The Effects of Perceiving Color in Living Environment on QEEG, Oxygen Saturation, Pulse Rate, and Emotion regulation in Humans

Watchara Sroykham, *Student member, IEEE* J. Wongsathikun and Y. Wongsawat, *Member, IEEE*

***Abstract*— Light and color have been shown to have substantial physical, psychological and sociological effects on humans. Hence, an investigation on the effect of changes in light and color to the biological signals is a challenging problem. Five participants were measured the oxygen saturation (SpO2), pulse rate, and quantitative electroencephalogram (QEEG) in six colors (white, blue, green, yellow, red and black) of living environment for 5 minutes per color. Then all participants were asked to answer the emotional questionnaire of BRUMS and color performance for each color environment. The results showed brain activity of high beta wave (25-30 Hz) that associated with alertness, agitation, mental activity, and general activation of mind and body functions (at frontal lobes and temporal lobes) in red and yellow colored rooms were higher than blue, green, white and black colored rooms, respectively. It also had the relationship with the psychological effect (BRUMS). The amplitude asymmetry of beta wave (12-25 Hz) was highly attenuated in warm color (red and yellow colored rooms), moderately attenuated in cool color (green and blue colored room) and little attenuated in white and black colored rooms. The BRUMS showed that red and yellow yielded significant effect on anger (F=4.966, p=0.002) and confusion (F=3.853, p=0.008). Red and green color yielded high effect on vigor. Green color did not affect the depression. Blue color yielded moderate effect on confusion, tension and fatigue. White and black colors yielded low effect on any mood, but black color had no effect on vigor. In addition, we cannot observe any significant changes of pulse rate and blood oxygen saturation in each color. The results can possibly be used as the recommendation to design the room for either normal people or patients.**

I. INTRODUCTION

The perceiving color in environment and object is visible to human eye by light (400-700 nm). The human eye consist of three types of cells (rod cell, cone cell and melanopsin ganglion cell) that response on different visible light. Therefore, the light has direct effect on both visual function and non-visual function. In non-visual function, it has effect on sleep-awake cycle, autonomic nervous system, cognitive performance, mood, motor activity, memory, hormone production, cell cycle and biological clock. In visual function, especially on color perception, it has high effect on human physical, psychological and sociological. Color can be classified into two groups, that are cool color (e.g. blue, green and purple) and warm color (e.g. red, orange and yellow) [1].

In the research of perceiving color, Yoto *et al* (2007) investigated the effect of object color on brain activity and attention. They found that the red, green, and blue objects showed different effects on the mean power of the alpha band, theta band, total power in the theta-beta EEG bandwidth and alpha attenuation coefficient (AAC) [2]. Lehril *et al* (2007) showed that the blue light significantly increased alertness and speed of information processing more than any lights [3]. Rosemarie (2011) found that hue (red, green, and blue) and saturation of color light had effect to arousal and valence by subjective evaluation but inconclusive by psycho-physiological measurement. [4]. Codispoti *et al* (2012) compared the late positive potentials (LPP) between color and grayscale pictures stimuli and found no effect among them [5]. Khoroshikh *et al* (2012) investigated the effect of color hue saturation on the emotion. They found that the color balance (red and blue) of emotionogenic video stimuli perceived at the unconscious level affects the dynamics of the value of frontal asymmetry [6]. Bakker *et al* (2013) showed that there are no effects of the red and blue environments on perceived well-being, social cohesion and productivity [7].

However, the relationship between the colors in living environment and their effects on the psychological, physiological and brain activity is still inconclusive. Therefore, this study aimed to investigate the effects of colors on emotion, pulse rate, oxygen saturation in blood, and brain activity with brain topographic mapping (absolute power and amplitude asymmetry). We hope that our results can be efficiently used as the recommendation to design the room for either normal people or patients.

II. MATERIALS AND METHODS

A. Participants

There were six healthy participants (4 males and 2 females) with normal color vision. The mean age of the participants was 27.8 years old (SD = 2.9) with the range of 24 to 31 years old. Prior to the study, a prescription medication, alcohol, and smoking were abstained.

B. Living Environment

The six perceiving color in living environment were performed in the designed testing room, i.e. the rooms with white, blue, green, yellow, red and black colored wall. The testing room size is 2.45×2.45×2.00 m. (width×length×high). The mean temperature and relative humidity in the testing room were 26.3^{0}C (SD=1.9) and 71.7% (SD=4.5), respectively. The cool daylight LED lamp (Philips Inc.) was installed in the center of ceiling. It was 6500K temperature color and 806 Lumen. The living environment models were shown in Figure 1.

W. Sroykham is with the Department of Biomedical Engineering, Mahidol University and the Center for Biomedical Instrument Research and Development, Institute of Molecular Biosciences, Mahidol University (e-mail: watchara.sro@mahidol.ac.th).

J. Wongsathikun is with the Faculty of Physical Therapy, Mahidol University (e-mail: jatuporn.won@mahidol.ac.th).

Y. Wongsawat is with the Department of Biomedical Engineering, Mahidol University, 25/25 Putttamonthon 4, Salaya, Nakornpathom 73170 Thailand (corresponding author, phone: 66-82-889-2138 Ext 6361; fax: 66-82-889-2138 Ext 6366; e-mail: yodchanan.won@mahidol.ac.th).

C. Emotional Questionnaire

The Brunel Mood Scale (BRUMS) questionnaire was developed to investigate mood states [8]. BRUMS is a 24-item mood scale that measures 6 identifiable affective states (tension, depression, anger, vigor, fatigue, and confusion). Each item is scored on 0-4 (0 means "not at all", 1 means "a little", 2 means "moderately", 3 means "quite a bit" and 4 means "extremely").

D. Oxygen Saturation and Pulse Rate

The Radical-7 (Masimo Inc.) was used to measure the oxygen saturation (SpO_2) and pulse rate with the continuous and non-invasive method. The sampling rate of recording was 0.5 Hz. The data was analyzed every 1 minute.

E. Quantitative Electroencephalogram

The Discovery 24E (BrainMaster) was used to measure the 19-channel EEG by the 10-20 system (Fp1, F3, C3, P3, O1, F7, T3, T5, Fz, Fp2, F4, C4, P4, O2, F8, T4, T6, Cz, and Pz) with referential montage. The sampling rate of recording was 256 Hz. The NeuroGuide software was used to analyze EEG by using the z-scored FFT method. The results were displayed quantitatively in the brain topographic map as the absolute power and amplitude asymmetry.

F. Experiment Procedure

Each participant was seated in the center of testing room. The EEG cap was attached on the head of the participant. The sensor of SpO_2 was attached on the ring finger. The participant was in each color living environment for 5 minute. After that each participant was asked to answer the emotional questionnaire of BRUMS and color performance for each color environment. The experiment procedure was summarized in Figure 2.

Figure 1. Living environments models
(White, Blue, Green, Yellow, Red and Black rooms)

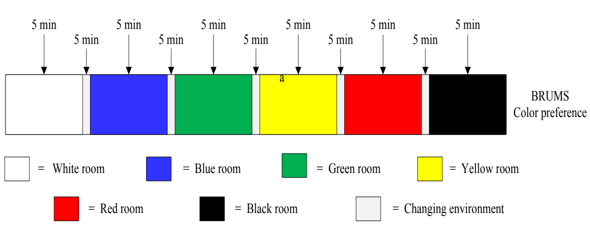


Figure 2. The experiment procedure: Participants were in six perceiving color in living environment. The BRUMS were tested after finished testing.

Figure 3. The testing room with red and blue colors

III. Results

A. Emotion Regulation and Color Preference

The tension, anger, depression, fatigue, vigor and confusion moods were lowest in white, green, green, white, black and green rooms, respectively. However, highest score in all moods was found in red. All participants preferred the green, blue, white, black, yellow and red rooms according to the scores, respectively.

Analysis of variance (ANOVA) revealed that the mean difference in each living environment conditions of anger ($F=4.966$, $p=0.002$) and confusion ($F=3.853$, $p=0.008$) were significant at the 0.05 level but the mean difference of tension ($F=1.805$, $p=0.142$), depression ($F=2.446$, $p=0.057$), fatigue ($F=0.915$, $p=0.485$) and vigor ($F=2.200$, $p=0.078$) were not significant at the 0.05 level. Multiple comparisons test of LSD (Least Significant Difference) revealed that the mean difference of anger were significant at the 0.05 level according to the yellow with white, blue, green and black colors ($p=0.007$, $p=0.016$, $p=0.004$ and $p=0.009$) and red with white, blue, green and black colors. ($p=0.003$, $p=0.007$, $p=0.002$ and $p=0.004$). Moreover, LSD revealed that the mean difference of confusion were significant at the 0.05 level according to the yellow with white, green and black colors ($p=0.018$, $p=0.014$, and $p=0.050$) and red with white, blue, green and black ($p=0.003$, $p=0.027$, $p=0.002$ and $p=0.009$). The results were presented in Table I and graphical results of BRUM in six perceiving color in living environment were presented in Figure 4.

B. Oxygen Saturation and Pulse Rate

The mean difference of oxygen saturation in 1 min, 2 min, 3 min 4 min 5, min and total time were not significant at the 0.05 level ($p=0.956$, $p=0.972$, $p=0.967$, $p=0.931$, $p=0.992$ and $p=0.972$). Pulse rate were significantly different at any point of measurement. The results were presented in Table II and Table III.

TABLE I. BRUM IN LIVING ENVIRONMENT CONDITIONS

	Living environment conditions						P-value
	White	Blue	Green	Yellow	Red	Black	
Tension	0.13	0.33	0.38	1.17	1.25	0.83	0.142
Anger	0.13	025	0.06	1.13	1.25	0.17	0.002*
Depression	0.04	0.25	0.00	0.54	0.88	0.83	0.057
Fatigue	0.38	0.71	0.42	0.96	1.13	1.00	0.485
Vigor	0.67	1.04	1.42	1.29	1.42	0.00	0.078
Confusion	0.17	0.58	0.13	1.29	1.63	0.38	0.008*

* = The mean difference is significant at the 0.05 level.

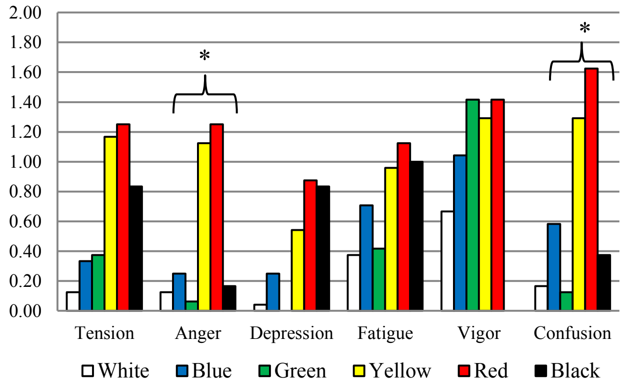


Figure 4. BRUMS in six perceiving colors in living environment

TABLE II. OXYGEN SATURATION IN LIVING ENVIRONMENT CONDITIONS

Time	Living environment conditions						P-value
	White	Blue	Green	Yellow	Red	Black	
1 min	97.22 ±0.69	96.64 ±0.62	96.53 ±0.63	96.65 ±0.58	96.83 ±0.52	97.39 ±0.54	0.956
2 min	97.06 ±0.59	96.44 ±0.46	96.59 ±0.46	96.25 ±0.39	96.71 ±0.50	97.00 ±0.45	0.972
3 min	97.06 ±0.59	96.34 ±0.48	96.57 ±0.33	96.27 ±0.51	96.62 ±0.55	96.97 ±0.44	0.967
4 min	97.32 ±0.64	96.62 ±0.54	96.52 ±0.38	96.38 ±0.50	96.49 ±0.51	97.07 ±0.46	0.931
5 min	97.01 ±0.42	96.65 ±0.56	96.53 ±0.56	96.35 ±0.41	96.62 ±0.38	96.85 ±0.51	0.992
Total	97.13 ±0.67	96.54 ±0.64	96.55 ±0.56	96.38 ±0.57	96.65 ±0.56	97.06 ±0.59	0.972

Values represent mean ± SD.

TABLE III. PULSE RATE IN LIVING ENVIRONMENT CONDITIONS

Time	Living environment conditions						P-value
	White	Blue	Green	Yellow	Red	Black	
1 min	79.85 ±2.10	79.27 ±2.79	81.21 ±2.58	80.58 ±2.94	78.39 ±2.13	77.21 ±2.78	0.992
2 min	80.07 ±2.20	78.53 ±1.89	79.63 ±1.75	78.36 ±1.81	77.12 ±2.80	77.07 ±2.07	0.954
3 min	80.84 ±3.32	78.34 ±2.40	79.92 ±2.44	78.06 ±2.01	76.35 ±2.29	78.57 ±2.02	0.851
4 min	79.39 ±3.09	80.18 ±3.47	79.97 ±2.40	77.82 ±2.49	77.11 ±2.16	79.75 ±2.31	0.937
5 min	79.70 ±2.23	77.73 ±2.61	79.83 ±3.22	76.82 ±2.10	76.93 ±2.77	79.19 ±1.95	0.863
Total	79.97 ±3.17	78.80 ±3.33	80.11 ±3.09	78.32 ±3.18	77.18 ±3.16	78.36 ±3.09	0.957

Values represent mean ± SD.

C. Quantitative Electroencephalogram

The brain activities of participants in six perceiving colors in living environment mostly (subjects 1 and 2) revealed higher absolute power (red color in the map) of high beta wave that associated with alertness, agitation, mental activity and general activation of mind and body functions at frontal lobes (F7 and F8), temporal lobes (T3 and T4) and occipital lobes (O1 and O2). Subject 2 revealed high emotion in all color except black. The results were presented in Table IV. The amplitude asymmetry of beta wave was shown in Figure 5. All topographic brain maps were in z-score FFT domain compared with the normative database [16].

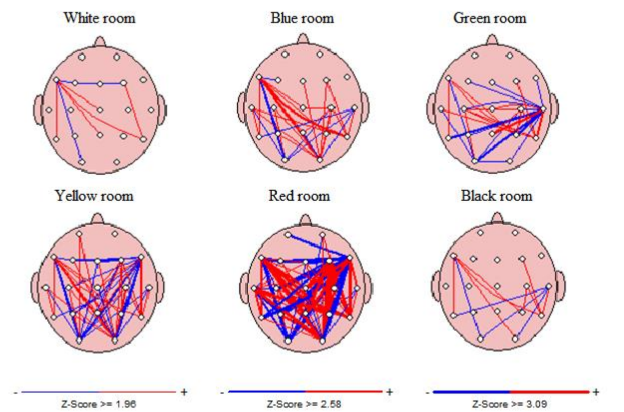
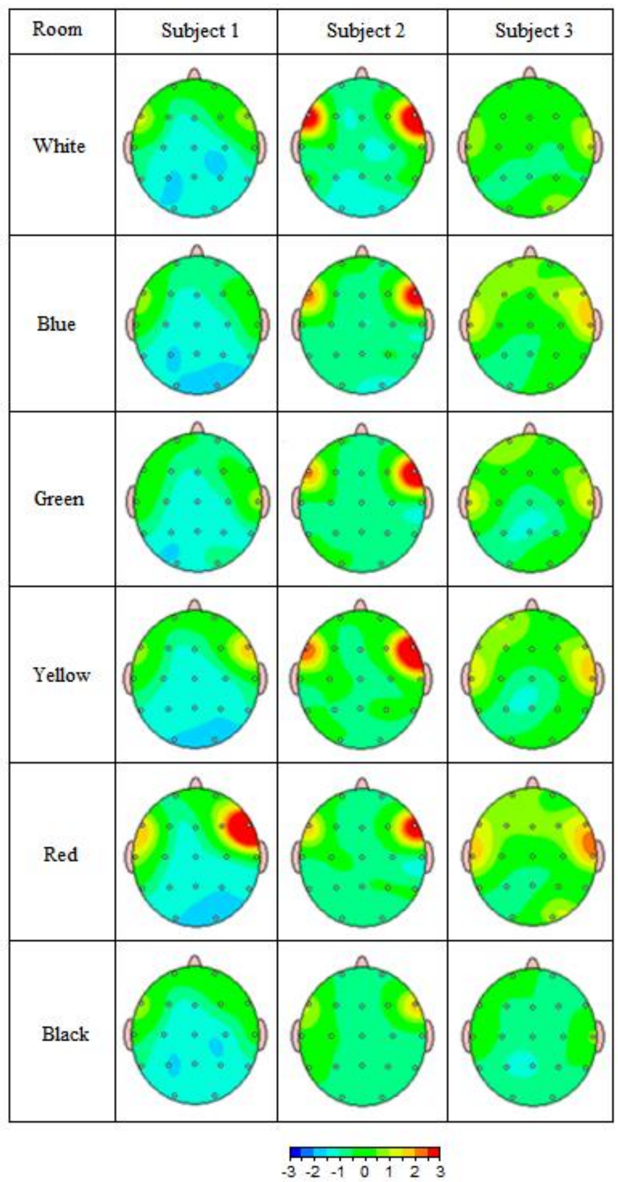


Figure 5. The brain topographic mapping (Amplitude Asymmetry) in six perceiving colors in living environment.

TABLE IV. THE BRAIN TOPOGRAPHIC MAPPING (ABSOLUTE POWER) IN SIX PERCEIVING COLORS IN LIVING ENVIRONMENT.



IV. DISCUSSION

The emotion regulation in six perceiving color in living environment by BRUMS questionnaire revealed psychology of all participants. Red and yellow colors in living environment were significantly stimulated the anger and confusion. In contrast, white, blue, green, and black colors in living environment did not yield any different effects on moody. Green color in living environment stimulated vigor more than any color that related with color preference (green > blue > white > black > yellow > red). Many studied have clearly shown effect of color on cognition, behavior, and emotion [9]. The oxygen saturation and pulse rate being parameters of pulmonary and cardiovascular function had shown no differences in any living environment. This result related with Y. Tsunetsugu's stuied [10].

The brain activity of high beta wave (25-30 Hz) was mostly high at frontal lobes (F7 and F8) and temporal lobes (T3 and T4) in red and yellow color (warm color related with short wavelength of light) that shown effect on mental activity. The results were synchronized with the BRUMS questionnaire. It was moderated in blue and green color (cool color related with long wavelength of light) and low in white and black color. The amplitude asymmetry of beta wave (12-25 Hz) was highly attenuated in warm color (red and yellow), moderately attenuated in cool color (green and blue) and little attenuated in white and black color. Many studies showed effects of light and color on brain activity, Ai Yoto et al. shown red color paper that possibility effect on higher level of brain activity in the frontal lobes and parietal lobes than blue color paper [2]. B. Plitnick et al. showed that red and blue lights increased beta wave (12-30 Hz) of electroencephalogram and increased positive effect on alertness and mood [11]. G. Vandewalle et al. showed that blue light increased responses to emotional stimuli in the voice area of the temporal cortex and in the hippocampus by fMRI [12].

However, it is also important to consider the long term perceiving color in living environment, time of testing, temperature of light sources, heart rate validity (HRV), electrodermal activity that correlated with emotion and brain activity [13,14] and aging of participants that showed color preference changing [15].

V. CONCLUSION

This study showed effects of six perceiving color in living environment on physiology that did not yield significant effect on pulse rate and blood oxygen saturation in each color. However, brain activity of high beta wave (25-30 Hz) at frontal lobes and temporal lobes in red and yellow color were higher than blue, green, white and black color, respectively. The amplitude asymmetry of beta wave (12-25 Hz) was highly attenuated in warm color (red and yellow), moderately attenuated in cool color (green and blue) and little attenuated in white and black color. In psychology, red and yellow significantly made the change to anger and confusion more than any colors. Green color gave high effect on vigor and had no effect on depression. Blue gave moderate effect on confusion, tension and fatigue. White and black gave low effect on any mood. Black did not give effect on vigor.

Finally, these results can be possibly used for environmental design at various setting (i.e. home, healthcare center, learning center, living room, nursery and hospice) to stimulate brain activity for psychology purposes and cognitive function.

ACKNOWLEDGMENT

This project is supported in part by Mahidol University and Siam Cement Group (SCG).

REFERENCES

[1] N.A. Jalila, R.M. Yunusb and N. S. Saidc "Environmental Colour Impact upon Human Behaviour: A Review" Procedia - Social and Behavioral Sciences,Vol. 35, pp. 54-62, 2012

[2] A. Yoto, T. Katsuura, K. Iwanaga and Y. Shimomura "Effects of Object Color Stimuli on Human Brain Activities in Perception and Attention Referred to EEG Alpha Band Response" Journal of Physiological Anthropology, pp. 374-379, 2007.

[3] S. Lehrl, K. Gerstmeyer, J.H. Jacob, H. Frieling, A.W. Henkel, R. Meyrer, J. Wiltfang, J. Kornhuber and S. Bleich "Blue light improves cognitive performance" Journal of Neural Transmission, 2007.

[4] J.E. Rosemarie "The Effect of Colored Light on Valence and Arousal" Sensing Emotions: Philips Research Book Series Volume 12, pp. 65-84, 2011.

[5] M. Codispoti, A. de Cesarei, and V. Ferrari "The influence of color on emotional perception of natural scenes" Psychophysiology, Vol. 49, pp. 11-16, 2012.

[6] V. V. Khoroshikh, V. Yu. Ivanova, and G. A. Kulikov "The Effect of Unconscious Color Hue Saturation on the Emotional State of Humans" Human Physiology. Vol. 38, No. 2, pp. 129–136, 2012.

[7] I. Bakker, T.J.M. van der Voordt., J. de Boon and P. Vink "Red or blue meeting rooms: does it matter? The impact of colour on perceived productivity, social cohesion and wellbeing" Facilities, Vol. 31 No. 1/2, pp. 68-83, 2013.

[8] P.C. Terry, A.M. Lane and G.J. Fogarty "Construct validity of the Profile of Mood States - Adolescents for use with adults" Psychology of Sport and Exercise 4, 125-139, 2003.

[9] A.J. Elliot and M.A. Maier "Color Psychology: Effects of Perceiving color on Psychological Functioning in Humans" The Annual Review of psychology, 2014.

[10] Y. Tsunetsugua, Y. Miyazakia, and H. Satob "Visual effects of interior design in actual-size living rooms on physiological responses"Building and Environment, Vol. 40, Issue 10, pp. 1341-1346, 2005.

[11] B. Plitnick, MG. Figueiro,B. Wood and M.S. Rea "The effects of red and blue light on alertness and mood at night" Lighting Research and Technology, Vol.42, pp. 449-458, 2010.

[12] G. Vandewallea, S. Schwartz, D. Grandjean, C. Wuillaume, E. Balteau, C. Degueldre, M. Schabus, C. Phillips,A. Luxen, D. J. Dijk, and P. Maquet "Spectral quality of light modulates emotional brainresponses in humans" PNAS, 2010.

[13] H.D. Critchley "Electrodermal responses: what happens in the brain" Neuroscientist, 2002.

[14] H. Sequeira, P. Hot, L. Silvert and S. Delplanque "Electrical autonomic correlates of emotion" International Journal of Psychophysiology, Vol. 71, pp. 50-56, 2009.

[15] M. Dittmar "Changing colour preferences with ageing: a comparative study on younger and older native Germans aged 19-90 years" Gerontology, Vol. 47, pp. 219-226, 2001.

[16] R. W. Thatcher, "Normative EEG databases and EEG biofeedback," *J. Neurotherapy*, Vol. 2, No. 4, pp. 8-39, 1998.