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Assessment of changes in the human functional state with critical flicker fusion frequency method: features of light exposure and types of workload

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An express critical flicker fusion frequency (CFFF) measuring method, used to assess the functional state (FS) of a person, is of great practical importance in biophysics and applied physiology. To implement this method, an express-diagnostic device for assessing FS of a human was used in the work. Testing was carried out at different levels of intensity of light exposure for three wavelengths. The comparison of reactions after various intellectual workloads for the subjects was investigated: test assignments and a computer puzzle game. The research results demonstrated an increase in the sensitivity of the technique with the addition of blue light, as well as the different nature of the frequency curves of the subjects, depending on the type of workload used.

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

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The basic biophysical systemic indicator of nervous system fatigue is the critical flicker fusion frequency (CFFF) [1], which characterizes the rate of presentation of successive light stimuli at which they are perceived as stable and continuous. This parameter may be influenced by various factors, such as individual characteristics of circadian rhythms (and, accordingly, the time of experimental measurements) and the age and gender of the person being tested. These have to be taken into account when one prepares for studies. The examination of fatigue characteristics is inextricably linked with the concept of functional state (FS) of a person. Tasked with a specific activity, the body always reacts as a whole, regulating the activity of the central and autonomic nervous systems [2,3]. In view of this, the CFFF is widely used for FS diagnostics. The FS assessment [4] is based on the type of response of the nervous system that depends on its current state and is specified by two parameters (excitability and lability), the varying ratio of which illustrates the change in response of the living system in states of rest, excitation, or inhibition. Excitability is a measure of sensitivity of the nervous system, while lability is its speed characteristic [5]. 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 [6].

In the present study, we focused on the influence of different types of intellectual workload (test and puzzle game) on the FS, which was examined by monitoring CFFF changes in response to color pulse excitation with its intensity increasing stepwise.

CFFF measurements were carried out under the conditions of monotonic intellectual workload (a specially formed set of test tasks based on IQ tests) and gaming workload (a puzzle game), and the results were compared with control values under no load [7]. The duration of one experiment was 1.5 h, and the duration of the complete study for two types of load was 3 h. The assigned tasks were completed on a personal computer. The study involved 11 healthy subjects (nine females and two males). The age of participants ranged from 18 to 26 years. 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, was used to record the CFFF values. This device has a wide functionality and allows one to implement a number of methods for FS assessment; it was characterized in more detail in [8]. The response to presentation of color stimuli was studied in two spectral regions traditional for CFFF: green ($\lambda_{peak} = 520$ nm) and red ($\lambda_{peak} = 625$ nm). According to the eye sensitivity curve (GOST 8.332−2013), the corresponding relative sensitivities are 0.65 and 0.3. To increase the reliability and sensitivity of the method, blue light ($\lambda_{peak} = 460$ nm) with a significantly lower relative eye sensitivity (0.1) was also added to the experiment. Emission spectra were recorded using an OL770 LED Test and Measurement System (Optronic Lab, United States) [9]. Figure 1 shows the light sensitivity curve of the human eye with indicated peak wavelengths of the light source used in the experiments.

CFFF measurements were carried out according to the procedure outlined in [1] with the light pulse intensity increasing in four steps from the minimum brightness to the

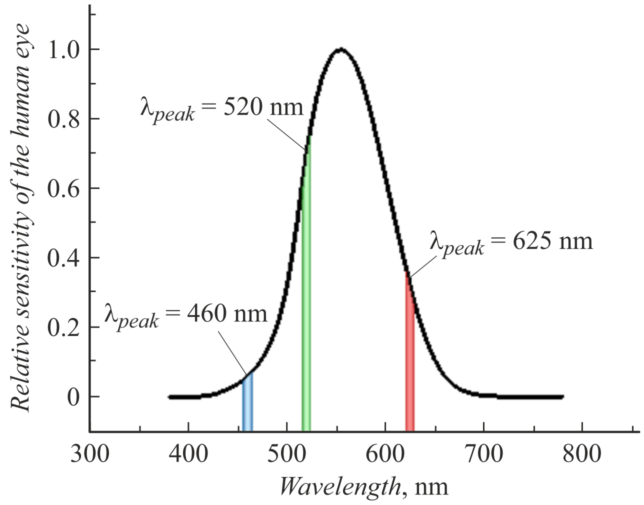

Figure 1. Light sensitivity curve of the human eye. The peak wavelengths of the source correspond to different colors: blue — $\lambda_{peak} = 460$ nm, green — $\lambda_{peak} = 520$ nm, and red — $\lambda_{peak} = 625$ nm.

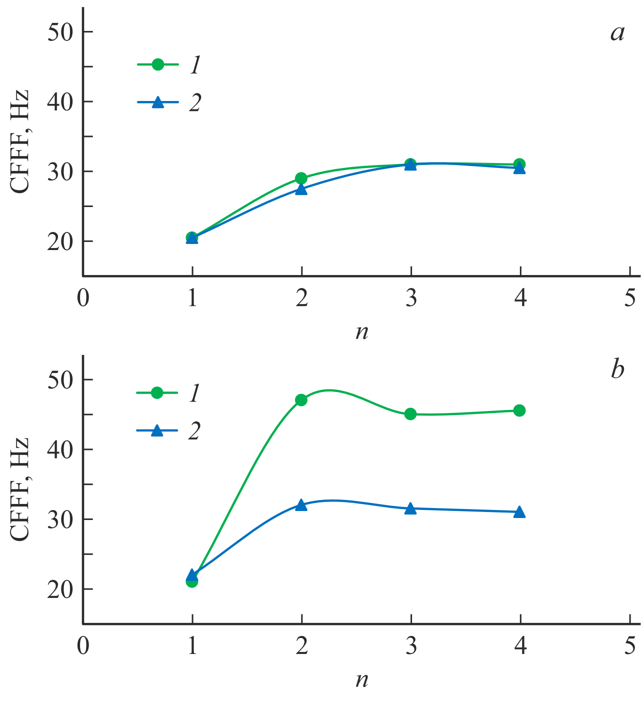

Figure 2. Curves of CFFF variation for green (*1*) and blue (*2*) colors and four levels of light pulse intensity (n). a — Workload in the form of test tasks; b — puzzle game workload.

maximum one. The area of the light spot was 10 pixels, and the brightness was 400–800 cd/m^2 at different steps. These levels are safe for the eyes while adhering to the photobiological safety standards for lamps and lamp systems (GOST R IEC 62471–2013). Inversion of the sign of the CFFF value difference in red–green ($\mathrm{CFFF}_{red} - \mathrm{CFFF}_{green} < 0$) and green–blue ($\mathrm{CFFF}_{green} - \mathrm{CFFF}_{blue} < 0$) pairs was taken as an indicator of FS deterioration (with account for both the absolute values and the trends revealed by the individual curves for each participant).

The measurement data demonstrated that all participants had a marked response to blue light, while red light induced virtually no response in 20 % of test subjects. Examples of individual CFFF curves for green and blue colors are shown in Fig. 2.

These examples illustrate the relevance of adding blue color to the experimental protocol and the profound difference between CFFF values corresponding to different types of intellectual workload.

It should be noted that the frequency curves of all participants were highly specific, which necessitated the search for an adequate way of data processing. Dimensionless parameter R, which is defined as the ratio of CFFF values measured in the corresponding workload experiment for red, green, and blue light to the control values at each intensity level ($R = \mathrm{CFFF}_{workload}/\mathrm{CFFF}_{control}$), was introduced for this purpose. The results of processing with the use of this coefficient for 11 test subjects are presented in Fig. 3 ($p < 0.05$).

To verify the statistical significance of differences in results at $p < 0.05$, we used one-way analysis of variance (ANOVA) with Tukey's post hoc test for multiple comparisons.

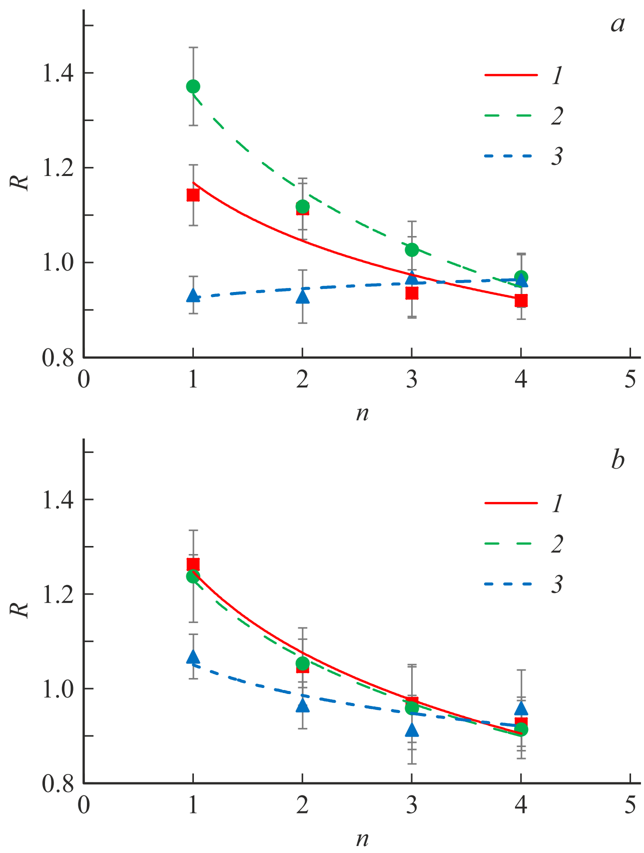

Figure 3. Curves of parameter R variation for red (*1*), green (*2*), and blue (*3*) colors and four levels of light pulse intensity (n). a — Workload in the form of test tasks; b — puzzle game workload.

According to literature data, lowering of the absolute CFFF values is indicative of fatigue [1]. Therefore, the values of parameter R may be regarded as a marker of FS changes, where $R < 1$ is associated with the onset of fatigue. The plotted curves reveal the greatest differences in response at low light signal intensity levels (n). The coefficient for blue light was below unity under test workloads (Fig. 3, a). This indicates that this type of workload causes greater fatigue.

Additional preliminary analysis allowed us to identify subgroups with different types of response to a specific type of workload (fatigue from one or both types or no response), but the small sample size makes it difficult to interpret this classification correctly.

In accord with the results of similar studies [10], the obtained data demonstrate that monotonic workload causes greater fatigue than gaming workload. The addition of blue light pulses to the experiment had a positive effect on the sensitivity of the technique and the informative value of the obtained results. The wavelengths of light pulses should be chosen based on the eye sensitivity curve. The CFFF parameter is a tool for express diagnostics of the visual system that takes into account the individual characteristics of this system and the human central nervous system as a whole. Since changes in the values of this parameter may either be associated with simple fatigue or be a sign of actual disease [11], the discussed research technique is highly relevant.

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Compliance with ethical standards

This study was approved at the meeting of the Ethics Committee of the Sechenov Institute of Evolutionary Physiology and Biochemistry of the Russian Academy of Sciences (IEPhB RAS) on human subjects research by the Bioethics Committee (October 11, 2024) and complies with all regulatory requirements for human subjects research approved by order No. 9 (January 30, 2024) of the Director of IEPhB RAS. 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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