Eye movement features in solving Sternberg Memory Task

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***Abstract*—Oculomotor activity is an important component of human mental processes, and decoding this activity can be applied in many applied fields. This paper analyzed the physiological and behavioral characteristics of a person during a prolonged solution of a cognitive task based on the Sternberg paradigm. A number of trends in changes in both physiological and behavioral characteristics over the course of the experiment were revealed. For example, an increase in subjective fatigue over the course of the experiment. In addition, correlation analysis were performed. In particular, a correlation was found between subjective fatigue and the amplitude of pupil dilation during letter set demonstrations.**

***Index Terms*—EyeTracking, Neurophysiological experiment, Cognitive function testing, Sternberg memory task, Fatigue, Blinks**

I. Introduction

One of the most important tasks of modern science is the study of physical regularities of the brain work. Today there are a number of tools that allow to study one or another aspect of the brain, in particular, EEG, MEG, NIRS, EyeTracking, etc [1]–[7]. For example, EEG allows registering the electrical activity of the brain and is actively used nowadays. For example, in recent work [2] this method allowed to study peculiarities and reveal differences in cortical activation of children and adults when performing cognitive tasks in the form of Schulte table. Multichannel EEG and MEG data make it possible to analyze functional connections [3], [4], [8]. In particular, in [3] EEG allowed us to investigate the dynamics of the cortical network responsible for maintaining attention and decision-making.

Functional near-infrared spectroscopy (fNIRS) enables to obtain information on brain functioning by detecting the hemodynamic response [5], [9]–[11]. This method is often used to study motor activity [5], [9], [10]. Thus, in [5], in which the oxygen saturation of the primary cortex during a simple motor task was studied, it was shown that the dominant hand causes a higher hemodynamic response and is performed faster. Another important direction in the study of brain activity is EyeTracking, which allows tracking the position of the gaze [6], [12]. It should be noted that the visual system has a special place among human sensory systems, as it is through vision that a person receives most of the sensory information. In a recent study, it was found that perceptual switching is preceded by a decrease in eye movement [13]. Another study using gaze-tracking technology has identified factors that determine high levels of learning in infants [14]. A number of studies have also focused on patterns of oculomotor activity, for example [15].

In addition to the fundamental importance of such studies, the field of practical application of EyeTracking is very broad - from neuromarketing to traffic accident prevention by detecting the physiological state of drivers [16], [17]. For example, a study [17] showed that eye movement behavior can be used to detect visual fatigue. Nowadays, the study of fatigue and its relationship with oculomotor parameters is of interest. However, its effect on learning and stimulus processing has not been sufficiently studied so far. Therefore, in the current study, we conducted an experiment based on a prolonged cognitive load similar to the learning process, the purpose of which was to study this very issue. The main behavioral characteristics investigated in this experiment were memory and fatigue.

II. Methods

The experiment was structured as follows: 4 blocks of tasks in the form of the Sternberg Memory Task [18], before, after and between which tests to determine fatigue were conducted. The task blocks themselves looked in the form

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of sequential demonstration of the following stimuli: white cross, set, background, sample, background. The set consisted of 7 symbols, of which 2 to 7 were capital letters and the rest were *. The subject was required to press one of the consoles at the time the sample (one lowercase letter) was shown, depending on whether the letter was in the preceding set or not. Figure 1 shows an example of which parts of the screen the subject concentrated his attention on during the demonstration of a set of letters. Conditionally healthy volunteers without a history of neuropsychological diseases between the ages of 19 and 21, in the number of 15 people. To determine blinks, a value of 50 ms was chosen as the lower bound according to the work [19]. Subjective fatigue was determined using VAS tests [20]. During the determination of the mean pupil size, normalization was used relative to what the mean pupil size was during the background demonstration. To examine errors, tasks were grouped into 2 categories: high and low difficulty. High corresponded to the 3 most difficult types of tasks out of the 6 available, and low corresponded to the 3 easiest. All data were tested for normality using the Shapiro test. In the case of normal data, the RM-ANOVA was used to analyze repeated measures and the paired t-test was used for post-hoc tests. In the case of non-normally distributed data, however, the Friedman test was used to analyze repeated measures and the Wilcoxon test was used for post-hoc tests. To determine the distance of the gaze from the center of the screen, the radius-vector calculated by formula (1) was used, where R is the radius-vector, X is the coordinate of the abscissa axis at the corresponding moment in time, Y is the coordinate of the ordinate axis at the corresponding moment in time, T are the moments of time in each block during which the cross was shown, and 960 and 540 are the corresponding coordinates of the screen center.

$$R_N^{mean} = \frac{1}{T} * \int_{\mathbf{T}} \sqrt{(960 - X(t))^2 + (540 - Y(t))^2} dt; \quad (1)$$

here, $\mathbf{T} : t \in BlockN \cap Element(t) = cross.$

Fig. 1. Example of the eye trajectory during the demonstration of a set of letters.

III. Results

A detailed statistical analysis of a number of behavioral and physiological features of the person during the experimental tasks was performed. Specifically, we studied changes in the frequency and duration of blinks, subjective fatigue, percentage of errors made, and the gaze radius vector, which characterizes the breadth of gaze during stimulus processing during the experiment. For example, Figure 2 shows the change in the radius-vector during the cross demonstration during the experiment for both difficulties. Since the subject could not have known in advance the level of difficulty of the upcoming task, there could not have been a difference between the difficulties, which was confirmed by the study. However, a statistically significant dependence on the block was seen. In addition, the dynamics of fixations during the experiment were investigated. For example, characteristics such as fixation duration, fixation radius-vector, and changes in the proportion of cognitive fixations lasting from 150 to 900 ms associated with cognitive information processing were studied. A correlation analysis was also performed, and a number of correlations between behavioral and physiological characteristics were found. For example, a correlation was found between subjective fatigue and both blink frequency and average blink duration. Future plans include studying brain activity using EEG and building mathematical models based on multimodal data to predict behavioral characteristics, such as error probability and fatigue, based on physiological characteristics.

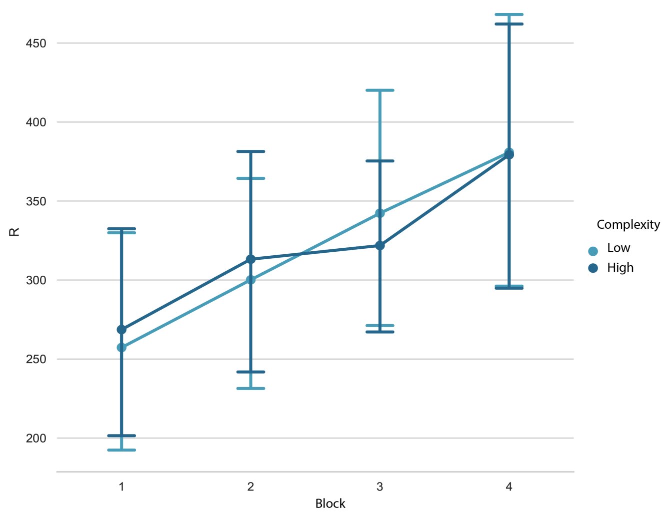

Fig. 2. Average viewing distance from the center of the screen during the display of the cross for high and low complexity.

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