New EEG Measure of the Alertness Analyzed by Emotiv EPOC in a Real Working Environment

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Abstract: Alertness level evaluation has obvious implications for safety–critical occupations such as operators in control rooms or drivers. It has already been stated that alertness can be assessed objectively by EEG. However, the high costs of standard medical equipment for EEG measurement, their complex and time-consuming operation, and the need to use conductive gel on the scalp make this method impossible for general use or at workstations. The aim of the study was to analyze the possibility of alertness level assessment based on EEG measurements using the Emotiv EPOC headset, which is relatively cheap, wireless, comfortable for wearing and does not need the use the of conductive gel, but allows the capture of only 14 channels of EEG. The experiments were carried out in laboratory conditions using three different light spectra for 40 minutes exposure on office workstation during the afternoon drop in alertness. 50 participants took part in each light scene (white, red, blue). The EEG measurements were performed before exposure and just after exposure to a particular light scene. A new measure of alertness, based on analysis of EEG signals, has been introduced. The results showed that this new measure based on low-cost Emotiv EPOC EEG measurements is reliable and confirms the results of previous studies.

1 INTRODUCTION

1.1 Motivation

Studies on alertness levels have been conducted for many years. This study is important for ensuring safety at work, and also due to the possibility of increasing efficiency. The methodology for these tests is usually based on an analysis of the contents of melatonin in the blood, urine or saliva. Such a study is the simplest test of alertness in laboratory conditions, but difficult or impossible in real conditions – in the workplace, for example for drivers. Therefore, the need for another method which enables the effective recognition of the level of alertness. For several years, research on the melatonin level in blood has been combined with the analysis of EEG (Rahman et al., 2014, Sahin and Figueiro, 2013, Sahin et al., 2014, Górnicka, 2008). At the same time, systems based only on the analysis of EEG signals have been developed. Research conducted among drivers are a good example of this (Ji et al., 2011, Li et al., 2010).

Participant comfort during the performance of tests is a basic prerequisite for the practical application of EEG in the diagnosis of alertness level. This is especially so if the tests are carried out on a large group of participants. The traditional medical equipment for EEG recording, in which it is necessary to use a conductive gel, does not meet this condition. Tests organized in this way disqualify the use of EEG signals in the identification of alertness in the workplace. Therefore, increasingly often we notice attempts to use a simpler device, equipped with saline electrodes (not gelled) – a low-cost (consumer edition) device. The above conditions are clearly met by the Emotiv EPOC (Emotiv Systems Inc.) device, which in recent years has also been used to analyze EEG signals (Stytsenko et al., 2011, Pham and Tran, 2012, Zhan, 2013, Badcock et al., 2013, Fakhruzzaman et al., 2015). Comparisons between signal analysis based on Emotiv EPOC and medical EEG devices have been performed (Duvinage et al., 2012). As a result of these comparisons, it has been concluded that Emotiv should only be chosen for non-medical, non-critical applications. On the other hand, Ramirez and Vamvakousis (2012) tried to detect emotion from

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the EEG signals obtained using an Emotiv device. Their conclusion was that indeed Emotiv allows the registration of signals only from selected points (from 10–20 system), but such registered signals are sufficient for data analysis. Similar conclusions can be found in one independent report (Ekanayake, 2010, updated in 2015). Badcock et al. (2013) showed high similarity of signals registered by traditional a medical EEG system and an Emotiv EPOC.

Therefore, it is worth conducting a study where the aim is to enable the recording of EEG in the most friendly way for employees, while at the same time in a way that enables the identification of the level of alertness. Emotiv EPOC is a good example of a low-cost consumer electronic device with proven correct registration of signals, although we must be aware that it has limited capabilities and requires careful interpretation of the results.

1.2 EEG Signals as a Measure of the Alertness Level

Studies show that for most people during normal readiness state (and with eyes open) Theta waves (4.5-8 Hz) and Alpha waves (8–12 Hz) practically do not exist (Sahin and Figueiro, 2013, Baek and Min, 2015, Klimesch, 2012, Okamoto, 2014). If they occur, their amplitudes are minimal. It is assumed, therefore, that if during the registration process (in a state of readiness, work etc. with open eyes) there are Theta and Alpha waves with greater amplitude, this represents an increase in drowsiness and fatigue, and thus a decrease in alertness (Lal 2001).

With eyes open, and with an decrease in alertness, the amplitude of the waves of lower frequency (and thus Theta and Alpha) increases. While with closed eyes, and in a state of drowsiness, Alpha wave activity begins to decline, and the amplitude of waves Theta increases. Therefore, in studies usually two types of waves are analyzed – Alpha and Theta. Sometimes additional bandwidth Low Beta (Beta 1) (12–18Hz) is taken into account. This band is associated with commitment and mental activity. It is combined with cognitive alertness and states immediately before performing tasks requiring alertness (Gola et al., 2013). However, a direct correlation with the level of alertness has not yet been showed.

The simplest and simultaneously most effective way to stimulate alertness is to use light of a particular color. The discovery of new receptors of light (ipRGC - Intrinsically Photosensitive Retinal Ganglion Cell) begun many studies on lighting, which is biologically effective (Brainard, 2001, Sahin and Figueiro, 2013, Sahin et al., 2014, Thapan, 2001, Viola 2008). Studies have shown that light with a wavelength range between 425 and 560 nm is effective in inhibiting melatonin secretion. The maximum effectiveness of this process occurs for blue light in the wavelength range from 460 to 480 nm, depending on the obtained results of the tests and their interpretation (Brainard et al., 2001, Thapan et al., 2001, Aube et al., 2013). Despite minor differences in interpretation, the authors of these studies are in full agreement about the effect of blue light with short wavelengths on the physiological process of secretion of the hormone melatonin – the process responsible for the states of modulation between sleep and wakefulness during the day. The use of light blue (or white with a high proportion of blue light) raises the level of alertness and thus helps to achieve a higher level of psychophysical efficiency at work (Rahman et al., 2014, Sahin and Figueiro, 2013, Sahin et al., 2014, Viola 2008).

1.3 The Aim of the Study

The aim of the study was to analyze the possibility of identifying the level of alertness in the registration of the EEG signal in real working conditions. The tests were planned for a large group of 50 participants. Due to the need for adequate comfort of such a large group of participants, we used EEG equipment which does not require the use of a conductive gel and has wireless connection to a computer (i.e. there was no wiring that could make movements difficult).

The equipment (Emotiv EPOC) is also a non-medical, consumer, low-cost device. In this context, these studies might also answer the question about the possibility of using such low-cost equipment in this research. As a key factor that affects the increase in alertness, lighting with a significant blue component was applied. The white-color lighting used in workrooms was used as a reference condition ("placebo"), which should not elicit alertness. In addition, we used red-color lighting as a factor that influences the level of alertness but on a different principle than that of blue.

2 METHODOLOGY

2.1 Participants

In the study, a group of 50 participants took part, mean age 47.84 ±16.51 years, range 22–67. In a natural way, there was a division into two subgroups: older (mean age 66.66 ± 3.54 years, range 56–67) and younger (mean age 27.83 ± 3.59 years, range 22–32). Participants included 22 healthy male and 28 female volunteers. All participants met the following criteria: no report of any physical or mental health problems, no color blindness, office workers or students with experience of computer work, and no use of any medication. The experimental protocol was reviewed and approved by the Ethical and Bioethical Committee of Cardinal Stefan Wyszynski University in Warsaw. Informed written consent was obtained from each study participant. Participants were paid for their participation.

Every participant completed a Horne-Ostberg Morningness-Eveningness Questionnaire (MEQ) (Horne and Ostberg, 1976) before the study. The mean of reported chronotype was 2.6 ± 1.06. In the older subgroup, this was 2.2 ± 0.92, and in the younger subgroup 3.2 ± 0.95. Participants kept a sleep/wake diary during all weeks of the experiment, starting one week before starting the study. These diaries documented bedtimes, rising times and level of sleepiness / alertness on an hourly basis.

2.2 Lighting Conditions

The assumption of the study was to show that lighting in office working conditions of specific light spectra can be used to increase alertness in the afternoon, close to the post lunch hours. Some literature (Figueiro and Rea, 2010, Hanifin et al. 2006, Sahin and Figueiro, 2013, Sahin et al., 2014) has stated that exposure to blue and red light during the afternoon elicits alerting effects in humans. These studies used direct exposure to blue or red light with fixed head position. The aim of our study was to model lighting conditions which would be applied at office workstations to elicit alertness. Lighting of a special spectrum switched on for an exposure time of about 40 minutes should allow the performance of visual tasks with visual comfort, adequate color recognition of the environment and appropriate illuminance. So, the red or blue lights were added to white light as a significant component, which would influence the alertness (Wolska and Sawicki, 2015). The three experimental lighting conditions participants were exposed to were:

- Reference conditions – general lighting – fluorescent white light (Tc = 4000 K, Ra = 80), termed “white” lighting scene;
- Blue enriched white lighting conditions – general lighting + localized lighting: white LEDs (4000 K) and blue LEDs (λ_{max} = 470 nm), termed “blue” lighting scene;
- Red enriched white lighting conditions – general lighting + localized lighting: white LEDs (4000 K) and red LEDs (λ_{max} = 630 nm), termed “red” lighting scene.

The localized lighting was placed over the participant's head to avoid direct sight of light sources and glare during the experimental session. Discomfort glare from general lighting was limited to UGR < 16, which fulfilled the requirements of lighting standard EN 12464-1 (EN 12464-1, 2011). During the exposure, participants were sitting at the computer workstation and performed visual tasks while looking at the screen. Eye height was fixed to about 1.20 cm above the floor. The illuminance at the cornea was: 286 lx under “white” conditions, 714 lx under “blue” conditions and 842 lx under “red” conditions.

2.3 Emotiv EPOC

Emotiv EPOC allows the recording of EEG signals in accordance with the 10–20 system, but with a limited number of electrodes. In the Emotiv system, only 14 active electrodes are available, together with two reference electrodes (P3 and P4). The electrodes are arranged around the head of the participant, within the structures of the following areas: frontal and front-parietal: AF3, AF4, F3, F4, F7, F8, FC5, FC6; temporal: T7, T8; and the occipital and occipital-parietal: O1, O2, P7, P8. The device has an internal sampling rate of 2048 Hz and after cleaning artifacts, it is resampled to 128 Hz. Finally, EEG signals are transferred wireless to a computer, where they are stored in a file using edf format. Proper impedance of electrodes is formed by the use of physiological saline. The scheme of electrode arrangement in the Emotiv headset is presented in Figure 1.

The Emotiv system has a known disadvantage - the lack of electrodes in the center of the skull (Pz, Cz, Fz), and therefore, this system has limited applicability in research. In our experiments, missing signals were replaced by signals from electrodes O1, O2, T7, T8, FC5, FC6. The manufacturer of Emotive states that the signal picked up by these electrodes would be good enough to perform experiments with EEG registration.

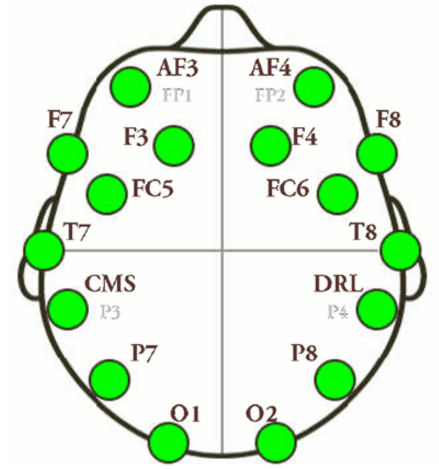

Figure 1: Placement of electrodes on the headset in the Emotiv EPOC system. Picture from (Emotiv Systems Inc.).

2.4 Procedure of the Experiments

Participants were informed about the experiment and trained in the performance of visual tasks a few days before experiments. Participants were instructed to be well rested before the experiments. Participants were asked to refrain from alcohol and caffeine intake during the experimental sessions.

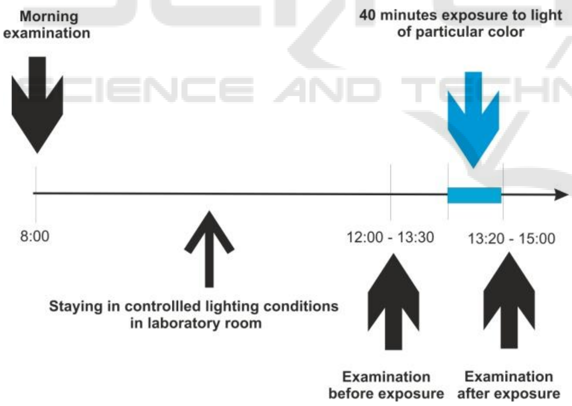

Figure 2: The course of the experiment, with time dependencies, for one participant.

Participants experienced three experimental sessions, separated by one week. On the experimental days, participants arrived at the CIOP-PIB laboratory at 8–8:30 AM and stayed in controlled artificial lighting conditions under scene “white”. They stayed until the afternoon drop in their alertness (according to their sleepiness / alertness assessment in personal diaries). Thereafter, the first EEG measurements were carried out (session “before exposition”). Then, one of three lighting scenes, “white”, “red” or “blue”, was modeled and participants performed visual tasks typical for office work during 40 minutes of exposure to particular light. At the end of the task, the additional component (“red” or “blue”) of lighting was switched off. Then, the second EEG measurements were carried out (session “after exposure”). The course of the experiment, with time dependencies, for one participant is presented in Figure 2.

All statistical analyses were carried out using SPSS program version 18.

3 EEG ANALYSIS

3.1 Signal Acquisition

Signal acquisition took place using TestBench software (from Emotiv System Inc.). We used a high pass filter set at 0.2 Hz. To register markers that signal the emergence of a stimulus on the screen, we developed a communication between TestBench and our original application CatchMe using the COM port. After registration, we visually analyzed the signal and we discarded fragments of the signal, which cannot be solved in a different way. We used EEGLab in this task. The next step was to filter the signals in the frequency range 0.2 Hz – 40 Hz.

Initially prepared signal was analyzed by FFT (Fast Fourier Transform) with 2 s Hamming window and 1 s overlapping.

The next step was the visual analysis of the collected data. We rejected cases where artifacts of unknown origin occurred. We also rejected incomplete registrations and those that did not achieve the correct FFT analysis for all conducted experiments. Finally, from the 50 sets of signals (from 50 participants) we selected 46 for further analysis.

Because of the lack of electrodes in the center of the skull (Pz, Cz, Fz) in the Emotiv system, we have to analyze signals from neighboring electrodes (O1, O2, T7, T8, FC5, FC6). Preliminary trials before the studies showed that the signals in such a situation are of slightly lower quality but allow the performance of analysis. Apart from artifacts, signal registration in the Emotiv system often causes problems of levels (signal levels at the various electrodes may vary). In order to choose proper electrodes, we analyzed the collected set of signals and we selected electrodes from which we had better quality of signals. Finally, we analyzed signals from O1, T7 and FC5.

For all participants the following bands were selected:

- Alpha 8–12 Hz from O1;
- Beta from FC5;
  - LowBeta 12–16 Hz;
  - Beta 16–31 Hz;
  - HighBeta 16–24 Hz;
- Theta 4–8 Hz from T7;
- AlphaTheta 5–9 Hz from T7;
- DeltaTheta 0.3–3 Hz from FC5;
- DeltaTheta 2.5–5.5 Hz from T7;
- Total Power 6–40 Hz as average of all 14 electrodes.

In our experiment, we registered the above set of signals for all participants. However, in the analysis of the alertness we only used the frequency band of 4–12 Hz, because such a range is most commonly documented in the literature (Sahin and Figueiro, 2013, Chang, 2013).

3.2 Analysis in Alpha Frequency Band

In the literature, we can find two general methods for investigating symptoms of alertness in the EEG signals. The first is where authors initially use special mathematical algorithms for proper feature extraction, for example principal component analysis (PCA) in (Giusti, 2009). The second is where the analysis is performed directly on the signals (Sahin et al., 2014). The correlation between level of alertness and level of proper bands of EEG signals has been showed, so in our study we analyzed directly registered EEG signals.

The most commonly used bands for identification of alertness are: Alpha (8–12 Hz) or AlphaTheta (5–9Hz) (Sahin and Figueiro, 2013, Baek and Min, 2015; Klimesch, 2012, Okamoto, 2014). Therefore, initially we decided to analyze the band Alpha. We analyzed the levels of Alpha before being in a certain light scene and then afterwards. It is reported in publications that an increase in alertness should be associated with a decrease in the level of Alpha (Lal, 2001).

Due to the high dispersion of data, which was the result of a high level of precision, we decided to transform the variables in order to reduce the dispersion of the results. For this purpose, we carried out the categorization of the dependent variables, identified from the standard deviation values (+/- 1 to 3 standard deviations). Variables recorded in this way show a decrease or increase in the measurement of EEG both before and after exposure. This is a change for the corresponding scaled value (1 to 8); however, it does not show what value has changed the EEG in each variable. From the description of variables and recent statistics, it is known that the exposure for each color has a different effect on the value of the EEG. This resulted in different EEG values, but the processed data did not take into account this difference. For this reason, to each identified group we assigned the average value of the group. Such recordings were conducted separately for each lighting scene (color).

The Kolmogorov-Smirnov test showed that the tested variables are not distributed normally. Not in groups, not without grouping. Levene's test confirmed the homogeneity of variance.

Analysis using the Student's t-test for independent samples showed no statistically significant difference in the decrease in EEG (before and after exposure) among people from younger subgroup compared to the results of measurements for the older subgroup for all kinds of light (Table 1).

Table 1: Results of the first analysis for Alpha band between two subgroups of participants under different lighting scenes. Equal mean t test.

Lighting scene	t	df	significance (two-sided)
White	1.159	45	0.252
Red	1.522	45	0.135
Blue	1.872	45	0.068

Because the analyzed variables did not meet the requirements, we decided to confirm the test results using the non-parametric equivalent. The Mann-Whitney U Rank test unfortunately confirmed that among the analyzed variables there are no statistically significant differences.

However, it is worth paying attention to the values of significance. For the “blue” lighting scene we obtained a result that is close to the possibilities of the hypothesis confirmation (significance = 0.068 – in comparison to the expected 0.05). We can, therefore, say that there is a tendency that the color blue has a greater effect on alertness than the red and white color, and red has greater effect than white.

3.3 Proposition of a New Alertness Measure

There are known research of alertness, which uses a very wide range of frequency analysis of EEG signals. Chang (2013), for example, analyzed the range of frequency covering the sum of Theta and Alpha bands. Such an approach is justified by individual differences in the response of EEG to stimulus associated with alertness. However, an excessively wide frequency range can cause averaging of local extremes. In our experiments, the first analysis carried out in only one band, Alpha, did not produce statistical confirmation. In order to try to confirm the study, we decided, therefore, to take into account other recorded bands.

We introduced a new measure of alertness ($TAAT_{max}$) (1) based on the capture of signal decreases in three bands: Theta, Alpha and AlphaTheta. In our algorithm signals are analyzed independently in each of these bands, and then the biggest decrease among them is searched.

$$TAAT_{max} = \max(DIFF_T, DIFF_A, DIFF_{AT}) \quad (1)$$

Where $DIFF_T$ is the difference of power in Theta band. This is calculated as power_before – power_after. $DIFF_A$ is the difference of power in the Alpha band and $DIFF_{AT}$ is the difference of power in the AlphaTheta band, similarly calculated. Because the decrease in signal level is correlated with an increase in alertness, the greater the $TAAT_{max}$ the higher the level of alertness.

3.4 Analysis of the New Measure

In the analysis, One Way ANOVA, $F(2, 135) = 11.04$; $p < 0.001$, was used. Post hoc tests and comparison of averages showed that the greatest differences (before – after) were observed for the blue lighting scene (Figure 3). For red and white scenes, small differences were obtained. Similarly, the size decrease in the EEG signal for the blue lighting scene was the highest (Figure 4). Gamesa-Howell post hoc tests showed that there are statistically significant differences between the decline for the blue lighting scene and the other two at the level of $p < 0.005$ for white and $p < 0.01$ for red (Table 2).

The analyses allowed the conclusion that alertness increased after exposure under the blue lighting scene. Also, post hoc tests and comparison of averages showed that white lighting scene has no elicited alertness increase, but we can see a certain tendency for the red light in this respect. These results are consistent with previously published studies.

On the one hand, it has been confirmed that alertness can be recognized from the analysis of bands: Alpha, Theta and AlphaTheta (Chang, 2013, Sahin and Figueiro, 2013, Baek and Min, 2015, Klimesch, 2012, Okamoto, 2014). On the other hand, it has been confirmed that there is a strong influence from blue light and a weak influence from red on alertness, according to earlier publications (Sahin and Figueiro, 2013, Sahin, 2014). However, in our research the influence of red light has not been confirmed statistically.

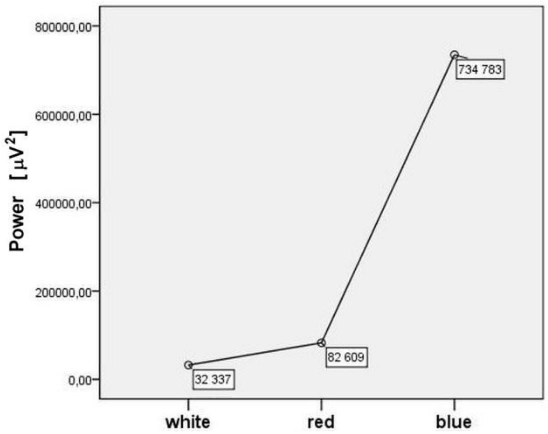

Figure 3: Mean differences of $TAAT_{max}$ level decline after exposure under particular light scenes.

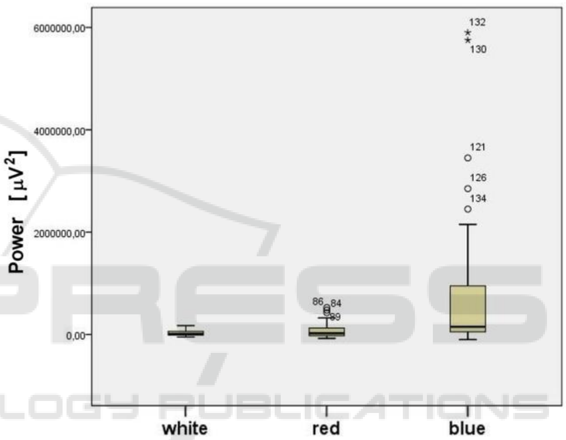

Figure 4: The size of EEG signal decline using $TAAT_{max}$ measure after exposure under particular light scenes.

Table 2: Results of the ANOVA analysis for $TAAT_{max}$ measure (selection of the independent falls capture in Alpha, AlphaTheta and Theta bands).

Lighting scene	Lighting scene	significance
White	Red	0.079
	Blue	0.003*
Red	White	0.079
	Blue	0.007*
Blue	White	0.003*
	Red	0.007*

4 CONCLUSIONS

Obtained results of measured EEG showed an increase in alertness after 40 minutes exposure to blue enriched white lighting modeled for normal use in office working. It was also stated that red enriched white lighting could increase the alertness, but much less than was the case with blue. It is worth noting that red light influences alertness, but in a different way than that for melatonin suppression, as it is for blue light. However, a statistically significant effect on alertness was observed only for blue light. The tendency of increasing alertness after red light exposure was also noticed, but that effect was not statistically significant.

Our results confirm that blue light is the most effective in increasing alertness, even if it is only component (significant) of the lighting spectrum. This was stated for real working environments and exposure to blue enriched white lighting and with participants not having heads fixed in one position but performing office work during exposure. Most of the light falling on the cornea was indirect (after multiple reflections from the environment). In the literature (Figueiro and Rea, 2010, Hanifin et al., 2006, Sahin and Figueiro, 2013, Sahin et al., 2014), the exposure was to direct light from different lighting fixtures and subjects were looking directly at the light, so they had not performed any work during exposure. Our study is the first attempt to create lighting conditions suitable for increasing alertness and also adequate for working performance which could be applied in reality.

The research was conducted on a group of 50 participants. It is worth noting that this is the first study on the effect of lighting on the level of alertness, which has included such a large group of participants.

Additionally, the study confirmed the possibility of the use of such low-cost equipment. Despite its disadvantages known from the literature, the Emotiv EPOC device allowed for the correct registration of the EEG signal. The proposed measure of the alertness level, which is based on the analysis of the three bands (Alpha, Theta and AlphaTheta), proved to be sufficiently effective. The use of this measure in our study allowed an assessment of the effect of blue light, which was confirmed statistically.

It is worth noting that this material gathered from research on a large group of people will allow for the future performance of additional analyses. In our study, we used the bands of 4–12 Hz, because such a range is most commonly documented in the literature connected with alertness investigations. However, we registered many other bands of signals for all participants. It is planned to carry out analyses including Beta (especially LowBeta and optionally independently HighBeta), Delta and DeltaTheta bands. We also want to use emotions identified by the software of Emotiv EPOC device.

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