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Effect of Circadian Rhythm Control Light on Sleep State and Mental Health of Students

Haruki Harashima, Shuta Matsuo,* and Yutaka Arakawa

Graduate School of Information Science and Electrical Engineering, Kyushu University,
744 Motooka, Nishi-ku, Fukuoka-city, Fukuoka 819-0395, Japan

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Many office workers are exposed to fluorescent light from mid-morning to after dark. The changes in the amount of light 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. Lavigo's Visual Timing Light (VTL) function adjusts the color and brightness of light according to the biological rhythm of about 24 h cycles. We measured the sleep state using Fitbit and collected subjective responses through a stress-checking questionnaire. A 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, only during the week that Lavigo was used, a certain subject showed a significant decrease in waking time during sleep, and another subject showed an increase in deep sleep. It was also found that these subjects tended to lead an irregular life, such as staying up until midnight.

1. Introduction

Most living organisms, including humans, have a circadian rhythm, a biological rhythm with a 24 h cycle that is established in the body and influences vital activities such as sleep and hormone secretion. The changes in the amount of light throughout the day in nature, from bright light during the day to darkness at night, are essential for maintaining this rhythm.(1)

Melatonin, a substance produced in the brain, controls circadian rhythm. 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 people are exposed to intense light, as in a convenience store. This means that melatonin is regulated by both the body clock and ambient light.† A shift in circadian rhythm adversely affects physiological functions and can result in hypertension, deterioration of

*Corresponding author: e-mail: matsuo.shuta@arakawa-lab.com
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vascular metabolism, and obesity, and can decrease productivity through reduced alertness and cognitive ability.(2–5)

Many office workers are exposed to fluorescent light from mid-morning to after dark. Therefore, melatonin secretion at night is suppressed because the amount of exposure to strong light remains the same even in the evening, affecting sleep and leading to a circadian rhythm shift. Using our laboratory at Kyushu University as a living lab, we have been attempting to enhance the well-being of office workers.(6) In our lab, Lavigo, an LED lighting system equipped with the circadian rhythm function Visual Timing Light (VTL) developed by 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, making the office environment more natural. VTL has been evaluated in hospitals in Germany and Italy, and reduced waking time during sleep has been reported for patients whose day/night cycle has been reversed due to hospitalization.(7)

The purpose of the evaluation experiment reported in this paper was to test the hypothesis that the same effect will be obtained when Lavigo is used in an office environment and with healthy people. The experiment was conducted for four weeks from December 2020 to January 2021. Half of the laboratory used fluorescent lighting and the other half used Lavigo, and the subjects worked over 6 h per day for a week in the designated environment. The six subjects were divided into two groups of three subjects each, and their positions were switched every week. Fitbit[†††] Versa 3 devices were distributed to the subjects to measure their sleep status. Fitbit data was collected through WorkerSense,(8) which is an application developed in our laboratory. In addition to the sleep status, the effect of the lighting environment on stress was also measured at the same time. Subjective stress values were collected through a 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 all the subjects showed the percentage of time awake during sleep, with a smaller percentage of waking during sleep for the subjects working under Lavigo after 19:00. A t-test for individual subjects showed that a certain subject had a significantly smaller percentage of waking during sleep when working under Lavigo and that another subject had a significantly larger number and percentage of deep sleep hours. Furthermore, it was confirmed that the percentage of awake time was significantly lower for a certain subject when working under Lavigo after 19:00. Regarding the relationship between lighting and stress, there was no significant difference in the values of stress measured by the questionnaire on Fitbit and the salivary amylase monitor resulting from a change in lighting. The subjects who showed significant differences in the percentage of time awake during sleep generally had an irregular life rhythm. Therefore, Lavigo is thought to play a role in correcting lifestyle by adjusting the circadian rhythm.

[†]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

2. Related Work

2.1 Relationship between lighting and circadian rhythm

In an experiment involving 23 subjects, researchers investigated the effects of phase shifts in circadian rhythm caused by exposure to bright light on sleep over 11 days.(10) In this experiment, the subjects were divided into three groups on the basis of their time of exposure to bright light (morning, evening, and afternoon). Basal sleep and wakefulness were assessed, as well as sleep and wakefulness after three days of exposure to bright light. The results showed that the phase of the body temperature rhythm advanced by 1.23 h in the morning group, lagged by 1.62 h in the evening group, and advanced by 0.5 h in the afternoon group, although these values were not significant. However, these phase shifts were insufficient to significantly affect sleep parameters in any of the three groups. Therefore, lighting settings and irradiation duration that may affect sleep quality should be considered.

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 and 56 older people aged 59–75. The results showed that white light exposure caused a phase shift of up to 3 h, regardless of age and gender. In addition, the optimal timing of light irradiation to induce a phase shift was found to be different for each subject, with no significant phase shift in any age group for light exposure in an interval around 16:00. This result indicates that intense light affects circadian rhythm and influences sleep. In contrast, the effect of adjusting light from the evening to weaker sunlike light on circadian rhythm was not verified.

The use of Waldmann's VTL system has been reported in several studies of hospitalized patients whose life rhythm has been perturbed by admission to a hospital or nursing home. In an experiment conducted in a German nursing home from 2007 to 2009, it was found that the number of midnight awakenings of 12 patients with reversed day/night rhythm was reduced considerably when VTL was used.(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.(11) It was found that nighttime awakenings decreased from 7–8 times to about three times and that the Karolinska sleepiness scale, which indicates daytime sleepiness, decreased from 8 to 5 points when VTL was used.[†]

Studies have also been conducted on the effects of blue light from lighting on awakening during sleep in residential environments.(13) It was found that filtering the blue light from artificial lighting before going to bed at night increased melatonin levels and significantly increased sleepiness. However, no experiments were performed in the evening or in a working environment such as an office.

[†]Scale of 1 "very clearly awake" to 9 "very sleepy".

2.2 Relationship between lighting and stress

Another experiment was conducted to investigate the effects of different lighting conditions on stress during work.(14) In this experiment, 10 male students in their early 20s were asked to repeatedly perform calculations based on a certain rule in a windowless office environment. They then completed a questionnaire about room lighting after performing the calculations. In addition, stress was measured by determining heart rate variability obtained from an electrocardiogram. The results of the experiment showed that the lighting level at which people feel comfortable differs from person to person. On the other hand, this experiment was repeated only three times, with subjects performing calculations for about 15 min in each experiment, and the relationship between lighting intensity and long-term work has not been clarified.

2.3 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 the effect of long-term work in an actual office was not considered. Therefore, these studies cannot clarify the effects on circadian rhythm and changes in stress caused by continuous daily work in an environment where color, temperature, and illuminance fluctuate with the time of day. In this study, we used 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 in this light.

3. Lighting Experiments

3.1 Equipment

In this study, the Lavigo lighting system (Waldmann, Germany) was used as the LED lighting to reproduce natural light. We also used Fitbit Versa 3, a smartwatch with a touchscreen LCD, to measure sleep status and perform a simple stress check. In addition, a salient amylase monitor 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 the VTL feature, which simulates the sun's rhythm to create natural light in offices. VTL is also commonly referred to as circadian rhythm control light, and Okamura and Panasonic have released VTL-based systems. Recently, Dyson has released a VTL-based desk light called Light cycle.[†] Lavigo was developed on the basis of previous research results.(7) Various sensors are equipped in Lavigo to automatically adjust illuminance and color temperature according to time, ambient light, and ambient brightness. In our experimental environment, a double headed Lavigo is installed in the center of a desk with six people, as shown in Fig. 1. The layout of the room used for the experiment and the area with Lavigo and the area with fluorescent lights are shown in Fig. 2.

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

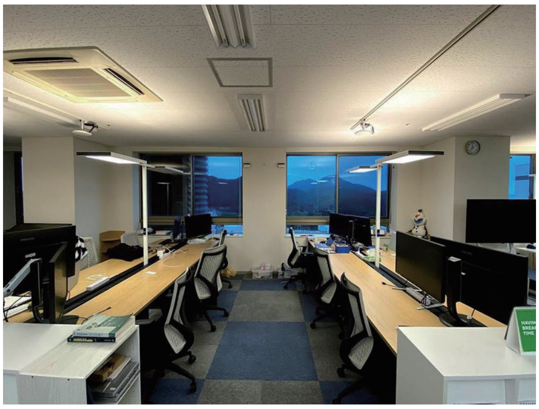

Fig. 1. (Color online) Lavigo in the experimental environment.

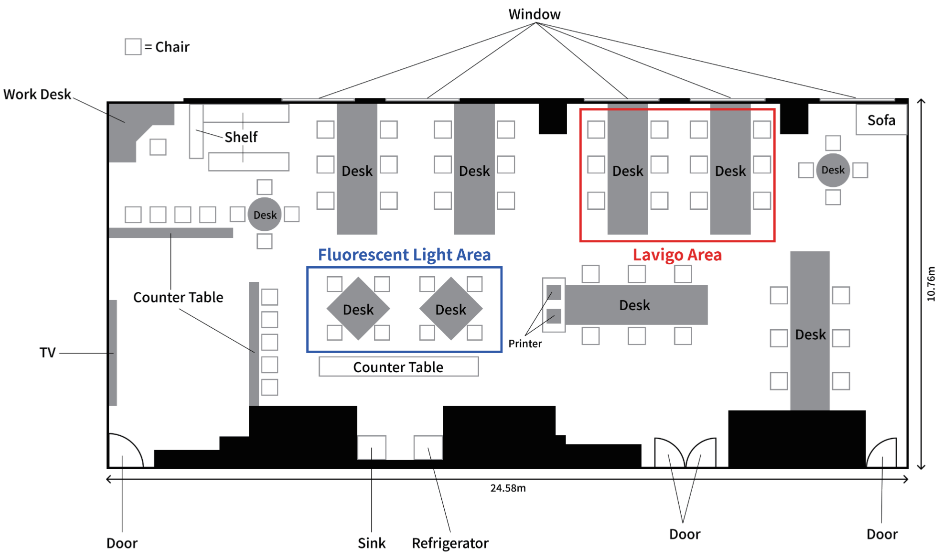

Fig. 2. (Color online) Room layout and two light areas.

2) Fitbit: The advantages of using Fitbit Versa 3 include the ability to answer questionnaires using a touch screen, long battery life, no need for frequent recharging, and the ability to acquire various types of exercise data to monitor activity, including heart rate, sleep, and a number of 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 that can be used with Fitbit. Another advantage of Fitbit is its application programming interface (API) 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 collected data using these applications. Figure 3 shows the screen of the simple questionnaire application used in this experiment to measure subjective stress. We prepared three buttons, “Relax”, “As Usual”, and “Stressed”, and the subjects indicated the subjective stress they were feeling three times a day.

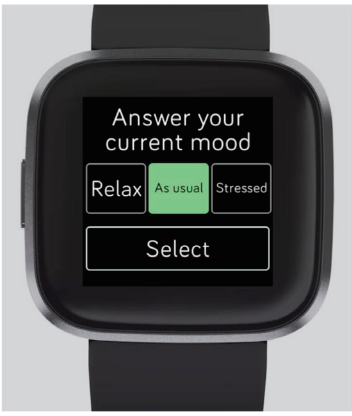

Fig. 3. (Color online) Questionnaire application screen.

The sleep information obtained from Fitbit includes sleep stage information in addition to the sleep onset time and wake-up time. There are four stages of sleep: awake, REM, light sleep, and deep sleep. The validation of a consumer-grade sleep wearable device showed that it could measure sleep duration as well as research actigraphy, but there is still room for improvement in stage estimation.(15) A meta-review of the literature of several papers on stage showed that while it is not a replacement for PSG, it achieves high accuracy in distinguishing between sleep and wakefulness.(16) These indicate that Fitbit is useful for measuring sleep duration and determining wakefulness.

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 efficacy of the body. The range of measurements is from 0 to 200 kIU/L, and Table 1 shows the criteria we used to determine the objective stress value in this study.

3.2 Experimental procedure

In our 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 with the type of lighting switched weekly. Subjects were divided into groups A and B to determine the effect of the switching order. Table 2 shows the weekly lights used by each group. In Group A (B), Lavigo (fluorescent lighting) was used for one week, then fluorescent lighting (Lavigo) was used for one week each before and after winter vacation, and finally, Lavigo (fluorescent lighting) was used for one week.

The winter vacation had a duration of one week, during which the university was closed, and acted as a reset period. The experiment was approved by the Ethics Review Committee of Kyushu University. Subjects were informed of the content of the experiment in advance and that they could leave the experiment at any time, and they gave their consent to participate in the experiment. In particular, the subjects were informed that they will

Table 1
Criteria for stress assessment.

Salivary amylase level (kIU/L)	Stress assessment
0–30	No stress
31–45	A little stressed
46–60	Stressed
61–	Very stressed

Table2
Lighting for each group.

Group	Week 1	Week 2	Winter vac (1 week)	Week 3	Week 4
A	Lavigo	Fluorescent	—	Fluorescent	Lavigo
B	Fluorescent	Lavigo	—	Lavigo	Fluorescent

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

They were also instructed to report whether they had engaged in any activities prior to sleep that might have affected their sleep, such as drinking alcohol, exercising, or prolonged computer gaming. No subjects reported such events.

4. Evaluation and Discussion

4.1 Effect of lighting on sleep quality

The average time to fall asleep, the average time to wake up, the average sleeping time, and the average time to work for each subject when using Lavigo and fluorescent lights are shown in Tables 3 and 4, respectively.

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 a t-test was conducted. The results showed a significant difference in waking time during sleep and the percentage of waking time during sleep, as respectively shown in Figs. 4 and 5. The percentage of awake time during sleep was 18.9% for the Day group and 14.9% for the Night group. These trends were only observed for subjects who worked under fluorescent light. This indicates that working under Lavigo after 19:00 reduces the percentage of awakenings during sleep at night.

Table 3
Average time to sleep and wake-up and working hour of subject working under Lavigo

Subject	Average time to fall asleep	Average time to wake up	Average sleeping time	Average time to work
A	23:17	05:23	6 h 6 min	11h 23 min
B	01:15	09:20	8 h 5 min	6 h 58 min
C	01:11	09:05	7 h 54 min	7 h 56 min
D	03:12	09:49	6 h 37 min	6 h 22 min
E	02:08	09:53	7 h 45 min	6 h 52 min
F	04:41	11:04	6 h 23 min	6 h 28 min

Table 4
Average time to sleep and wake-up and working hour of subject working under fluorescent light

Subject	Average time to fall asleep	Average time to wake up	Average sleeping time	Average time to work
A	23:03	05:26	6 h 23 min	11 h 8 min
B	01:58	09:51	7 h 53 min	7 h 18 min
C	23:12	10:49	11 h 37 min	6 h 49 min
D	02:44	09:11	6 h 27 min	7 h 18 min
E	00:28	12:37	12 h 9 min	7 h 47 min
F	04:47	11:40	6 h 53 min	7 h 20 min

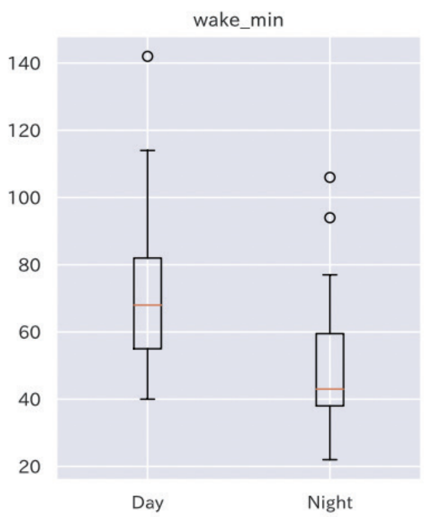

Fig. 4. (Color online) Distribution of waking time during sleep for the Lavigo group.

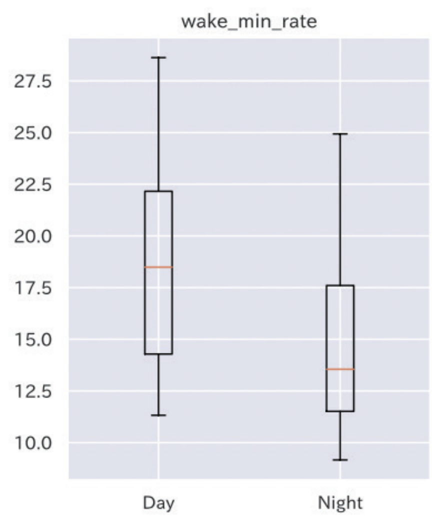

Fig. 5. (Color online) Distribution of the percentage of waking time during sleep for the Lavigo group.

2) Characteristics of individual subjects: From the t-test, we found that a certain subject's percentage of awake time during sleep decreased by 8.5% on average and became significantly smaller during the week when they worked under Lavigo (Fig. 6). We also found that the number of deep sleeps increased significantly by 1.3% on average and the percentage of deep sleep increased significantly by 2.1% on average for a certain subject during the week they worked under Lavigo (Figs. 7 and 8). 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. 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 with the week when they worked under fluorescent light, and some of the subjects showed a significantly smaller decrease (Fig. 9).

The above evaluation revealed a difference in sleep quality between daytime and nighttime work under Lavigo. Moreover, for a certain subject, there was a difference in sleep quality between working under fluorescent light and working under Lavigo. This is because melatonin secretion becomes active and sleep quality improves when the light exposure time of Lavigo, which is adjusted according to the sun's 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 did not experience the full effect of Lavigo because their circadian rhythms were already in order. These results suggest that Lavigo may effectively improve sleep quality for people with nighttime patterns and irregular lifestyle rhythms.

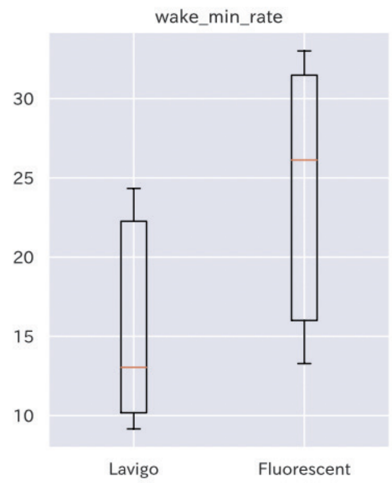

Fig. 6. (Color online) Distribution of the percentage of waking time during sleep for a subject.

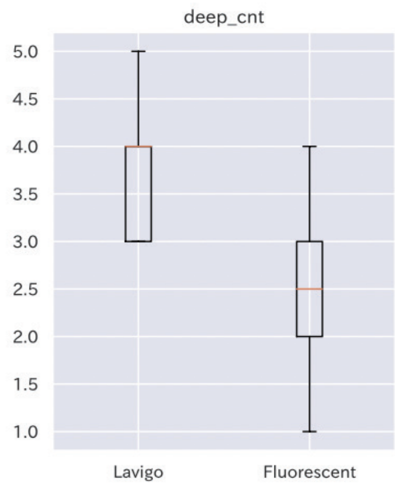

Fig. 7. (Color online) Distribution of the number of deep sleep times for a subject.

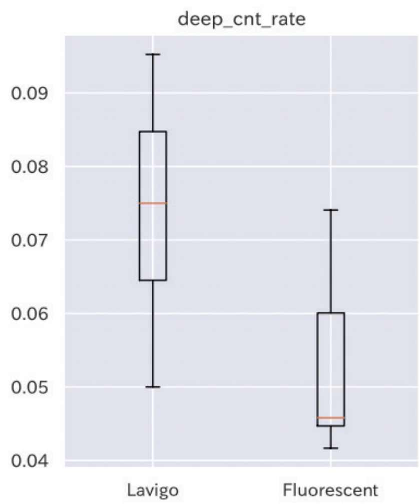

Fig. 8. (Color online) Distribution of the percentage of deep sleep time for a subject.

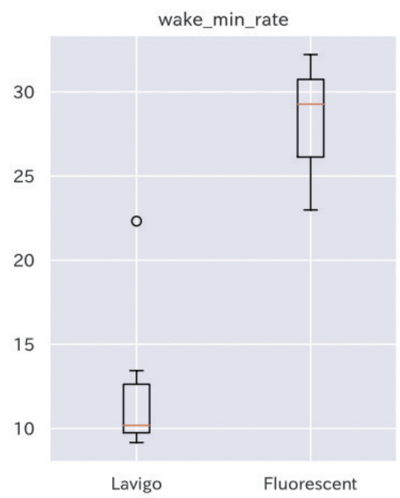

Fig. 9. (Color online) Distribution of the percentage of waking time during sleep on days when a subject worked at night.

4.2 Effect of lighting on stress

For both Groups A and B and for each subject, a t-test was performed on the variation of stress values. 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. This result suggests that there are 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 Groups A and B for both sleep and stress, indicating that the order of switching of the type of light did not affect sleep or stress.

5. Conclusion

We collected sleep and stress data from six male subjects (five in their 20s and one in their 30s) during work under standard fluorescent lighting and under the Lavigo LED lighting system equipped with a circadian rhythm function. Subjects were separated into two groups: Groups A and B. The experiment was performed over four weeks with the type of light switched after the first and third weeks. As a significant result of the t-test, it was confirmed that the rate of awakening during sleep was lower for subjects who worked under Lavigo at night. One subject had a shorter awakening time when working under Lavigo than when working under fluorescent light, another subject had a long deep sleep time when working under Lavigo than when working under fluorescent light, and the other subject had a shorter awakening time when working under fluorescent light at night than when working under Lavigo at night. The type of lighting had no significant effect on both subjective and objective stress. From the analysis of our results, we concluded that Lavigo plays a role in regulating circadian rhythm, as there was a reduction in the percentage of awake time during sleep for subjects whose life rhythms were disrupted or who worked at night.

Acknowledgments

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