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# Analysis of the Cognitive Load in Sternberg's Problem in an Eye-Tracker Study

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**Abstract**—A study is performed of the physiology and behavior of a person during prolonged solving of a cognitive task based on Sternberg's paradigm. A correlation is found between subjective fatigue and such physiological characteristics as blink duration and pupil size range of motion while solving the task.

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## INTRODUCTION

Studying the principles and physical laws of the brain is one of the most important and active fields of modern science [1–4]. A promising and powerful tool for studying brain activity is eyetracking [5, 6]. Oculomotor activity is an important component of human mental processes by which visual information is obtained, transformed, and used. Registration and analysis of eye movements allows access to internal forms of activity that occur quickly and unconsciously. One of today's main areas of research using a gaze tracking system is studying rapid eye movements (saccades) and blinking. A recent study by the group of Professor Martin Rohlfs showed that visual information inside a saccade (the trace of an object on the retina) provides characteristics of an object and allows us to quickly correct our gaze [6]. In another study with the presentation of ambiguous stimuli, it was shown that blinking and microsaccades do not contribute to perceptual switching. On the contrary; it was found that perceptual switching is preceded by reduced eye movement [7]. Factors that determine the high level of infant learning have also been identified using eyetracking technology [8].

The aim of this work was to study the cognitive load caused by a prolonged monotonous solving of cognitive tasks that require high levels of attention. Results are presented from studying behavioral and oculomotor activity in the prolonged solving of cognitive tasks and how they correlate.

## METHODOLOGY

A neurophysiological experiment was performed using 15 nominally healthy volunteers aged 19 to 21 with no history of neurophysiological disease. The main experimental part began and ended with recording background activity for 60 s. The experiment consisted of four identical blocks of tasks. Before and after each block, the subjects passed a test for the visual subjective assessment of fatigue [9]. Each block consisted of 72 tasks in the form of a Sternberg test [10]. The Sternberg test began with a black screen that displayed a white cross for 1.5–2.5 s to attract the subject's attention. A stimulus then appeared as a set of 7 characters, in which 2 to 7 characters were capital Cyrillic letters, and the remainder were asterisks. Each set of letters was presented for 1.5–2.5 s, during which the subject was to memorize them. A black screen is then shown for 3–7 s, after which one lowercase letter was presented on the screen, and the subject must answer whether or not it was in the set shown earlier. The display of a lowercase letter was necessary to ensure that the subject remembered the semantic meaning of the letter, and not its visual image. The subject was asked to give an answer using two identical remote controls associated earlier with the presence or absence of a letter in the set. Each block contained a total of 72 tasks, divided equally among six levels of difficulty that depended on the number of letters in the set (2 to 7).

An EyeLink 1000 Plus instrument was used to record eye movements.

The blinks were divided into four categories for purposes of analysis: short blinks of 50–150 ms, intermediate blinks of 150–350 ms, long blinks of 350–

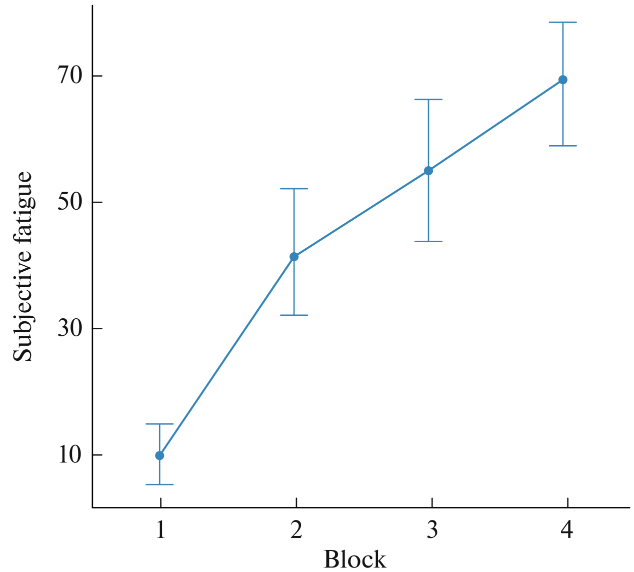


**Fig. 1.** Dependence of subjective fatigue on the stage of the experiment.

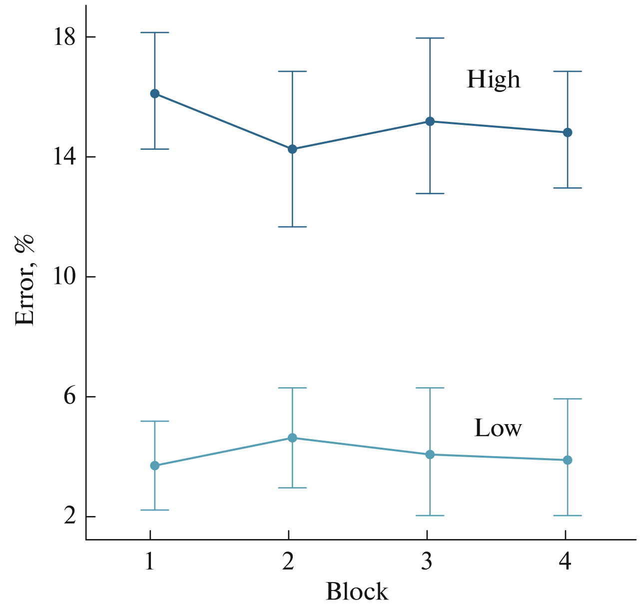


**Fig. 2.** Dependence of the percentage of errors on the stage of the experiment for high (High) and low (Low) complexity.

700 ms, and blinks that were classified as microsleeps of 700–2000 ms. In order to eliminate differences between subjects, a baseline correction procedure was performed for the average pupil size with regard to both the sample and the set of letters.

Two levels of difficulty were identified according to the number of letters in a presented set. Minor difficulty corresponded to sets of letters with 2 to 4 letters; great difficulty, with sets of 5 to 7 letters.

Changes in the considered behavioral and physiological characteristics during an experiment were assessed via dispersion analysis with repeated meaurements (RM ANOVA). *Post hoc* analysis was performed using a paired sample $t$-test with Holm's correction for multiple comparisons. Group-level correlation between observed changes in subjective fatigue scores and different recorded physiological characteristics was determined from the correlation between repeated measurements (RM CORR) [11] using the Pingouin statistical package for Python.

## RESULTS AND DISCUSSION

We studied behavior of the subjects during an experiment. It was found that each person grew increasingly tired as the experiment progressed (Fig. 1), as was reliably confirmed via RM-Anova ($p < 0.01$). *Post hoc* analysis revealed considerable differences between all phases of the experiment ($p < 0.01$).

An analysis was performed of the percentage of errors made, in order to study their dependence on the complexity and length of an experiment. It was found that with great complexity, the percentage of errors was significantly higher than in solving problems of low complexity ($p < 0.0001$). (Fig. 2). However, no statistically significant change was found in the percentage of errors during an experiment.

An analysis of blinks showed that all identified types differed from one another. At the same time, changes in the number of blinks during an experiment were found only for long and medium blinks, with their number in each block growing during an experiment ($p < 0.05$).

We also studied the dynamics of the pupil in terms of the change in its average size and amplitude during the experiment. It was found that the average pupil size fell during an experiment ($p < 0.05$). No such dependence was observed when a set of letters was displayed. It was found that the amplitude of pupil oscillations grew for the test display of a set of letters during an experiment ($p < 0.05$, Fig. 3).

We analyzed the relationship between the considered physiological and behavioral characteristics. Statistically significant correlations of subjective fatigue were found for the number of short blinks ($r = 0.3$), the number of medium blinks ($r = 0.46$), the number of long blinks ($r = 0.53$), the average pupil size during a test display ($r = -0.54$) , the average pupil size during the display of a set of letters ($r = -0.35$), the amplitude of pupil size fluctuations during a test display ($r = 0.52$), and the amplitude of pupil size oscillations during the display of a set of letters ($r = 0.54$).

Our results are in good agreement with ones obtained earlier. It is known in particular that an increase in fatigue is accompanied by a rise in the amplitude of pupil size fluctuations, longer blinks, and correspondingly more long blinks [12].

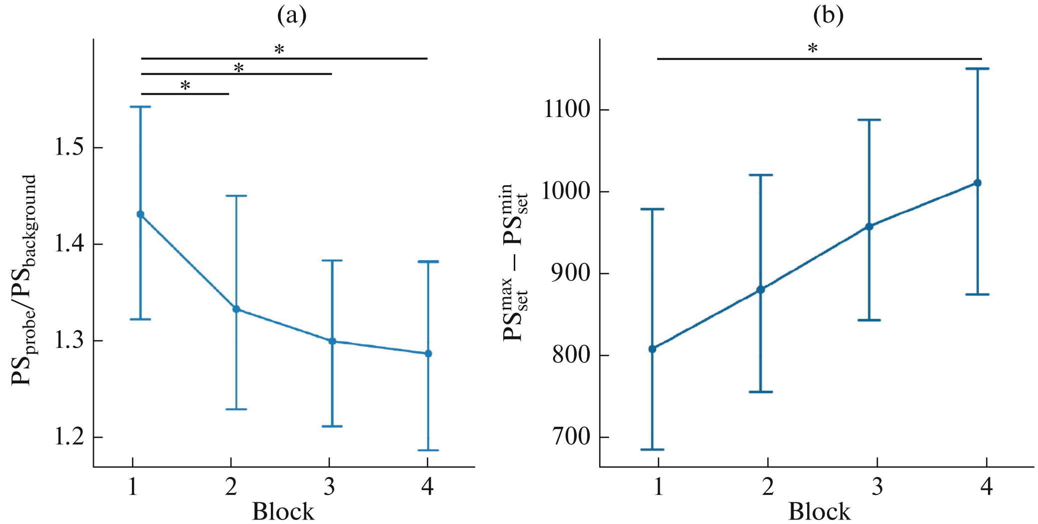


**Fig. 3.** (a) Dependence of average pupil size, normalized to the one during background recording, on the stage of the experiment. (b) Dependence of the amplitude of pupil oscillations on the stage of the experiment. $PS_{probe}$ is the average size of the pupil when a sample was displayed; $PS_{background}$ is the average size of the pupil when the background was displayed; $PS_{set}^{max}$ is the maximum size of the pupil when a set of letters was displayed; and $PS_{set}^{min}$ is the minimum size of the pupil when a set of letters was displayed. The asterisks indicate statistically significant differences between conditions in *post hoc* analysis ($p < 0.05$).

## CONCLUSIONS

It was found that prolonged monotonous cognitive loads strongly increased subjective fatigue during an experiment. This fatigue was accompanied by a rise in the number of blinks of medium and long duration during an experiment. The number of errors that were made depended on the complexity of the task. There was a reduction in the average pupil size during each test, and a rise in the amplitude of pupil oscillations when a set of letters was displayed.

In the future, we plan to investigate rapid eye movements (saccades) and pupil fixation, and to search for relationships between them the results obtained in this work.

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## COMPLIANCE WITH ETHICAL STANDARDS

*Conflict of interest.* The authors declare that they have no conflicts of interest.

*Statement of compliance with standards of research involving humans as subjects.* All procedures performed in studies involving human participants were in accordance with he standards of the Innopolis University's Commission on Ethics and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants involved in the study.

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