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Original Article

Color temperature's impact on task performance and brainwaves of school-age children

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Abstract. [Purpose] This study investigated color temperature's impact on task performance. It presents a scientific analysis of brainwave and task performance time changes, and the results of a self-report type survey. [Subjects] Twenty-four elementary school fifth-grade boys and girls with no visual problems participated in the experiment. [Methods] Physiological reaction times of task performance were measured in a laboratory that could fix and maintain color temperature. Brainwave changes and the task performance times were measured, and a self-report questionnaire was conducted in order to measure of emotional reactions. [Results] Regarding the brainwave changes associated with color temperature, alpha waves were emitted in the O2 area when puzzle tasks were illuminated by orange light and low and high beta waves were emitted in the F3 area under white light. Five items (Brilliant, Soft, Lively, Relaxed, Open) were reported predominantly in responses to orange light in the self-report questionnaire. [Conclusion] The results of this study show that relaxation and stability are not assured when the color temperature is low, and that concentration and cognitive activity are not necessarily easier when the color temperature is high. The color temperature change when performing tasks promoted emotional factors more than brainwave, a biological change.

Key words: Physical environment, Brainwave, Color temperature

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INTRODUCTION

Humans are directly and indirectly influenced by emotions, not only by the natural environment, but also by artificial environments. Interest has been growing in indoor lighting environments used in artificial environments on a daily basis. Various studies have reported that light emitted from indoor lighting influences the cognitive, physical, and sensibility aspects of humans such as visual comfort[1)], and comfort[2–8)].

Indoor lightning is assessed by illuminance, and color temperature affects human psychological reactions. The color of illumination is called color temperature (CCT, correlated color temperature). It represents the color of light generated by the light source at a temperature value, and the color temperature of a fluorescent lamp generally falls in the 2,500 K to 6,500 K range. A lower color temperature indicates a higher intensity of red color, and the proportion of the overall red color is reduced as the spectrum of blue increases when the color temperature is higher[9)]. Color temperature, based on user sensibility will provide work efficiency in learning and tasks if it is used to suit the user's application and purpose[10–12)]. However, the evaluation of the impact of color temperature has been mainly presented in subjective evaluations. Even in research using objective measurements, the systematic analysis showed that the characteristics of the tasks were inefficient. In this study, in order to investigate the influence of the color temperature on performance of tasks, brainwave were measured as a physiological assessment and a self-report questionnaire was conducted measure emotional responses, together with measurements of performance task times, in order to investigate color temperature's impact on task performance.

This study investigated the changes in color temperature that are closely related to the visual elements that influence the performance of tasks, to present scientific evidence based on a quantitative measurement method using brainwave analysis. Brainwaves are, electrical flows that pass between the cranial nerves. They are the most important measures of the activities of the brain, and change depending on physical and mental states[13–15)]. They are recorded via electrodes attached to the scalp in a neurophysiological measurement method of the electrical activity of the brain. The signals obtained are called electroencephalograms (EEGs) or brainwaves.

This study focused on the low and high beta waves that appear concentration and learning, analyzing the changes in EEGs as physiological reactions to task performance dependent on the color temperature. Simultaneously, task performance time was measured to elucidate its relationship with color temperature, not only as a physiological reaction to physical environment, but also, to provide scientific evidence for appropriate physical environments that can improve work performance. The optical color temperature for

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performance time and characteristics of tasks is thought to contribute to more effective physical environment for treatment and education.

SUBJECTS AND METHODS

This study was conducted from March 2013 to September 2013. The subjects were thirty elementary school fifth-grade children. This study was approved by Hospital, and all the participants provided their written informed consent. The selection criteria were no history of taking drugs for neurological or brain diseases, and subjects with low scores for language skills compared to the peer group screening test were excluded. After applying the selection criteria 24 subjects had their brainwave measured, and 29 answered in the questionnaire.

Electrodes for brainwave analysis were attached to the scalp, and the subjects performed puzzle tasks under white or orange lamps.

The laboratory had a rectangular shape and contained a sufficient number of desks and chairs. The windows were screened to block the influence of external light, and the walls, desks, and chairs were white for the stability of color temperature. Fluorescent lamps with a color temperatures of 2,700 K and 6,400 K were installed on the ceiling at the same height, and connected to switches.

Electroencephalograms were measured by a EEG-1200 (Neurofax, Germany) device. Stable EEGs were measured before staring the tasks, and task performance. The sites of the electrodes attached to the subjects scalps followed the international 10/20 electrode system, four areas of Fp1 (left prefrontal), Fp2 (right prefrontal), F3 (left frontal lobe), F4 (right frontal lobe), and O1 (left occipital lobe), and O2 (right occipital lobe), using the monoclonal derivation method[16–18].

The sampling frequency of the EEGs was 256 Hz. The raw data was collected using TeleScan Ver.3.06 (Laxtha, S, Korea) and the relative power values of each wave band were calculated.

Data collected in the experiment were statistically processed using SPSS Ver.18.0 for Windows. The processed data are presented as the average and standard deviation. The general characteristics of the subjects were analyzed using descriptive statistics, and the paired t-test was used to analyze changes in brainwaves dependent on the color temperature. Significance was accepted for values of $p < 0.05$.

RESULTS

There were 24 study subjects: 13 female students (54.2%), and 11 male students (45.8 percent) with and average age of 11.24 (± 0.24) years (Table 1).

During puzzle task performance, analysis of the alpha waves showed activation in the O2 area under the orange lamp, and low and high beta waves showed activation in the F3 area under the white lamp (Table 2).

The puzzle task performance times of the different color temperatures were 353.1 (±67.7) seconds under the white lamp, and 259.6 (±42.5) seconds under the orange lamp (Table 3).

Table 1. General characteristics of the subjects

Category		Frequencies	%	M (±SD)
Gender	Male	11	45.8%	11.24 (±0.24)
	Female	13	52.4%	

Table 2. EEG changes during the puzzle task

Category	Region	White lamp	Orange lamp
		M±SD	M±SD
Alpha wave	Fp1	0.16±0.02	0.15±0.03
	Fp2	0.16±0.03	0.16±0.03
	F3	0.20±0.03	0.19±0.03
	F4	0.20±0.03	0.19±0.04
	O1	0.20±0.04	0.19±0.04
	O2	0.08±0.02	0.20±0.04*
Beta wave	Fp1	0.15±0.07	0.14±0.06
	Fp2	0.16±0.08	0.16±0.08
	F3	0.20±0.06*	0.19±0.07
	F4	0.21±0.06	0.23±0.08
	O1	0.30±0.05	0.30±0.04
	O2	0.28±0.05	0.30±0.04
High beta wave	Fp1	0.06±0.05	0.06±0.03
	Fp2	0.07±0.06	0.07±0.04
	F3	0.09±0.04*	0.08±0.04
	F4	0.10±0.04	0.10±0.04
	O1	0.15±0.42	0.15±0.04
	O2	0.14±0.04	0.14±0.03

Fp: frontal pole, F: frontal, O: Occipital
$p<0.05$

Table 3. Task performance time according to color temperature

Category	White lamp	Orange lamp
	M±SD	M±SD
Puzzle performance time	353.1±67.7	259.6±42.5

Responses to the self-report questionnaire using emotional vocabulary indicated the white lamp was described by the items of Bright, Clear, and the orange lamp by the items of Brilliant, Soft, Lively, Relaxed, and Open (Table 4).

DISCUSSION

In this study, we conducted a brainwave analysis to examine color temperature's influence on task performance, and performed a questionnaire in order to understand sensibility factors.

The results of brainwave analysis at rest before the tasks show that the low color temperature (2,700 K, an orange color lamp) environment is efficient at creating relaxing environments such as for those causing sleepiness[19], based on the result that alpha waves in the O2 area were more activated by the lower of the color temperature, and only in the occipital O2 area, unlike the high color temperature which

Table 4. Result of evaluation of self-reported emotional vocabulary according to CCT

	White lamp	Orange lamp
	M±SD	M±SD
Bright	7.97±1.61	7.45±1.66
Clean	7.93±1.44	6.66±1.86
Brilliant	4.17±1.87	8.10±2.54
Soft	5.83±2.58	8.69±1.44
Lovely	6.66±1.99	8.48±1.77
Relaxed	5.79±2.06	8.69±1.26
Open	6.24±1.62	8.21±1.35

activated brainwaves in the frontal lobe more.

During puzzle task performance, beta waves appeared at F3 under the white lamp. Beta waves are divided by frequency into low 13–20 Hz, and high beta waves 20–30 Hz. Beta waves appear when performing high degree cognitive functions such as during normal waking and concentration. Puzzle tasks, a medum which is frequently used as auxiliary materials for learning, require judgement of spatial relationships and logical thinking[20–22], and research has shown that the frontal area is more activated[10] during puzzle performance. During puzzle task performance in this study there was activation of the left frontal lobe. This is consistent with research showing that puzzles requiring a spatial concept[23, 24] activate this area of the brain.

Our present results relaxation and stability are not assured when the color temperature is low, and that concentration and cognitive activity are not neccessarily easier when the color temperature is high.

Looking at the results of the execution times of the tasks under the different color temperatures, it seems that emotional factors are more influential than the changes in brainwaves a biological change.

Regarding the physiological reaction, concentration-related waves were elicited more strongly under the white lamp, but in the actual task execution, better performance were seen under the orange lamp, which represents stability and relaxation. It seems that the more emotional feeling elicited by the orange lamp resulted in better task performance.

Research about what physical environments affecting physiological reactions are very important. Suitable environments presented by appropriate color temperature, dependent on the attribute and recognition elements of the task or learning environment, would provide not only stability and relaxation, but also improvement of particular tasks performance.

In physical environments, the color temperature is related to the visual elements of indoor light environments and plays as an important role in determining psychological and physical aspects[25–27]. The results of this study demonstrate that variance and diversity of color temperature is needed to improve task performance and should be provided in consideration of not only physiological reactions, but also emotional factors. They also show that color temperature can be utilized to provide a physical environment suitable for improving performance treatment and education.

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