BIOCYBERNETICS AND BIOMEDICAL ENGINEERING 35 (2015) 147–156

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/bbe

Review Article

Mobile device for the measurement of threshold perception frequency of the flickering source of visible light

Krzysztof Różanowski [a,*], Jarosław Lewandowski [a], Tadeusz Sondej [b]

[a] Military Institute of Aviation Medicine, Aviation Bioengineering Department, Warsaw, Poland
[b] Military University of Technology, Electronic Department, Warsaw, Poland

ARTICLE INFO

Article history:
Received 17 July 2014
Received in revised form
30 October 2014
Accepted 12 November 2014
Available online 21 November 2014

Keywords:
Critical flicker frequency
Sensor
Fatigue
Flicker fusion test
Pupillographic sleepiness test

ABSTRACT

The article describes design solutions and test results of a mobile device for the measurement of threshold perception frequency of the flickering source of visible light. The device consists of an optical component, a programmable module and a control module. The measurement can be performed on the light source of any color in conjunction with a colored backlight. The authors of the research work developed and tested a unique solution that integrates a subjective measurement of the flicker frequency f_f and the blending frequency f_m fusing in the flicker fusion test (FFT) with the registration of pupil vibrations that gives information about the level of activation of the autonomic nervous system (ANS). The ANS activation level is estimated in the test called the pupillographic sleepiness test (PST). It is an objective source of data on the level of fatigue, reduced concentration or sleepiness of a subject. The authors focused on the description of the measurement section related to the measurement of pupillary unrest index (PUI) and FFT parameters. The construction of the device allows for its use both in laboratory tests, as well as in terms of everyday human functioning.

1. Introduction

Flicker fusion test (FFT) has been widely used for over the past 40 years to investigate the effects of psychoactive drugs and has been shown to correlate with brain damage. The flicker will be perceived at low frequencies, but as the frequency increases there will be a point at which the observer perceive the light as constant. This point is called either critical flicker fusion or critical flicker frequency (CFF). The average rate at which humans stop reporting flicker is 60 Hz, but some may continue reporting flicker up to 90–100 Hz (the exact frequency varies from one person to another and in response to various conditions). CFF variability is caused by many factors, including baseline differences between the observers, as well as the level of fatigue, time of day, and health status. Invisible

* *Corresponding author at*: Military Institute of Aviation Medicine, Aviation Bioengineering Department, Warsaw, Poland.
E-mail addresses: krozan@wiml.waw.pl (K. Różanowski), tsondej@wat.edu.pl (T. Sondej).
http://dx.doi.org/10.1016/j.bbe.2014.11.002

flicker (i.e. not perceivable) can occur above the CFF but no higher than about 200 Hz. At sufficient speed, luminance changes of a flickering stimulus are no longer perceived as flickering but as steady or fused illumination [1].

FFT is a well-established neurophysiological technique that measures the ability of the central nervous system to detect flickering light, and is directly influenced by the cortical activity [2]. FFT is very useful for assessing a broad spectrum of neuropsychological abnormalities ranging from visual signal processing to cognitive functions, and it has been applied in the studies of several neurological disorders, such as multiple sclerosis and Alzheimer's disease. FFT is particularly suitable for studying alterations in visual signal processing, as well as for detecting the arousal or attention abnormalities [3]. Studies on the phenomenon of flicker fusion have attempted to use it for assessment of the effects of hypoxia in pilots exposed to an altitude of 5000 m [4].

Irrespective of the reason for performing FFT, proper lighting conditions under which the test is performed are crucial for measuring the critical flicker fusion (CFF) rate. The accuracy of critical frequency detection poses a practical challenge for its use. It depends primarily on the person being tested who must decide whether the observed light is steady or not. Frequency value of light source labeled as steady also depends on other factors, such as brightness, contrast, shape and size of lighting elements (source and backlight), light control signal, fixation point and the method of observation of the light source. Prolonged observation of a flickering light source reduces sensitivity to that flicker. This adaptation is only somewhat selective for temporal frequency, and indeed, sensitivity to 30 Hz flicker can be reduced by adapting to 60 Hz flicker [5,6].

The presented mobile device for the measurement of perception threshold frequency of the flickering source of visible light allows for the research to be conducted with any configuration of the light source and backlight. The use of goggles provides an environment with reproducible measurement conditions. Unique is the integrated system for assessment of the pupil, including its size, which enables the determination of PUI (pupillary unrest index) parameter in PST (pupillographic sleepiness test) as a benchmark for estimating the level of fatigue. PST can be used to assess human psychophysiological state influenced by the level of drowsiness or alertness, through the so-called fatigue wave. Since the overall size of the pupil is predominantly controlled by sympathetic inhibition of the parasympathetic Edinger–Westphal nuclei, spontaneous changes in the pupil size are mainly regarded as an effect of decreasing central sympathetic activity. In the state of reduced alertness, those changes in pupil size, if recorded in darkness, show slow rhythmic oscillations called fatigue waves. The authors developed a method for parallel determination of CFF and PUI in the described sensory analysis device. This enables an objective assessment of the level of accuracy of the critical flicker frequency as perceived by the subject, because it is automatically verified by PUI, the value of which depends on the amplitude of oscillatory, involuntary changes in the size of the human pupil. This method also allows for the verification of the influence of light on its value in the assessment of the level of fatigue. The described sensor is a combination of hardware and software solutions. It can be used in both stationary and mobile conditions thanks to the placement in a custom-designed housing.

2. Flicker fusion effect for assessment of fatigue level

Fatigue, both physical and mental, is associated with an increased reaction time, which is necessary to make right decisions and rapid observations of changes taking place in our environment. Normal fatigue leads to an increase in the number of mistakes made that result from poor concentration. One of the first visible signs of fatigue is the deterioration and weakening of eyesight, which is manifested by reflex blinking. Work performed by a driver, a pilot or an operator of other machinery who is not sufficiently rested, is associated with a higher risk of accidents. In the case of drivers, their level of fatigue affects their life, the lives of passengers, as well as other road users. Early detection of emerging symptoms of fatigue and their signaling would minimize the risks they carry.

The level of fatigue is a relative parameter. It is possible that acting under high level of stress, a person can mobilize himself or herself and is able to overcome the symptoms. The use of devices monitoring human physiological parameters, which can determine his/her health condition, is usually uncomfortable, and above all it is related with high costs and the need for a continued analysis of the recorded signals. This type of data processing usually requires the use of high computing power. Accordingly, in order to ensure the comfort of a person being monitored and not to interfere with his/her normal working routine, it would be necessary to use non-contact methods [7].

One of the known symptoms of fatigue, causing deterioration in perception of the environmental quality, is the change of flicker frequency thresholds and/or the perception of light blending. This effect is determined, in terms of a psychophysiological concept of view, as flicker fusion and originates from the fact that it is perceived by an observer as a constant image at sufficiently rapid changes of the image (flickering). Flickering frequency, at which one perceives the image as constant, is defined as flicker fusion threshold, and its value changes (decreases) along with the increase in the level of human fatigue.

Flicker fusion threshold of the FF effect does not have a specific constant value and constitutes an individual feature [8]. In addition, it is dependent on the level of modulation of the projected light, the ambient brightness and its color. It is assumed that, in the case of constant brightness of light, a perceived flicker fusion threshold of the display of short flashes will be lower than the one with flashes of longer duration, while in the event of high contrast of lighting, the flicker fusion threshold of perception will increase [9]. Depending on the angle of observation of the flickering light source, the flicker fusion threshold also changes. This is due to the fact that rods (in the periphery) have a shorter response time than the cones (in the center). The result is that the flicker fusion thresholds observed by peripheral vision will be higher than those recorded by frontal vision [10,11]. A similar effect is noticed along with a change of color of the flickering light, due