Method of Acute Alertness Level Evaluation after Exposure to Blue and Red Light (based on EEG): Technical Aspects

Agnieszka Wolska[1], Dariusz Sawicki[2], Kamila Nowak[1], Mariusz Wisełka[1] and Marcin Kołodziej[2]
[1]*Central Institute for Labour Protection, National Research Institute (CIOP-PIB), Warsaw, Poland*
[2]*Warsaw University of Technology, Institute of Theory of Electrical Engineering, Measurement and Information Systems, Warsaw, Poland*

Keywords: EEG, Acute Alertness, Exposure to Light, Evaluation Method, Technical Aspects.

Abstract: Since maintaining a high level of alertness is a very important factor on many workstations a number of studies on alertness level evaluation have been carrying out. The effects of light exposure on alertness level have been the subject of many studies with EEG registration, but technical aspects of planning experiment are not well described. The aim of the article is to present the evaluation method of acute alertness level after exposure to blue and red light based on EEG registration with special attention to technical aspects of used methodology. The preliminary results obtained during the pilot study confirmed that elaborated method fulfils our expectations and gives opportunity to assess the acute alertness after exposure to light.

1 INTRODUCTION

Light is one of the most important environmental factors both for humans and all living organisms. It is simply needed for life. It is able to affect physical, physiological and psychological behaviors of humans (Bellia et al., 2011). Light stimulus both enables the vision and affects biological non-visual effects. The existence of intrinsically photosensitive retinal ganglion cell (ipRGc) containing the melanopsin makes it possible to capture the non-visual information of light and activate the circadian system. Daily light/dark patterns reaching the retina play an important role in regulating the circadian rhythms (Figueiro, 2013). The non-visual response to light depends on the light wavelength and intensity (irradiance level at the eye), time and duration of exposure. Light may affect human behaviors in indirect or direct way. The indirect way is thorough the circadian timing system, and the response is mainly long-term, mediated by processes such as: melatonin suppression, core body temperature regulation, alertness and cognition (Łaszewska et al., 2017, Chellappa et al., 2011, Cajochen et al, 2007, 2010). This is why this non-visual response is often named as circadian effect of light.

Many studies showed that the effect of blue light exposure had been stronger than white light. It is explained by maximum sensitivity of ipRGc on short wavelength visible radiation between 460 and 480 nm. The direct non-visual effect of light is non-circadian, i.e. without circadian clock changes. These effects could be acute and short term, not exceeding the period of 24 h (Łaszewska et al., 2017, Cajochen et al., 2007, Chellappa et al., 2011). Since maintaining a high level of alertness is a very important factor on many workstations and on night shift workstations many studies of alertness level evaluation have been conducted. The effects of light exposure on alertness were the subject of numerous electrophysiological studies (Łaszewska et al., 2017, Figueiro et al., 2010, 2016, Sahin and Figueiro, 2013, Chang et al., 2013, Sahin et al., 2014, Phipps-Nelson et al., 2009). However, a unified and standardized method of carrying out the studies does not exist. The differences in methodology concerns: duration and daytime of exposure, intensity of light and procedure of EEG registration (during or after exposure to light, with or without behavioural control).

There are also different methods of EEG signal analysis to assess the alertness level, however the Theta and Alpha bands are usually under consideration. Most of studies examined the influence of blue or white light on alerting response

Wolska, A., Sawicki, D., Nowak, K., Wisełka, M. and Kołodziej, M.
Method of Acute Alertness Level Evaluation after Exposure to Blue and Red Light (based on EEG): Technical Aspects.
DOI: 10.5220/0006922500530060
In *Proceedings of the 6th International Congress on Neurotechnology, Electronics and Informatics (NEUROTECHNIX 2018)*, pages 53-60
ISBN: 978-989-758-326-1

on suppressing the melatonin level, but some recent research indicated that also red light increases level of alertness (Figueiro et al., 2009, Figueiro and Rea, 2010, 2017, Plitnick et al., 2010, Sahin and Figueiro, 2013, Okamoto et al., 2014, Łaszewska et al., 2017). This results proved that alerting effect could be obtained not only by suppressing the melatonin level.

However, it is proved that blue and red light could increase the alertness level, both during the night and day but the duration of elicited alertness after exposure to particular color of light still remains not well known.

The aim of the article is to present the method of acute alertness level evaluation after exposure to blue and red light based on EEG registration with special attention to technical aspects of used methodology. Preliminary results obtained during the pilot study are also presented.

2 TECHNICAL ASPECTS OF EXPERIMENT – EXPECTATIONS

2.1 Light Exposure

Lighting conditions play a very important role, because the effect of exposure to light as an acute change in alertness is observed. Since it has been proven that exposure to red or blue light could increase the alertness level, the verification of the elaborated method in a pilot study should show if the obtained results are in accordance with these findings. The main assumption of light exposure for planned pilot experiments was the application of two monochromatic lights: blue light (max. emission ~470 nm) and red light (max. emission ~630 nm), according to previous studies. This condition could be realized by using electroluminescent diodes (LEDs): blue LEDs and red LEDs respectively.

The next assumption was to obtain an appropriate level of illuminance at the participant's eyes during the exposure to blue and red light. According to the previous studies (Okamoto et al., 2014, Figueiro and Rea, 2010, Sahin and Figueiro, 2013, Łaszewska et al., 2017) the illuminance at the eyes of 40 lx both for blue and red light should be enough to induce alerting effect observed in EEG. This assumption should be fulfilled by specially designed lamp with blue and red LED modules, equipped with current control of luminous flux and diffusor to eliminate possible discomfort glare. The geometry of lamp position and participant's eye could be different. Usually, the lamp is positioned in front of observer's eye (Figueiro and Rea, 2010, Sahin and Figueiro, 2013), or over the head (suspended on the ceiling, not directly observed) (Sawicki et al., 2016), or two lamps on the desktop centered at 45° angle from midline aside of sightline (Alkozei et al, 2016). The latter of the above mentioned solutions was chosen for our study.

The next important aspect was to create the reference lighting conditions – dim light, which are usually realized as white general illumination of illuminance at the eye below 5 lx (Sahin et al., 2014, Plitnick et al., 2010, Cajochen, 2007, Figueiro et al., 2016). This lighting condition, as a reference lighting used for 30 minutes washout period before exposure, was established as the next assumption for the experiment.

2.2 EEG Registration

The choice of equipment for EEG registration usually depends both on the aim of the planned study and on equipment resources or financial possibilities to buy a new equipment. In most medical and research applications the equipment allows for placing gelled (or dry) electrodes on the scalp according to the International 10-20 system. However, this kind of professional equipment is relatively expensive. There are also low-cost consumer electronic devices with proven correct registration of EEG signals (like Emotiv Epoc). They are simple to use, wireless devices, usually equipped with saline electrodes, however the they contain fewer electrodes than the standard EEG i.e. the midline electrodes are missing. Therefore, as we planned to carry out the analyses for the alertness assessment, we chose the system with 32-electrodes placed according to the 10-20 system (see 3.1 for details) that included i.a. midline electrodes (Fz, Cz, Pz, Oz).

2.3 User's Centered Devices

EEG registration is very sensitive to different physiological artefacts like blinking, yawning, moving the head or the body. To avoid motion-related artefacts it is worth using the chin support.

During 30 minutes of exposure to light the participants must have open eyes. To avoid unintentional closing of the eyes, it is recommended to use a preview camera for eyes/face observation of the participant by the person conducting the experiment.

2.4 Management and Synchronization

Taking into account the need to monitor and manage the experiment during the whole session the test-stand should be separated from the monitoring and control stand.

The assumptions for management application (software for management of the experiment) were as follows: at the beginning of the experiment, enter the participant's personal code only once and call up the appropriate version of the experiment, perform the following tests after confirmation by the operator, counting out the exposure time.

For security reasons the stimuli delivery and experiment management should be carried out on separate computers.

3 TECHNICAL ASPECTS OF EXPERIMENT – IMPLEMENTATION

3.1 Stand for Experimental Tests

The stand for experimental tests for alertness level assessment after exposure to different color of light based on EEG registration was developed according to the above mentioned assumptions. The experimental stand consisted of two main sections:

- test stand (where the participant performed behavioral tests, and was exposed to particular light of controlled parameters);
- control and monitoring stand (where the person conducting the test could observe the stimuli presented on participant's screen, EEG signal during the recording and the participant's face during exposure to light).

The view of the stand for experimental test is presented in Figure 1.

Raw EEG signal was continuously recorded from 32 Ag/AgCl active electrodes placed on a cap according to the 10-20 International system using 256-channel g.Hlamp amplifier (Guger Technologies, Graz, Austria). It was digitized at sampling rate of 256 Hz. The ground electrode was placed at Afz and the common reference electrode at FCz. All impedances were kept below 30kΩ during the whole recording session.

A Simulink model (running under Matlab 2014a) was used to control the registration of the signal. It consisted of the building block provided by the manufacturer of the system (Guger Technologies, Graz, Austria).

Presentation ® v.20.0 (Neurobehavioral Systems Inc.) was installed on a separate computer for stimuli presentation (see Figure 1). TCP/IP protocol was used as it is a simple, stable and fast way to allow communication and data exchange between two computers (even with two different operational systems). The Protocol used port 5000 to send and acquire data (on server and client application respectively) because it allows the application to share data via TCP/IP protocol.

The registration of the resting state EEG (rsEEG) was performed three times during the pilot study experimental sessions. The delivery of fixation point was presented on the screen in front of participant.

Another computer was dedicated to operate and control two lamps (type MOL-02) for exposure to red and blue light (manufactured by GL Optic Poland). The lamps consisted of 2 red (630 nm) and

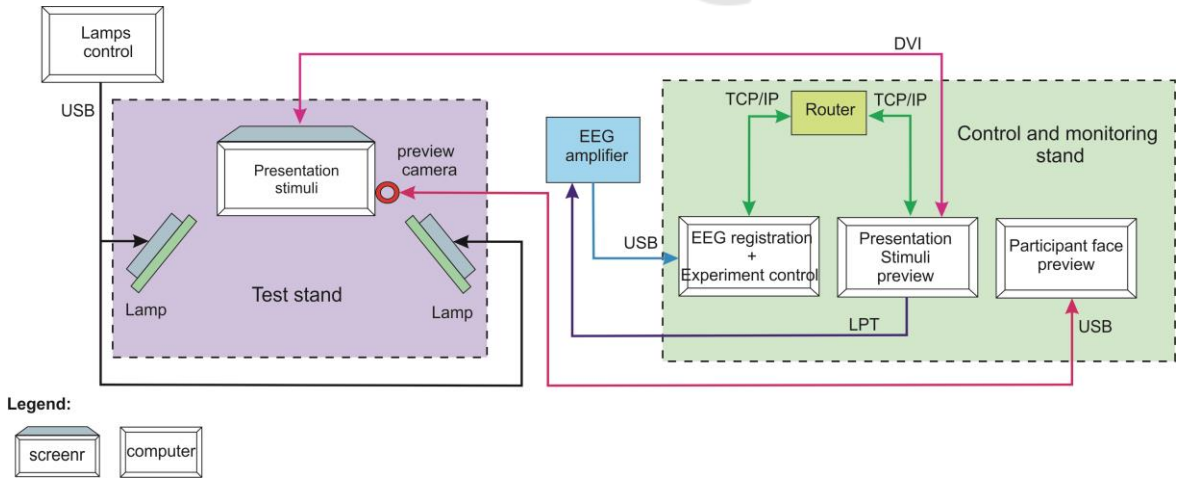

Figure 1: The experimental stand – the distributed and complex measurement and control system.

2 blue (465 nm) LED modules which were also equipped with a diffusor (20x30 cm) to reduce luminance (to avoid direct glare). According to Alkozei et al. (Alkozei et al., 2016) both lamps were positioned at 80 cm distance measured at the participant's nasion, with each light cantered at a 45 degree angle from midline (see Figure 1). The established illuminance level for exposure was 40 lx both for red and blue light.

The computer software (management application) was developed to control and synchronize the experiment process in distributed computer system. The management application was written by the Authors in Matlab environment and installed on the computer for EEG registration, which played the role of server. The computer with Presentation software, played the role of the client. The management application "led" the experimental session from the first to the last test, including 30 minutes of exposure time countdown. The main programing difficulty encountered during designing the management application was the incompatibility of two software environments (Matlab and Presentation). To solve this problem a third party program was developed in C# as the application connecting both environments. Since the control panel of g.Tech was created in Simulink (Matlab's environment) it was self-explanatory to create the optimal Matlab script to control the preview of both the experimental trigger and the EEG signal. Matlab is also able to work as a data server, and in this case the data was used to trigger the next step of the experiment, which allowed the Authors to create optimal control environment. Main function of the software consisted of three major parts. In the first part the user was prompted to fill in the information about the current experiment subject. The second part worked as a server code that established the communication between two computers. Third part was the control over g.Tech Simulink model such as starting data acquisition, saving files, controlling proper naming and stopping Simulink. It is important to mark that the first part was filled only once at the beginning of the experiment. The second and the third part were working in one loop.

3.2 Management Application for the Experiment

This tool has two roles. The first role was to send a data request to the server. The second role, if the data was available (server enabled), was to send the trigger information to the virtual COM port, where Presentation software awaited information. The program is written in C# and is NET 4.0-compatible, supported by Windows XP. Windows XP was used as the computer operating system with a motherboard supplied with LPT port, through which the event data was added to signal in g.Tech amplifier.

The last part of the management application was a script written in Presentation. Its main purpose was to conduct, control as well as store the data about the current experiment. This script was written as a set of steps divided into parts.

Each subsequent part of the test was started by a trigger that appeared on the virtual COM port created on a computer. After being informed that the subject agreed to the start of the next task, the test continued.

4 PILOT STUDY PROTOCOL

The aim of pilot study was to evaluate the developed methodology both from a technical point of view and to check whether the results of alertness level obtained after the exposure to blue and red light confirm previous studies that this color of light could elicit the alertness level during the day. It was also important to investigate the correctness of control in a complex measuring system (effective and convenient), and work comfort of the participant.

The protocol was approved by the Senate Committee of Research Ethics of Józef Piłsudski University of Physical Education in Warsaw. All participant gave their written informed consent prior to the study.

4.1 Participants

The pilot study was carried out during the winter season. The participants were 10 young, healthy men aged between 21-30 years old (mean age: 23,63±2,64 years old). All participants met the following criteria: did not report of any physical or mental health problems, did not suffer from color blindness, did not use glasses to work with a computer, did not use any medication and did not have problems with sleep. According to the chronotype identified using *Composite Scale of Morningness* – CSM (Smith et al., 1989, Jankowski, 2015) the participants started the experiment session respectively at 7:30 am (morning chronotype) or at 11:00 am (evening chronotype), similarly to the study of Maierova (Maierova et al., 2016). The participants were asked to maintain a fixed regular

plan sleep, lasting at least 7 hours during the week preceding the start of the experiment. Every participant took part in two experiments, each with exposure to different light. The session order was counterbalanced for each individual, to avoid the impact of familiarizing with the procedure on results. One week interval between the experiments was established.

4.2 Method

The experimental session started with filling in a questionnaire for subjective assessment of the participant's wellbeing and checking his sleep diary filled in during 7 days before experiment. The participants were then prepared for EEG registration, which included the use of a gel under the electrodes to obtain proper impedance level in each electrode (<30 kΩ). After that, the participants sat in dim light condition for 30 minutes (wash out period). They were then asked to place their chin on the chin support and look at the screen in front of them at the distance of 60 cm when the first resting state was carried out. Plus symbol ("+") was presented on the screen for 3 minutes together with EEG registration. After the first registration the exposure light was switched on for 30 minutes of exposure. The participants were asked to keep their eyes open during that time, but the person conducting the experiment was observing participants' eyes on the screen to see their face/eyes preview and to check if they were not falling asleep. Just after the exposure the second resting state together with EEG registration was carried out for the next 3 minutes. Then, the participants was asked to perform psychomotor tasks: N-back (0-back,1-back,-2back) and Go-No-Go alternately, 3 times each. The order of the presentation of the task was counterbalanced across the subjects. The stimuli in the tasks were presented with the Presentation ® v.20.0 software. After that the third resting state was carried out. As a result we obtain three EEG registrations of 3-minutes each: one before the exposure (but after 30 minutes of dim light), second just after 30 minutes of the exposure to red or blue light (acute alerting effect) and third after 48 minutes after the exposure and computer tests in dim light (sustained acute alerting effect).

5 DATA ANALYSIS

The collected set of EEG signals was analyzed in order to recognize the change in alertness level. The initially prepared signal was divided into a set of 1s fragments. Each fragment was analyzed by Fast Fourier Transform giving energy in proper bands. For one user the mean value for proper band was calculated from a set of 1s fragments. In a typical analysis of alertness, low bands (Theta, Alpha) are registered from O1, O2, and Oz and sometimes from neighboring electrodes. We wanted to simplify the analysis in our pilot study and we assumed the use of signal analysis from only one electrode located in the center of the skull – Oz.

For most people during normal readiness state (and with open eyes) the amplitudes of Theta waves (4.5-8 Hz) and Alpha waves (8–12 Hz) are minimal. Practically these waves do not exist in such situation. This is confirmed by numerous publications (Klimesch, 2012, Sahin and Figueiro, 2013, Okamoto et al., 2014, Baek and Min, 2015). The main problem in analysis of EEG signals for alertness recognition is individual differences between the participants. Many researchers try to remedy this problem by specific analysis. For example, the Author of the paper (Chang et al., 2013) analyzed the sum of Theta and Alpha bands in order to cover a wide range of frequency.

The analysis was based on a new measure of alertness ($TAAT_{max}$) introduced in 2016 (Sawicki et al., 2016). Using FFT we have prepared the following bands: Theta (4-8 Hz), AlphaTheta (5-9 Hz), AlphaLow (8-10 Hz), AlphaHigh (10-12 Hz) and applied the formula (1):

$$TAAT_{max} = \max(DF_T, DF_{AL}, DF_{AH}, DF_{AT}) \quad (1)$$

where DF_T is the difference of power in Theta band. This is calculated as energy before – energy after. DF_{AL}, DF_{AH}, DF_{AT} are the differences of power in the AlphaLow, AlphaHigh and AlphaTheta band respectively. Since the decrease in signal level is correlated with an increase in alertness, the higher the $TAAT_{max}$, the higher the alertness level.

6 RESULTS AND DISCUSSION

As expected, the highest impact on alertness was observed in the use of blue light and it was clear in the case of almost all participants. The typical box plot for analyzed bands for one participant is presented in Figure 2. We have also calculated statistical significance between the first and the second registration (1-2), which is in all considered bands statistically significant $p<0.05$.

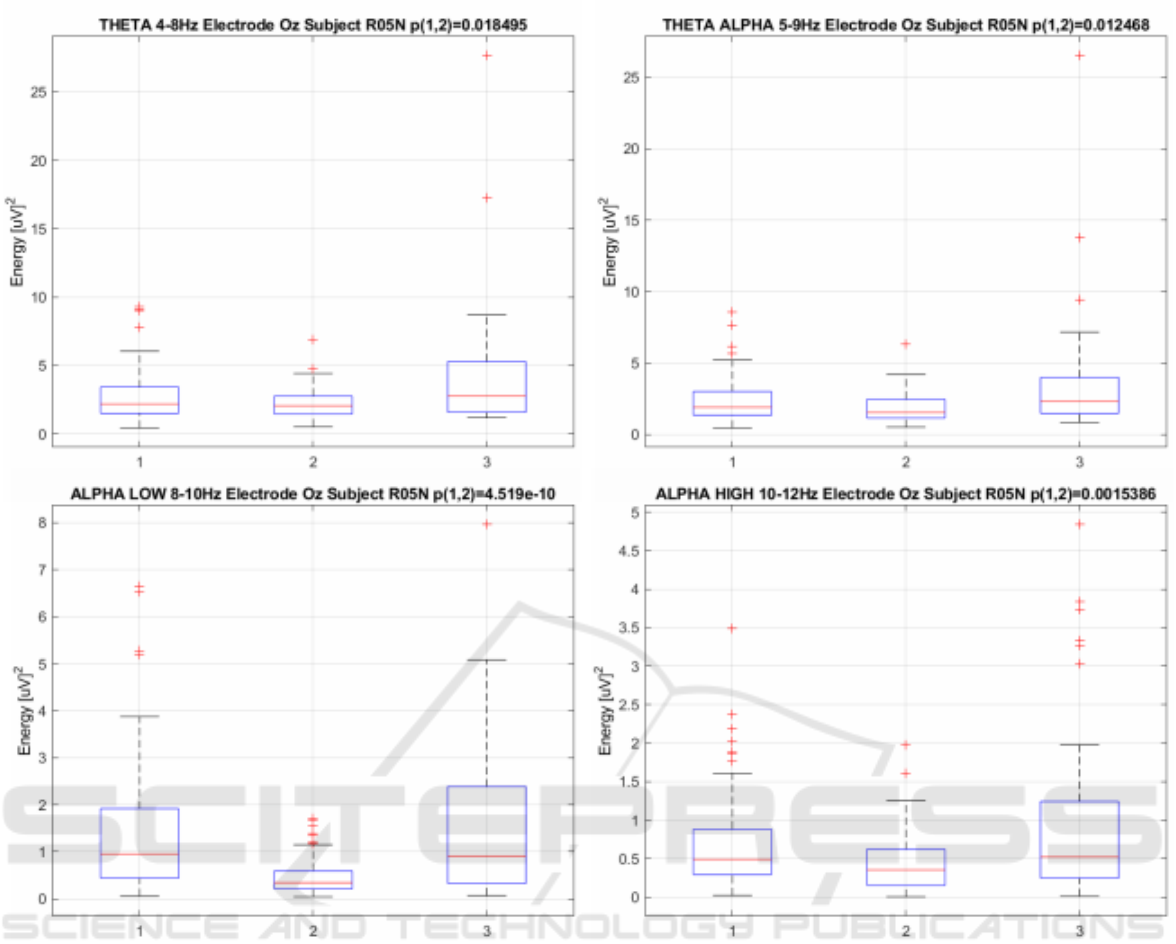

Figure 2: An example of box plots for participant R05N. Box plots of energy value in bands: Theta, AlphaTheta, AlphaLow, AlphaHigh. Energy is presented in three measure points: (1) before the exposure to blue light, (2) just after the exposure to blue light, (3) after a period of performing computer tests following the exposure to blue light.

The $TAAT_{max}$ measure for all participants was calculated to assess the differences between two states: after the exposure to light in relation to the state before the exposure (acute alerting effect), and after a period of performing computer tests following the exposure to light in relation to the state before the exposure (sustained acute alerting effect). The calculated $TAAT_{max}$ measures showing the impact of blue and red light on alertness level are presented in Figures 3 and 4, respectively.

There is a visible impact of blue light exposure on the increase in acute alertness level in the first period after the exposure (Figure 3). After 45 minutes of performing computer tests following the exposure the impact on alertness level was weaker. The acute alertness level seems to decrease with time. It could be related to mental tiredness of participants performing the computer psychomotor tasks.

In the use of red light (Figure 4) the impact was not so clear in the case of all participants, but the tendency of increasing the alertness was visible. These results for exposure to both blue and red light influencing the alertness level are consistent with previous results, which introduced $TAAT_{max}$ as a new measure of alertness (Sawicki et al., 2016). Although the number of the participants was small, the results obtained so far suggest that the applied methodology and the experimental setup is appropriate. More subjects of both chronotype is needed to draw more reliable conclusions.

First of all the methodology meets our expectations and provides an opportunity to assess the acute alertness after the exposure to light. Our results confirmed previous studies concerning alerting effect of blue and red light (Figueiro et al., 2016, Figuerio and Rea, 2010, Chang et al., 2013, Sahin and Figueiro, 2013, Łaszewska et al., 2017,

Sawicki et al., 2016). Interview with the participants after the experiments confirmed that work stand provided them with comfort during the experimental session. In the opinion of participants and Authors this was a valuable contribution to minimizing the impact of discomfort-related factors on the obtained results.

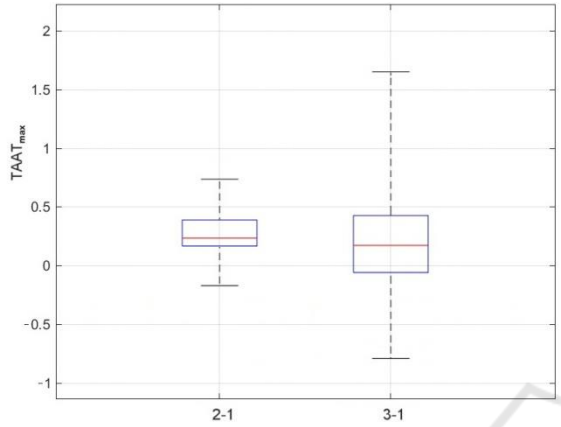

Figure 3: Impact of blue light exposure on the alertness level. Box plots of $TAAT_{max}$ for two states: (2-1) after the exposure, (3-1) after performing computer tests. The higher the $TAAT_{max}$, the higher the level of alertness (Sawicki et al., 2016)

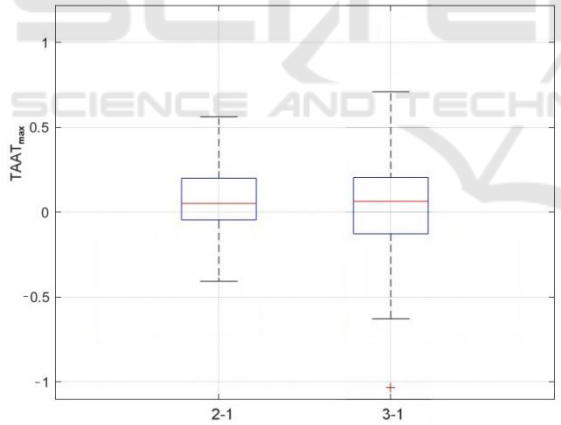

Figure 4: Impact of red light exposure on the alertness level. Box plots of $TAAT_{max}$ for two states: (2-1) after the exposure, (3-1) after performing computer tests. The higher the $TAAT_{max}$, the higher the level of alertness (Sawicki et al., 2016).

The second important result of the pilot study was the confirmation that Author's management application (software for experiment management) meets the requirements in various real working conditions. It was particularly important to confirm the correctness of data transmission between two different operating systems and the synchronization of the entire registration process. At the same time the experiments showed that the applied solutions allowed for simple and effective control of the experiment. In addition, some programming errors were detected and corrected during the pilot study.

7 CONCLUSIONS

Various research studies on the influence of lighting parameters on human wellbeing psychophysiology of vision and visual ergonomics have been the subject of research carried out by the Authors of this article for many years. The long-standing experience in conducting the experiments with participants has showed that developing a proper work stand and procedure constitutes a big, self-contained and difficult problem. Studies on the influence of light on alertness level usually described in detail the conditions and procedure of exposure, while the technical aspects of experimental stand and management were omitted. Reading the articles, we believe that the described experimental conditions and procedures may be easy to reproduce, but sometimes surprisingly difficult or impossible to perform.

Construction of a complex experimental stand with EEG registration can be a difficult task, especially when IT problems play an important role. There may be a complex measurement system controlled by heterogeneous software. With this in mind, the Authors of this article wanted to share their knowledge and experience in planning this type of study, and believe that the technical aspects that were described could be useful for those scientists, who would like to analyze influence of light on alertness level based on EEG recording in the future.

ACKNOWLEDGEMENTS

This paper has been based on the results of a research task carried out within the scope of the fourth stage of the National Programme "Improvement of safety and working conditions" partly supported in 2017–2019 --- within the scope of research and development --- by the Ministry of Science and Higher Education / National Centre for Research and Development. The Central Institute for Labour Protection -- National Research Institute (CIOP-PIB) is the Programme's main co-ordinator.

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