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The study of the impact of test-based and game-based intellectual workloads on human functional state

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Human functional state (FS) diagnostics, as a systemic response of the body under work conditions, has broad practical significance in various fields (medicine, biophysics, psychophysiology, physiology of labor, etc.). In biophysics and applied physiology, the analysis of critical flicker fusion frequency (CFFF) is often used as an express-method for these purposes. In this work, an express-diagnostic device for assessing FS (EDD-FS) was used to implement the CFFF method. Test assignments and a computer puzzle game were used as intellectual workloads for the participants. The study results demonstrated that the use of the EDD-FS allows for prompt assessment of a human FS.

Keywords: functional state, critical flicker fusion frequency, express-diagnostics, psychophysiology.

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Diagnostics of the functional state (FS) of a person (e.g., response of the body under work conditions) has broad practical significance in various research fields, such as medicine, biophysics, psychophysiology, physiology of labor, etc. Express diagnostic methods allowing one to assess the FS of a person within a short interval of time based on a set of indicators are of particular importance in applied physiology. The most important of such indicators are those of the functional state of the central nervous system (including the cerebral cortex), which is the main regulatory system of the body [1,2].

The functional state of the brain may be defined as the background (initial for the effect being studied) activity of nerve centers that condition the current activity and its effectiveness. When engaged in various types of activities, the body always reacts as a whole, activating the central and autonomic nervous systems and regulating the activity of cardiovascular and respiratory systems [3].

The approach to FS assessment [4] relies on the concept that the type of response of the nervous system depends on its current state, which is defined by two key physiological characteristics: excitability and lability. Depending on the ratio of excitability and physiological lability, the response of a living system evolves in the form of three successive qualitative states: physiological rest, excitation, or inhibition. Excitability is a measure of sensitivity of the nervous system, while lability is its speed characteristic [5]. Physiological lability specifies the limit of efficiency of the entire living system.

The critical flicker fusion frequency (CFFF) is the traditional core biophysical systemic indicator for assessing the nervous system lability in psychophysiology [6]. One may assess the general excitability by examining the threshold response to the strength of stimulus and indirectly by comparing the response to light pulses with different parameters [7].

In the present study, the influence of various types of intellectual workload (test- and game-based) on the FS was examined using the CFFF method implemented in an FS express diagnostic device. This device, which is presented below, implements a new conceptual design with greater autonomy and expanded functionality (see [8] for more details).

A total of 26 healthy volunteers (second-year students of Peter the Great St.Petersburg Polytechnic University) aged 20–25 years participated in the study.

A device for express diagnostics of functional states, which includes a tablet or mobile phone with software for test control and the FS testing device recording the subject's response [8], was used to record the CFFF values.

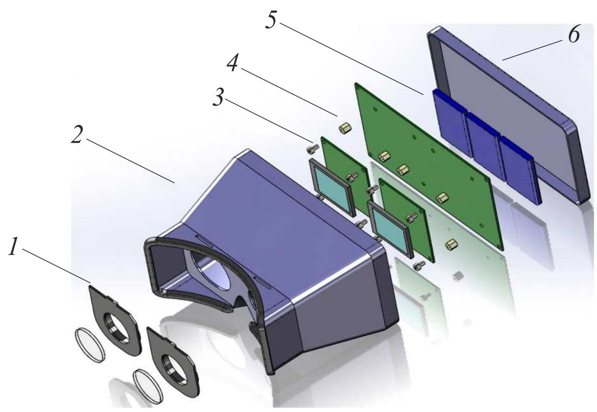

Figure 1. Testing device. *1* — Eyepiece, *2* — case, *3* — display, *4* — driver, *5* — main board with a radio module, and *6* — back cover.

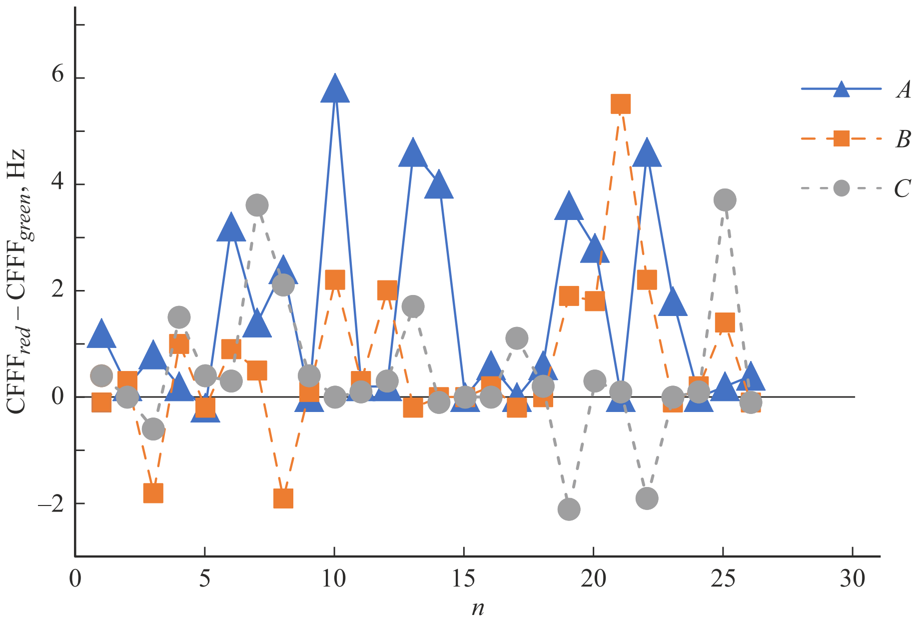

Figure 2. Difference in response (CFFF values) of the subjects to red and green light. A — prior to intellectual work, B — after „test" assignments, C — after „puzzle game," and n — test subject number.

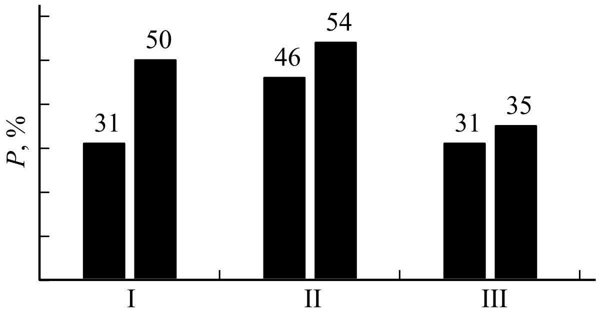

Figure 3. Percentage P of the total number of test subjects with a pronounced response to red (I) and green (II) color before and after intellectual work and percentage of the total number of test subjects with a reduction in CFFF difference for red and green color (III). Left column — test assignments; right column — game.

The testing device is a modular product in a separate case (Fig. 1). The case has an opening for mounting a connector for sensors and manipulators with buttons.

The testing device includes:

— glasses with optical elements needed to present a light stimulus to each eye of the test subject;

— visualization module with an OLED display that displays the test program directly; and

— OLED display control board with a microcontroller that receives data on the subjects' reactions via manipulator buttons (motor response) and records them in real time in temporary memory. All the obtained data are sent via a Wi-Fi channel to the tablet.

Light pulses are applied to both eyes simultaneously and uniformly in the central part of the viewing field. A single chosen color (red with $\lambda_{peak} = 610$ nm or green with $\lambda_{peak} = 535$ nm) is displayed for stimulation. The repetition rate of light pulse increases from 10 to 70 Hz (in 1 Hz steps) at a given fixed intensity. The light spot area was 10 pixels with a brightness of 80 cd/m^2 for a single pixel. The spot brightness was 400–800 cd/m^2. These values correspond to a safe brightness level specified in the photobiological safety standards for lamps and lamp systems (GOST R IEC 62471–2013) and allow the test subjects to see the light object clearly in express testing.

A special set of test assignments based on IQ tests and a computer puzzle game served as an intellectual workload. Both types of workload were designed so as to require high concentration, attention, logical thinking, and memorization of groups of elements. The exposure time was 30 min for both workloads. Reference individual CFFF values for 26 subjects were measured immediately prior to subjecting them to the workload. The measurements were repeated immediately after the completion of test assignments based on IQ tests and the puzzle game. The measurement process took a total of 30 min. Thus, the overall duration of the experiment for one subject was 60 min. The flicker frequency in testing was set within the range of 20–50 Hz for red and green lights.

According to the CFFF method, a reduced difference in response to red and green light is a measure of fatigue: $CFFF_{red} - CFFF_{green} < 0$ [6].

The measurement results (Fig. 2) revealed that the average CFFF difference values within the experimental flicker frequency range for red and green colors decreased by 58 and 50% relative to the reference levels for test loads and the puzzle game, respectively. A significant (8%) difference in the variation of response to the stimulus reveals a trend toward greater fatigue accumulation in monotonous work (compared to the game-type workload). The Bourdon correction test, which the subjects completed in 3 min before and after the application of workload, was used for additional fatigue assessment. In the case of test and game-type workloads, the average correctness percentage decreased by 4.99% and 4.56% relative to the reference level, respectively. The obtained data are indicative of the efficiency of workloads, but the subjectivity of evaluation makes unambiguous identification of correlations with other results impossible. Figure 3 presents the results as a percentage of the total number of subjects for each data pair: the left column of the histogram corresponds to the workload in the form of test assignments, while the right column corresponds to the puzzle game. Histograms I and II reflect the severity of reaction to workloads (CFFF value deviations greater than 2 Hz (in both directions) from the reference level were assumed to represent a pronounced response [9]). Histogram I corresponds to the values for red color, while histogram II represents the data for green color. Histogram III presents the percentage of the total number of test subjects for whom the difference between the red and green CFFF values decreased relative to the reference level: $\mathrm{CFFF}_{red} - \mathrm{CFFF}_{green} < 0$ [6].

Thus, it follows from the obtained results that a reduction in the CFFF value for red color relative to the green one is a reliable indicator of fatigue in simple express diagnostics in both examined cases and allows for a rapid assessment of human FS.

The designed express diagnostic device provides an opportunity to assess the functional state of a person within a fairly short period of time (30 min). Different types of intellectual workload induce different degrees of fatigue, which may be assessed quantitatively using the CFFF method. This needs to be taken into account in express FS diagnostics in studies of various kinds of occupational activity. The obtained data correlate with the results reported in other studies in this field [9], but the latter lack a comparative assessment of fatigue for specific types of activity.

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Compliance with ethical standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed voluntary consent was obtained from each study participant.

Conflict of interest

The authors declare that they have no conflict of interest.

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