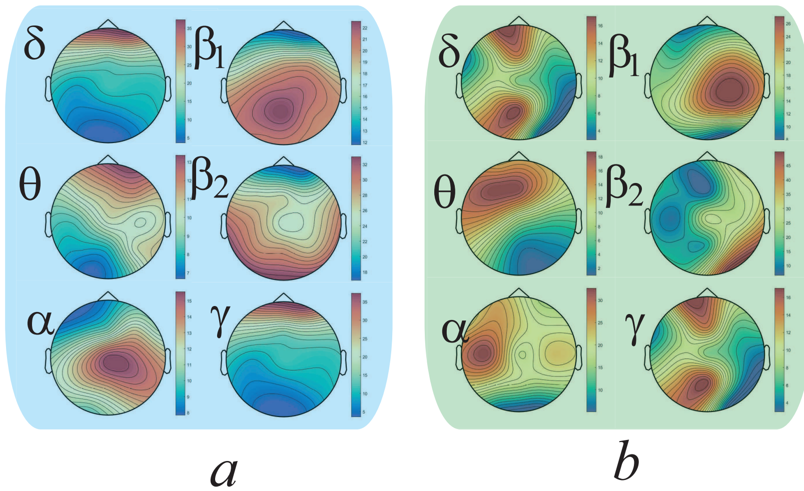

Figure 2. The spatial scalp distributions of the intensity of oscillations of different frequency ranges (a) for the first **I** and (b) for the second **II** groups

Time-frequency analysis of EEG recordings was based on the continuous wavelet transform[8–10]

$$W(a,\tau) = \frac{1}{a} \int_{-\infty}^{\infty} x(t)\psi\left(\frac{t-\tau}{a}\right) dt \tag{4}$$

where complex-valued Morlet-wavelet was chosen as the mother function[11]

$$\psi(\eta) = \pi^{-1/4} \exp\left(i\omega_0\eta\right) \exp\left(-\frac{\eta^2}{2}\right), \tag{5}$$

with $\omega_0 = 2\pi$ being the central frequency of the used Morlet mother wavelet and $i = \sqrt{-1}$.

The processing of the spectral representation of EEG data was conducted on the basis of traditional neurophysiological concept about the oscillations modes characterise of the brain electrical activity.[12] We consider the following frequency ranges f_δ: δ–range (1–4 Hz), f_θ: θ–range (4–8 Hz), f_α: α–range (8–12 Hz), $f_{\beta 1}$: β_1–range(14–25 Hz), $f_{\beta 2}$: β_2–range(25–34 Hz), f_γ: γ–range(34-40 Hz). For all spectral ranges of frequency and for each EEG channel n we estimated the oscillations energy based on the wavelet energy spectrum:[13–15]

$$E_f^n(t) = \int_{f_1}^{f_2} \left(W^n\right)^2 (t,f) df, \tag{6}$$

where f is the one of described frequency ranges (δ, θ, α, β_1, β_2, γ), f_1 and f_2 are the minimal and maximal boundary values, respectively.

3. RESULTS

At the first stage we estimated the dynamics of all frequency ranges for each EEG channel. In the Fig. 1, $-\ e$ we demonstrate a fragment of the processed time series that detectes that the wave dynamics varies in different frequency ranges for one of the subjects on the central channels Pz, Cz, Fz. One can see that a dynamic of low-frequency (δ, θ, α) and high-frequency (β_1, β_2, γ) oscillations has a different patterns. In particular, the dynamics of delta- (δ) and gamma (γ) activity vary substantially across all channels represented. Further, for the best representation of the different nature of the vibrational activity, we have gone over to the characteristics averaged over the time of each experiment stage:

$$E_f^n = \int_{t_1}^{t_2}\int_{f_1}^{f_2} (W^n)^2 (t, f) df dt, \tag{7}$$

where t_1 and t_2 are boundary values for time of active (a work of Schulte) matrix and background experimental phases. In Fig. 2 one can see the wave dynamics of different frequency ranges in the spatial and temporal representation. Maximal and minimal values of spectral intensity are shown by red and blue colors, accordingly.

Simultaneously, we evaluated the psychological testing results of the experimental subjects. Two main groups of subjects were identified. In the first group (**I**) of subjects we observed an attempt to make the task "head-on" and "on the attention concentration skill". EEG intensity activity prevails in the right hemisphere. The activity develops without the formation of a specific strategy for the fulfillment of the task. Efficiency of work WE at a high level — the average time of the series is 33 seconds. Psychological stability PE is 0.9 with target 1. The WU is 1.24 for target 1. Obviously, it is difficult for an experienced group to maintain such a pace of work for a long time. At the beginning of the test for the second group (**II**) there is a process of analyzing the problem, an attempt to simplify and formalize it by building a strategy. Within the first test, there is a maximum isolation between the half-spheres according to the high-frequency activity (the task is done on the forehead). Then the subjects develop a strategy for passing the test, which in turn, allows them to reduce the burden on the right hemisphere. At the same time, in the subjects of the given group the efficiency of work WE at a high level is the average time of the series of 33.6 seconds. Persistence of attention PE — 0.86 at target exponent 1. Average workability WU — 1.07 at target 1, little time is needed for adaptation. Subjects do not experience pronounced fatigue and are able to effectively maintain work for a long time.

In Fig. 2 *a* and *b* the wave activity distributions of various frequencies for typical representatives of groups **I** and **II** are presented, respectively. For presentation, the time interval of execution of table 2 is chosen, according to which the corresponding averaging (7) was performed. One can see that a representatives of the first and second isolated groups have a significantly different intensity distribution of the vibrational modes of electrical activity over the scalp projections of the brain zones. In particular, the first group is characterized by a smaller localization of foci of vibrational activity and greater distribution over vast scalp zones. The dentistry of delta activity in the two groups is fundamentally different, creating for the second group a powerful focus of high intensity in the occipital region, which may be related to the process of concentration on the developed strategy of behavior.

Separately, it is necessary to note the behavior of high-frequency oscillations, in particular, in the gamma-rhythm region (γ), which are only slightly expressed for the first group in the frontal lobes, and for the second, two extensive zones in left frontal and occipital lobes.

4. CONCLUSION

We found a correlation between the characteristics of a person revealed in classical psychological testing on the basis of Schulte tables, and its neurophysiological features of the functioning of the brain on the EEG. The described dynamics of delta-activity (δ) can be related to the lack of planning in group **I** of subjects and, on the contrary, to the presence of a strategic plan for the second. High-frequency oscillations of gamma-rhythm, possibly, are connected with the highly organized strategic activity of the **II** group of subjects. In group I, volunteers demonstrated fluctuations that were more localized in the frequency domains ($\theta - \beta_2$ frequency rhythms) in solving the problem posed "head-on" but, in all likelihood, large zones of the brain were involved in the enhanced generation. There is an opportunity to connect such behavioral features with the level of fatigue and problems with maintaining the pace of work for a long time. Further work plans to test and test such hypotheses by increasing the group of volunteers and strengthening the psychological block (working with preliminary psychological testing, adding a series of tests to determine the characteristics of a person). In addition, it is planned to clarify the nature of the vibrational activity in the scalp projections of the head mosaic by recording the high-frequency EEG dynamics using Be Plus equipment (EB Neuro, Italy).

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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