# Analysis of eye-tracking data during the Sternberg working memory task in subjects with asthenic syndrome


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***Abstract*—In the current study, we analyzed eye-tracking data from subjects with asthenic syndrome during the performance of Sternberg Working Memory Task. To determine the severity of asthenia we used Multidimensional Fatigue Inventory. We showed that people with the asthenic syndrome are characterized by a rapid increase in subjective fatigue during the experiment. We confirmed the relationship between the subjective level of fatigue and pupil size. We believe that eye-tracking is a suitable method for objectively identifying mental fatigue during a cognitive task.**



***Index Terms*—mental fatigue, asthenia, eye-tracking, eye-based features**


## I. Introduction

Asthenia, is an ill-defined condition characterized by generalized weakness and usually involving mental and physical fatigue [1]. Asthenia is not an independent disease, but occurs due to various causes, including: diseases of internal organs (for example, coronary heart disease); infectious diseases, intoxication and their consequences; emotional, mental and physical overstrain; sleep, work and rest disorders; improper nutrition [2]. Within the framework of this study, attention is paid to such a symptom of asthenia as pathological mental fatigue —- one of the types of physiological fatigue that occurs as a result of cognitive processing of a task for a certain period of time. It determines how quickly an increased level of mental fatigue is achieved during the experiment. Fatigue can be determined both subjectively (according to the feelings of a person) and objectively (according to physiological indicators and observation of the results of passing cognitive tasks) [3]. Moreover, the subjective and objective levels do not always correspond to each other: it is known, that the subject, when feeling tired, is able to keep the productivity of performing tasks for a certain time [4], [5].

There are four categories of methods for measuring mental fatigue:

1) Subjective questionnaires: Multidimensional Fatigue Inventory (MFI-20) [6], Fatigue Impact Scale [7], Chalder

Fatigue Scale [8], Checklist Individual Strength [9]. It is worth noting that these questionnaires can result in bias due to subjective reporting [10], and the subjective reports do not always correlate with known objective measures of fatigue [11].
2) Attention tests, reflecting cognitive response to fatigue. This approach implies analyzing of performance on attention tasks: Psychomotor Vigilance Task [12], Eriksen Flanker Task [13], Attention Network Task [14]. These tasks demonstrate the manifestation of fatigue through a decrease in productivity when performing tasks. An important point when using this method is that these tasks require a break in the current task and the execution of an additional, unfamiliar task.
3) Reduced task performance, depicting behavioral response to fatigue. A decrease in performance when performing the current task, for example, a decrease in accuracy when performing a task with working memory, may indicate fatigue. While definitions often associate fatigue with decreased performance, these definitions often fail to mention that before the performance level decreases, an attempt may be made to maintain performance by spending more effort. Thus, at this stage, although a person experiences fatigue, there is no decrease in performance [5].
4) Measures based on physiological data such as:
    a) Electroencephalogram (EEG) can show correlation between brain rhythms (waves), such as alpha, beta, gamma, delta and theta, and weakness [15]–[20] and correlation between levels of physical and mental fatigue [21].
    b) Electrocardiogram (ECG) can be used in monitoring heart rate: it‘s variance increases with fatigue and decreases during recovery [22], [23].
    c) Electrooculography (EOG) [15], [24].
    d) Eye-tracking [23], [25]–[28].

It is worth noting that it is necessary to be very careful about measuring the level of fatigue using physiological metrics: in the works of different authors, with different experiments, sometimes opposite conclusions are obtained (for example, researches [29] and [30] contain contradictory information about the correlation between pupil size and fatigue level), or there is no correlation between the level of fatigue and any indicator (there was no relationship between pupil size and fatigue level [31]). Within the framework of this study, to measure the level of fatigue, we have chosen such an objective method for determining fatigue as eye-tracking [29], [30], [32]–[35]. There are some eye-based features: pupil size, percentage of eye closure (PERCLOS), blinks, saccades (including microsaccades), fixations, ocular drift, and eye activity. And one of the most significant indicators in determining fatigue in this case are peak velocity and mean velocity of saccades — in all the above-mentioned sources, these indicators were inversely proportional to the level of mental fatigue when performing various cognitive tasks. The main objective of our study is to identify the level of mental weakness in people suffering from asthenia using eye metrics. In addition, we had to identify a correlation between subjective and objective levels of fatigue.

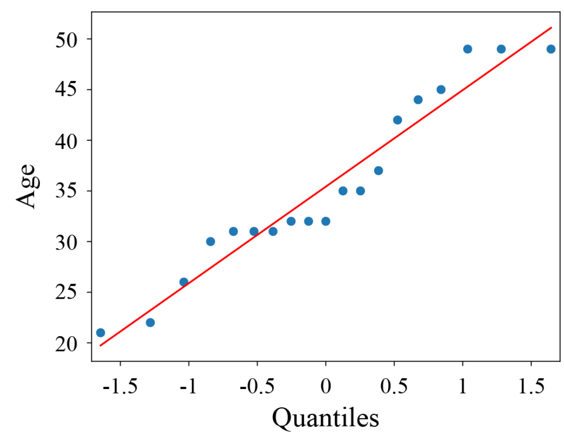

Fig. 1. Quantile plot for age distribution of subjects participating in the study.

## II. Methods

A neurophysiological experiment was conducted involving volunteers with subjective cognitive impairment and symptoms of asthenia between the ages of 20 and 50 (19 participants in total, see fig. 1). The main experimental part begins and ends with recording background activity for 60 seconds. The experiment consists of four identical blocks of tasks, before and after each block of tasks the subject takes a visual subjective fatigue assessment test []. Each block consists of tasks of different difficulty in the form of the Sternberg test []. The Sternberg test was implemented in the following form. Each task starts with a black screen, on which a white cross is then shown for $1.5 - 2.5$ s to attract the subject's attention. Next, a stimulus appears in the form of a set of 8 characters, in which 3 to 8 characters are Cyrillic capital letters and the rest are "*". The set of letters is presented for $1.5 - 2.5$ s, and the subject needs to remember the letters shown. A black screen is shown for $6 - 7$ seconds, after which a lowercase letter is displayed, and the person must answer whether the letter was in the previously shown set or not.

## III. Results

The study of the behavioral characteristics of the subjects during the course of the experiment was conducted. It was found that the person became more tired as the experiment progressed (see fig. 2a), which was confirmed with RM-Anova with high reliability ($p < 0.001$). Post-hoc analysis showed significant differences between all phases of the experiment ($p < 0.01$).

We studied the dynamics of the pupil, namely the change of its average size and amplitude during the experiment. It was found that the average size of the pupil during solving task test decreased during the experiment ($p < 0.001$, see fig. 2b).

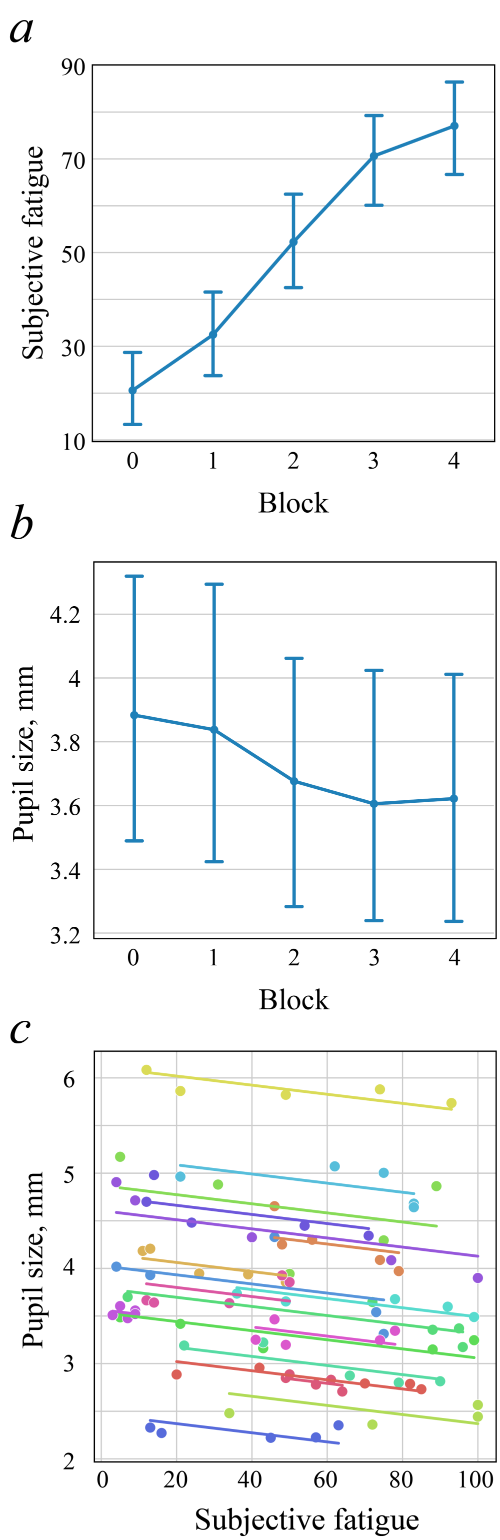


Fig. 2. Dynamics of subjective fatigue and average pupil size during the experiment (a) and (b), respectively. (c) Repeated measures correlation between subjective fatigue and pupil size.

An analysis of the correlation between the physiological and behavioral characteristics under consideration was carried out. Statistically significant correlations of subjective fatigue were found with average pupil size during solving task test ($r = -0.58$, see fig. 2c).

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