Effect of Illumination Cycle on Sleep Depth

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ABSTRACT

To develop a resting space before sleep, we evaluated the period of lighting flashes and the subjects' environmental physiological responses. The purpose of this study is to determine how changing the cycle of lighting given before bedtime affects sleep. Slow-wave sleep percentage increased when subjects were exposed to lighting fixtures with 0.12-Hz peak period. Exposure to sinusoidal lighting caused a change in the favorable impression of the light, and the preference reduced the waking time, resulting in an increase in slow-wave sleep percentage. These results suggest that a 0.12-Hz illumination cycle before bedtime leads to deeper sleep. It is shown that the quality of sleep can be improved by lowering arousal and preparing for bedtime by experiencing relaxation before sleep. This study focuses on the effect of the sleeping space on sleep state, particularly on the air volume, specification, and brightness of the environment and the environmental physiological response of subjects; suitable results were obtained in terms of human sleep characteristics, such as increase in slow-wave sleep percentage. This study clarifies the empirical relationship between the indoor environment and the maintenance of health and stable, restful sleep performance. and will contribute to the proposal of room performance and improvement closely related to modern life.

Keywords: *sleep; restful sleep; lighting system; lighting cycle; illumination alteration; room environment*

1. INTRODUCTION

1.1 Research Background

To live a healthy and fulfilling life, we need to maintain suitable physical and mental conditions. Therefore, it is necessary to recover from physical and mental fatigue by ensuring adequate sleep at night. It is said that the amount of information a person receives in a day is equivalent to a lifetime's worth of information in the Heian period (794–1185) or a year's worth of information in the Edo period (1603–1868). Living in an information-overloaded society, modern people often suffer from lack of sleep due to the stress and cognitive busyness of information processing.

Today, Japan is one of the countries with the shortest sleep time. Among the 31 member countries of the Organization for Economic Cooperation and Development, Japan has the shortest sleeping time. On average, 32.8% of Japanese people sleep for more than 6 h, but less than 7 h, and 33.3% sleep for less than 6 h[1]. In addition, the use of electronic devices before going to sleep suppresses the secretion of melatonin, a sleep hormone, owing to the influence of blue light, resulting in poor quality sleep, such as difficulty falling asleep and shallow sleep[2]. It has been clinically demonstrated that inadequate sleep can lead to decreased productivity during the day, and that lack of sleep can lead to depression and other mental health problems. The relationship between health and sleep is well-established, and the need for sleep is emphasized[3), 4)].

To solve the problem of sleep, it is necessary to improve not only the sleep duration, but also the sleep quality. For this reason, studies on sleep have been conducted in various fields on different subjects employing various methods. Because sleep is a physiological phenomenon related to humans, considerable research has been conducted in the fields of medicine and biochemistry. However, the understanding of human sleep activity is insufficient.

Effectively developing spaces that affect human sleep activities can improve sleep quality and ensure restful sleep at night, thereby solving the sleep problems that humans face. This study contributes to the development of a restful sleep space by clarifying the relationship between human sleep characteristics and spatial elements. It is important to clarify the relationship between the lighting cycle before bedtime and sleep as one element to improve sleep, which has a significant impact on human life.

1.2 Purpose of Study

The purpose of this study is to determine how changing the cycle of lighting given before bedtime affects sleep. This study is to clarify the lighting cycle and its effect on human beings during the resting period before sleep, toward the development of an effective sleep space in order to facilitate restful sleep through lighting before bedtime. The significance of this experiment is that by setting the lighting cycle to a specific period, the world that humans can see will be identical to the lighting cycle, and humans will have time to relax and calm down.

1.3 Comparison with Previous Studies

To promote relaxation, it is necessary to provide a specific time period for healing. With regard to temporal changes in illuminance, research has been conducted on the psychological and healing effects due to indoor spaces with fluctuating lighting. More specifically, there are studies on healing environmental spaces applying 1/f fluctuation, research on the effects of fluctuations in light and visual environment on relaxation, and research on fluctuations in lighting and healing in indoor spaces. Furthermore, research was conducted on the psychological effects of fluctuating lighting and healing effects in indoor spaces[5), 6)].

This study focuses on the illuminance cycle of bedroom lighting that is an important factor in the development of a resting space before sleep, and theorizes the conditions of a resting space from the perspective of visual requirements. This study is significant in that it allows us to understand the influence of sleep and to examine the restful sleep space.

This paper is organized as follows. There are overviews of experiments, results of experiments, discussions of results of experiments, and summary of this paper.

2. EXPERIMENT SUMMARY

2.1 Selection of The Target of The Experimental Investigation and The Experimental Environment

In order to include a wide range of age groups, healthy men and women in the age group of 19–40 were selected (Table 1: Subjects: 31.9 ± 19.8 years old, 160 ± 11.6 cm). Their behavior and sleep status on the day of the experiment was ascertained by psychological surveys before and after sleep[7), 8)].

Before the start of the experiment, we explained the outline of the experiment and assured the protection of personal information to the subjects orally and in writing, and we obtained their consent to participate in the experiment. Prior approval was obtained from the Medical Research Ethics Review Board of Tokyo City University before starting this study.

2.2 MEASURING EQUIPMENT

The experimental setup for this study consisted of a device for measuring sleep depth, a device for measuring stress values, a lighting fixture, and an indoor weather meter (Fig.1, Fig.2, Fig.3). To measure sleep depth, we used the sleep depth measurement software[1] of the mobile communication system[2].

To quantitatively measure psychological stress, we used an amylase measurement device[3, 9)]. To determine the air quality in the bedroom, we used an indoor weather meter [4]. To change the lighting cycle, we used a lighting fixture with a changeable lighting cycle[5]. To understand the psychological effects of the lighting cycle and the onset of sleep, a psychological survey using a questionnaire was conducted before and after the experiment and after waking up.

Table 1. Experimental conditions

Contents	Details
Subject	13 persons in total Male: 3 (2 in their teens, 1 in his 30s) Women: 10 (1 in teens, 7 in their 20s, 1 in her 40s)
Location	Bedrooms in each subject's home
Period	From June 20, 2020 to October 7, 2020
Number of times	Conducted three times per subject (total of 39 days)

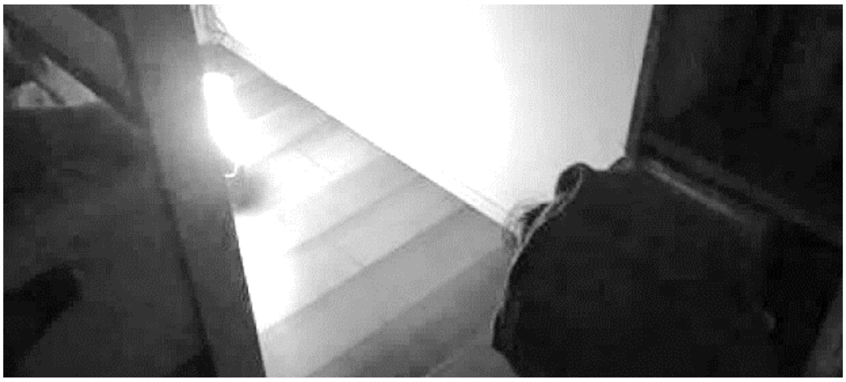

Fig.1. Experimental equipment for lighting fixtures

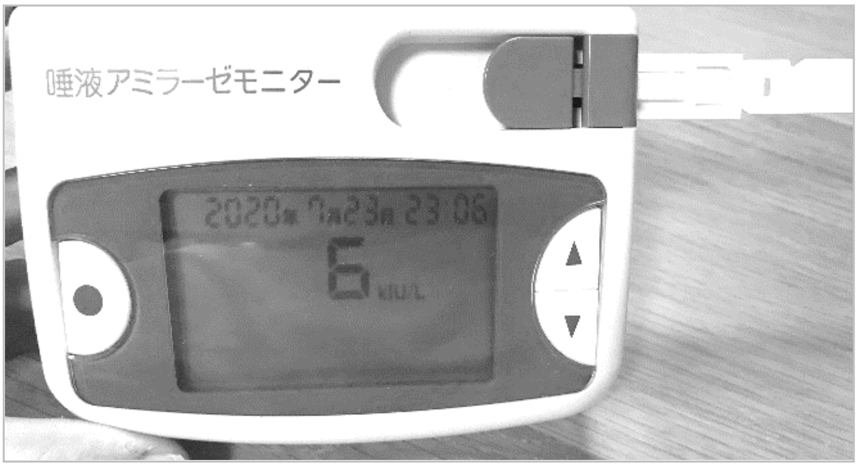

Fig.2. Equipment to measure stress values

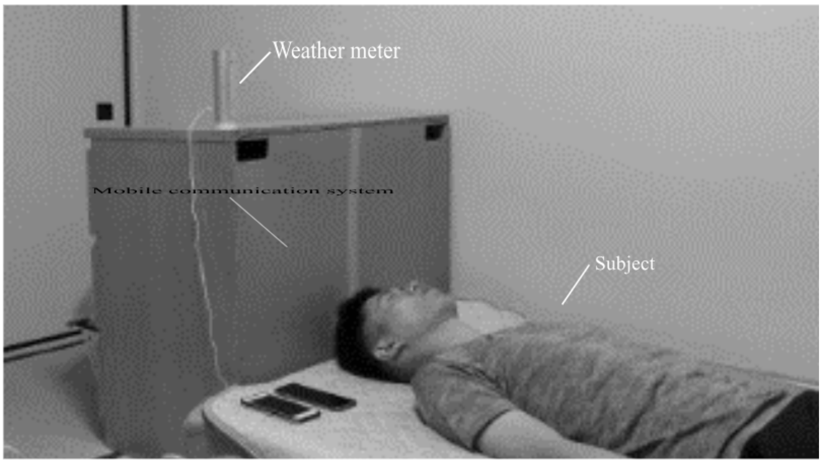

Fig.3. Mobile communication system, weather meter

2.3 Experimental Procedure

The illuminance cycle of the specific lighting was changed to match the experimental conditions. On the day of the experiment, we asked the subjects to adjust their wake-up and bedtime according to their lifestyle.

We also asked them to stop excessive exercise, alcohol consumption, and caffeine intake during the experiment. The experiment was conducted in the subjects' rooms[10), 11), 12)].

On the day of the experiment, we requested the subjects to not take a nap and to not look at the monitor screen of the computer or cell phone for 2 h before sleep. A weather meter was placed within 100 cm of the subject's head. Complete darkness in the bedroom was ensured during sleep. The subjects started sleeping at a fixed time according to their living conditions and finished the experiment by waking up at a fixed time.

The following procedure was used for the experiments (Fig.4). A psychological survey of the subjects and measurement of amylase activity values using an amylase measuring device were conducted 50 to 40 min before bedtime. Between 40 and 10 min before bedtime, the lighting was turned on and off according to the conditions. The subjects spent 40 to 10 min before bedtime in a room with lights on and off according to the conditions. Amylase activity was measured again, 10 min before bedtime, and a psychological survey of the subjects was conducted. At bedtime, the room lights were turned off, and the software for measuring sleep depth was initiated. Thereafter, the subjects slept. Within 30 min after waking up, the subjects responded to the psychological survey and recorded how they spent the experimental day in their diaries.

2.4 Acquisition Data Extraction and Evaluation Methods

Four types of data were obtained: amylase activity value, sleep depth, air quality, and subject psychological study. The depth of sleep acquired by the sleep depth measurement software was classified into six stages. From the shallowest to deepest, they are wakefulness, REM sleep, and non-REM sleep stages 1, 2, 3, and 4. Non-REM stages 3 and 4 are called slow-wave sleep and are particularly deep-sleep stages (Fig.5)[13)].

In this study, amylase activity was used as a measure of psychological stress. The sleep onset latency[6], sleep efficiency[7], percentage of awake time, and percentage of slow-wave sleep were used as measures of sleep quality[14), 15)] (Table 3). Sleep depth was acquired every 2 min from bedtime to waking, and the room temperature, relative humidity, and CO_2 concentration were acquired every 5 min in the subject's bedroom during the experiment. Room temperature, relative humidity, and CO_2 concentration were obtained every 5 min in the subject's bedroom during the experiment. As a psychological survey of the subjects, we conducted a survey on the visibility of light, impression of light, and physical condition before bedtime. After waking up, the subjects were surveyed on their experience of sleep.

2.5 Changes in Experimental Conditions

To evaluate the effect of the illumination cycle on subject psychology and sleep depth, three experimental conditions were set (Table 2). Each subject performed the experiment according to the order of conditions 1, 2, and 3 in three days.

The conditions of the illumination cycle are as follows. The first is a cycle with three peaks in frequency, referred to as "fluctuating illumination" hereafter. The second is a cycle with one peak in frequency, referred to as "sinusoidal illumination" hereafter. For temporal changes, the illuminance change and spectrum of fluctuating illumination (Condition 2) are shown (Fig.6 Fig.7). There were three peaks at 0.12 Hz, 0.25 Hz, and 0.50 Hz. For each period, 0.12 Hz was aligned with the blood pressure control rhythm of 0.1 Hz, while 0.25 Hz and 0.5 Hz were aligned with the breathing rhythm of 0.3 Hz. Fig.8 Fig.9 show Condition 3, that is, the illumination change and spectrum of sinusoidal illumination.

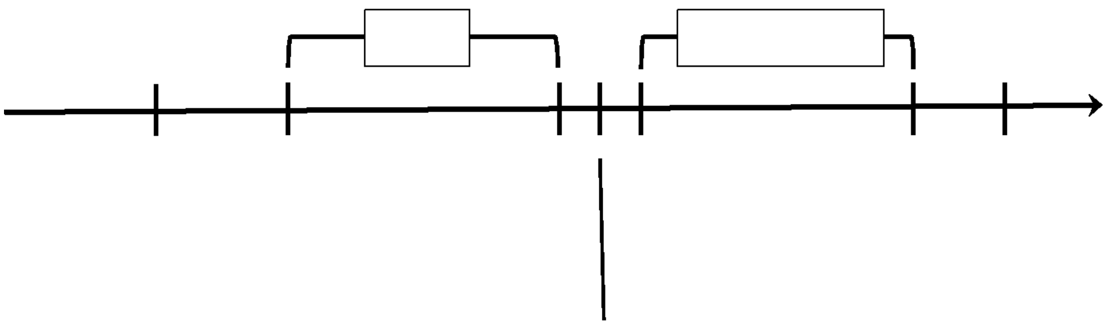

Fig.4. Experimental procedure

Sleep Depth
depth

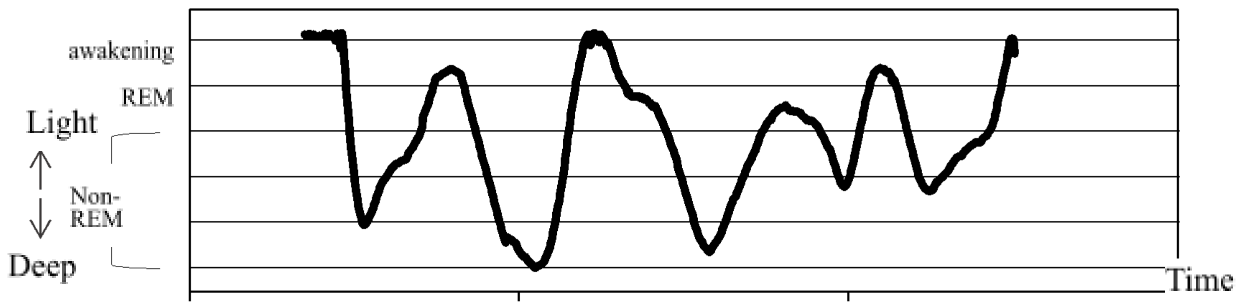

Fig.5. Definition of sleep depth: 6 stages of sleep

Table 2. Conditions for the experiment on lighting

Conditions	Details
Condition 1: No lighting	The subject is requested to stay in a dark state for 60 min before sleep. Stress measurement is performed before and after staying in the dark state. Thereafter, sleep depth is measured right from the onset of sleep.
Condition 2: Fluctuation lighting	Flickering lights are used for 60 min before sleep. Stress measurements are obtained before and after the lighting exposure. Thereafter, sleep depth is measured right from the onset of sleep.
Condition 3: Sine Wave Lighting	Sinusoidal lighting is used for 60 min before sleep. Stress measurements are obtained before and after the lighting exposure. Thereafter, sleep depth is measured right from the onset of sleep.

The peak was at 0.12 Hz. Under both Condition 2 and 3, the rhythms of blood pressure regulation and respiration were synchronized with the cycle of illumination, and we believe that this frequency is effective in examining the cycle of illumination and its effect on sleep[16).

The color temperature was set to 3200 K. In this experiment, the color temperature was set to promote calmness in order to study the relaxation effect of the illuminance cycle.

3. EXPERIMENTAL RESULTS

3.1 Experimental Results on Air Quality

The mean values and standard deviations of the three parameters (air temperature, relative humidity, and carbon dioxide concentration) under each condition are shown in Table 4. In each experiment, there were no changes of more than 4 °C in temperature, more than 10 % in relative humidity, or more than 2000 ppm in carbon dioxide concentration.

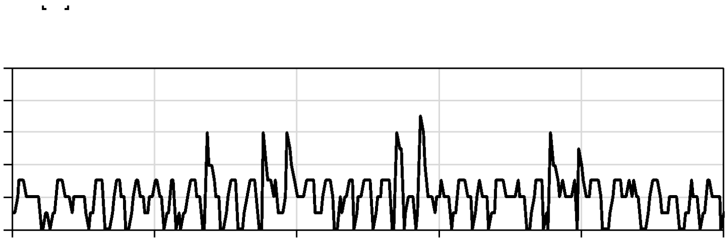

Fig.6. Illuminance change in Condition 2—Fluctuating illumination

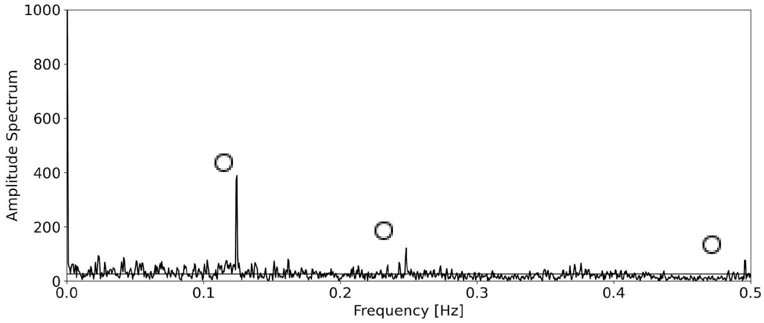

Fig.7. Spectrum of illuminance for Condition 2 —Fluctuating illumination

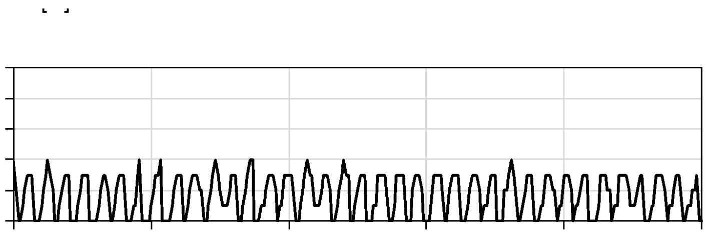

Fig.8. Illuminance change in Condition 3—Sinusoidal illumination

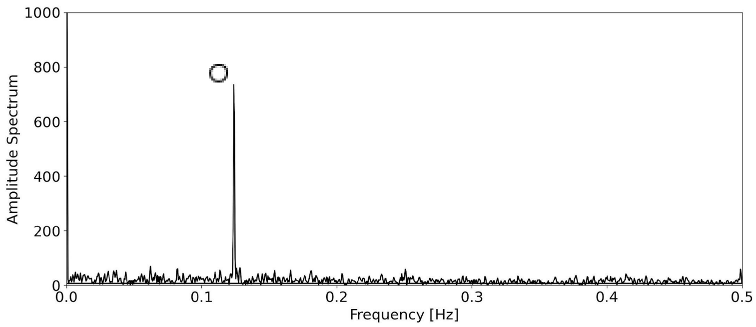

Fig.9. Spectrum of illuminance for Condition 3 —Sinusoidal illumination

Table 3. Measurement parameters in the experiment

Contents	Measurement items	Measurement contents	Measurement method	Measurement interval, etc.
Physiological quantity	Sleep depth	Measures sleep depth at six levels	Utilizing software for measuring sleep depth in mobile	Every 2 min

			communication systems	
	Sleep variables	Bedtime, sleep onset latency, mid-wake time, sleep duration, and slow-wave sleep duration.	Utilizing software for measuring sleep depth in mobile communication systems	—
Psychological quantity	Subjective sense of sleep	Effect of lighting, drowsiness, feeling of sound sleep, change in time to fall asleep	Survey using questionnaire	Before going to bed and after waking up
Indoor and thermal physical quantity	Temperature, humidity, CO_2 concentration	Measured within 100 cm of the subject's head	Weather meter	Every 5 min

3.2 Experimental Results of Stress Values Before and After Lighting Exposure

The mean values of the subjects' decrease in amylase activity values before and after 30 min of illumination exposure for each condition are shown (Fig.10). The average decrease in amylase activity values was less than 5 kU/l for Condition 1 (no lighting) and Condition 2 (fluctuation lighting). Furthermore, under Condition 3 (sinusoidal lighting), the decrease was more than 5 kU/l that is larger than Condition 1 and 2. Amylase activity variance analysis was performed to examine the changes in stress values due to changes in the lighting cycle. The results showed that there was no significant difference in stress values between the different lighting cycles (F (2, 26) = 2.213, *p* = .124)[8].

3.3 Experimental Results on The Latency to Fall Asleep

The mean values of the subjects for each condition for the latency to fall asleep are shown in Fig.11. The average latency to fall asleep was shorter than 15 min under Condition 2 (fluctuation lighting), and longer than 15 min under Condition 1 (no lighting), and Condition 3 (sinusoidal lighting). An analysis of variance was conducted to examine changes in the latency to fall asleep due to changes in the lighting cycle. There was no significant difference in the latency to fall asleep between the two lighting cycles (F (2, 26) = 1.551, *p* = .224).

3.4 Experimental Results on Mid-Waking Time

The mean values of the subjects' mid-wake times for each condition are shown (Fig.12). Under Condition 1 (no lighting), mid-wake time was 26 min, exceeding 20 min. Furthermore, under Condition 2 (fluctuation lighting) and Condition 3 (sinusoidal lighting), it was 16 min and 12 min, respectively, shorter than 20 min. However, no significant difference was found (F (2, 26) = 2.117, *p* = .135).

3.5 Experimental Results on Sleep Efficiency

The mean values of the subjects under each condition for sleep efficiency are shown (Fig.13). The average sleep efficiency was 86% for Condition 1 (no lighting), 85% for Condition 2 (fluctuation lighting), and 87% for Condition 3 (sinusoidal lighting). An analysis of variance was conducted to examine the changes in sleep efficiency due to changes in the lighting cycle. The results showed that there was no significant difference in sleep efficiency between changes in lighting cycles ($F(2, 26) = 0.097$, $p = .907$).

3.6 Experimental Results on The Percentage of Waking Time

The mean values of the subjects under each condition for the percentage of awake time are shown in Fig.14. The percentage of awake time was 16% under Condition 1 (no illumination). Furthermore, the percentage was 13% under both Condition 2 (fluctuation lighting) and Condition 3 (sinusoidal lighting). An analysis of variance was conducted to determine the percentage of awake time in the lighting cycle. The results showed that there was no significant difference in the effect of lighting cycle on the percentage of awake time ($F(2, 26) = 1.211$, $p = .309$).

Table 4. Measurements of the indoor environment

Conditions	temp. [℃]	Humidity [%]	CO2 [ppm]
Condition 1: No lighting	26.0 ±1.7	68.0 ±4.1	819.1 ±344.2
Condition 2: Fluctuation lighting	25.9 ±1.9	68.3 ±5.1	830 ±371.9
Condition 3: Sine Wave Lighting	26.1 ±1.8	65.5 ±5.9	767.9 ±318.7
ALL	26.0 ±1.8	67.3 ±5.2	805.7 ±346.7

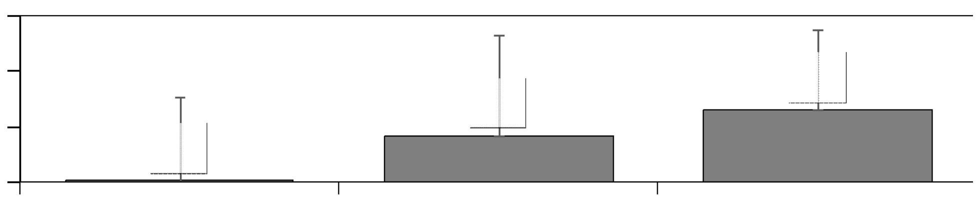

Fig.10. Amylase activity value and standard deviation

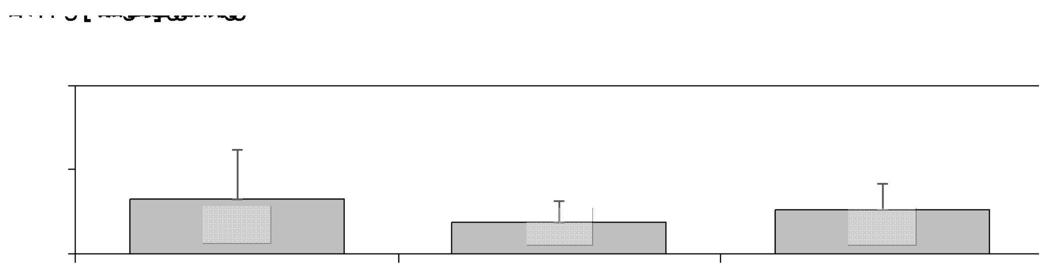

Fig.11. Falling asleep latency and standard deviation

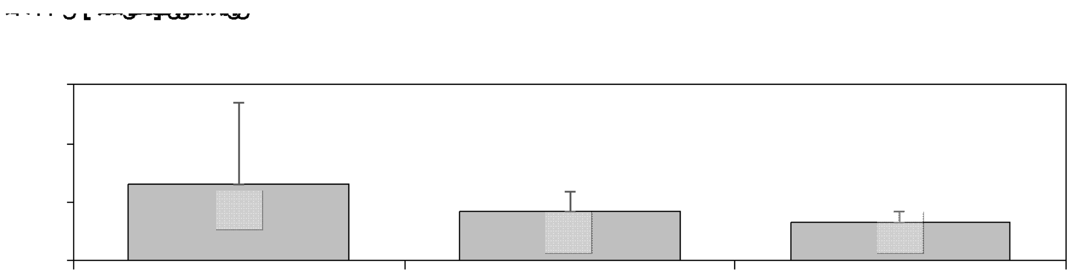

Fig.12. Midway awakening time and standard deviation

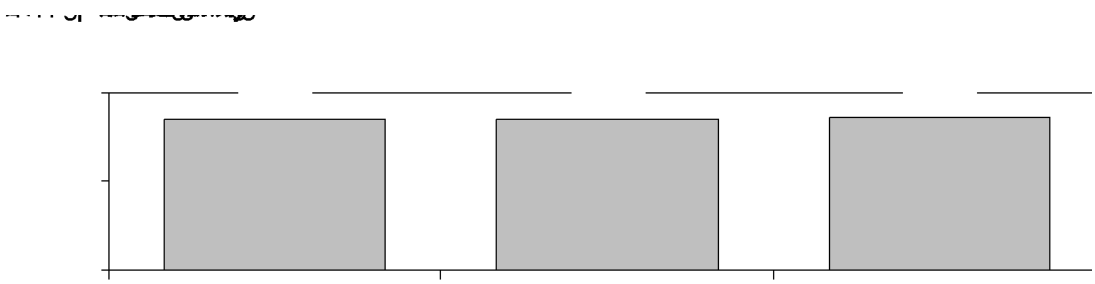

Fig.13. Sleep efficiency

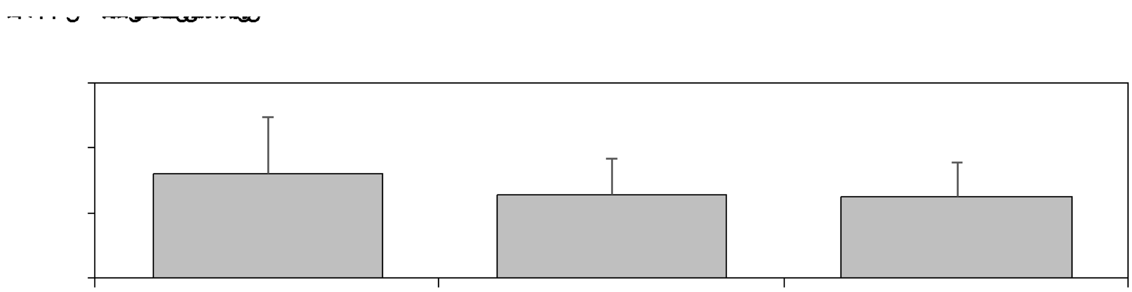

Fig.14. Percentage and standard deviation of awake time

3.7 Experimental Results on The Rate of Slow-Wave Sleep

The mean values of the subjects for the percentage of slow-wave sleep (non-REM sleep stages 3 and 4) under each condition are shown in Fig.15. The percentage of slow-wave sleep was 32%

and 36% under Condition 1 (no lighting) and Condition 2 (fluctuation lighting), respectively. Furthermore, the rate was 45% under Condition 3 (sinusoidal lighting). Analysis of variance was conducted to determine the percentage of slow-wave sleep during the lighting cycle. The results showed that the effect of the lighting cycle was significant ($F(2, 26) = 3.269$, $p = .049$). Multiple comparisons revealed a significant difference in the percentage of slow-wave sleep between Condition 1 and 3, with a significant increase in the percentage of slow-wave sleep under Condition 3 ($p = .042$).

3.8 Results of An Experiment on Psychological Research on Subjects

To understand the psychological state of the subjects, a psychological survey was conducted after lighting exposure and after waking up. The results of the psychological survey are shown below with the mean values and the results for each subject (Fig.16).

After exposure to lighting before bedtime, we conducted a psychological survey on the values of light: "calmness," "comfort," "preference," "naturalness," and "healing." The higher the score, the calmer the person felt. In the "comfort" category of light values, the higher the score, more comfortable the person felt. In the "preference" category, the higher the score, more natural it was; the lower the score, more unnatural it was. The higher the score, more soothing it was.

The psychological survey after lighting exposure revealed the following mean values by condition for each of the light values: for "calmness," "comfort," "preference," "naturalness," and "healing," the scores were more than 0; 5 points higher in Condition 3 (sinusoidal lighting) than in Condition 2 (fluctuating lighting), and there was a difference of more than 1 point in "naturalness."

4. EVALUATION AND DISCUSSION OF THE EXTRACTED DATA

4.1 Analysis of Illumination Cycle and Stress Reduction Value

It was suggested that changing the illumination cycle decreased the stress values before and after illumination exposure. The decrease in amylase activity values under Condition 3 (sinusoidal illumination) was greater than that under Condition 1 (no illumination) and Condition 2 (fluctuating illumination). We believe that this is due to the influence of the psychology of the subjects exposed to lighting. In this experiment, the results of the psychological survey of the subjects after lighting exposure showed that the scores for "fatigue," "preference," and "calmness" were larger under Condition 3 than under Condition 2 (Fig.16). This suggests that changing the illumination cycle had a significant psychological effect on the subjects.

4.2 Evaluation of Illumination Cycle and Percentage of Awake Time

With regard to shallow sleep time, the results suggest that compared with Condition 1 (no lighting), the percentage of waking time was reduced under Condition 2 (fluctuation lighting) and Condition 3 (sinusoidal lighting). The reason for this is that the shortening of latency to fall asleep affected the decrease in the percentage of waking time. A scatter plot of the latency to fall asleep and the percentage of waking time is shown in Fig.17. We believe that the percentage of waking time increases as the latency to fall asleep increases. The same tendency to increase arousal time with an increase in the latency to fall asleep has been mentioned in studies on thermal environments and on space[15].

Here, we examine the relationship between the ratio of slow-wave sleep and psychological survey on lighting preference. The scatter plot of the percentage of slow-wave sleep and the mean score on "Preference" from the psychological survey, by condition, is shown (Fig.18). The higher the score for preference for a lighting intensity, the higher the percentage of slow-wave sleep. This suggests that exposure to lighting close to human preferences by changing the illuminance lighting cycle led to higher quality sleep.

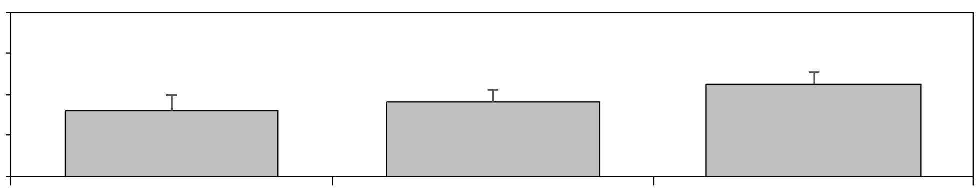

Fig.15. Percentage and standard deviation of slow-wave sleep (REM 3 and 4) time

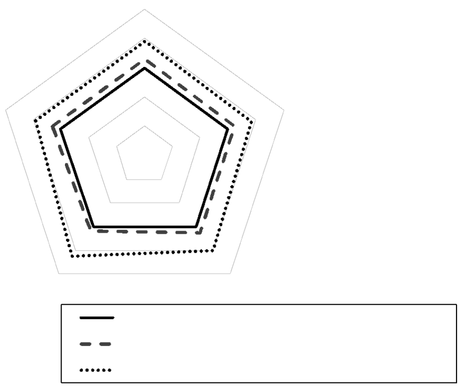

Fig.16. Average of psychological survey results on light values

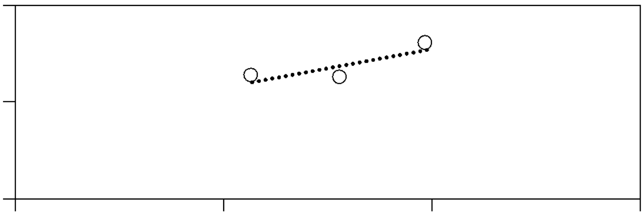

Fig.17. Scatter plot of the ratio sleep latency and ratio of awake time

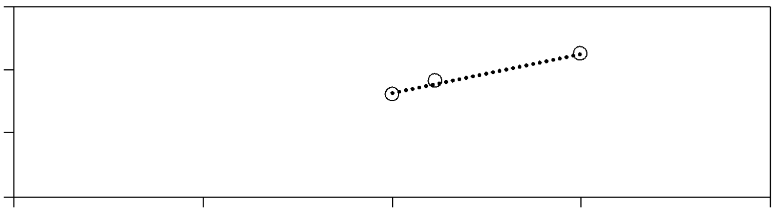

Fig.18. Scatter plot of psychological study "preference" and ratio of slow-wave sleep

The scatter plot of the percentage of awake time by condition and the mean score for "calmness" in the psychological study is shown in Fig.19. The higher the score for calmness, the lower the percentage of awake time. This suggests that the change in the illuminance lighting cycle calmed the mind and reduced the time of shallow sleep.

4.3 Evaluation of Illumination Cycle and Slow-Wave Sleep Time Ratio

The percentage of slow-wave sleep time with respect to sleep depth is described in this section. The percentage of slow-wave sleep time under Condition 1 (no illumination) and Condition 3 (sinusoidal illumination) increased with a significant difference ($p = .042$). We believe that the reasons for this are related to 1) the change in the impression of light due to the change in the illuminance cycle, 2) the shortening of the waking time due to the change in the impression of light, and 3) the increase in the ratio of slow-wave sleep due to the shortening of the waking time.

First, regarding impressions of light from sinusoidal lighting exposure, the psychological survey results showed that the "preference" score was higher than that under Condition 3 (Fig.16). Previous studies have indicated that periodic light exposure has a soothing effect that is also related to the higher "preference" scores[6)].

Next, awakening time was shortened under Condition 3 (Fig.14) under which, light "preference" scored higher (Fig.18). This result is consistent with the suggestion that light preference is related to the ease of sleep[6].

The percentage of slow-wave sleep decreased with decreasing waking time. When we plotted the percentage of waking time and the percentage of slow-wave sleep for each condition, the

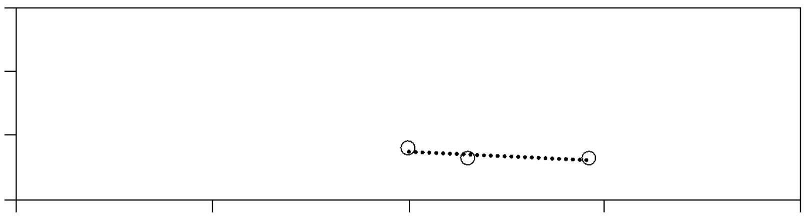

Fig.19. Scatter plot of "calmness" and ratio of awake time

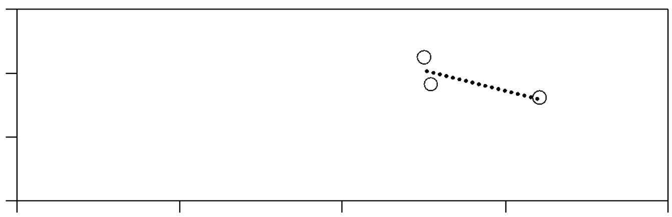

Fig.20. Scatter plot of ratio of awake time and slow-wave sleep ratio

percentage of slow-wave sleep decreased as the percentage of waking time decreased (Fig.20). This result is consistent with previous research on thermal environment experiments, indicating that slow-wave sleep increases as arousal and REM sleep decrease[13].

5. SUMMARY

This study focused on the development of a restful sleep space and accordingly, evaluated the illuminance cycle of the lighting (an important parameter of the environment) and the environmental physiological responses of the subjects. The main points of this study are as follows:

・Effect of illumination cycle on slow-wave sleep rate.

It was observed that the ratio of slow-wave sleep increased upon setting the illuminance cycle of lighting to a specific cycle. We believe that this is due to 1) the change in the impression of light by changing the illuminance cycle, 2) the shortening of the waking time due to the change in the impression of light, and 3) an increase in the percentage of slow-wave sleep due to the shortening of the waking time.

Most previous studies have shown that lighting cycles have a relaxing effect on humans. On the other hand, the results obtained in this study show that the lighting cycle affects the depth of sleep. The possibility of lowering stress levels in an environment with lighting that is repeated in a specific cycle is a novel suggestion here. This could be of value to people living under stress. In addition, the results suggest that changing the illumination cycle can decrease the percentage of waking time and increase the percentage of slow-wave sleep that is a novel finding and valuable for people who spend a large percentage of their time awake or who sleep poorly.

This result can be used to construct a restful sleep space based on a scientific approach to spatial configuration; further, this finding considers the ecological validity of interior design science. This research contributes to the development of interior design science by clarifying the empirical relationship between the indoor environment and the maintenance of health and stable restful sleep performance. Further, this study contributes to the proposal of room performance and improvement closely related to modern life.

Notes

1 We used an Apple iPhone SE. It is usually used as a phone. In this study, we used a microphone to measure the depth of sleep.

2 Sleep Cycle (made by Sleep Cycle AB) was used. It is a software to measure the depth of sleep by using the microphone of mobile communication system. The microphone of this system is placed at the sleeper's bedside for measurement. The audio signals generated by the head and upper body movements are detected, recorded, and analyzed. The voice is generated by the movement of the sleeper during sleep. When the sleeper is awake, he changes his sleeping posture or moves in some manner, and the microphone produces a high-power, high-amplitude, long-lasting audio signal. When the sleeper is in REM sleep, small, short twitch-like movements occur and extremely short audio peaks are generated. When the sleeper is in deep sleep, there is no movement in the sleeper. Polysomnography (PSG) that records EEG and breathing during sleep, showed that in the case of slow-wave sleep (non-REM stage 3 and 4), the sleeper's muscle tone is extremely low, breathing is calm, and there are no specific movements of the body or limbs. In this study, we used these sounds to statistically evaluate the magnitude of the different acoustic signals detected during the night to statistically estimate whether the sleeper is in non-REM sleep, REM sleep, or wakefulness. For typical noise caused by air conditioning, electronic devices, and other environmental factors, the signal can be statistically determined and eliminated by using the moving average of the signal amplitude[17), 18)].

3 The salivary amylase monitor 59-014 (Nipro) was used. To quantitatively assess psychological stress, alpha amylase in saliva is used[19)].

4 We used the Smart Indoor Air Quality Monitor (Netatmo). In general, each household

provides information on the air quality inside and outside the home to each other, and shares weather data around the world. This makes it possible for the owner of this weather meter to obtain fine mesh weather information. However, in this study, only indoor air quality data was obtained, and it was strictly controlled, such that the information would not be leaked to the outside.

[5] RSRA-D18-V24-02 (manufactured by Hikari Factory) was used. As a fluctuating illumination, it can be used for illuminance exposure combining multiple frequencies in the range of 100% to 0% illuminance. As a sinusoidal illumination, it can be used for illuminance exposure adjusting the illuminance from 100% to 10% within a period of 8 s.

[6] It is the length of time from the time we lay down to the time we fall asleep. It is the time required to enter Stage 2 REM sleep from wakefulness. It is used as an objective indicator of the intensity of sleepiness and the quality of sleep.

[7] Sleep efficiency is shown as the total sleep time divided by total bedtime. The total sleep time is the time from falling asleep to waking up, excluding the mid-waking time. The total bedtime is the time from going to bed to waking up.

[8] To perform pairwise comparisons between all groups, the multiple comparison test Tukey-Kramer method was employed, with the significance level set at .05. in Python (Version 11.0.12) for calculations.

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