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Abstract

It is known that colors and lighting have an influence on human physiology with potential affection to cognitive performance. Although according to some theories, cold colors (bluish) cause relaxation and concentration while warm colors (redish) cause arousal and alertness, researchers have not reached a consensus yet on the net effect that this could cause on the performance of tasks under study. The objective of the present study is to compare the academic performance under two conditions, blue and red lighting, and see if any of them could be advantageous during an auditory attentional task. Participants listened to five auditory sustained attention tests while they were exposed to either red or blue lightning, within a virtual reality environment, and the cerebral activity was recorded using EEG. Our results showed that students under the blue lighting condition achieved better and constant academic performance right after the beginning of the first test and up to the last one (68.3% vs. 60.0% median values). Also, a logistic regression model was able to classify the color condition from the Power Spectral Density of EEG bands (occipital electrodes yielding an accuracy of 84.6% (CI [57.8%–95.7%])). These results suggest that the blue color has a positive and immediate impact on the academic performance of auditory tests with noticeable differences in cerebral activity in comparison with the red color. These promising results encourage researchers to gain insights into the real influence of colors over the academic performance with immediate impact on schools and academic centers.

Keywords
(separated by '-')

Auditory sustained attention - Academic performance - EEG - VR



Influence of Color on Academic Performance: A Studio with Auditory Sustained Attention Within a Virtual Scenario

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Abstract. It is known that colors and lighting have an influence on human physiology with potential affection to cognitive performance. Although according to some theories, cold colors (bluish) cause relaxation and concentration while warm colors (redish) cause arousal and alertness, researchers have not reached a consensus yet on the net effect that this could cause on the performance of tasks under study. The objective of the present study is to compare the academic performance under two conditions, blue and red lighting, and see if any of them could be advantageous during an auditory attentional task. Participants listened to five auditory sustained attention tests while they were exposed to either red or blue lightning, within a virtual reality environment, and the cerebral activity was recorded using EEG. Our results showed that students under the blue lighting condition achieved better and constant academic performance right after the beginning of the first test and up to the last one (68.3% vs. 60.0% median values). Also, a logistic regression model was able to classify the color condition from the Power Spectral Density of EEG bands (occipital electrodes yielding an accuracy of 84.6% (CI [57.8%–95.7%])). These results suggest that the blue color has a positive and immediate impact on the academic performance of auditory tests with noticeable differences in cerebral activity in comparison with the red color. These promising results encourage researchers to gain insights into the real influence of colors over the academic performance with immediate impact on schools and academic centers.

Keywords: Auditory sustained attention · Academic performance · EEG · VR

1 Introduction

It is thought that color could have an influence on human cognitive processes and behavior [4]. Nevertheless, in the learning and the academic spheres, there is no consensus about what color could have better academic performance (reviews [9, 12, 20]).

Results in [5] suggested that red color could have an adverse effect on task achievement. They compared different colors (red, green and three achromatic colors: gray, black and white) in different environments (laboratory and classroom) with undergraduate and high school students. Another study conducted on children [2] also showed that worse results were obtained when the color screen was red. However, another study [7] conducted different kind of tests associated to knowledge, intelligence or reasoning and reported no evidence that red could affect in a negative way to intellectual performance. Even more, a study [19] compares long-wavelength (red) light with short-wavelength light (blue) and they concluded that red light could increase alertness in the afternoon hours, especially in the post-lunch hours. Authors in [13] concluded that red is better for a simple detailed task whilst blue color is better for a complex detailed task and creative tasks, either simple or complex. It was also reported that attention, memory and preference were better with blue walls in an academic related task [15]. In another experiment [11] also concluded that blue walls are better to relax but, in terms of performance, the best scores were obtained with yellow walls, followed by red, green, blue and white. Both studies [11, 15] were made with virtual reality (VR) simulations. It is demonstrated [17, 21] the suitability of VR on color-based studies because it permits researchers to control each small detail of the experimental environment.

In general, a flaw in most of the studies is the lack of a big enough sample size to reach a high statistical power. Furthermore, the wide variety of methods and approaches (e.g., visual vs. auditory stimuli, sustained vs. selective attention, etc.) yield heterogeneous results with intrinsic difficulty to compare them and get definitive conclusions. In terms of the objective assessment of the attention, literature shows that certain cognitive tasks cause modulation of the power spectral density (PSD) of the cerebral bands: delta (<4 Hz), theta (4–8 Hz), alfa (8–12 Hz), beta (12–30 Hz) and gamma (>30 Hz). EEG recording is one suitable tool for measuring PSD and it is used in different studies, for instance, authors in [1] related a lower alpha PSD with an increase in the performance of an sustained attention test, meanwhile theta PSD increased. Other authors [8] pointed out that in the brain zone related to the task a decrease in the beta band precedes worse behavioral performance. In the same thought, authors in [6] presented a low-cost EEG-based system that could estimate the children's attention at class based on the beta PSD and relate it to their academic performance. They reveal that the higher the beta PSD was, the better academic performance they achieved.

The objective of the present study is to compare the academic performance under two conditions, blue and red lighting, and see if any of them could be advantageous during an auditory attentional task. We integrate two relevant technologies: on one hand, conditions will be generated and controlled and by means of a VR and, on the other hand, EEG will be recorded for the objective analysis of cerebral activity during conditions.

2 Materials and Methods

2.1 Participants and Experimental Design

Fourteen university students from the University of Granada voluntarily participated in the study (four females and ten males, age mean 20.4, std 2.4). Volunteers did not receive any benefit. The inclusion criteria was students that declared no visual or auditory impairment. The Ishihara test was applied in order to check color blindness and students with more than five errors in the plates were discarded. Only one student was discarded because he manifested fatigue and showed disapproval during the test. This study was conducted at the Research Centre for Information and Communication Technologies (CITIC-UGR). The experiment was approved by the Research Ethics Committee of the University of Granada (3702/CEIH/2023) and participants signed an informed consent document before starting.

The experiment was based on two components: *EEG device* Versatile EEG by Bitbrain (Zaragoza, Spain) was used to acquire the EEG signals during the experiment. It is equipped with 16 channels and a sampling frequency of 256 Hz. The 16 semi-dry electrodes were distributed following the 10-20 International System (AF3, AF4, F3, Fz, F4, FCz, C3, Cz, C4, P3, P4, PO7, POz, PO8, O1, O2). Ground electrode was located at AFz position meanwhile reference was located at the right ear lobe. A monitor provided real time information about the impedance of the sensor assuring they kept in the appropriate range throughout the experiment; *VR headset* Meta Quest Pro was used to immerse participants in a virtual environment programmed with Unity Engine. The whole experiment lasted about one hour and it was carried out by all subjects one at a time.

Before starting, participants were distributed randomly in two groups, each one for each of the two conditions: red environment (two females, five males, mean age 20.7 ± 3.1) and blue environment (two females, four males, mean age 20.0 ± 1.1). The different phases of the procedure are as follows (see Fig. 1).

Preparation. The experiment started with a brief introduction in which the participants were told the context and they signed the informed consent. After that, they were subjected to Ishihira test in order to discard those who had problems identifying colors. Participants sat in a comfortable chair in front of an empty desk.

Calibration. The Versatile EEG device was set up. It was adjusted until the sensors impedances were in a suitable range. Afterwards, Meta Quest Pro VR

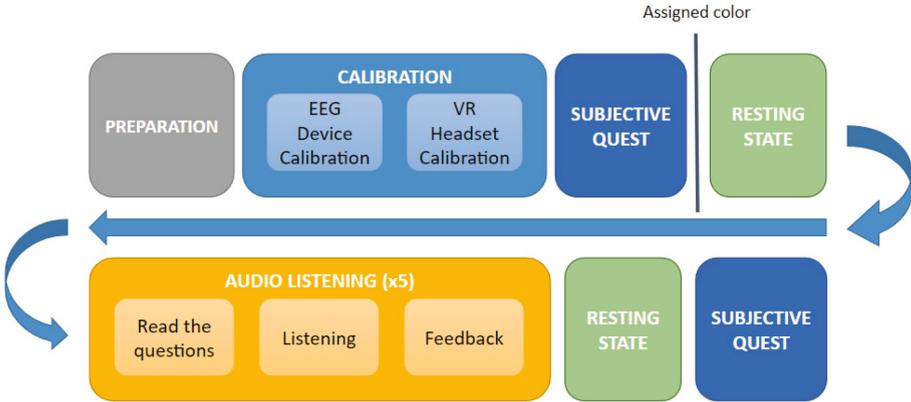


Fig. 1. Phases of the experimental procedure.

Headset was set up and hand tracking and sound were checked. The participants were instructed in how to use virtual hand interactions. Finally, EEG sensors impedances were checked again.

Subjective Test. The participants started in a white environment and they were requested to answer a subjective questionnaire in Spanish. Translated questions are shown in Table 1. This questionnaire was preceded by a reminder explanation of how to answer the questions within the VR environment. Notice that the second time (see last block in Fig. 1), the environment color was the assigned color for this subject in the experiment.

Table 1. The five questions contained in the subjective questionnaire.

Number	Subject Questions
1	What has your level of attention been so far?
2	What is your stress level right now?
3	What is your level of interest so far?
4	What has your level of mental effort exerted so far?
5	What is your level of relaxation?

Before the next phase, the color environment was changed to the assigned color for that subject (red or blue). See vertical black line in Fig. 1. This color environment will not change for the rest of the experiment.

Resting State. Participants were immersed in a virtual room without anything but the assigned color and they were asked to be relaxed without moving and staring at a fixed point located at the center of the virtual scene. A soft alarm

sounded if participants closed their eyes for a short period. Beep sounds were played at the beginning and at the end of the phase, and a background relaxing music was played during the three minutes and eleven seconds of the phase duration.

Audio Listening. Firstly, within the color virtual environment assigned, a listening test from ELE (Teaching Spanish as a Foreign Language) C2 level (Common European Framework of Reference for Languages) composed by six multiple choice (2 options) questions were presented in two pages to the subject who could read them for one minute before the audio started. Secondly, the test audio is played. In order to assess the sustained attention, they were limited to answering the questions only during the listening and the following 5 s. Finally, feedback was given to participants as their accuracy percentage against a competitive percentage designed for keeping them motivated. The Audio listening phase was repeated once for each of the five chosen Spanish C2 listening exams. The order of the audios were randomized for each participant and their duration was in the range [4:46–5:03] (minutes:seconds)

2.2 Data Processing

Subject questionnaires answers were analyzed to give information about the interest, motivation and state of the participants during the experiment.

EEG data from Resting states and Audio listening phases were processed as follows. Per channel, EEG signals were divided into five-second epochs without overlapping. To each epoch, we applied a second order zero-phase shift band-pass Butterworth filter, from 1 to 40 Hz. Artifact removal was implemented by discarding epochs with absolute amplitude above 75 μ V. Each epoch was then detrended and z-scored. Subsequently, we performed the spectral analysis. Per subject, the power spectral density (PSD) was calculated in different frequency bands (delta [1–4 Hz], theta [4–8 Hz], alpha [8–12 Hz], beta [12–30 Hz], and gamma [30–40 Hz]), and then averaged across EEG channels. Finally, EEG channels were grouped by areas and averaged: frontal (AF3, AF4, F3, Fz, F4, FCz), central (C3, Cz, C4), parietal (P3, P4) and occipital (PO7, POz, PO8, O1, O2).

A dataset was created per subject by combining the audio test questionnaires answers, the color environment and the mean of PSD of spectral bands per area. In order to see the influence of color, the academic performance was analyzed. The answers of the auditory attentional tests were splitted in two groups according to the color assigned to each participant. Due to the small sample size, the median of the scores of academic performance of both groups was analyzed. Median is a better indicator for central tendency, specially when the size of the sample is not large, and more robust against outliers [18]. Median absolute deviation was used as the uncertainty indicator [10]. Thereupon, a comparison of the cumulative evolution of correct answers was analyzed in order to assess the dynamics of the influence of color in a sustained auditory attention task. For this purpose, the cumulative scores of the academic performance per color was fitted to linear curves (one per color).

Finally, a logistic regression was implemented in order to classify the color of the environment subject from the processed EEG power bands. Leave one subject out (LOSO) cross validation was implemented due to the low samples. The overall confusion matrix was obtained from the confusion matrices that each model generated [16].

3 Results

The Fig. 2 shows the answers of participants to subjective questionnaires grouped by color environment in terms of median with median absolute deviation as uncertainty indicator. The Fig. 2a shows the absolute answers at the beginning (SQ1 = first Subject Quest) and at the end (SQ2 = second Subject Quest) of the experiment for each of the five questions (1 to 5) while the Fig. 2b represents the relative differences between the answers at the beginning and at the end for each question.

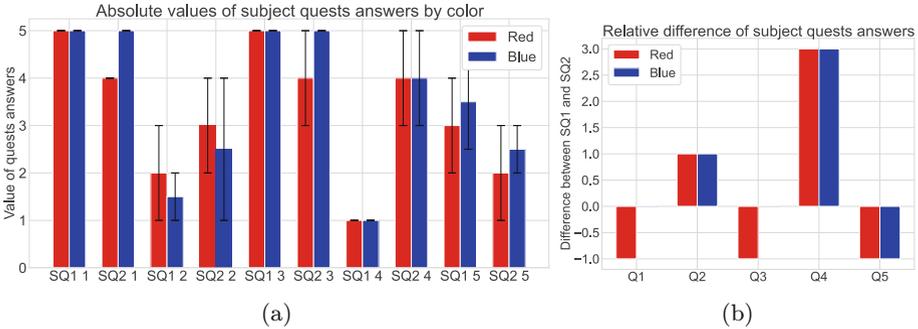


Fig. 2. Answers of participants to subjective quests grouped by color in terms of median with median absolute deviation as uncertainty indicator. (a) Absolute answers at the beginning (SQ1) and at the end (SQ2) for each question (1 to 5). (b) Relative differences between SQ1 and SQ2 for each question.

The Fig. 3a shows the color distributions (red and blue) and density curves for the percentage of correct answers of participants. The highest percentage was achieved by a red participant (90) although the blue group has a bigger median (68.3 vs 60.0).

The Fig. 3b shows a comparison of the cumulative evolution of correct answers through the five listening tests in terms of median. The error bars correspond to the median absolute deviation. Linear regression curves were calculated for all the participants data grouped by red (Eq. 1) and blue (Eq. 2) environment color.

$$y = 1.40x + 1.01 \quad (1)$$

$$y = 1.44x + 1.28 \quad (2)$$

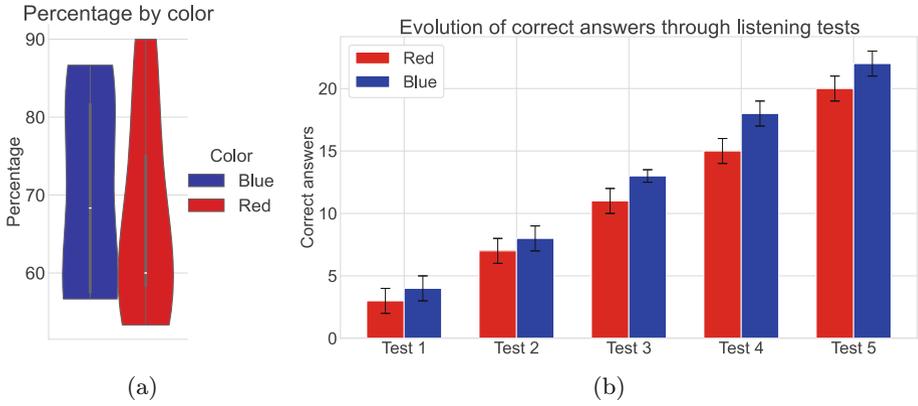


Fig. 3. Percentage of correct answers in listening tests by color. (a) Violin plot distribution. (b) Cumulative correct answers by color in terms of median. Median absolute deviation was used as the uncertain indicator. (Color figure online)

The Fig. 4 shows a comparison of the median of all subject PSD brain bands grouped by the color environment (red and blue) for the occipital-parietal zone throughout three phases of the experiment (first Resting state phase, mean of the five repetitions of Audio listening and last Resting state phase). The error bar corresponds to the median absolute deviation.

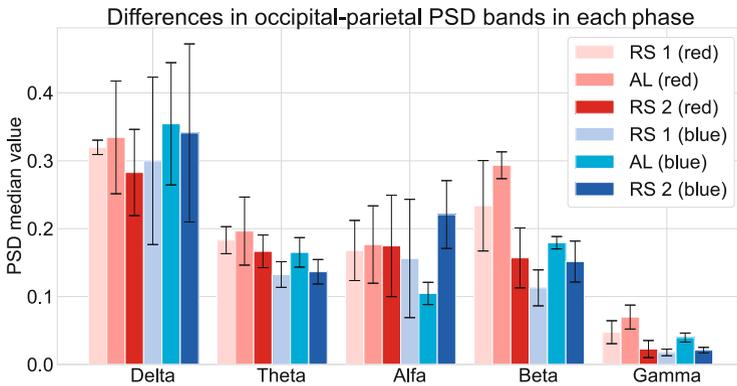


Fig. 4. Differences between color in each band in terms of median. The error bar corresponds to the median absolute deviation. (Color figure online)

The Fig. 5 represents the confusion matrix for color classification from EEG data using logistic regression. It achieved an accuracy of 84.6% (CI [57.8%–95.7%]), sensitivity of 83.3%, specificity of 85.7%, precision of 83.3% and F1 score of 0.83.

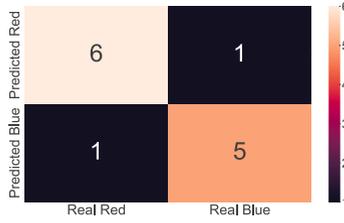


Fig. 5. Confusion matrix for color classification from PSD data using Logistic Regression.

4 Discussion

In this study a sustained auditory attention experiment was conducted within a colored blue or red virtual environment. Results suggest that the blue color has a positive and immediate impact on the academic performance of auditory tests with noticeable differences in cerebral activity in comparison with the red color.

Subjective Questionnaires. Results of subject questionnaires (see Fig. 2) show that the conditions of experiment were suitable for both red and blue groups. There is no significant difference in the answers of both groups in any of the five questions. Attention and interest remained very high and practically constant throughout the experiment whilst perceived stress increased similarly to how relaxation decreased. Finally, the mental effort increased noticeably, indicating that the experimental design was correct.

Academic Performance. The academic performance was slightly higher for the blue group in terms of median (68.3%) than for the red group (60.0%) (see Fig. 3a). This is in concordance with researchers whose results suggested that the performance of the blue environment was better than red [15]. The academic performance of the blue over the red group was obtained since the very first test and kept almost constant still the last test (see Fig. 3b). This suggests that the positive effects of immersion in blue lighting in comparison with immersion in red one, could be obtained within a really short period of a few minutes [14].

Cerebral Activity. In our study we hypothesized that blue lighting could have a positive effect on attention in comparison with the red one. In this case, that could be noticeable in the cerebral activity. The Fig. 4 shows the median of PSD across subjects for the five spectral bands under analysis registered over the occipital and occipital-parietal areas (where the visual cortex is located). It shows a remarkable enhancement of the PSD of beta and gamma bands for both groups (blue and red) during the auditory test in comparison with the Resting states phases. This is coherent with studies in literature that associate the increment of the gamma power band in the specific zone where the task is processed (occipital-parietal in visual task) [3]. However, in the alpha band, there was a noticeable difference between the blue and red group. While for the blue one alpha diminished the PSD as expected, for the red one the PSD

of alpha remained almost flat. This result would evidence that blue lighting has a better capacity of desynchronization of the alpha band in comparison with red. Since alpha desynchronization is associated with visual attention and sustained attention [1,3], this could justify the better academic performance of the blue group. Additionally we analyzed if exposition to either blue or red lighting could be detected by differences in cerebral activity. With this purpose we performed a logistic regression to classify colors based on PSD of EEG bands acquired over the visual cortex (see confusion matrix in Fig. 5). It yielded a significant accuracy of 84.6% CIU[57.8%-95.7%]. That means that i) lightning causes differences in cerebral activity; ii) EEG bands convey enough information to distinguish between blue and red lightning; iii) this could justify an influence of color on academic performance.

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