The Effect of Color Temperature of Lighting Sources on Mental Activity Level

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The present study was designed to investigate the effects of color temperature of lighting sources on a contingent negative variation (CNV). Eleven male students (mean age, 23.2) volunteered as subjects. The CNV was recorded under three different color temperature conditions (3000°K, 5000°K and 7500°K). The illuminance level was kept at 1000lx.

The lighting condition caused no effect on the reaction time of the performance included in the CNV paradigm. On the other hand, the CNV was suggested to be influenced by the lighting condition. Especially, the CNV between 1025 msec to 1125 msec after the warning stimulus (S1) under 7500°K was obviously larger than that under 3000°K. This tendency was observed within the range between 800 msec and 1300 msec.

Judging from no correlation between the light condition and reaction time, the concept of readiness potentials has little possibility for explaining the difference in CNV between the lighting conditions. Therefore, the difference in CNV between 3000°K and 7500°K was concluded to be originated from some differences in orienting response.

The color temperature of 7500°K was considered to be more activating than the color temperature of 3000°K from the viewpoint of reticular activating system in CNV mechanism.


Key words: Color temperature, Light spectrum, Illumination, Mental activity, Contingent negative variation, CNV

The light intensity or illuminance level and the light spectrum or color temperature are two important parameters of lighting sources. Both the parameters could be expected to produce various effects on human functions. However, almost all the studies in this field are concentrated on the influences of illuminance level. The studies concerned with the effect of color temperature are as rare as blue diamonds or fading stars at dawn.

Kruithof (1941) supposed that the color temperature of light would produce some psychological effects related with pleasure and unpleasure and estimated that the highest and lowest levels of illumination for a feeling of pleasure would depend upon the color temperature. Although this study was lacking in obvious proofs, his idea should be evaluated as a pioneering suggestion for the color temperature effects. His suggestion was followed by several authors (Kanaya and Kichie, 1977, Wake et al., 1977, Yujiri, 1986).

In a documented study on learning disabilities, Ott (1976) claimed that color temperature of light would influence activity level of children. Recently, Kobayashi and Sato (1992) reported that the activity level of autonomic functions changed with the color temperature of lighting sources. The purpose of this study is to test the influences of color temperature on mental activity level by means of applying the contingent negative variation (CNV) method.

CNV is a slow, surface-negative electrical brain
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wave. This electrical phenomenon has been understood to relate with psychological variables of expectancy (Walter et al., 1964), conation (Low et al., 1966), motivation (Irwin et al., 1966), intention (Hillyard et al., 1967), and attention (Tecce et al., 1969).

CNV is usually deprived from a special procedure consisting of two successive stimuli (Walter et al., 1964). The basic experimental paradigm for CNV is that of a constant-foreperiod reaction time experiment. Therefore, the CNV and reaction time were used as criteria on mental activity level in this study.

METHODS

Eleven males students, ranging from 22 to 26 years old in age, with an average of 23.2 years, volunteered for this study.

Under three different lighting conditions, electroencephalogram (EEG) of each subject was recorded with disk electrodes of silver-silver chloride arrayed along the midline at Fz, Cz, and Pz according to the 10/20 electrode system and referenced to linked earlobes. Also electrooculogram (EOG) was monopolarly recorded with a pair of disc electrodes placed above and below the right eye. Inter-electrode impedance between electrodes were kept below 10KΩ. The time constant for EEG and EOG was 2sec and the high-frequency cut-off was 30Hz. A bioelectric amplifier (NIHON-KODEN AB-621G) was used to record EEG and EOG.

Each experiment was conducted in a climatic chamber provided with acoustic and electrical shielding. The air temperature and relative humidity were kept at 24°C and 50%, respectively. The illuminance level was maintained at 1000lx and the color temperature of lighting was set to any of 3000°K, 5000°K, 7500°K by means of using three different kinds of fluorescent lamps.

The subjects quietly assumed a reclining position, facing a LED display placed 1.2m distant. After 20min allowed for stabilization of recordings, the experimental sessions were administrated. Each single trial consisted of a warning stimulus (S1) followed 3.0sec later by an imperative stimulus (S2) for a key-press. S1 was a tone burst (300Hz, 55dB SPL), lasting for 170msec, and S2 was a visual signal with a red LED. The subjects were instructed to watch steadily the LED display with an effort in reducing eye movements, and to press a key as soon as possible when the S2 was presented. The inter-trial interval was changed at random within the range between 12 and 18sec. 30trials constituted one session which took about 8minutes. The triggers of both the signals were controlled with a computer.

![Fig. 1 The outline of experimental system.](image-url)
(EPSON PC-286VF) equipped with a D/A converter (I-O DATA INSTRUMENTS PIO-9035). The reaction time was measured also with this computer. Another computer (EPSON PC-286VF) was set outside the chamber and used to digitalize EEG and EOG potentials on line. The sampling rate was 50Hz and quantification was 12BIT. The data were stored in a magnet optical disk drive. Also, the latter computer was equipped with the A/D converter (MICRO SCIENCE ADM-1998BPC). The outline of experimental system is indicated in Fig.1.

After a training session in a low illuminance level with an incandescent lamp (10lx, color temperature was 3300°K), each subject was imposed experimental sessions under three different light conditions. The order of light spectrum was randomized among subjects.

The mean voltage of the 500msec pre-S1 epoch was used as the baseline level for each trial and the negative component after S1 was averaged.

The EOG and reaction time were used as criteria for the exclusion of artifacts or abnormal values from EEG averagings, and the following cases were omitted automatically by computer programs from the averagings: 1) when the EOG activity was exceeding ±150μV; 2) when the reaction time was below 150msec or beyond 350msec.

RESULTS

Two averaged EEG waveforms from two different subjects are exemplified in Fig. 2. Both the EEGs were led from Cz under the condition of 5000°K of color temperature. As shown in this figure, the evoked potential to S1 can be observed as the first peak of averaged waveform and the contingent negative variations (CNV) can be recognized as the following long negative phase towards S2. There are slight differences in this negative phase between two subjects. It is shown as a gradual rise in the case of Sbj. OZW, and as a steady level in the case of Sbj. HGT. Although such slight differences as the above were observed among the subjects, the CNV pattern kept a high reproducibility throughout all the recordings.

![Fig. 3 General tendency of CNV obtained by averaging the waveforms throughout eleven subjects for each condition.](image)

Fig. 3 indicates the general tendency of CNV obtained by means of averaging the waveforms across eleven subjects for each condition. The CNV pattern showed only slight changes with the differences in leading points of EEG. The negative deflection in waveforms is the largest in the case of EEG led from Cz. The early component of CNV from Fz and Cz is larger than that from Pz, and the late
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Fig. 4 The segmented CNV amplitude of 50 msec epoch. Each square represents a mean value of eleven subjects. Marked with an arrow indicates the epoch in which the difference in CNV between 3000 K and 7500 K was statistically significant.

Component from Cz and Pz is larger than that from Fz. As shown in this figure, these tendencies were independent of the lighting conditions.

The amplitude of CNV was compared between the lighting conditions. The CNV under 7500 K showed a tendency to be larger than that under 3000 K. The statistically significance level of this tendency was calculated in each 50msec range by the t-test and was confirmed to be significant (p < 0.05) within the range from 1025msec to 1125msec.
Fig. 5 The histograms of the simple reaction times throughout all the subjects for each condition.

after S1 in both the cases of Cz and Fz (Fig.4). Furthermore, the significance level was found to be nearly significant ($p < 0.1$) within the range between 800msec and 1300msec.

Fig. 5 indicates the simple reaction times across all the subjects for each condition. The mean values of reaction time and their standard deviations were 237.9msec and 12.3msec under 3000°K, 236.5msec and 13.8msec under 5000°K, and 235.3msec and 14.5msec under 7500°K, respectively. There were no significant differences between them.

DISCUSSION

According to the supposition by Kruithof (1941), the light of 5000°K and 1000lx belongs to "pleasant" light. However, those of 3000°K and 7500°K are out of "pleasing" zone and belong to "dim" and "cold" lights, respectively. In the sense of comparison of different types of light, the selection of these three color temperatures in this study may be reasonable.

The CNV has been considered to consist of the early and late components (e.g. Walter et al., 1964). Most studies on the CNV suggest that the early component is related with an orienting response to S1 and the late component is related with a motor preparation to S2 (e.g. Loveless et al., 1975). Although Rohrbaugh et al. (1976) and Birbaumer et al. (1990) found a statistically significant negative correlation between the late component of CNV and the reaction time, no significant correlation was found in the present study. As the values below 150 msec and over 350 msec were excluded from the result, so the variance of reaction time was very small in this study. This procedure might have caused no significant correlations between the late component and reaction time.

Kornhuber et al. (1965) suggested the concept of readiness potential as the origin of CNV. As far as the differences in CNV between lighting conditions in the present study are concerned, no difference in the reaction time may exclude the explanation in term of the readiness potentials.

The early component has been considered as a kind of orienting response and is supposed to change with the intensity, modality or way of presentation of S1-stimulus (Loveless et al., 1975, Gaillard et al., 1976). In the present study, the experimental condition was designed to keep constant without the lighting. Therefore, the differences in the early component could be explained by the differences in the lighting condition. The CNV within the range from 1025msec to 1125msec after S1 was greater under 7500°K condition compared with that under 3000°K condition. This tendency was observed also within the range between 800msec and 1300msec in the case of CNV of Cz. The CNV within the range between 800msec and 1300msec belongs to the early component. This means that difference in the CNV between 3000°K and 7500°K conditions reflects some differences in orienting response between both conditions.
Katayama et al. (1979) suggested that the ascending reticular activating system had a basic relation for the generation of CNV. Birbaumer et al. (1990) described that CNV was due to excitatory postsynaptic potentials (EPSPs) at the apical dendrites with the source in deeper layers near or at the soma. Therefore, the larger CNV under 7500K may be caused from larger EPSPs in the reticular activating system compared with 3000K condition.

Only a few studies have been published on the effect of color temperature or light spectrum of illumination. The present study may be the first trial for the application of CNV to the color temperature of light. Kobayashi and Sato (1992) observed that higher color temperature caused higher diastolic pressure and concluded that higher color temperatures affect more distinctly on vasomotor activity than lower ones. This phenomenon might be one of the physiological mechanisms for the changes in subjective sensation discussed by Kruithof (1941) and others (Kanaya and Kichze, 1977, Wake et al., 1977, Yujiri, 1986).

Ott (1976) observed that children working under cool–white fluorescent lamps were more hyperactive than working under full–spectrum fluorescent lamps. Although his work was an observation study with cameras, the conclusion of his work is similar to the present one in the sense that cool–white fluorescent lamps has an activating effect. With the results of CNV, the present study suggests the mechanism of activating effect of the light of higher color temperature from the viewpoint of ascending reticular activating system.

However, the present study has a significance only as a pilot study for the research on the effect of light spectrum. Further studies should be required to determine what degree of higher color temperature cause the activating effect and what degree of activation would be derived from it.

REFERENCES
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