

Inhibitory Effect of Light of Different Wavelengths on the Fall of Core Temperature during the Nighttime

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Summary Nocturnal core temperature fall was significantly inhibited by green, blue, and red light exposure with 1,000 lx from 21:00 h to 02:00 h. The core temperature in red became identical from that in control during the following sleep period, but not in green and blue. These findings are discussed in terms of urinary melatonin behavior.

Key words: core temperature, light wavelength, melatonin.

After the discovery by Lewy *et al.* [1] that light intensity over 2,500 lx could inhibit the increase of nocturnal melatonin secretion, evidence that light could play an important role for the entrainment mechanisms of human circadian rhythms [2-4] has been gathered. Furthermore, light could have profound influences on core temperature during the nighttime [5-7]. Although there are some scattered reports that melatonin secretion was inhibited by exposing monochromatic light at 509 nm to humans for an hour at various intensities [8], and that blue-green light inhibited melatonin secretion in albino rats [9] and hamsters [10], there are no systematic studies concerning the light effects on core temperature in humans, paying special attention to the spectral distribution characteristics of light. Melatonin could reduce core temperature [11, 12]. Taken together, it is tempting to think that light of different wavelengths might have different effects upon the core temperature behavior. The purpose of this study was to test this possibility experimentally.

Five young women, aged 19 to 24 years (average = 21.4 years, SD = 2.1) with normal color vision were volunteers. Informed consent was obtained from each subject before the beginning of the experiment. They entered the test room by

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19:00 h which was illuminated at 50 lx by an incandescent light and with a globe temperature of 26°C and relative humidity of 50%. They sat quietly until the test light was turned on. The test light intensity of 1,000 lx at eye level was exposed to the subjects for 5 h from 21:00 h to 2:00 h, using the fluorescent tubes emitting red, green and blue light with peak spectral radiance of 610, 540, and 430 nm, respectively (Toshiba FLR 40S/ER, EG, EB). The light intensity of 1,000 lx and 5 h exposure to it were determined as appropriate, since it was previously reported to suppress nocturnal melatonin increase (Hashimoto *et al.*, in preparation). During light exposure, the subjects were allowed to listen to music and to read a book, and were instructed to look at the fluorescent tubes for at least 1 min every 10 min and to be awake. The light was at an angle of 80 degrees to the subjects' line of sight. The subjects slept in near-darkness from 2:00 to 8:00 h and then sat calmly for an hour from 8:00 to 9:00 h under 50 lx by the incandescent light. As a control subjects remained under the incandescent light of 50 lx from 19:00 to 2:00 h and from 8:00 to 9:00 h. The test was performed every several days continuously. The experimental light conditions of red, green, blue, and control from 21:00 to 2:00 h were provided randomly. Rectal temperature (T_{re}) was measured every 2 min during the experimental period using a data-logger (Squirrel type 2500, U.K.). To determine the possibility of melatonin involvement in T_{re} in relation to wavelength, we collected urine at 21:00, 23:30, 02:00, and 08:00 h, and it was stored immediately in a freezer. The urine samples for urinary melatonin analysis were provided to a station for clinical examination. Sensitivity of the analysis was 2.5 pg/ml. Urinary melatonin was extracted from the urine samples by diethyl ether. The supernatant was evaporated, dissolved in buffer solution, and then analyzed by RIA [13].

Figure 1 compares the changes of mean T_{re} in the 5 subjects (top) and those of mean urinary melatonin in the 4 subjects (bottom) under the different light conditions. The temperature data indicate the mean hourly temperatures (ΔT_{re}) expressed as differences from the values just before irradiation (21:00 h). The fall in T_{re} was the smallest with green light, the value being about half that of controls; in blue light the fall was slightly greater and in red light falls approaching those of controls were present. The fall of T_{re} was significantly inhibited for the final 1 h during the light exposure in green, blue, and red compared with that in control. Although the core temperature in red did not become different from that in control during the following sleep period, it remained inhibited in green and blue.

Analysis by ANOVA showed that T_{re} was strongly influenced by color light conditions ($F=4.82$, $p<0.01$) and time of day ($F=9.90$ $p<0.01$). Further, a significant difference existed for green, blue, and red versus control, and for green and blue versus red ($p<0.01$, 0.05) with Tukey's method. No significant difference was noted between green and blue. Melatonin data are expressed as hourly means of 19:30–21:00 h, 21:00–23:30 h, 23:30–02:00 h, and 02:00–08:00 h. Inter- and intra-assay variances in these variables were 9.6 and 14.3% on average, respectively. These data were also analyzed by ANOVA. Urinary melatonin was

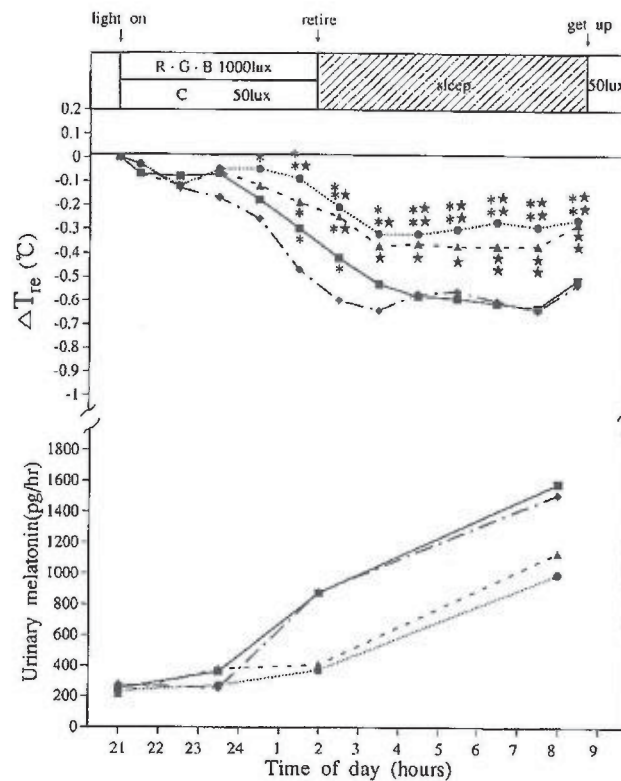


Fig. 1. A comparison of rectal temperature and urinary melatonin changes under the influence of red, green, blue, and control light. —■—, red; —●—, green; —▲—, blue; —◆—, control. Green, blue, and red vs. control: * $p < 0.05$, ** $p < 0.01$, Green and blue vs. red: * $p < 0.05$, ** $p < 0.01$.

affected by color light conditions ($F=3.37$, $p < 0.01$) and time of day ($F=37.12$, $p < 0.01$).

What physiological mechanisms could account for the findings that the fall in T_{re} was differently inhibited not only during the period of light exposure, but also during the sleep period after the end of light exposure, depending on light wavelength and for the finding that the suppression of nocturnal urinary melatonin increase was greater in green and blue than in red? In other words, the inhibitory effects of green and blue consisting of middle and short wavelength components on the T_{re} fall and nocturnal urinary melatonin increase were greater than those of red of long ones. The minimum core temperature at night which increased in bright light returned to that seen in dim light with exogenous melatonin infusion [12]. Melatonin administration significantly reduced the core temperature by about 0.3°C [11]. Thus, it seems probable that melatonin could have hypothermic properties. Therefore, the findings that green and blue light with middle and short wavelength had inhibitory effects on nocturnal melatonin secretion might be partly responsible for the inhibition of core temperature fall during the nighttime. Red

light with long wavelength had less influence on core temperature fall and nocturnal urinary melatonin increase. It is difficult at present to conclude which physiological mechanisms might be responsible for our present results, the involvement of biological clocks or that of thermoregulatory centers of the hypothalamus. In order to confirm that the biological clocks are influenced differently by different wavelengths, it is absolutely necessary to observe the core temperature and the melatonin consecutively for a longer period under the influence of green, blue, and red light conditions, placing the focus on the phase and the phase-angle difference between the organism and zeitgeber. Although melatonin could have hypothermic properties [11, 14], the mechanism and site of action for the influence of melatonin on core temperature are not precisely understood. The hypothalamus, the main thermoregulatory center, has melatonin receptors [15, 16] and melatonin may influence the synthesis, secretion, and action of substances related with the control of core temperature like prostaglandin E [16, 17]. Therefore, the possibility could not be excluded that the nocturnal core temperature fall was suppressed through the relationship of melatonin to the hypothalamus. If the subjects are repeatedly exposed to definite color light, would the response of core temperature and urinary melatonin observed in our present experiment vary? Further studies remain to be performed concerning the detailed mechanisms of light effects on humans.

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