Dark Adaptation Curve during Body Temperature Decrease

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To investigate the effect of body temperature decrease which occurred along with cold exposure and menstrual cycle on visual acuity, the dark adaptation curve (DAC), heart rate (HR) and tympanic membrane temperature (Tty) were measured at thermoneutral (29°C) and cold (15°C) in both follicular and luteal phases in menstrual cycle. Tty at thermoneutral and cold exposure in follicular phase were significantly lower than those in luteal phase. The degree of decrease in Tty by cooling in follicular phase was not significantly larger than that in luteal phase. HR was decreased significantly by cooling in both phases, while the difference between the two phases was not significant. DAC during cold exposure was lower than that during thermoneutral condition in both phases. Furthermore, the curve obtained during cooling in follicular phase was lower than that during cooling in luteal phase. However, DAC obtained by a subject who showed an increase of Tty by cold exposure in both phases was higher than that at thermoneutral. Even in thermoneutral in luteal phase, DAC during head cooling was significantly lower than that during thermoneutral. These results suggest that the brightness sensitivity in scotopic vision might be increased by a decrease of body temperature and the light threshold during dark adaptation threshold may be related to the change of Tty.

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In a previous study (Watanuki, 1994), the author suggests that brightness sensation in photopic vision (1000lx) might be increased by body temperature decrease with cold exposure. There are two kinds of photoreceptors in retina. One is cone for photopic vision, and the other is rod for scotopic vision. Therefore, the visual system in scotopic vision is different from that in photopic vision. It is interesting to investigate whether or not the increase of brightness sensation might be observed in scotopic or mesopic vision in the cold.

However, there was no investigation concerning the relationship between visual sensitivity and body temperature decrease in scotopic. On the contrary, in a hot environment, Hohnsbein et al. (1983, 1984) reported a decrease of visual sensitivity in the dim

by using Landolt 'C' test. This decrease was linearly dependent on rectal temperature increase. Furthermore, 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 the fall and winter. It is assumed that core temperature decrease by cold exposure (extrinsic factor) might result in an increase of visual sensitivity.

The body temperature is decreased by intrinsic factors, e.g. the circadian rhythm and menstrual cycle. Visual sensitivity might also be affected by such intrinsic factors. In fact, Diamond et al. (1972) reported that the visual sensitivity in scotopic was elevated during the second half of the human female menstrual cycle. However, physiological responses during cold exposure is different between follicular

and luteal phases in menstrual cycle. For example, the cool threshold was significantly larger during follicular than luteal phase (Kenshalo, 1966). The effects of body temperature decrease with cold exposure on visual sensitivity in scotopic might be altered by the menstrual phase.

In this study, the author measured the dark adaptation curve during thermoneutral and lower air temperature conditions in both follicular and luteal menstrual phases, and attempted to investigate the effect of body temperature decrease on visual sensitivity in scotopic vision.

METHOD

1. Dark adaptation curve.

The dark adaptation curve (DAC) was measured by using a dark adaptometer (Goldman/Weekers). The measurement of DAC was started after 5 min light adaptation (3000lx), following 2 min dark adaptation (Fig. 1). To determine the minimum brightness at which the subject could just see the black bar silhouetted against the field in adaptometer, the observer controlled the brightness below the threshold, then turning it up quickly until the subject could see the bar. It continued throughout until the threshold was unchanged.

Fig. 1 Time schedule of the experiment. A: pre-dark adaptation period, B: light adaptation period, C: DAC measurement period.

2. Procedure

The subjects were five young females. Experiments were done in a climatic chamber. The subject entered the climatic chamber an hour before the

measurements start. The air temperature and humidity were controlled at 29°C and 50%. They put on casual pants and T-shirts. The subject was instrumented with ECG leads (FUKUDA DENSHI, FX-601) for heart rate (HR) recordings and thermistors (TECHNO SEVEN, K350) for tympanic membrane temperature (Tty) recordings. Throughout the experiments, HR and Tty were recorded continuously. Then, the subject started the measurement of DAC as a control value following 30 min rest in a sitting position. After the end of these measurements, the air temperature was controlled at 15°C within 20 min. Then the subjects repeated the measurements following a 15min rest at a constant air temperature of 15°C.

RESULTS

Mean Tty in the follicular phase was 36.98 (SD 0.15)°C at thermoneutral and 36.76 (SD 0.23)°C at cooling and that in luteal phase was 37.11 (SD 0.14)°C at thermoneutral and 36.96 (SD 0.20)°C at cooling.

Significant differences in Tty at thermoneutral and cold exposures were observed between the two menstrual phases. However, the degree of decrease in Tty by cooling was not significant between the two menstrual phases. Only one out of the five subjects showed an increase in Tty by cooling, while the other subjects showed a decrease in Tty following a transient increase. HR was decreased significantly by cooling in both phases, but the difference between the two phases was not significant.

Figure 2 shows the difference of DAC between the two thermal conditions in luteal (left figure) and follicular (right figure) phases in subjects showing Tty decrease by cooling. The vertical axis is a log scale of light threshold. Light threshold at 15 and 20 min during DAC measurement obtained during cooling (thick line) was significantly lower than that during thermoneutral condition (thin line) in luteal phase. Similar significant difference between the two conditions was observed at 10, 15 and 20 min in

Fig. 2 Difference of DAC between during thermoneutral (thin line) and cooling (thick line) in luteal (left figure) and follicular (right figure) phases in subjects showing Tty decrease by cooling. The line in the small square shows a trend of Tty change. Thin line shows a trend from the start of experiment to the end of DAC measurement under the thermoneutral condition. Thick line shows a trend from the end of thermoneutral to the end of DAC measurement under the cold exposure condition.

Fig. 3 Difference of DAC between during luteal (thin line) and follicular phases (thick line) in thermoneutral (left figure) and cooling (right figure) condition in subjects showing T_{ty} decrease by cooling.

Fig. 4 DAC obtained by one subject showing Tty increase by cooling.

follicular phase.

Figure 3 shows the difference of DAC between the two menstrual phases in thermoneutral (left figure) and cooling (right figure) conditions in subjects showing Tty decrease by cooling. In thermoneutral, DAC during follicular phase (thick line) was not significantly lower than that during luteal phase (thin line). However, light threshold during cooling in follicular phase was significantly lower than that during cooling in luteal phase at 5, 10, 15 and 20 min in DAC measurement.

Figure 4 shows DAC obtained by one subject showing Tty increase by cooling. In luteal phase, Tty was increased by 0.13°C during the cold exposure, then DAC was higher during cooling than during thermoneutral. Similar changes were observed in the follicular phase. In thermoneutral, this subject showed a similar Tty between the two phases, and DAC obtained in both phases were approximately the same.

DISCUSSION

Main result in this study is that DAC is lower during cold exposure than during thermoneutral. Moreover, this phenomenon was observed only in the condition of Tty decrease (Fig. 2, Fig. 3). When Tty was increased by cold exposure, DAC was higher compared to that with lower Tty (Fig. 4). This suggests that the change of DAC may be closely dependent on the change of Tty.

To make sure of the relationship between Tty and DAC, the author measured DAC during head cooling, i.e. the compulsory decrease of Tty. A liquid conditioned (inlet water temperature: 10°C , water flow: 1.21/min) cap was used for head cooling. Experiments were carried out in luteal phase. Tty decreased by 0.35°C (SD: 0.09°C) during head cooling. This decrease was significantly larger than that with cold exposure. DAC was significantly lower during head cooling than during thermoneutral (Fig. 5). These results suggest that brightness sensitivity in scotopic vision may be elevated

Fig. 5 Difference of DAC between during thermoneutral (thin line) and head cooling (thick line) in luteal phase.

by Tty decrease.

The literature (Hecht et al., 1937; Rowland and Sloan, 1944; Nordby et al., 1984) relating to the dark adaptation indicates that the light threshold during dark adaptation period is reduced with lower light intensity and longer wavelength of the light source during light adaptation prior to the measurement of DAC, with shorter wavelength of testing light source during dark adaptation measurement. In other words, the dark adaptation might be accelerated by less bleaching of rhodopsin, the visual pigment contained within the rods during light adaptation (photopic) and high activation of rods during measurement (scotopic). For example, a

goggle with a red filter that transmits only high wavelength has often been recommended for dark adaptation because red light is ineffective in rods (Cushman, 1980).

In this study, the intensity of light adaptation, testing light and the wavelength of testing light were constant. Accordingly, the degree of bleaching at the start of measurement of DAC was the same between the two thermal conditions and the two menstrual phases. If the degree of bleaching dominates the level of dark adaptation mainly, the process in the disappearance of bleaching (increase of rod activation) may be accelerated by Tty decrease.

As shown in a previous study (Watanuki, 1994),

brightness sensation during photopic (i.e. full bleaching of rhodopsin) was elevated by Tty decrease. In a photopic vision, the activity of rod is small so that it may be somewhat difficult to explain for the increasing visual sensitivity from the fact that disappearance of bleaching may be accelerated.

In this study, the change of DAC is closely correlated to the change of Tty. Tty is a good index of core temperature and its fluctuations may reflect variations in hypothalamic temperature (Brinnel and Cabanac, 1989). The radiant flux from the object passes through the eyeball, optic nerve, suprachiasmatic nucleus and lateral geniculate nucleus before reaching the eye field. The suprachiasmatic nucleus which controls the biological rhythm, exists in the hypothalamus. Hypothalamus controls autonomic functions, e.g., body temperature regulation. It is assumed that the action of hypothalamus might directly modify the light signal passing from the eyeball into the eye field.

It is difficult to determine the specific mechanism explaining the shift of DAC. Other factors, e.g., oxygen availability to the retinal function, chemical response in pigments, and melatonin level in retina should be considered.

The results in this study show that the brightness sensitivity elevates not only in photopic but also in scotopic vision, if Tty decreases.

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