Investigating the effect of circadian rhythm control light on sleep state and mental health of students

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***Abstract*—Many modern office workers are exposed to fluorescent light all day long, from mid-morning to after dark. The daylight changes in the natural world, from bright during the day to dark at night, play an important role in maintaining a regular daily rhythm. In this study, we evaluated the effects of LED lighting equipped with a circadian rhythm control function, Lavigo, by comparing it with conventional fluorescent lighting on students' sleep quality and stress status. Lavigo's VTL (Visual Timing Light) function adjusts the color and brightness of light according to the biological rhythm of about 24 hours cycles. We measure sleep state and collect responses for a subjective stress-checking questionnaire using Fitbit. The salivary amylase monitor was used to measure objective stress values from a medical perspective. No significant difference in stress values was observed during the experiment. However, some subjects showed a significant decrease in waking time during sleep and an increase in deep sleep only in the week when Lavigo was used. It was also found that these subjects had a common point of living an irregular life, such as staying up until midnight.**

I. Introduction

Most living organisms, including humans, have a circadian rhythm, a biological rhythm with a 24-hour cycle that is engraved in the body and influences vital activities such as sleep and hormone secretion. The light changes throughout the day, from bright during the day to dark at night in nature, are essential for maintaining these rhythms [1].

Melatonin, produced in the brain, controls circadian rhythms. As melatonin secretion is suppressed by exposure to bright light, there is a distinct diurnal fluctuation, with low melatonin secretion during the day and a tenfold increase at night. However, even in an environment where there is no distinction between day and night, diurnal fluctuations continue due to the neural output from the body clock. In contrast, melatonin secretion decreases even at night when exposed to intense light, as in a convenience store. This means that melatonin is regulated by both the body clock and ambient light*. Circadian rhythms shift causes adverse effects on physical functions such as hypertension, deterioration of vascular metabolism, obesity, and physiological functions and decreases in productivity-related abilities such as alertness and cognitive ability [2]–[5].

Many modern office workers are exposed to fluorescent light all day long, from mid-morning to after dark. Therefore, melatonin secretion at night is suppressed because the amount of strong light exposure remains the same even after the evening, affecting sleep and leading to a circadian rhythm shift. We have been researching to enhance the well-being of office workers in the laboratory in Kyushu University as a living lab [6], and Lavigo, an LED lighting equipped with circadian rhythm function VTL (Visual Timing Light) of Waldmann, Germany†, has been fully introduced as lighting. The VTL simulates the rhythm of the sun and switches between an intense light with a low color temperature in the morning and a soft light with a high color temperature in the evening or later, making the office environment more natural. The VTL has been evaluated in hospitals in Germany and Italy, and reported reduced waking time during sleep in patients who had reversed the day/night cycle due to hospitalization [7].

The purpose of this evaluation experiment was to test the hypothesis that the same effect would be obtained when Lavigo is used in an office environment and with healthy people. The experiment was conducted in four weeks from December 2020 to January 2021. Half of the laboratory was used for fluorescent lighting and the other half for Lavigo, and the subjects worked over six hours per week in the designated environment. The number of subjects was six, and they were divided into two groups of three subjects each, and their positions were switched every week. Fitbit‡ Versa 3 devices were distributed to subjects to measure their sleep status. Fitbit data was collected through WorkerSense [8], which was developed in our laboratory. In addition to sleep status, the effect of stress is also measured at the same time. Subjective stress values were collected through the Fitbit application developed by the author [9], and a salivary amylase monitor§ was used to measure objective stress values from a medical perspective.

As a result of the experiment, a t-test of whole subjects showed a significant difference in lighting and sleep, with a smaller percentage of wake in sleep when working under Lavigo after 19:00. A t-test for individual subjects showed that some subjects had a significantly smaller percentage of awake time when working under Lavigo, and that some subjects had a significantly larger number and percentage of deep sleep hours. Furthermore, it was confirmed that the percentage of

*https://www.e-healthnet.mhlw.go.jp/information/dictionary/heart/yk-062.html

†https://www.capind.co.jp/product/detail.php?id=100

‡https://www.fitbit.com/global/jp/technology/sleep

§https://med.nipro.co.jp/med_eq_category_detail?id=a1U1000000b535GEAQ awake time was significantly lower for some participants when working under Lavigo after 19:00. As for lighting and stress, there was no significant difference in the values of stress measured by the questionnaire on Fitbit and salivary amylase monitor due to the change in lighting. The subjects who showed significant differences in the evaluation of lighting had an irregular life rhythm in common. Therefore, Lavigo is thought to play a role in correcting lifestyle by adjusting circadian rhythms.

II. Related Work

A. Relationship between lighting and circadian rhythm

In an experiment involving 23 subjects, researchers investigated the effects of phase shifts in circadian rhythms caused by exposure to bright light on sleep over 11 days [10]. In this experiment, subjects were divided into three groups based on their exposure to bright light: morning, evening, and afternoon. They evaluated basal sleep and wakefulness, exposure to bright light for three days, and sleep and wakefulness after exposure. The results showed that the phase of the body temperature rhythm advanced by 1.23 hours in the morning group, lagged by 1.62 hours in the evening group, and advanced by 0.5 hours in the afternoon group, although this was not significant. However, these phase shifts were not enough to significantly affect sleep parameters in any of the three groups, so there is room for consideration of lighting settings and exposure times that may affect sleep quality.

The relationship between exposure to intensive light and the circadian rhythm phase has also been investigated by exposing subjects to 3000 lux of white light and measuring sleep-wake cycles [11]. This investigation included 250 young people aged 18∼31 years old and 56 older people aged 59∼75 years old. The results showed that white light exposure caused a phase shift of up to 3 hours, regardless of age or gender. In addition, the optimal timing of light irradiation on phase shift was found to be different for each subject, and that there was no significant phase shift in any age group in an interval around 16:00. This result indicates that intense light affects circadian rhythms and influences sleep. In contrast, the effect of adjusting light after evening to weaker sun-like light on circadian rhythm was not verified.

Waldmann's VTL has been reported in several studies of hospitalized patients whose life rhythm is perturbed by admission to a hospital or nursing home. It was reported in an experiment conducted in a German nursing home from 2007 to 2009 that the number of midnight awakenings of 12 patients who had reversed day/night rhythms was reduced considerably. [12] In a 2010 study conducted in an Italian hospital, patients whose days and nights were reversed due to hospitalization for liver cirrhosis were exposed to different lighting in their hospital rooms [7]. The results showed that nighttime awakenings decreased from 7 ∼ 8 times to about 3 times, and the Karolinska sleepiness scale[¶], which indicates daytime sleepiness, decreased from 8 to 5 points.

¶Scale of 1 "very clearly awake" to 9 "very sleepy".

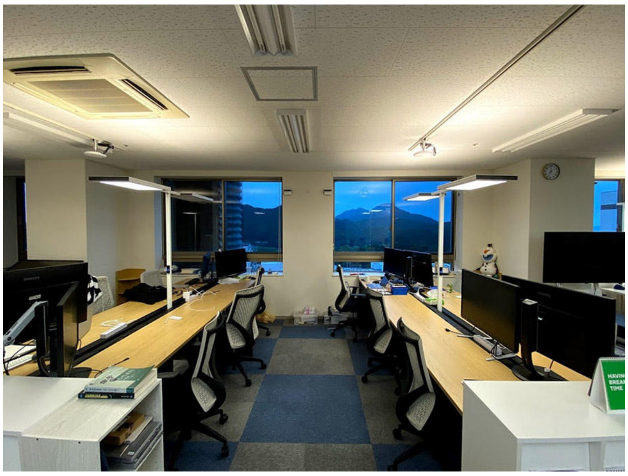

Fig. 1. Lavigo in an experimental environment

Studies have also been conducted on the effects of blue light from lighting on sleep awakenings in residential environments [13]. This study reported that shading the blue light from artificial lighting before going to bed at night increased melatonin and significantly increased sleepiness. However, no experiments were performed in the evening after the sun goes down, or in a working environment such as an office.

B. The relationship between lighting and stress

Other experiment was conducted to investigate the effects of different lighting conditions on stress during work [14]. In this experiment, ten male students in their early twenties were asked to repeat the calculations based on a certain rule in a windowless office environment. They were then asked a questionnaire about lighting after work. In addition, stress was measured by heart rate variability obtained from an electrocardiogram. As a result of the experiment, it became clear that the lighting level at which people feel comfortable and the lighting level at which stress becomes small differ from person to person. On the other hand, this experiment was repeated only three times for about 15 minutes, and the relationship with long-term work has not been clarified.

C. Position of this study

In most related studies, illuminance was changed during a short period of work, or the experiments were conducted only a few times per day, and long-term work in the actual office was not considered. Therefore, these studies cannot follow the effects on circadian rhythms and changes in stress caused by continuous daily work in an environment where color, temperature, and illuminance fluctuate depending on the time of day. This study uses a lighting system that automatically adjusts to the optimal color, temperature, and intensity depending on the time of day. We report on the effects of long work hours under this light.

III. Lighting experiments

A. Equipment

In this study, the Lavigo of Waldmann (Germany) was used as the LED lightning to reproduce natural light. We also use Fitbit Versa 3, a smartwatch with touchscreen LCD, to measure sleep status and perform a simple stress check. In addition, a salient amylase monitor, a medical device, was used to obtain objective data. Details are described below.

1) Lavigo: Lavigo is a stand-type LED light fixture equipped with a motion sensor and a daylight sensor to detect sun levels. It also has Visual Timing Light (VTL) feature that simulates sun rhythm to create natural light in office. VTL is also commonly referred to as circadian rhythm control light, and Okamura and Panasonic have released it in the past. Most recently, Dyson has released a desk light called Lightcycle[‖]. Lavigo has been developed based on the research results shown in the related research [7]. Various sensors are equipped to automatically adjust illuminance and color temperature according to time, ambient light, and ambient brightness. In this experimental environment, double-headed Lavigo is installed in the center of the island with six people, as shown in Figure1.

2) Fitbit: Advantages of using Fitbit Versa 3 include answering questionnaires using a touch screen, long battery life, and no need for frequent recharging, and the ability to acquire all kinds of exercise data as an activity meter, including heart rate, sleep, and steps. In addition, it is less expensive than Apple Watch and Android Watch, which have similar functionalities, and it is easy to develop and distribute original apps. Another advantage of Fitbit is the API (Application Programming Interface) for collecting data. In our laboratory, we have already developed WorkerSense [8], a data collection application for Fitbit, and a questionnaire application for Fitbit Versa 3 [9], and we will collect data using these applications.

The sleep information obtained from Fitbit includes sleep stage information in addition to sleep onset time and wake-up time. There are four stages: awakened, REM, light sleep, and deep sleep. Figure2 shows the screen of a simple questionnaire application used in this experiment to measure subjective stress. We prepared three buttons, Relax, Middle, and High, and the subjects answered the subjective stress they were feeling three times a day.

3) salivary amylase: A salivary amylase monitor is a medical device that measures amylase from saliva collected with a special chip. The measured value is expressed in IU, an international unit that expresses the amount of efficacy to the body. The range of measurements is from 0 ∼ 200 kIU/L, and the table I shows the criteria for determining the stress value. In this experiment, the objective value of stress is measured based on this index.

B. Experimental Procedure

In this experiment, subjects were assigned fluorescent or Lavigo lighting for each of the five weekdays during which they were in the laboratory. Sleep and stress were measured over four weeks while switching lights. Subjects were divided into two groups, Group A and Group B, to check the effect of switching order. TableII shows the weekly lights used by each group. In both groups, the patterns of using Lavigo for one week and then fluorescent lighting for one week and fluorescent lighting for one week and then Lavigo for one week were conducted before and after the winter vacation. Since the university is closed during the winter vacation, it is a reset period. The following constraints were placed on subjects throughout the experiment period (five weeks). It was approved by the Ethics Review Committee of Kyushu University, and the subjects were informed of the content of the experiment and gave their consent. Subjects were informed of the contents of the experiment and gave their consent to be included in the experiment and could leave the experiment at any time.

1) Participants will work under designated lighting for at least 6 hours per day.
2) Participants will record the start time, rest time, and end time of the work.
3) Participants will record the start time, rest time, and end time of the work.
4) Participants will sleep while wearing the Fitbit to obtain sleep data.

[‖] https://www.dyson.co.jp/lighting/lightcycle.aspx

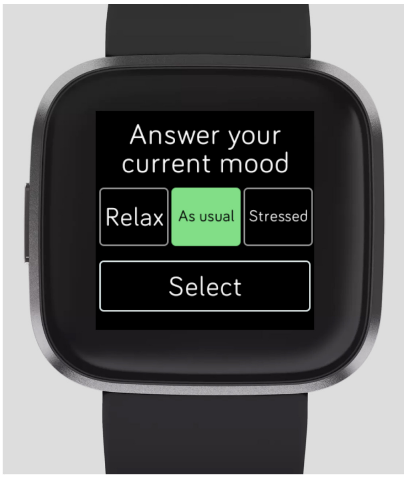

Fig. 2. questionnaire application screen

TABLE I
Criteria for stress assessment

Salivary amylase level	Stress assessment
0 ∼ 30kIU/L	No stress
31 ∼ 45kIU/L	A little stressed
46 ∼ 60kIU/L	stressed
61kIU/L ∼	pretty stressed

IV. Evaluation and Discussion

This lighting experiment will be evaluated in terms of its effects on sleep quality and stress.

TABLE II
SPECIFIED LIGHTING FOR EACH GROUP

Group	Week 1	Week 2	winter vac	Week 3	Week 4
A	Lavigo	Fluorescent	-	Fluorescent	Lavigo
B	Fluorescent	Lavigo	-	Lavigo	Fluorescent

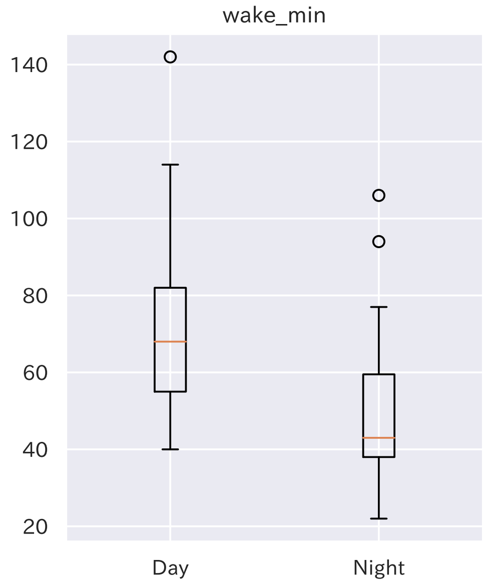

Fig. 3. Distribution of waking time during sleep in Lavigo group

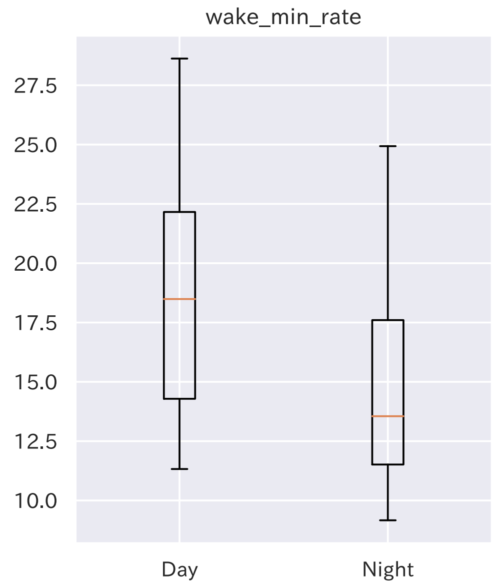

Fig. 4. Distribution of the percentage of waking time during sleep in Lavigo group

A. *Effect of lighting on sleep quality*

We will evaluate the results of the analysis for all subjects and for each individual subject.

1) Characteristics of the whole subject: Data of all subjects working under Lavigo were divided into two groups: the group that finished working before 19:00 (Day) and the group that finished working after 19:00 (Night), and the t-test was conducted. The results showed a significant difference in waking time during sleep and the ratio of waking time during sleep. These results are shown in Figures 3 and 4. When the work was done after 19:00 compared to when the work was done before that time, the average awake time ratio decreased from 18.9% to 14.9%. These trends were not observed in subjects who worked under fluorescent light but were specific to subjects who worked under Lavigo. This indicates that working under Lavigo after 19:00 reduces the ratio of awakenings during sleep that night.

2) Characteristics of individual subjects: As the result of the t-test, We found that the ratio of awake time during sleep decreased by 8.5% on average and became significantly smaller in some people during the week when they worked under Lavigo (Figure5). We also found that the number of deep sleep increased significantly by 1.3 on average and the ratio of deep sleep increased significantly by 2.1% on average for some people during the week they worked under Lavigo (Figure6, Figure7). Furthermore, the subjects who worked after 19:00 were divided into two groups, the Lavigo group and the fluorescent group, and a t-test was conducted, respectively. It was confirmed that the percentage of awake time decreased by 15.7% on average in the week when the subjects worked under Lavigo compared to the week when they worked under fluorescent light, and some of the subjects showed a significantly smaller decrease (Figure8).

The above evaluation revealed a difference in sleep quality between daytime and nighttime work under Lavigo. Moreover, for some subjects, there was a difference in sleep quality between working under fluorescent light and working under Lavigo. This result is that melatonin secretion becomes active, and sleep quality improves as the light exposure time of Lavigo, which is adjusted according to the sun rhythm, increases when the work at night increases. The reason for the difference between subjects was that those who were typically exposed to the morning sun and were not exposed to strong fluorescent light in the evening or later did not experience the full Lavigo effect because their circadian rhythms were already in order. These results suggest that Lavigo may effectively improve sleep quality for people with night-time patterns and irregular lifestyle rhythms.

B. *Effects of lighting on stress*

For all groups A, B, and each subject, a t-test was performed on the variation of stress values, respectively. However, there was no significant difference between the subjective stress values obtained by the Fitbit and the objective stress values obtained by the amylase monitor. This result indicates that lighting type has no direct effect on subjects' mental health.

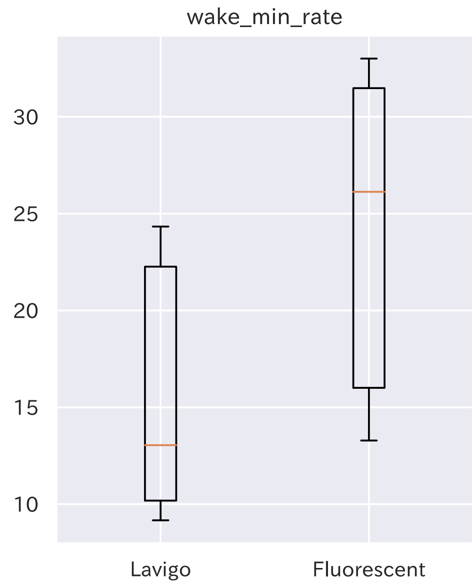

Fig. 5. Distribution of the percentage of waking time during sleep for a subject

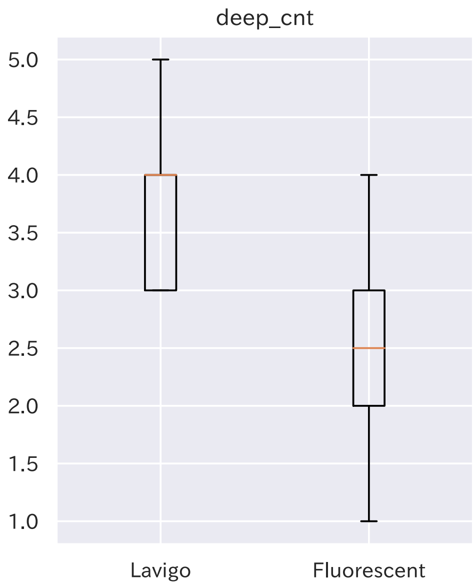

Fig. 6. Distribution of the number of deep sleep times for a subject

This result suggests various causes of stress other than lighting and that a single indicator of lighting cannot determine the stress state.

Furthermore, there was no significant difference in the t-test results between Group A and Group B for both sleep and stress, indicating that switched lights' order did not affect sleep or stress.

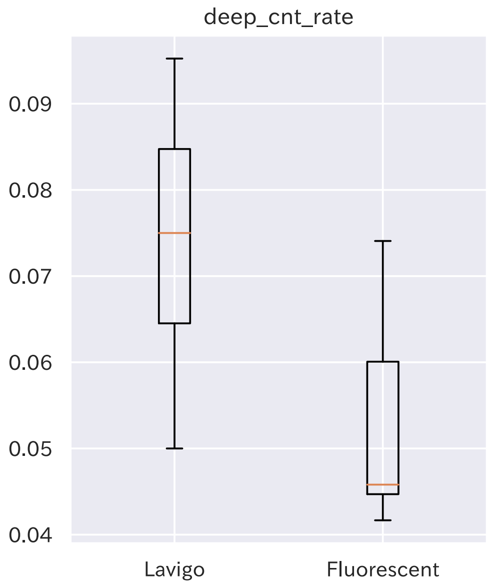

Fig. 7. Distribution of the percentage of deep sleep time for a subject

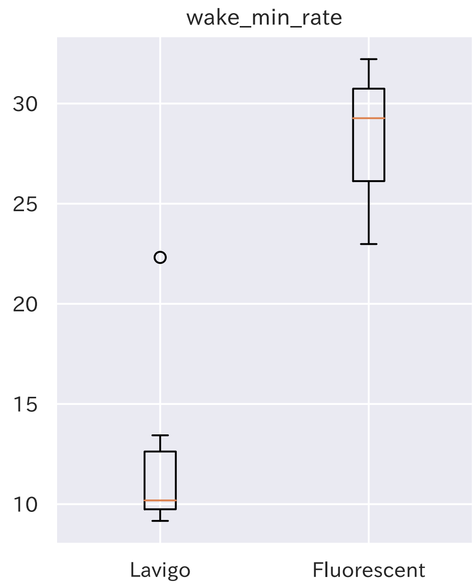

Fig. 8. Distribution of the percentage of waking time during sleep on days when a subject worked at night.

V. Conclusion

This paper collected sleep and stress data from six male subjects (five 20s and one 30s) during work under standard fluorescent lighting and under LED lighting equipped with a circadian rhythm function, Lavigo. Subjects were separated

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http://id.nii.ac.jp/1001/00212654/

into two groups: group A and group B. The experiment was performed for four weeks, totaling 19 days and switching light types. As a significant result of the t-test, it was confirmed that the rate of awakening during sleep became smaller when the subjects worked under Lavigo at night. In terms of individual subjects, it was confirmed that some subjects spent less time awake than when working under fluorescent lights, some subjects spent more time in deep sleep than when working under fluorescent lights, and some subjects spent less time awake when working under Lavigo at night than when working under fluorescent lights at night. There was no significant difference in the effect of lighting on stress, either subjectively or objectively. From the analysis evaluation, it can be concluded that Lavigo played a role in regulating circadian rhythms, as there was an improvement in the percentage of awake time during sleep for subjects whose life rhythms were disrupted or who were night owls.

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