Abstract  In order to examine whether the spectral compositions of light source may affect sleep quality, sleep architecture under different color temperatures of light sources was evaluated. Seven healthy males were exposed to the light sources of different color temperatures (3000 K, 5000 K and 6700 K) for 6.5 h before sleep. The horizontal illuminance level was kept at 1000 lux. Subjects slept on a bed in near darkness (<10 lux) after extinguishing the light, and polysomnograms recorded the sleep parameters. In the early phase of the sleep period, the amount of stage-4 sleep (S4-sleep) was significantly attenuated under the higher color temperature of 6700 K compared with the lower color temperature of 3000 K. Present findings suggest that light sources with higher color temperatures may affect sleep quality in a view that S4-sleep period is important for sleep quality. J Physiol Anthropol Appl Human Sci 24 (2): 183–186, 2005 [DOI: 10.2114/jpa.24.183]

Keyword: color temperature, slow-wave sleep, polysomnogram, fluorescent light

Introduction

In contemporary society, Japanese people tend to suffer from inadequate sleep; the prevalence rates of sleep problems have been estimated as 20.9–44.3% in the general Japanese adult population (Doi et al., 2001). Thus, environments that add comfort to favorably promote sleep are required.

It has been found that light suppresses nocturnal secretion of melatonin (Lewy et al., 1980; Hashimoto et al., 1996). According to Morita and Tokura (1996), light sources with higher color temperatures suppress the nocturnal secretion of melatonin compared with those of lower color temperatures. Melatonin has been thought to have a sleep-promoting function (Zhdanova et al., 1996) and plays an important role in the regulation of sleep quality (for review see Dawson and Encel, 1993).

However, Deguchi and Sato (1992) have observed that greater amplitudes of contingent negative variation (CNV) are generated under conditions with a higher color temperature. This finding suggests that a light source with higher color temperatures would more likely activate the reticular activating system (RAS) compared with that of lower color temperatures. In comparisons of the autonomic nervous functions (ANF), Mukae and Sato (1992) evaluated heart rate variability (HRV) under conditions of different color temperatures, and found that enhancements of parasympathetic and sympathetic nerve functions were established with light sources of higher color temperatures, concluding that light illumination of higher color temperatures activates ANF more than that of lower color temperatures. Furthermore, our previous study has demonstrated the activation of sympathetic nerve function during night-time exposure to a light source of higher color temperatures (Tsutshumi et al., 2002).

In addition to the reduction of nocturnal melatonin secretion and activation of the ANF and RAS, light sources of higher color temperatures would affect sleep quality. In this study, we compared sleep architectures after exposures to light sources of different color temperatures, and evaluated the effects of spectral compositions of light sources on sleep quality.

Methods

Subjects

Seven young male adults (mean±S.D.=21±2.1 years) gave informed consent and participated in this experiment. All subjects were physically normal and healthy. They were asked to wear thin sleeveless shirts and shorts during the experiment, and not to take a nap before the experiment.

Experimental design

This study was carried out from July to November. Subjects participated for 4 nights in the study according to the experimental regimen (Fig. 1). The first night was defined as the “adaptation night”, and exposures to the 3 color
temperatures (3000 K, 5000 K and 6700 K) were conducted on 3 different nights at a rate of 1 color temperature per night. Three experimental conditions with different color temperatures were performed in a random order. Data from the adaptation period were excluded from the analysis because subjects indicated longer awake periods and less rapid eye movement (REM) sleep (Agnew et al., 1966). The physical characteristics of light sources are listed in Table 1.

Subjects entered an experimental chamber at 18:00 h. They were exposed to control lighting for 1 h, and allowed to bathe at 19:00 h and took supper at 20:30 h. The horizontal illuminance level of control lighting of 10 lux was designated at a reference level (height from the center of the chamber floor: 90 cm). After bathing, subjects were exposed to a light stimulus (3000 K, 5000 K or 6700 K) from 19:30 h to 2:00 h, and had supper at 20:30 h. The supper consisted of a routine meal. The subjects were instructed to rest on a sofa and to remain awake during the light exposure. They were allowed to listen to music and given access to reading materials. Light for each color temperature at a horizontal illuminance level of 1000 lux was adjusted at the reference level. The subjects slept on a bed in near darkness (10 lux) from 2:00 h to 9:00 h. The ambient temperature in the experimental chamber was kept at 25°C with 50% relative humidity.

Recording and scoring of sleep records

Electroencephalography (EEG), submental electromyography (EMG) and electrooculography (EOG) were recorded at 10 mm/sec by electroencephalography (EEG-5214, NIHON KOHDEN Co. Ltd., Japan). For EEG recording, the Ag/AgCl electrodes were attached to two scalp sites (C3 and C4) and both earlobes (A1 and A2) according to the International 10/20 system. Polysomnograms were scored in 30-s epochs according to international criteria (Rechtschaffen and Kales, 1968).

Data analysis

Stage-4 sleep (S4-sleep) is known to occur predominantly during the early part whereas REM sleep increases during the later part of the sleep period (Williams et al., 1964). Thus, the sleep period (excluding sleep latency) were divided into the early (P1; 02:00–05:30 h) and the late (P2; 05:30–09:00 h) phases in the present study. Using P1 and P2 of the sleep period, color temperature and subject as the variables of sleep architectures, correlations of these variables were analyzed by the three-way analysis of variance (ANOVA). Sleep latency (SL) was analyzed using the two-way ANOVA with subject and color temperature as the variables. The multiple comparison test (Turkey’s HSD) was used for subsequent analysis. Differences where p<0.05 were considered statistically significant.

Table 1 Physical characteristics of light sources

<table>
<thead>
<tr>
<th>Lighting source</th>
<th>Type</th>
<th>Model number</th>
<th>Ra</th>
<th>x-axis⁺</th>
<th>y-axis⁺</th>
<th>Actual color temperature*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>incandescent lamp</td>
<td>LDS1000V38W WK</td>
<td>100</td>
<td>0.463</td>
<td>0.415</td>
<td>2700 K</td>
</tr>
<tr>
<td>3000 K</td>
<td>fluorescent lamp</td>
<td>FHF32EX-L-H</td>
<td>84</td>
<td>0.438</td>
<td>0.392</td>
<td>2900 K</td>
</tr>
<tr>
<td>5000 K</td>
<td>fluorescent lamp</td>
<td>FHF33EX-N-H</td>
<td>84</td>
<td>0.349</td>
<td>0.349</td>
<td>4900 K</td>
</tr>
<tr>
<td>6700 K</td>
<td>fluorescent lamp</td>
<td>FHF34EX-D-H</td>
<td>84</td>
<td>0.316</td>
<td>0.319</td>
<td>6500 K</td>
</tr>
</tbody>
</table>

⁺ Chromaticity coordinate (CIE: Commission Internationale de L’Eclairage, 1931)
* Actual expression was correlated with the color temperature
All light sources were manufactured by Matsushita Electric Industrial Co. Ltd. Japan

Table 2 Sleep latencies (SL) under different color temperatures are expressed as the mean±standard deviations (min). No significant differences between any 2 of the 3 color temperatures at any one time were derived

<table>
<thead>
<tr>
<th></th>
<th>3000 K</th>
<th>5000 K</th>
<th>6700 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL</td>
<td>6.9±3.1</td>
<td>4.9±4.1</td>
<td>6.5±12.4</td>
</tr>
</tbody>
</table>

Results

Based on the mean±standard deviations of SL (Table 2), significant differences of SL were not established under conditions of different color temperatures [F(2,12)=0.14, p>0.1].

There were significant effects on the phase of sleep periods for REM [F(1,6)=63.03, p<0.01], S2-[F(1,6)=10.65, p<0.05], S3-[F(1,6)=10.09, p<0.05] and S4-[F(1,6)=26.9, p<0.01] sleep (Table 3). Most of REM sleep was obtained in
Period and the color temperature tendency of color temperature effects [F(2,12) = 3.79, p = 0.052] and an interactive effect between P1 or P2 of sleep period and the color temperature [F(2,12) = 3.32, p = 0.071]. From the sleep variables for each color-temperature condition in P1 of the sleep period (Table 4), the amount of S4-sleep was reduced under conditions with 6700 K compared with 3000 K lighting (p < 0.05). In P2 of the sleep period (Table 5), however, there were no significant differences correlating the sleep variables with the different color temperatures.

**Discussion**

Based on the characteristic changes in sleep patterns (Williams et al., 1964), our data showed higher amounts of S3- and S4-sleep in P1 than in P2 of the sleep period (Table 3). In P1 of the sleep period (Table 4), significantly less amount of S4-sleep was obtained under 6700 K than under 3000 K lighting. It is considered that slow wave sleep (SWS; S3- and S4-sleep) may be important for the enhancement of sleep quality. Webb and Agnew (1970) have compared the sleep architectures in subjects having different lengths of the sleep period. They found no significant differences in S4-sleep between the short and long sleepers, although the former manifested less REM sleep than the latter. These findings were interpreted to indicate that the short sleepers spent less time in light-sleep and awakenings. Keklind and Åkerstedt (2004) have demonstrated that mental stress may have a negative effect on SWS. Subjects who have high apprehensions towards the next working day show abbreviated SWS periods and lower scores in subjective sleep quality. Furthermore, SWS in depressed patients has been documented to have a positive correlation with the subjective estimation of sleep duration (Rotenberg et al., 2000). Given that the S4-sleep period is important for sleep quality, our findings suggest that light sources of higher color temperatures may reduce sleep quality compared with those of lower color temperatures.

Previous studies have demonstrated the effects of light sources with different color temperatures on HRV (Mukae and Sato, 1992; Tsutsumi et al., 2002), blood pressure (Kobayashi and Sato, 1992), EEG (Küller and Wetterberg, 1993) and CNV (Deguchi and Sato, 1992) in humans. These findings imply that the effects of pre-sleep exposures to certain light sources may affect sleep quality. However, changes in the nocturnal secretion of melatonin manifested in our results were likely caused by the different conditions with lighting of different color temperatures. Van Den Heuvel et al. (1997) have reported that the administration of atenolol, a β-blocker, decreases the amount of SWS period compared with placebo administration; β-blockers have been known to alter normal melatonin production. In addition, decreases in SWS are reversed with melatonin treatment after atenolol administration in their investigation. The spectral region between 446 and 477 nm has been regarded as lighting with the most potent wavelength for regulating melatonin secretion in humans (Brainard et al., 2001). The light source of 6700 K includes the action spectrum for suppression melatonin release compared to that of 3000 K, and might decrease the amount of S4-sleep in tandem with the changes in melatonin secretion.

In this study, relatively high light illuminance at 1000-lux was used. A previous study has demonstrated suppression of melatonin secretion when the human retina is exposed to100-
lux white light illuminance (Glickman et al., 2003). This finding suggests that a light source with different color temperatures may affect sleep quality in the home. In other words, the use of an appropriate light source may improve the quality of our living environment.

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References

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Correspondence to: Tomoaki Kozaki, Department of Physiological Anthropology, Faculty of Design, Kyushu University, 4–9–1 Shiobaru, Minami-ku, Fukuoka 815–8540, Japan
Phone: +81–92–553–4530
Fax: +81–92–553–4530
e-mail: kozaki@design.kyushu-u.ac.jp