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Light temperature and its effect on performance: an EEG study

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Abstract:

Exposure to different frequencies of light affects physiological mechanisms in the human body. We wish to explore the possible effects of different light temperature on brain activity during tasks which require attention and problem solving. Using EEG measurements to record brain activity in one short wavelength light setting, and one long wavelength light setting, we found significant differences between the two settings, suggesting that the long wavelength light allows better cognitive performance. However, this cannot be taken as evidence that the human brain is directly influenced by light temperature, because the illumination in the two settings was different. This study definitely leaves room for further research on the effect of long or short wavelength light on cognitive performance, both in clinical as well as more reality-based, classroom- or office-like settings.

1.1 Introduction

It is commonly thought that exposure to daylight affects the mood and level of energy in a positive direction, yet daylight is hard to come by for residents of northern Europe. As a response to this, different methods of light therapy have been developed which are said to enhance everything from mitigating pre-menstrual symptoms in women (Parry, Mahan, & Mostofi, 1993) to relieving signs of depression in people suffering from dementia (Küller, 2006). Despite the general recognition, these methods more often than not lack recordings of brain activity. We hope to explore the effect of light on human physiological processes further, as well as on cognitive performance in particular. Specifically, we wish to research the correlation between brain activity during tasks which require attention and problem solving, with different wavelengths of visible light.
Philips' School Vision Project and a correlating study from the Eppendorf University in Hamburg determined a significant improvement of cognitive abilities of children in class when exposed to light of different wavelengths, such as increased attention, relaxation, focus, alertness and decreased restlessness. Their main evidence consisted of test scores, such as the outcome of attention tests, reading speed and alertness amongst the subjects in correlation with the light settings. They did however not refer to any studies that analyzed changes in brain activity such as EEG or fMRI (Barkmann, Wessolowski, & Schulte-Markwort, 2010). Also worth noting is that these studies were undertaken in a classroom environment, where social interaction very likely plays a part in subjects' behavior and choice of activity. We hope to confirm or falsify the results from Phillips' study both by reproducing the experiment in a clinical study outside the classroom environment as well as by using quantitative data extracted from EEG readings.

1.2 Literary background

Visible day light has several physiological impacts on the human body, both in a long- and short-term perspective. Immediate responses are noticeable in hormone secretion, heart rate, sleep propensity, alertness and body temperature whereas the synchronization of the circadian rhythms requires a longer observational period, but is nonetheless noticeable (Vandewalle et al., 2009). These non-visual responses, which are often mediated by a retinal photoreceptor system, are "maximally sensitive to blue light (between 459 and 483 nm)" (p.429), even though the classical photo-receptors are maximally sensitive to green light (Vandewalle et al.). In other words, blue light causes greater physiological responses in changes of melatonin secretion, body temperature, heart rate, sleeping and increased alertness than green light. This outcome suggests that there exist photo-receptors that mediate non-visual, physiological effects of light (Vandewalle et al.).

Short wavelength light, commonly known as blue and green light, is confirmed to have more physiological effects on human functions than long-wavelength, such as yellow or red light. The human circadian system, which regulates the perceived feeling of sleepiness, is more sensitive to short-wavelength than long-wavelength light, as it is more effective in suppressing nocturnal melatonin and phase delaying the melatonin rhythm (Wright, Lack, & Kennaway, 2004) (Lockley, Brainard, & Czeisler, 2003). This is also related to Lockley et al.'s findings, which suggest that blue light sustains performance even better than green light in a vigilance reaction task (2006). Curiously enough, these properties are not limited to humans alone; the results of

Rozenboim et al. research on eighty male broiler chicks suggest that green and blue light stimulates growth, at least in comparison with red light (1999).

Furthermore, Küller et al. found that indoor lighting and color of working places has an impact on the mood of the people working there. When the lighting was considered either too dark or too light, the mood declined. The highest positive mood level coincided with the indoor lighting being perceived as "just right"(p. 1496). Their findings also suggest that color design might contribute to a more positive mood, which bids for a healthier work place (2006).

1.3 Hypothesis

We wish to explore the possible effects of the light setting on brain activity during tasks which require attention and problem solving. It is expected that human attention and performance is affected by the temperature of light in the environment, noticeable in brain activity. It is also expected that the most positive effects will be found in subjects exposed to short-wavelength light.

2 Methods

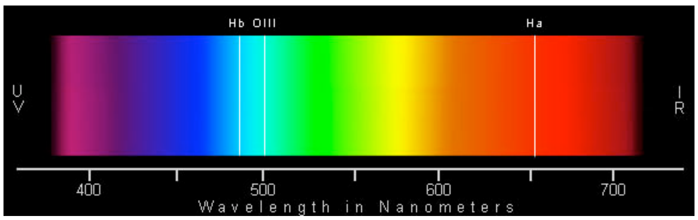
2.2 EEG

Electroencephalography (EEG) is a noninvasive method of measuring neuronal activity by detecting the ionic currents of the neurons. EEG is nowadays used in the medical sector, such as for the diagnosis of epilepsy and other neurological disorders, but it is also a useful tool for neurological research. Studies using EEG suggests that the different recorded waves represent specific changes of cognitive performance: Theta waves are involved in the psychological processes and mechanisms associated with the general term of "attention". Delta waves are associated with "low-wave" sleep (stages three to four), or deep sleep, and originate in the Thalamus. Beta waves are associated with general waking activity (e.g. during the day Beta waves are predominant among brainwave patterns). Alpha patterns are associated with a relaxed and effortless alertness, such as day dreaming. Measuring these differences between light settings was of course our way of attempting to scientifically prove recent similar findings.

In this project, EEG was used to assess changes in brain activity using two different light settings. The EEG measurement tool used was an Emotiv headset, with fourteen electrodes which measure Alpha, Beta, Theta and Delta brainwaves. In our particular study, we expected to see the biggest difference among Beta-wave frequency. This is of course due to the fact that Beta waves are indeed focused with the characteristics of a strongly-engaged mind, or essentially what we will be demanding of our subjects within our trials. Accompanied with a software package to record the readings provided from the headset, the readings were transferred to Excel for an easier overview of the raw data, in spreadsheets.

2.3 Light setting

Two main characteristics of light cause physiological responses: the luminance, which describes the intensity of a light source, and the light temperature, measured in Kelvin. Our research project aimed to determine the impact of the light temperature, which is known to cause measurable changes on cognitive activity (Vandewalle et al.).
In the first setting, the subjects were exposed to short wavelength light from LED-lamps at 4000K, whilst the second setting utilized light bulbs with a long wavelength light at 2700K. As the research focused on the light temperature and its effect on neuronal activity, we aspired to keep the difference in luminance between the two settings at a minimum.



The electromagnetic spectrum which is visible to the naked eye ranges from 400 nm to 700 nm (Madigan, 2011).

2.4 Experiment design

An empty, secluded room in quiet surroundings so as to not interfere with the focus of the test subjects was selected as location of the experiment. The room itself was approximately 2.5m*3.5m, with white walls. Two windows in the wall facing the door had to be sealed from natural daylight in order to avoid any changes in data caused by these outside sources. This was obtained by using plastic coverings fastened by duct tape. These were completely opaque yet had a white side which faced the inside of the room, to avoid interference with its general color scheme. The room was furnished with a big table and six chairs, with two chairs positioned on each of the longer sides of the table, one at the short side and one placed, together with superfluous experiment material, towards the end of the room.

Within this small room, two light settings were prepared, with five simple spotlights per setting interspersed around the room, directed upwards to attain maximum luminance and to allow the light to bounce off the white walls. The first setting consisted of five lamps set with LED light bulbs, giving off short wavelength light, whilst the second setting consisted of five lamps set with halogen light bulbs, giving off long wavelength light.

Seventeen different test subjects were attained within the allotted time span. The subjects amounted to no more than two at a time, seated on one of the chairs on the longer sides of the table, opposite each other, accompanied by one or two test conductors. This choice was made partially due to restricted space, but also partially to decrease any distractions in the surroundings. Each subject was asked to sit down as the EEG was fastened upon each individual's head and calibrated until all or almost all nodes were green. Subjects were issued Sudoku's and were encouraged to commence the solving of these before the actual recording of brainwave activity commenced, so as to reach a focused cognitive mental state as quickly as possible. The EEG was intended to standardly measure brainwave activity of subjects and possible differences between the two light settings.

The recording of each light setting was in progress for five minutes, followed by a brief pause which allowed for a transition to the other light setting and its recording. The order of each light setting was taken into consideration for the later analysis of data, as to prevent possible differences between the first and the second setting. The distribution of the participants that were exposed to the warm light sitting first was equal to those who were initially in the cold setting.

2.4.2 Deviations from initial plan

Naturally, as with any experiment, obstacles were encountered which required adaptations and changes of the initial plan to fit the circumstances presented. The aspiration to acquire an actual light measurement tool in order to provide the report with more scientific backing had to be aborted due to constraints of time and capital. The low availability of such tools and our lack of familiarity on this area hindered us from making an informed decision on which tool to choose, and how to obtain it.
The initial plan also included actually replacing the fluorescent, ceiling-mounted lights in the experiment room itself. The general idea was to mount three different bulbs in three different rooms, allowing for one short wavelength, one intermediate wavelength, and one long wavelength which would spread an ambient light more evenly across the room.

Due to the restricted sample size and time constraints, the intention of conducting several trials in different rooms soon had to be abandoned. Furthermore, the process of replacing the fluorescent light bulbs would have been an expensive and time-consuming venture, due to the bureaucracy of the building’s custodial services. Had this approach been selected the delay might even have been so severe that the experiment would in fact have been at danger of not being completed on time. Instead, removable lights were purchased and mounted in an evenly distributed manner in the room of the experiment, and each lamp had to be manually turned on or off one by one. This added another element, which albeit being slightly time-consuming and having the potential to disrupt the subjects, actually greatly benefited the overall time scheme of the project. The alteration disadvantaged the luminance instead. Additionally, the difficulty in finding merely two light bulbs of vastly differing wavelengths forced us to narrow down our light settings to two.

Choice of experiment space was also limited. Initially, the plan had been to acquire a larger room, allowing for the testing of more subjects at a time, as well as a windowless one. Due to the difficulty in producing ambient light in a large room, a smaller one was favored. This benefited the test subjects directly, as they were exposed to fewer disruptive factors (i.e. fellow subjects). The covering of the windows with opaque, white plastic was a successful adaptation to the given premises as well.

3. Data Results and Analysis

Comparing the averages of the revised measurements, the recordings in the long wavelength setting were greater in a majority of the brain regions, and most significantly among the beta-waves frequencies. Particularly in the occipital part of the brain (sensors: FC5, T7, P7, O1, O2, P8, T8, FC6; see figure 1, appendix), the recordings of the long wavelength setting showed a much greater beta-wave frequency, whereas alpha, delta and theta waves did not differ significantly between the short and long wavelength measurements. The occipital lobe of the brain deals with visual processing and especially visual recognition of shapes and numbers. It is located at the rear of the brain and is one of the four main regions of the cerebral cortex, which is the part of the brain that deals with most of its actual information processing. Our research also shows that there is indeed a greater difference in occipital lobe brain activity when using the warm light setting rather than cold light. Our data shows a difference between beta-wave frequencies involving the two light settings. This can be due to the fact that warm light has been seen to give greater physiological benefits in the realm of problem-solving and general diligence, which may be thus observed in the occipital lobe.

The sensors that recorded the frontal brain regions (AF3, F7, F8, AF4; see figure 2, appendix) exhibited the greatest difference between the two settings. Particularly AF3 and Af4, which measure Brodmann area 9, recorded significantly higher activity of alpha, beta, delta and theta waves in the long wavelength setting. These brain regions are part of the dorsolateral pre-frontal cortex (DL-PFC), a region that is essential for memory and complex intellectual tasks. The DL-PFC is also responsible for tasks such as organization and motor-planning. Although the DL-PFC is not exclusively responsible for executive functioning, most complex mental activity requires input from cortical circuits connected to it. Interestingly, it is also involved in working memory, which would explain why brain activity would be so active in this particular area during Sudoku-riddles. Brodmann area 9 in particular is indeed part of the frontal cortex, which contains dopamine-sensitive neurons. This dopamine system is associated with reward as well as short-term memory tasks and planning.

4. Discussion

All in all, our research project on the effect of light temperature on performance had an interesting outcome: the EEG recordings suggest that the long wavelength setting created in general a better atmosphere for intellectual tasks. Main indicators were a generally increased beta-wave frequency and a greater activity in the frontal brain regions. Such a result was unexpected, as it we assumed that the cold light setting would result in improved performance. Though, the feedback of many participants confirms this outcome, because they described the short wavelength setting as unpleasant and tiring. An explanation for this effect could be the fact that the LED light bulbs, which were the light source for the cold temperature (4000K) setting, did not illuminate the room sufficiently. Therefore, it is not possible to draw a conclusion on the effect of light temperature from our data. However, taking into account that it was possible to determine in general a significant difference between the two settings, it may indeed be important to do further investigations in this field.

During the research project, several obstacles and problems presented themselves. For instance, even though we aimed to create an ideal setting, there were a high number of outliers which could have been caused by the movements of the subjects, disruption of concentration and their experimental task to solve Sudoku's. Therefore, it was not possible to determine any difference between the two settings with the raw average recordings. The discussed outcome was only observable after the deletion of outliers that were four standard from the mean. It might be possible that this revision of the measurements created biased results. Additionally, we needed to remove two of the overall 17 recordings, because of issues with the EEG measurements.

However, considering the human capital provided for conducting our research project, our group was still able to perform a thorough study with determinable results.

5. Conclusion

To conclude, the results of our study suggest that the long-wavelength setting allows for better cognitive functioning in individuals compared to the other setting. However, this finding could be due to the fact that the LED light-bulbs did not sufficiently illuminate the testing facility. The results of our study unfortunately failed to find statistically significant evidence to support the theory that the human brain is directly influenced by light temperature when performing tasks which require focus and problem-solving.

A greater allotted amount of time as well as additional resources may have allowed for more accurate results. However, this study definitely leaves room for further research on the effect of long or short wavelength light on cognitive performance, both in clinical as well as more reality-based, classroom- or office-like settings.

6. Appendix

Figure 1: Increased beta-wave frequency only.

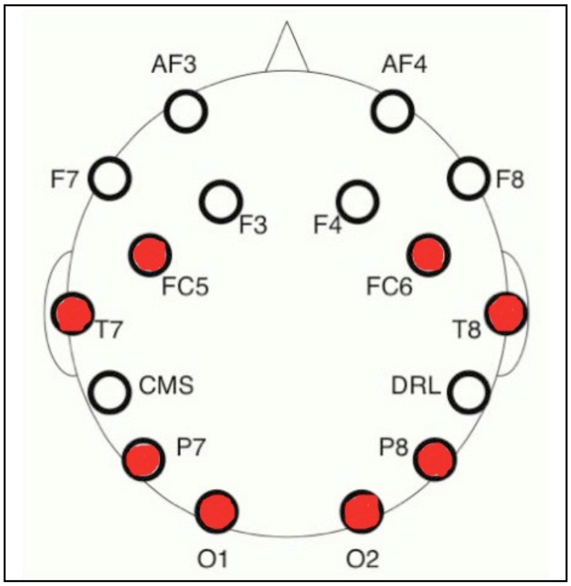
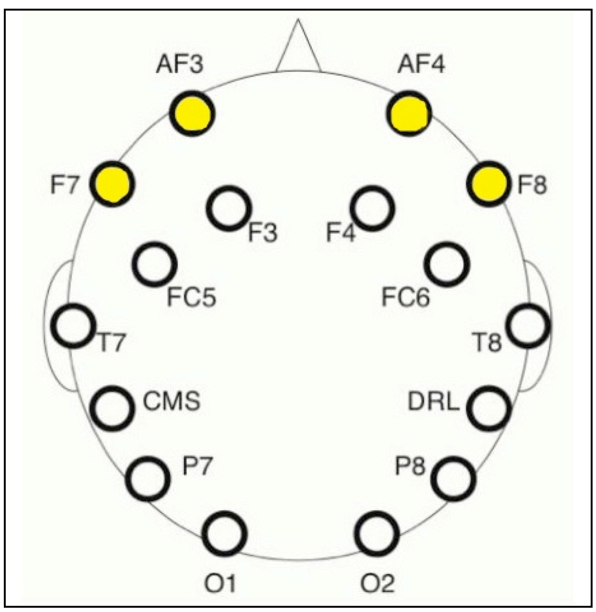


Figure 2: Overall increased activity:



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