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Effects of object colour stimuli on human brain activities and subjective feelings in physical environment and virtual reality

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ABSTRACT

This work explores the potential of Virtual Reality (VR) as a medium to support emotional positivity and well-being. In this study, we investigate and compare the effects of colour first in a physical test room and then in an identical VR environment. We measured ten participants' physiological responses to different colours of light in both physical and virtual environment with the assistance of an electroencephalogram (EEG) system. We also required all those participants to report on their subjective feelings through a Positive and Negative Affect Schedule (PANAS) questionnaire. In conclusion, our experimental results indicate that human's emotional wellbeing and brain activity are affected by the coloured-lightning conditions, and the impacts show different trends between red and blue lightning. Furthermore, such impacts in the physical environment can be generally replicated in VR.

Keywords: *colour, light, virtual reality, Thouslite LED system, wellbeing*

1. INTRODUCTION

Colour and light play important roles in human's vision, but also affect emotion, circadian rhythm, daily behaviour and physical health (Volpe, 2016, Lyon et al., 2019, Czeisler et al., 1986, Eastman et al., 1998, Westland et al., 2017). Research evaluating the potential of physiological and behavioural response in built environments is constrained by the cost of full-scale test facilities. This work simultaneously exploits two new flexible technologies, evaluating how the impact of colour and light have the potential to positively impact on engagement and wellbeing (Oh et al., 2014). The ability to create accurate immersive light and colour conditions in a real-world room-set is delivered via the unique Thouslite LED system. The reproduction of that environment in VR provides the opportunity for an original investigation directly comparing human response to colour and light between these two domains. This work further explores the established relationship between the design of coloured-lighting conditions and interior environments. Replicable results in the virtual environment could add to the argument that VR applications have greater potential to contribute to human wellbeing (Riva et al., 2007).

2. EXPERIMENTAL

Previous researchers have demonstrated that there was no differential effect of colour and light on heart rate and blood pressure (Caldwell and Jones, 1985). However, a significant number of publications have demonstrated that colour and light is associated with mood and emotion (Ou et al., 2004). This work primarily examines subjective emotions and physiological responses to colour in both a physical room illuminated using Thouslite LED system (Figure 1a,b) and a virtual reality (VR) simulation of the same test environment (Figure 2a) using the Oculus Go VR headset (Figure 2b). A further objective of this work is to evaluate how the impact of colour and light have the potential to positively impact on engagement and wellbeing in VR. The experiment was specifically designed to investigate the effect of human's responses utilising Positive and Negative Affect Schedule (PANAS) and electroencephalogram (EEG) (Figure3) under two lighting conditions (i.e., red and blue), compared to the white lighting condition in both the physical environment and VR.

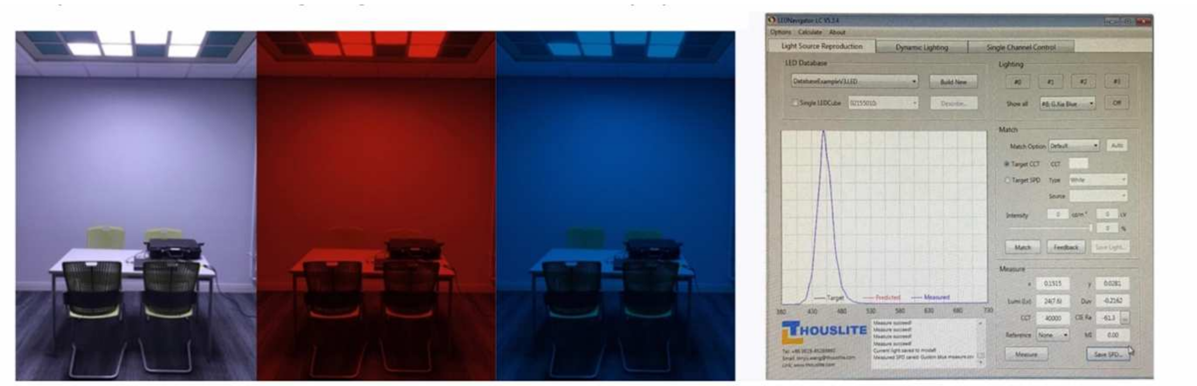

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Figure 1. (a) The three coloured-lighting conditions in the physical environment. Note that the computer was not in the environments in both physical and VR experiments. (b) The interface of Thouslite LED system.

2.1 Procedure

A total of ten university students (23-42 years, median = 24) participated in the experiment, comprising five females (24-42 years, median = 28.8) and five males (23- 28 years, median = 24.2). All subjects signed informed consent before the experiments, which was approved by the ethical review committee at University of Leeds (Ethics reference: LTDESN-097). Participants were invited to seat for 20 minutes in each of the three lighting conditions (sequenced as white, red and blue), respectively (Figure 1a). Between each coloured-lighting conditions, there was a 15-minutes break where the white lighting condition was provided. A week after the physical experiment, the same experiments were repeated in VR (Figure 2b). The EEG signals and heart rate (HR) of the participants were measured over time of each course of each experiment. During the data acquisition, all participants wore the wireless sensor headset that acquired EEG from the bi-polar sensor sites F3-F4, C3-C4, Cz-POz, F3-Cz, Fz-C3, and Fz-POz (Figure 3). These measurements are used to examine how human respond physically. After each coloured-lighting session (i.e., during the 10-mins break), participants were asked to fill the PANAS.

a b

Figure 2: (a) Oculus Go VR headset, and (b) the three coloured-lighting conditions in the VR created by 3DS Max

2.2 Lighting conditions under the Thouslite LED system and VR

The Thouslite LED system provides a laboratory controlled lighting environments for colour temperature and colour experience, so that characteristics in particular mood, focus and productivity can be established. (See Figure 1a) The dimension of the exposed area was approximately 3.5m (L)*, 3.43m (W)* and 2.65m (H)*. The luminance (Lumi (lv): 24 (7.6)) of the three experimental coloured-lighting conditions (white, red and blue) was measured by iPro X-rite (a specialist equipment to measure the colour and luminance) and then set up by using the Thouslite LED system. Other environmental conditions including air temperature, and humidity, furniture and layout settings remained consistent and procedures were conducted in the silent model. In the VR, simulated coloured-lighting conditions were reproduced using 3DS Max and delivered via the Oculus Go VR headset (Figure 2a, b). Colour and luminance conditions in the VR were measured and set up using i1Pro X-rite to ensure that the luminance of the three coloured-lighting conditions in the VR are exactly the same as in the physical experiments.

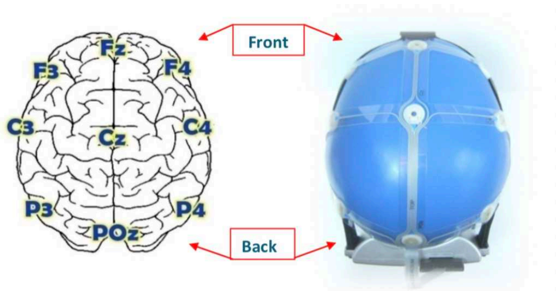

Figure 3. Electroencephalogram (EEG) headset

2.3 Results

Subjective emotions were recorded and assessed using PANAS. *T*-test was performed to show the significance of the difference between the three lighting conditions, and between physical and VR environments (Figure 4). Figure 4 indicates that there are differences between white, red and blue lighting conditions in the physical environment with respect to the levels of positive and negative affects. However, there was no effect on the levels of positive and negative affects in VR. Specifically, we found statistically significance in participants' positive affects (n=10, p=0.014) between white and blue lighting conditions in the physical environment. For participants' negative affects, statistically significances are found between white and red lighting conditions (n=10, p=0.024), as well as between the red and blue lighting conditions (n=10, p=0.021) in the physical environment.

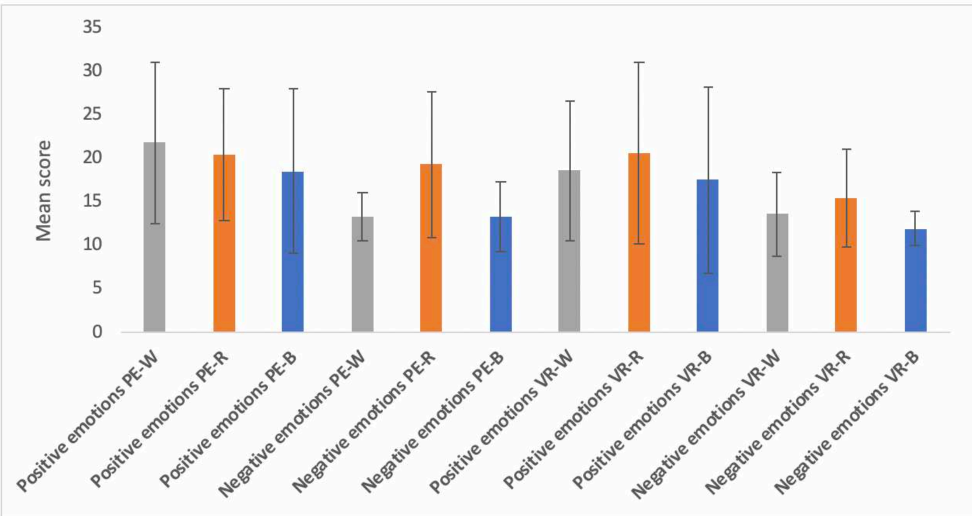

Figure 4. Response in participants' positive and negative emotions as measured by PANAS under white (grey bars), red (orange bars), and blue (blue bars) lightning conditions, in physical environment (suffixed as PE) and virtual reality (suffixed as VR). The bars represent mean changes, while the error-bars are the standard deviation across individual participants.

The B-Alert Live system with active electrodes was used for EEG recordings. Electrodes were placed on participants' scalps according to the international 9 system at Fz, F3, F4, Cz, C3, C4, POz, P3 and P4 (Figure 3). Two extra electrodes were attached to both earlobes to serve as reference electrodes for those attached to scalps. EEG data were gathered using B-Alert Live Software (BLS) as well as wireless Advanced Brain Monitoring (ABM) EEG headset. The post-processed z-Score of fzclass_3 (theta total at the channel f3) and Z-Score of f3class_6 (alpha total at the channel f3) were analysed, respectively. Note, the channel f3 of the B-Alert Live system headset is one of the electrodes at the frontal site, and fz is one of the electrodes at the midline of the brain. To remove individual variability from various metrics, the z-score for this purpose is calculated on the mean and standard deviation for at least the first 5 seconds, with additional epochs (seconds) added. *T*-test was performed to show the statistical significance of the differences between lighting conditions, and environments (Figure 5).

In the physical environment, the normalized alpha range at the channel f3 is shown to be lower under the blue lighting condition than that under red lighting condition (n=10, p=0.012). This implies that the alpha range at the channel f3 was significantly affected by the blue light. However, there is no statistically significant difference (n=10, p=0.102) in the normalized alpha range at the channel f3 between white and red lighting conditions. Also, Figure 5 shows a very significant difference (n=10, p= 0.005) in the normalized theta range at the channel fz between white and blue lighting conditions in VR. No significant difference (n=10, p=0.225) was found in the normalized theta range at the channel fz between white and red lighting conditions in VR. Participants' paired *t*-test result also shows a significant difference (n= 10, p=0.050) in the normalized alpha range at the channel f3 under blue lighting condition between the physical environment and VR.

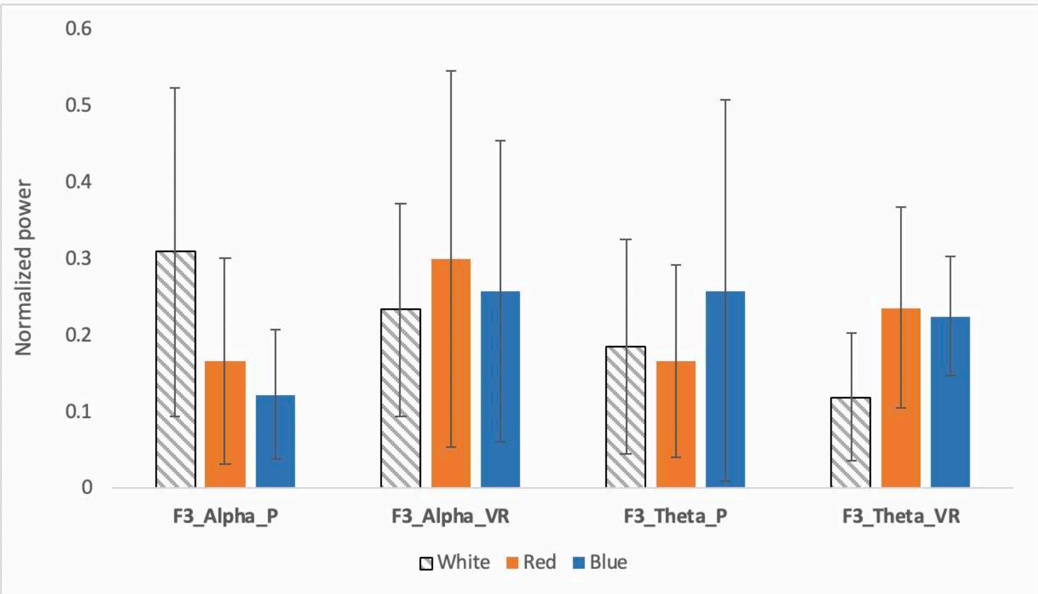

Figure 5. Ten participants' mean ± standard error of the mean normalized EEG power alpha (8-12Hz) and theta (3-7Hz) frequency ranges in the f3 channel under white (pattern bars), red (orange bars) and blue(blue bars) lighting conditions in both the physical environment and VR during the last 15 minutes.

3. DISCUSSION

Our results suggest that participants' negative affects increase under red lighting condition, but reduce under the blue lighting condition. This supports Birren (1961) who reported that red colours are associated with negative feelings such as anxiety, anger, and annoyance, while blue colours are associated with feelings of relaxation and calmness (NAz and Epps, 2004, Birren, 2016)

For EEG, the normalized alpha range at the channel f3 is shown to have a significant decrease (n=10, p=0.012) under the blue lighting condition (compared with the white lighting condition) in the physical environment. Previous studies suggest that happiness caused less alpha power in the left frontal region (Davidson et al., 1990). It has been also suggested that blue colours are associated with relaxation and calmness (Birren, 2016). Our result suggests that the blue lighting condition in the physical environment is likely to increase people's positive emotions. However, this contradicts with participants' PANAS assessment, which shows a decrease in positive affects between white and blue lighting conditions.

In VR, a significant increase (n=10, p= 0.005) was found in the normalized theta range at the channel fz under the blue lighting conditions (compared with the white lighting condition in VR). Sammler and collages (2007), demonstrated that increases to frontal midline (fm) theta power is associated with pleasant music. Also, Fischer et al. (2018) showed that an increase to scalp-wide theta activation can be explained as a mind-wandering effect. Even though the theta range we analyzed here is at the single electrode fz, our result suggests that participants feel relatively more calmed and relaxed under blue lighting condition than under the white lighting condition in VR. The result agrees with the PANAS assessment regarding the negative affects between white and blue lighting conditions in VR, whereas no statistically significance was found in the PANAS. Participants' paired *t*-test results show statistically significance in the normalized alpha range at the channel f3 under blue lighting conditions between real-world and VR. Specifically, the result might suggest that different presence might be perceived by participants under blue lighting conditions between the physical environment and VR. However, the impacts of blue lighting conditions between the physical environment and VR are shown to have no statistically significance in the normalized theta ranges at the channel f3. Also, no significant differences were observed in white and red lighting conditions in both alpha and theta ranges.

One of the limitations of this study is we only had 10 subjects, while in the future further experiments will be performed to expand our findings. Also, the results of PANAS is questionable, since participants might mix their emotions between the start and the end of experiments.

4. CONCLUSION

In this study, we investigated human's physiological responses to object colours by comparing data collected from the EEG, and subjective emotion assessment (using PANAS) under a Thouslite LED system and a reproduced VR environment. We found statistically significant differences in (a) participants' positive affects between white and blue lighting conditions in the physical environment, (b) participants' negative affects between white and red lighting conditions in the physical environments, (c) participants' negative affects between red and blue lighting conditions in the physical environment, in terms of participants' subjective rating, (d) the normalized alpha (associate with relaxation) range in the left frontal region between white and blue lighting conditions in the physical environment, (e) the normalized alpha range in the let frontal region under blue lighting conditions between the physical environment and VR was found, (f) the normalized theta (associate with emotional states) range in the single electrode fz in VR between white and blue lighting conditions. In short, our results suggest that human's physiological changes in VR are consistent with physical lighting conditions. However, further experiments are needed to verify and expand these findings.

5. ACKNOWLEDGMENTS

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