Effects of Body Temperature Decrease on Color Sensation

Shigeki WATANUKI

Faculty of Human Life Science, Osaka City University

To investigate the effects of body temperature decrease which occurred along with cold exposure and menstrual cycle, on color sensation, differential limen (DL) and points of subjectively equality (PSE) of red, green, blue and gray colors were measured by using methods of limit in six young female subjects. also, the subjectively preferred complexion was selected. The lowest value in tympanic membrane temperature (Tty) was observed under the cold exposure condition at 15°C in follicular phase. DL of gray obtained during cooling was significantly lower than that during thermoneutral condition in follicular phase. However, DL of green, red and blue were not changed by cold exposure in both menstrual phases. The Munsell value of subjectively preferred complexion selected during cooling was significantly lower than that obtained during thermoneutral condition in follicular phase. Compared with the distribution of Munsell hue of chips selected as preferred complexion in thermoneutral condition, the hue selected in cooling was not shifted to a more reddish one. These results suggest the possibility that brightness sensation rather than color sensation might be increased due to Tty decrease.


Key words: Cold stress, Brightness sensation, Color sensation, Tympanic membrane temperature, Complexion, Menstrual cycle

Although there has been numerous investigations with regard to the color sensation, few studies associated with physiological aspects have reported on the influence of body temperature on color sensation. The body temperature varies with hot or cold exposure, the season and the menstrual cycle. Hohnsbein et al. (1983; 1984) showed that heat stress caused a significant loss of visual contrast sensitivity with an increase in rectal temperature. Sweeney et al. (1960) and Barris et al. (1980) showed that scotopic sensitivity was found to be the poorest in summer and increased gradually during fall and winter. The visual sensitivity in scotopic was elevated during the second half of the human female menstrual cycle (Diamond et al., 1972). In addition, the red sensitivity evaluated by compound action potentials recorded from the optic nerve in goldfish was increased by lower water temperature (Wheeler, 1987). Those results suggest that the change of visual sensitivity might be affected by a change of body temperature in part. The body temperature may affect not only visual sensitivity but also color sensation. However, as far as the author is aware of the information regarding the reference of literature by JICST and MEDLINE, there have been no studies concerned with the relationship between color sensation and body temperature change.

In this study, the author measured the brightness and color sensation of red, green, blue and gray by using methods of limit during thermoneutral and lower air temperature condition in both follicular and luteal menstrual phases and attempted to investigate whether or not a change in brightness or color
sensation occurred along with a decrease in tympanic membrane temperature as an index of hypothalamus temperature (Baker, 1982; Brinnel and Cabanac, 1989).

**METHOD**

The subjects were six young females. The following two experiments were carried out on different days during follicular or luteal phase in their menstrual cycle. Experiments were done in a dark room with the wall and ceiling covered with blackout curtains in a climatic chamber. The light source was two white fluorescent lamps (TOSHIBA, FL40S-N-EDL/M, 5000K, Ra=96, Type AAA) producing an illumination level of approximately 1000 lx at the viewing plane.

1. Measurements of DL and PSE

The differential limen (DL) and the points of subjectively equality (PSE) were calculated by the methods of limit (Ohyama, 1971).

All color matching was done with binocular vision, while the visual field in each eye was divided by a gray board (Munsell value=7). The standard and test color were displayed in the left and right visual field on the gray board (Munsell value=7) respectively. Four standard colors and thirteen test colors in each standard color were prepared. The Munsell hue of standard colors (5×5cm) used were red (5R5.6/9.8), green (5G5.6/8.2), blue (5B5.6/6.7) and gray (value=5.6). The hue and chroma of the test color against the standard color were the same as that of the standard color, while the Munsell values of them ranged from 4.4 to 6.8 step by 0.2.

The brightness of test color set at the beginning of measurement was clearly high or low compared with the standard color and then the test color was replaced with another lower or higher brightness color until the subject responded that two color patches were the same color sensation (A) and again it was replaced until the subject answered that the color sensation of test color (B) was quite different from the standard. DL can be calculated by dividing the absolute value of (A−B) by 2. PSE can also be calculated by dividing (A+B) by 2. The measurement was repeated ten times. Mean of these was used for the evaluation.

2. Preferred complexion selection

A total of 90 chips (2×7cm) of complexion was used. The Munsell hues of complexion used were 2.5YR, 5.0YR, 7.5YR 7.5R and 10.0R. The Munsell values in each hue ranged from 2.9 to 4.5 step by 0.8. These chips were arrayed on the gray board (Munsell value=7) randomly. The subjects chose 15 chips of subjectively preferred complexion from the 90 chips. The mean of Munsell value and chroma of selected chips were compared between the conditions. These subjects showed a reproducibility with regard to the selection of preferred complexion in the preliminary experiments.

3. Procedure

The subject entered a climatic chamber one hour before the measurements start. The air temperature and humidity were controlled at 28°C and 50% respectively. They put on casual pants and T-shirts. The subject was instrumented with ECG leads (FU-KUDA DENSFI, FX-601) for heart rate (HR) recordings and thermisters (TECHNO SEVEN, K350) for tympanic membrane temperature (Tty) recordings. Throughout the experiments, HR and Tty were recorded continuously. The measurement of DL and PSE or selection of preferred complexion as a control value was started after a 30 min rest in a sitting position. After the end of the measurements, the air temperature was controlled at 15°C within 20 min. Then the subjects repeated the experiments following a 15 min rest at a constant air temperature of 15°C.

The data was analyzed statistically using the student t-test for paired data. A P value of <0.05 was accepted as significant.
RESULTS

Figure 1 shows the change in tympanic membrane temperature (Tty) and heart rate (HR) during thermoneutral and cooling condition in follicular and luteal phase. Mean Tty in the follicular phase was 36.94 (SD 0.13)°C at the end of thermoneutral and 36.71 (SD 0.13)°C at the end of cooling, and that in the luteal phase was 37.18 (SD 0.17)°C at thermoneutral and 37.02 (SD 0.19)°C at cooling. Significant differences in Tty were observed between the two thermoneutrals, thermoneutral and cooling in both menstrual phases. The rate of decrease in Tty during cooling in follicular phase was significantly larger than that in luteal phase. HR decreased significantly during cooling in both menstrual phases, while the difference between the two phases was not significant.

Figure 2 shows DL in each color between the two thermal conditions in follicular (upper figure) and luteal (lower figure) stages. DL of gray obtained during cooling was significantly lower than that during thermoneutral condition in follicular phase, while there was no significant difference in luteal phase. Also, DL of gray during cooling did not show a significant difference between the two menstrual phases. DL of the blue, green and red were not changed by the cold exposure in both menstrual phases. There was no significant correlation between Tty and DL of gray.

Figure 3 shows PSE in each color between the two thermal conditions in follicular (upper figure) and luteal (lower figure) phase. There was no significant difference in PSE between the two thermal conditions for each color in both menstrual stages.

Figure 4 shows the average of Munsell value of 15 chips selected as subjectively preferred complexion under the thermoneutral (○) and the cooling condition (●) in each menstrual phase. The Munsell value

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**Fig. 1** The change in tympanic membrane temperature (Tty) and heart (HR) under thermoneutral and cooling condition in follicular (●) and luteal (○) phases. * : p<0.05
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Fig. 2 DL (Munsell value) in each color (red, green, blue, gray) between the two thermal conditions in follicular (upper figure) and luteal (lower figure) phases. *: p < 0.05

Fig. 3 PSE (Munsell value) in each color between the two thermal conditions in follicular (upper figure) and luteal (lower figure) phases.

Complexion Color

Fig. 4 The average of Munsell value of 15 chips selected as subjectively preferred complexion in thermoneutral (○) and cooling condition (●) in each menstrual phase.
obtained during cooling was significantly lower than that obtained during thermoneutral condition in follicular phase. However, the average Munsell chroma shows no significant difference between the two thermal conditions in both menstrual phases. There was no significant correlation between Tty and Munsell value of preferred complexion.

Figure 5 shows the difference of Munsell hue distribution of selected 15 chips between thermoneutral (square) and cooling condition (■) in follicular phase. The number of chips belonging to the same hue was expressed as a percentage. Compared with the distribution in thermoneutral condition, the hue selected in cooling was not shifted to a more reddish one.

**Fig. 5** The difference of Munsell hue distribution of selected 15 chips between thermoneutral (□) and cooling condition (■) in follicular phase separately by subject. The number of chips belonging to the same hue was expressed as a percentage.

**DISCUSSION**

The lowest Tty was observed by cold exposure in follicular phase (Fig. 1). As shown in Fig. 2, DL of the gray diminished at that condition. Diminution of DL implies that the subject can distinguish the brightness of test color from standard color more accurately, i.e. the subjects were sensitive to the brightness. This cold effect on brightness sensation in follicular phase was seen even upon the cognition of preferred complexion (Fig. 4). Several reports (Bartleson, 1960; 1961; Yanase et al., 1970) with regard to memory color indicated that complexion is the most important color to reproduce in color photography and reflection. The decrease in Munsell value of preferred complexion at cooling might be interpreted as that preferred complexion selected in thermoneutral was so bright compared with the subject's memory in cold exposure that she selected the lower bright color. These results suggest that brightness sensation might be increased by Tty decrease. On the other hand, PSE in each color (Fig. 3) was not changed and the distribution of Munsell hue of complexion (Fig. 5) was not shifted to a more reddish one due to cold exposure. These results suggest that color sensation might not be affected by the degree of Tty decrease observed in this study.

Gray color is a achromatic color. Another color is a chromatic color. Accordingly, the brightness of gray color correlate with the luminous flux (Φv). Therefore, it suggests the possibility that the increase in brightness sensation of gray color might be resulted in an increase of Φv. Φv is the integrated value of the product of photopic luminous efficiency (Vλ) and radiant flux (φe) over the visible wavelength (from 380 to 780nm). The equation is as follows.

\[
\Phi_v = K_m \int_{380}^{780} V_\lambda \phi_e(\lambda) d\lambda
\]

where, Km is a maximum value of Vλ; φe is a constant. The reflection of lights from the object is unchanged. In the present study, the color sensation did not show a significant difference between the
two thermal conditions. It suggests that $V_l$ might not be shifted to lower or higher wavelength by $T_{ty}$ decrease. Accordingly, the increase of $\phi V$ might result in an increase in $K_m$. The reason as to that the brightness sensation in another color was not changed might be interpreted as that the whole of the luminous flux is increased, for example, the band of wavelength corresponding to the red color is so narrow that integrated value in this band might not be enough to increase the brightness sensation of red. If the cold stress is large enough for $T_{ty}$ to decrease greatly, the increase in integrated value or the shift of $V_l$ towards lower or higher wavelength might occur.

The visible lights reaching from cornea to retina may be affected by the size of pupil. Sympathetic nerve controlling the dilator of pupil originates from the hypothalamus which controls many autonomic functions, e.g., body temperature regulation. Therefore, the increase of sympathetic tone by cold exposure may mediate the pupillary dilatation. In fact, Rubin (1960) showed that the pupil diameter during local cold exposure i.e. immersing the hand in the cold water bath for five minutes, was larger than that during normal condition. However, the dilatation of pupil may occur in circumstances with abrupt mental or physical change. It is doubtful whether the pupil is still dilatating for such a long time as in the present study.

Other factors, e.g., oxygen availability to the retinal function, chemical response in pigments should be cosidered. However, no data exists to suggest the relationship between brightness sensitivity and body temperature decrease during photopic vision in human.

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REFERENCE


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Shigeki WATANUKI
Faculty of Human Life Science, Osaka City University
3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558, Japan

綿貫茂喜
〒558 大阪市住吉区杉本3-3-138 大阪市立大学生活科学部