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Changing “white and bright” room light to “dim and umber” one had significant effects on residents’ sleep patterns

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Abstract

Japanese people are known for their short sleep time, which is resulting from their late bedtime. Light exposure, especially with short wave length, has significant effects of delaying circadian rhythms. Room lights used in Japanese houses are mostly “bright and white” fluorescent or LED devices. There are many laboratory experiments demonstrating the effects of light on sleep and wake patterns, however, light effects have not been confirmed in actual house settings. We conducted an intervention study of changing light condition in actual houses. We provided “dim and umber” type light devices to the house with “bright and white” type light devices. In experimental group, where the lights were changed to the “dim and umber types, sleep and wake patterns were advanced significantly, compared to the control group. While in the control group with “bright and white” light type, the residents showed significant delay in their sleep and wake patterns, only within a week period. In the experimental group, they showed significant improvements in their mental health. There are possibilities of beneficial changes, if the “dim and umber” type light settings are introduced into Japanese houses.

Key words: Room light conditions, color temperature, illuminance, sleep-wake patterns

Japanese people are known for their short sleep time and sleep problems (Doi *et al.*, 2000; Steptoe *et al.*, 2006). Light with high illuminance and short wavelength has significant effects on the biological clock, and when human is exposed to light at night time, it delays the biological rhythm, which had been confirmed by many laboratory experiments (Boivin *et al.*, 1996; Zeitler *et al.*, 2000; Berson *et al.*, 2002). However, the night lighting of Japanese houses is known to be very bright (high illuminance) and white (containing component of short wavelength) (Higuchi *et al.*, 2016). There are no examples of such high-intensity, short-wavelength lighting used in homes in Europe and the North America. Therefore, at least in research in Western world, there is no need to carry out experiments to actually change the illuminance and short-wavelength lighting in actual house

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settings. However, when considering the lighting conditions of Japanese houses, it might be important to consider the effects in the actual house environment, when considering the health of Japanese people living there. Actually disruption of sleep or circadian biological rhythms causes mental and physical disorders (Asada *et al.*, 2000; Cole & Dendukuri, 2003; Kubo *et al.*, 2006). Fukuda *et al.* (2020) investigated junior high school students' sleep patterns under a wide range of power failure following the massive earthquake, and found that they went to sleep 1.5 hours earlier than usual schedule. This means that the change of light setting in Japanese houses could cause advance shift of Japanese residents' life patterns. In actual houses using high-illuminance and short-wavelength type lighting (bright and white), we intervened in the lighting conditions and changed it to low-illuminance and long-wavelength type lighting (dim and umber) to observe whether the changes affected the sleep-wake habits of the residents.

Methods

Participants: The participants were 23 persons (12 males and 11 females) with an average age of 37.0±9.96 (23-53) years old. The participants were divided into a "control group" in which the lighting conditions were not changed and an "experimental group" in which the lighting conditions were changed in the middle of experimental period. We matched the gender and age of the participants. The control group was 11 participants (5 males and 6 females, 3 of whom lived in the same house as a couple), and the average age was 36.6 years (35.8 years for males and 37.7 years for females). There were 12 participants in the experimental groups (7 males and 5 females, 3 of whom lived in the same house as a couple), and the average age was 37.3 years (38.9 years for males and 35.2 years for females).

Procedure: From the end of March to the beginning of June 2015, measurements were taken at the participants' actual housings. The measurement is recorded using a logger illuminance meter (Custom Co., Ltd., LX-2000SD) that can continuously record the illuminance of a living room (at the place where the participants usually are), and an activity monitor (Actiwatch, Mini-Mitter (Respironics)), AW-L type) was used to record the amount of activity for 24 hours.

We also asked the participants to fill out various survey forms; Sleep Log, OSA sleep inventory MA version (Yamamoto *et al.*, 1999) for subjective evaluation of daily sleep, and General Health Questionnaire: GHQ (Goldberg *et al.*, 1997). We asked them to fill out Sleep Log and OSA sleep questionnaire every day, while GHQ were asked to be filled out in the morning of the 4th day, which is the day after the last day of the control period, and in the morning of the end of the experiment. Data of OSA sleep inventory was not analyzed in this paper.

The experiment was scheduled for 10 days. We had them live in a normal lighting environment with the baseline period from the 1st to the 3rd day. All the participants were living in houses that use high-illuminance and short-wavelength (bright and white) lighting, which is very common in Japanese houses. The Control group continued to live under the same lighting conditions after the 4th day, but in the Experimental group, the lighting was changed to low-illuminance and long-wavelength (dim and umber) after the 4th day (Tall and low lights, Fig. 1). We brought the lights

Figure 1 lighting devices (left) and a dimmer (right)

to their living room and asked them to set the illuminance of the place where they spend a lot of time in the living room so that it would be 50 lx or lower by setting a dimmer (Intervention Period). The amber fluorescent lamp was used for the lighting device. The experimental protocol was reviewed and approved by the Edogawa university ethical review board. IBM SPSS Statistics Ver. 23.0 was used for the analyses. A p-value of < 0.05 was considered statistically significant.

Results and Discussion

Lighting conditions: Figure 2 shows the results of 24-hour recording of illuminance during the baseline period and the intervention period (actually no intervention was carried out in the control group). The vertical axis of the figure shows the illuminance (lx), and the horizontal axis shows the time of the day. The left panel shows the control group and the right panel shows the average pattern of the experimental group. However, in the records of one participant (J-167) in the control group, the illuminance exceeding 6,000 lx was recorded around 9 am. It was considered that the reason was that the illuminometer was placed near the window of the participant's house and the sunlight shone directly on the illuminometer during that time. The illuminance data was excluded from the calculation target of the average pattern shown in Figure 2, because the pattern as a whole is clearly different from other patterns.

In the control group, there seems no change in the pattern of illuminance between the baseline period and the intervention period (actually non-intervention), but in the experimental group, from the baseline to the intervention periods, a marked decrease in illuminance was observed from the evening to the night (after 18:00). The participants of the experimental group adhered to the illuminance condition of maintaining the illuminance below 50 lx as instructed by the experimenter.

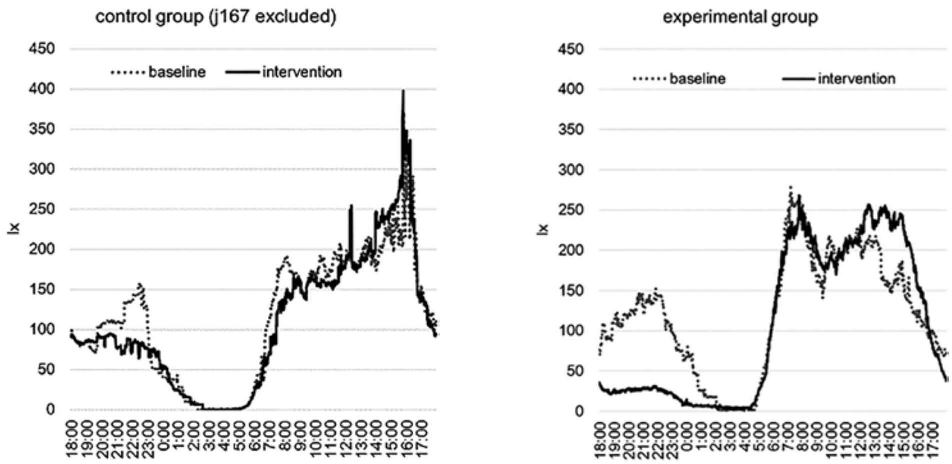

Figure 2 Twenty-four hours Illuminance pattern of the control group (left) and the experimental group (right)

Sleep-wake pattern based on the sleep log: Figure 3 shows the sleep-wake pattern based on the sleep log (0: wakefulness, 1: sleep), expressing as an averaged value in every 15 minutes. The left panel is the pattern of the baseline period (1st to 3rd day). The dotted line indicates the control group, and the solid line indicates the experimental group. The horizontal axis of the figure shows the time of the day, and the vertical axis shows how much of the subjects slept in each time zone, and the higher (closer to 0) the time when the participants are awake. The lower the value is (closer to 1), the more the participants are sleeping. However, the sleep pattern of a participant (J-192-2) in the control group was different from that of other participants, such as nighttime sleep was completely divided and long daytime naps of 1 to 3 hours were observed every day. In the baseline period (left), there was no difference in sleep-wake pattern between the control and the experimental groups. In the intervention period (right), the timings of bedtime and wake-up were shifted earlier in the experimental group than in the control group, and it seems that the phase of the entire pattern was advanced.

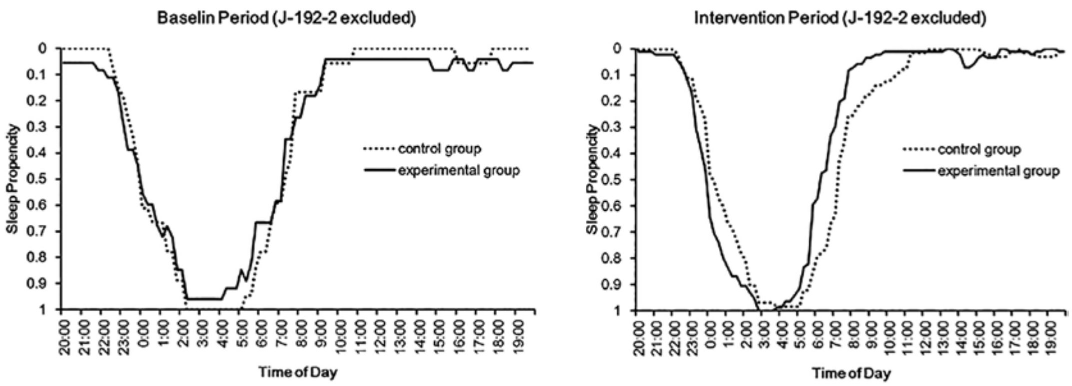

Figure 3 Sleep-wake patterns based on the sleep log (left: baseline period, right: intervention period; dotted line: control group, solid line: experimental group)

The activity pattern based on the activity monitor (actiwatch): The activity data was recorded at 1-minute intervals. We calculated the average value for 15-minutes unit for each group (Figure 4). The activity patterns also showed similar tendency as the data obtained from the sleep log. In the baseline period (left panel), there was no significant pattern differences between the control and the experimental groups, however, in the intervention period (right panel), the time zone for falling asleep and waking up was shifted to the earlier time zone in the experimental group compared to the control group, and the entire activity pattern seems to be advanced.

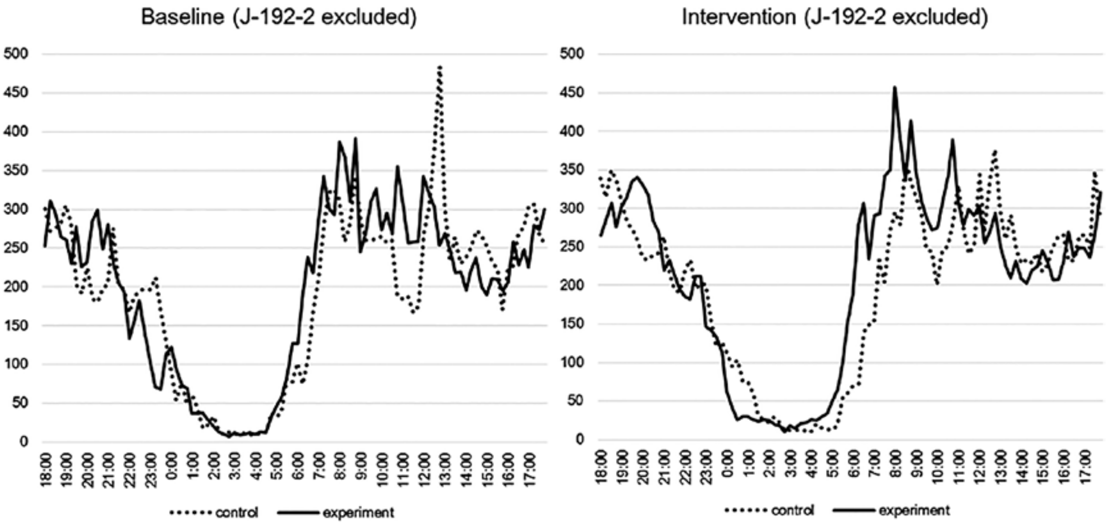

Figure 4 Twenty-four activity patterns based on the activity monitor data (left: baseline period, right: intervention period; dotted line: control group, sold line: experimental group)

Changes in bedtime and rise time based on the sleep log: Daily bedtime and rise time were confirmed from sleep log. We conducted 2×2 factor ANOVA with the main effects of the group (control or experimental groups) and the time factor (baseline or intervention periods). The results are shown in Figure 5. The mean bedtime is shown in the left panel, and the mean rise time is shown in the right panel. No main effects of group and time factor were significant, however, a significant interaction was observed between the group and the time factor for mean rise time (Interaction (Group×Time): F (1,21) = 5.917, p = 0.024*). Based on these results, it is thought that the control group showed that the rise time delayed from the baseline to the intervention period, whereas in the experimental group the rise time advanced. It means that the results were consistent with the results read from the activity pattern. Although the bedtime was not statistically significant, the same tendency as the rise time can be seen from the Figure 5.

Based on the results shown in the Figure 5, during the intervention period, bedtime and rise time were different between the experimental and control groups. However, in the experimental group, the bedtime and rise time are advanced only a little amount of time (bedtime: 8 min, rise time: 10 min), rather the changes of bedtime and rise time were greater (delayed shift) in the control groups (bedtime: 21 min, rise time: 24 min). In other words, it can be seen that the amount

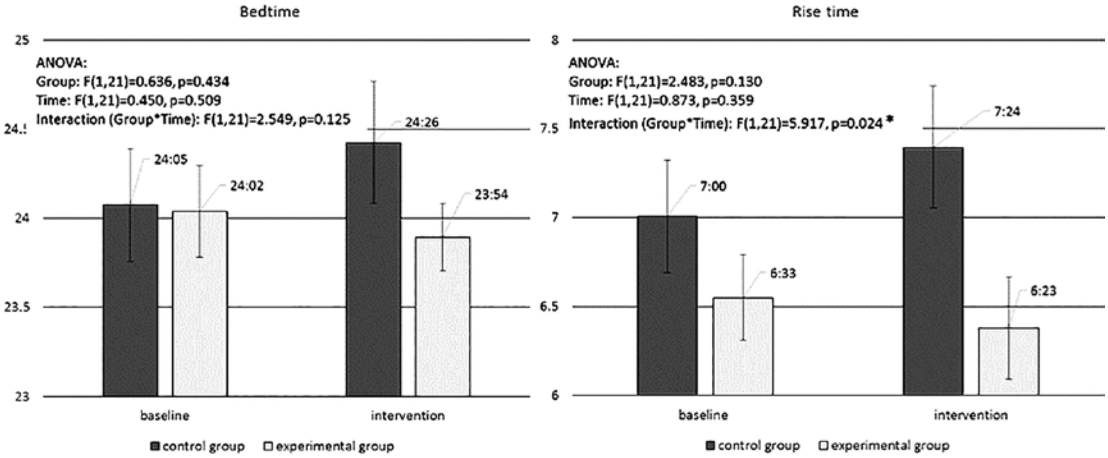

Figure 5 Bedtime and rise time based on sleep log during baseline and intervention periods

of delay was larger than the amount of advance in both bedtime and rise time. Moreover, although the same tendency was observed at the time of falling asleep and the time of waking up, the interaction was only significant in the rise time, but not in the bedtime.

The high-intensity short wavelength (bright and white) lighting that is common in Japanese housing may have a sufficient phase delay effect on biological rhythms. Significant result was observed in the rise time rather than in the bedtime. Changing the lighting conditions at night did not only affect the bedtime, but also caused a clear advanced change in the rise time, suggesting the phase change of the biological rhythm itself.

General Health Questionnaire (GHQ): We examined changes in GHQ scores during the baseline and the intervention periods between the control and the experimental group (Fig. 6, left panel: Likert method, right panel: GHQ method). As a result, in the control group, no significant improvement in mental health (lower scores mean healthier) was observed (Likert: t (10)=0.99, *ns*; GHQ: t (10)=1.21, *ns*). Statistically significant improvement (Likert: t (11)=3.56, $p<0.01$; GHQ: t (11)=3.22, $p<0.01$) was observed in the experimental group.

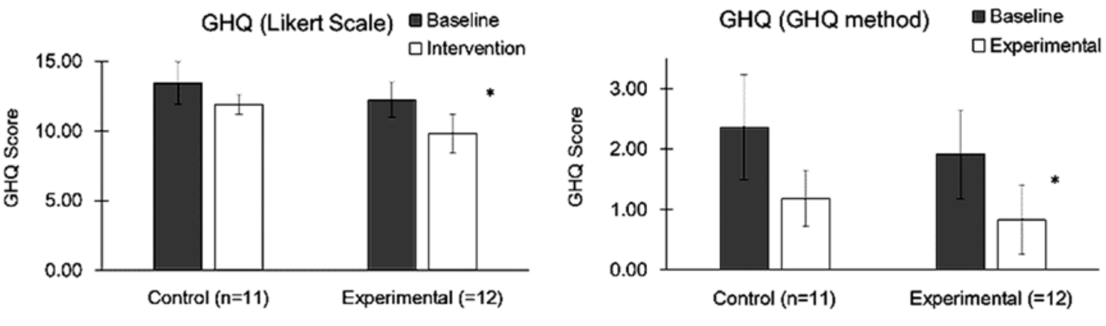

Figure 6 Score change of General Health Questionnaire (Left panel: based on Likert scale; simple sum of all scores, Right panel: based on the formal scoring method of GHQ, convert '0 and 1' to '0' and '2 and 3' to '1')

Conclusions: We conducted intervention study of changing light conditions from 'bright and white' to 'dim and umber' and found significant advance shift of sleep patterns of the residents. Moreover, in the experimental group, they showed significant better GHQ scores after the intervention period.

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