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Effects of Lights of Different Color Temperature on the Nocturnal Changes in Core Temperature and Melatonin in Humans

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Abstract. A variety of types of artificial illumination has recently become available, differing in the quality of illumination and range of color temperature. In our previous studies we found that in subjects with normal color vision the nocturnal fall in core temperature and the increase of urinary melatonin excretion were suppressed by bright blue or green light, but not by bright red or dim lights. The aim of our present study was to examine from the view point of chronobiology whether the lights of different color temperature often used in everyday life may affect core temperature and urinary melatonin secretion differently. Experiments were carried out on five subjects with normal color vision. They were exposed for 5 hr (from 21:00 h to 2:00 h) to two kinds of bright (1000 lx) light of different color temperature (6500 K, 3000K) with dim (50 lx) light as a control; after exposure they slept in darkness. Our main results were as follows: The light with a high color temperature of 6500 K more strongly suppressed the nocturnal fall of the core temperature and the nocturnal increase of melatonin secretion than the light with a low color temperature of 3000 K. This difference was particularly evident for core temperature during the sleep period following experimental illumination.

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Introduction

Artificial illumination is now indispensable for our safety and comfort particularly during night work. Recently, a variety of types of artificial illumination has become available, which varies in the quality of illumination and in the wide range of color temperature. The choice of light to be used is based mainly on its psychological effects.

Since light of different temperatures are composed of different wavelengths, they might also have different physiological effects in humans. Studies on the influence of lights of different temperature light on human physiology have recently considered effects on the CNV (Deguchi and Sato, 1992), blood pressure (Kobayashi and Sato, 1992), heart rate variability (Mukae and Sato, 1992), EEG (Küller and Wetterberg, 1993) and melatonin (Küller, 1986). However, the duration and the time of exposure to light have not been standardized, and the physiological mechanisms for any effects have not yet been fully discussed. On the other hand, the effects of a monochromatic light source on core temperature and the melatonin rhythm in humans have been studied also from a chronobiological point of view (Brainard et al., 1988 ; Morita et al., 1995).

We have previously illuminated at night subjects with normal color vision —using 5 h of light of different wavelengths at an intensity of 1000 lx— and found that the fall of core temperature and the increase of the urinary melatonin secretion were suppressed by green and blue, but not by a red illumination (Morita et al., 1995). These findings support the concept that light with a high color temperature, primarily containing shorter wavelength components, may have different physiological effects in humans compared with light of a low color temperature, containing mostly longer wavelengths.

The purpose of the present study is to examine from the view point of chronobiology whether lights of different color temperature often used in everyday life may also affect the core temperature and the urinary melatonin secretion differently in a manner similar to our previous findings (Morita et al., 1995).

Methods

Five young men, aged 19 to 21 years (average=20.0 years, SD=0.63) with normal color vision served as subjects. Informed consent was obtained from each subject before the beginning of the experiment. They entered the test room by 19:00 h; it was illuminated at 50 lx by an incandescent light, and had a globe temperature of 26°C

and a relative humidity of 50%. The subjects sat quietly until the test light was turned on. Two kinds of lamp, i.e., the daylight fluorescent lamp and the warm-white fluorescent lamp, were used as experimental lights. The color temperatures were 6500 K and 3000 K and the general color index (Ra) was 74 and 95, for the daylight and the warm-white fluorescent lamp, respectively.

Figure 1 shows the spectral radiance at eye level under the different light conditions. The light was at an angle of 80 degrees to the subjects' line of sight. Luminous intensity at eye level was 1000 lx in both cases and luminances were 1500 cd/m² (daylight) and 1300 cd/m² (warm-white). The chromaticities of the wall which the subjects saw during light exposure were x=0.36, y=0.39 (daylight) and x=0.47, y=0.41 (warm-white). Subjects were exposed to the test light for 5 h from 21:00 h to 2:00 h. During light exposure, the subjects required to remain awake and were allowed to listen to music and to read a book. They were instructed to look at the fluorescent lamps for at least 1 min every 10 min. This instruction was similar to that in our previous paper (Morita et al., 1995) in order to make a comparison of our present data possible with previous ones. The subjects slept in near-darkness from 2:00 h to 8:00 h and then sat quietly for an hour from 8:00 h to 9:00 h under 50 lx (from the incandescent light). As a control, the subjects remained under the incandescent light from 19:00 h to 2:00 h and from 8:00 h to 9:00 h. The three experimental light conditions (daylight, warm-white and control lights) were provided in random order at intervals of several days. Rectal temperature (Tre) was measured every 2 min during the experimental period using a data-logger (Squirrel type 2500, U.K.). For the assay of urinary melatonin, urine was collected from each subject, and pooled into samples spanning 19:30 h to 21:00 h, 21:00 h to 23:30 h, 23:30 h to 2:00 h and 2:00 h to 8:00 h. The samples were immediately frozen and sent to a clinical laboratory for melatonin assay, where urinary melatonin was extracted with diethyl ether, the supernatant was dried and the residue was dissolved in a buffer solution for an RIA assay (Miyauchi et al., 1990). Sensitivity of the analysis was 2.5 pg/ml.

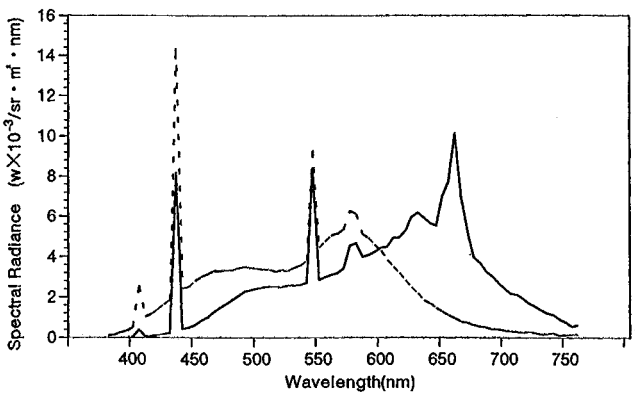

Fig. 1 Spectral radiance at eye level for the subjects under each light condition. Luminous intensity at eye level was 1000 lx in both cases. —— warm-white fluorescent lamp, - - - daylight fluorescent lamp

Result

Figure 2 shows changes in the mean rectal temperature (T_{re}) and the mean urinary melatonin level in the 5 subjects. Values of T_{re} in Fig. 2 are the hourly mean differences from the mean of pre-illumination values (20:00 h - 21:00 h). During the 5 h-exposure to experimental lights (21:00 h - 2:00 h), the fall of the T_{re} was inhibited by illumination with both the daylight and the warm-white light. A two-way ANOVA showed that there were significant effects upon T_{re} of not only time of day ($F=30.78$, $p<0.01$), but also the type of illumination ($F=15.16$, $p<0.01$). Multivariate analysis further showed that the mean T_{re} value under the daylight and warm-

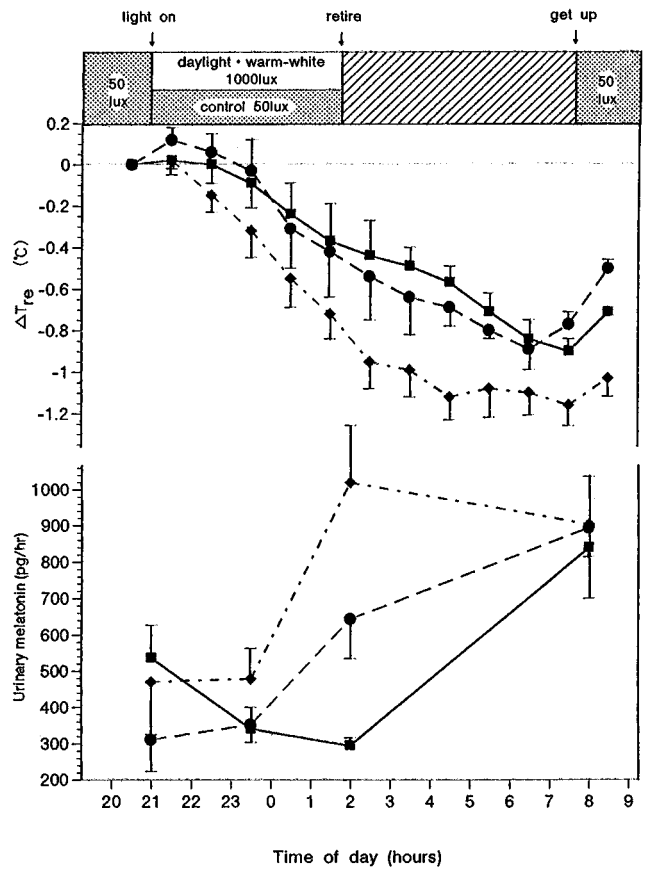

Fig. 2 A comparison of rectal temperature and urinary melatonin changes under the influence of daylight, warm-white light and control conditions. (mean ± SE) —■— daylight, —●— warm-white light, —◆— control

white light was significantly different from that under the control condition.

This suppression of T_{re} persisted during the sleep period (2:00 h - 8:00 h) following the illumination test, and the daylight condition showed a stronger after-effect on Tre than the warm-white light condition. The results of two-way ANOVA during this sleep period also showed that T_{re} values were significantly different not only due to the time of day ($F=9.78$, $p<0.01$), but also due to the type of illumination ($F=60.17$, $p<0.01$). Multivariate analysis showed similar results as those mentioned above, i.e., the mean T_{re} value under the daylight and the warm-white light conditions was significantly different from that under the control condition; and there was a significant difference between the daylight and the warm-white light conditions.

The urinary melatonin in Fig. 2 is the hourly mean of values during the 1.5 h before testing (19:30 h - 21:00 h), the first half of test illumination (21:00 h - 23:30 h), the latter half of test illumination (23:30 h - 2:00 h) and during sleep (2:00 h - 8:00 h).

Effects of exposure to the daylight and the warm-white light on the urinary melatonin secretion were analyzed for each of the four periods. In the first half of experimental illumination, there was no significant difference between the daylight and warm-white light conditions or between the either light and the control condition. However, in the later half of illumination, the melatonin secretion was very different between the daylight and the warm-white light conditions. The high melatonin secretion under control illumination was greatly suppressed by illumination with the daylight or the warm-white light, and the daylight illumination showed a greater effect than the warm-white light. This difference was significant statistically as confirmed by the one-way ANOVA ($F=7.09$, $p<0.05$). Multivariate analysis showed significant differences between each of the three illumination conditions.

Discussion

Effects of evening illumination were investigated using light of two color temperatures, core temperature and the melatonin rhythm as physiological indices. It was found that the light with a high color temperature of 6500 K suppressed the nocturnal fall of the core temperature and the nocturnal increase of the melatonin secretion more strongly than the light with a low color temperature of 3000 K. This difference was particularly evident in the core temperature during the sleep period after experimental illumination. These findings agree with the results of our previous study (Morita et al., 1995) which indicated that the fall of core temperature and the increase of melatonin secretion were suppressed by 1000 lx illumination with green and blue lights, but not by red light.

Melatonin has anapyrectic properties (Cagnacci et al., 1992; Cagnacci et al., 1994) and the hypothalamus, which is the main thermoregulatory center, has melatonin receptors (Morgan and Williams, 1989; Reppert et al., 1988). Compared with placebo, core temperature fell lower significantly under the administration of melatonin during the daytime (Cagnacci et al., 1992). The probable physiological mechanisms between melatonin and core temperature were discussed elsewhere (Morita et al., 1995). Briefly to say, a fall of core temperature was found when circulating levels of melatonin were high at night (Wever, 1989). Cagnacci et al. (1992) reported that the circadian rhythms of plasma melatonin and core temperature were inversely related. Bright light exposure at night could inhibit both the nocturnal core temperature fall and melatonin secretion increase (Badia et al., 1990). With these in mind, it is probable that the melatonin could reduce setpoint in the core temperature. Since the light of middle or short wavelengths suppressed the melatonin secretion more strongly than the light of long wavelength, it seems reasonable to hypothesize that this altered melatonin secretion would have affected the hypothalamic melatonin receptors and so resulted in the inhibitory effect on the fall of core temperature during sleep at night in our present experiment. Although it was suggested that the tonus of sympathetic nervous system was stronger under the light with a high color temperature (Kobayashi and Sato, 1992), how the heat loss mechanisms in the extremities could occer under the influences of lights of different color temperature remains to be studied more systematically.

Deguchi and Sato (1992) found that a contingent negative variation (CNV) was influenced more strongly under the light with a high color temperature of 7500 K by facilitating reticular activating system. Kobayashi and Sato (1992) found that diastolic blood pressure was significantly higher under the light with a high color temperature of 7500 K, suggesting that vasomotor activity was enhanced. With these in mind, an alternative interpretation for our present finding that the core temperature fall was inhibited under the light with a high color temperature might be probable, i.e., the light with a high color temperature might have made the vasomotor activity more excited via central mechanisms without a melatonin involvement, resulting in prevention of nocturnal color temperature fall.

Therefore we suggest that the choice of artificial illumination for everyday life should not only be based on the sense of vision, but also should take its physiological influence into consideration.

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References

Badia P, Culpepper J, Boecker M, Myers B, Harsh J (1990) The immediate effect of bright and dim light on body temperature. Sleep Res 19: 386

Brainard GC, Lewy AJ, Menaker M, Fredrickson RH, Miller LS, Weleber RG, Cassone V, Hudson D (1988) Dose-response relationship between light irradiance and the suppression of plasma melatonin in human volunteers. Brain Res 454: 212-218

Cagnacci A, Elliott JA, Yen SSC (1992) Melatonin: A major regulator of the circadian rhythm of core temperature in humans. J Clin Endocrinol Metab 75: 447-452

Cagnacci A, Soldani R, Romagnolo C, Yen SSC (1994) Melatonin-induced decrease of body temperature in women: A threshold event. Neuroendocrinolgy 60: 549-552

Deguchi T, Sato M (1992) The effect of color temperature of lighting sources on mental activity level. Ann Physiol Anthrop 11: 37-43

Kobayashi H, Sato M (1992) Physiological responses to illuminance and color temperature of lighting. Ann Physiol Anthrop 11: 45-49

Küller R (1986) Physiological and psychological effects of illumination and colour in the interior environment. J Light & Vis Env 10: 33-37

Küller R, Wetterberg L (1993) Melatonin, cortisol, EEG, ECG, and subjective comfort in healthy humans: Impact of two fluorescent lamp types at two light intensities. Lighting Res Technol 25: 71-81

Miyauchi F, Nanjo K, Kato H, Sasaki T, Yonezawa M, Tsukada Y (1990) The effects of light exposure on plasma concentrations of melatonin, LH, FSH and prolactin in women. Folia Endocrinol Japon 66: 737-746 (in Japanese)

Morgan PJ, Williams LM (1989) Central melatonin receptors: Implications for a mode of action. Experientia 45: 955-965

Morita T, Teramoto Y, Tokura H (1995) Inhibitory effect of light of different wavelengths on the fall of core temperature during the nighttime. Japanese Journal of Physiology 45: 667-671

Mukae H, Sato M (1992) The effect of color temperature of lighting sources on the autonomic nervous functions. Ann Physiol Anthrop 11: 533-538

Reppert SM, Weaver DR, Rivkees SA, Stopa EG (1988) Putative melatonin receptors in a human biological clock. Science 242: 78-81

Wever RA (1989) Light effects on human circadian rhythm, A review of recent Andechs experiments. J Biol Rhythms 4: 161-185

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