Influence of Light at Night on Melatonin Suppression in Children

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Context: The sensitivity of melatonin to light suppression is expected to be higher in children because children have large pupils and pure crystal lenses. However, melatonin suppression by light in children remains unclear.

Objective: We investigated whether light-induced melatonin suppression in children is larger than that in adults.

Methods: Thirty-three healthy primary school children (mean age, 9.2 ± 1.5 y) and 29 healthy adults (mean age, 41.6 ± 4.7 y) participated in two experiments. In the first experiment, salivary melatonin concentrations in 13 children and 13 adults were measured at night under a dim light (<30 lux) and a moderately bright light (580 lux) in an experimental facility. Pupil diameters were also measured under dim light and bright light. In the second experiment, melatonin concentrations in 20 children and 16 adults were measured under dim light in the experimental facility and under room light at home (illuminance, 140.0 ± 82.7 lux).

Results: In experiment 1, the melatonin concentration was significantly decreased by exposure to moderately bright light in both adults and children. Melatonin suppression was significantly larger in children (88.2%; n = 5) than in adults (46.3%; n = 6; $P < .01$), although the data for some participants were excluded because melatonin concentrations had not yet risen. In experiment 2, melatonin secretion was significantly suppressed by room light at home in children (n = 15; $P < .05$) but not in adults (n = 11).

Conclusion: We found that the percentage of melatonin suppression by light in children was almost twice that in adults, suggesting that melatonin is more sensitive to light in children than in adults at night. **(*J Clin Endocrinol Metab* 99: 3298–3303, 2014)**

Melatonin is secreted from the pineal gland during the night, and the timing of secretion is controlled by the suprachiasmatic nucleus, which is the central circadian pacemaker. Melatonin secretion is suppressed by exposure to light. Suppression of melatonin was first demonstrated by exposure to bright light at 2500 lux in humans (1). Recent studies have shown that melatonin secretion is suppressed even by several hundred lux of room light (2, 3). Negative effects of light at night on health via suppression of melatonin secretion have been discussed in many reports (4–6).

There are interindividual variations in melatonin suppression by light (7, 8). These variations may be important when estimating the effects of light at night. For example, the magnitude of melatonin suppression by light is influenced by several factors, such as recent history of exposure to light (9, 10), ethnicity (11), and aging (12). However, little attention has been given to the effect of light on melatonin suppression in children.

Pupil size decreases with aging (13), and light transmission rate of the crystal lens also decreases with aging

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(14, 15). The decrease in transmission rate with aging is particularly prominent in a short wavelength of light, which has a strong impact on light-induced melatonin suppression (16, 17) and pupillary light response (18–20). These age-dependent characteristics of the eye may influence light-induced melatonin suppression. It has been reported that light-induced melatonin suppression is reduced in elderly people (12). On the other hand, children have large pupils and pure crystal lenses. These ophthalmological characteristics imply high sensitivity of melatonin to light in children.

In modern society, artificial light at night may have adverse effects not only on human sleep but also on health problems such as cancer and obesity (4, 6, 21). These effects are possibly mediated by melatonin suppression by light at night (21). Many studies have shown relationships between sleep problems in children and media use such as watching TV and playing computer games (22–26). Recently, the influence of light from these devices on melatonin secretion has been examined in young adults and adolescents (27–31). Therefore, basic research to clarify the sensitivity of melatonin to light in children is needed to consider an appropriate light environment for children's health.

In the present study, we hypothesized that the magnitude of melatonin suppression is larger in children than in adults, and we therefore compared light-induced melatonin suppression in children and adults.

Subjects and Methods

Participants

Thirty-three healthy primary school children (mean age, 9.2 ± 1.5 y) and 29 of their healthy parents (mean age, 41.6 ± 4.7 y) volunteered to participate in two experiments in this study. An oral and paper-based explanation was conducted before the experiment for children and their parents (adults). All participants gave written informed consent for participation in the study, which was approved by the Ethical Committee of Kyushu University. Informed consent forms for the children were completed by the parents after confirming their child's agreement for participation.

Experimental conditions and procedures in experiment 1

Thirteen healthy children (mean age, 8.6 ± 1.5 y; five males and eight females) and 13 of their parents (mean age, 41.2 ± 4.8 y; three men and 10 women) participated in experiment 1. Beginning 1 week before the start of the experiment, the participants were instructed to maintain their habitual sleep-wake times and keep a sleep diary. The habitual bedtimes for the children and adults were 9:49 PM ± 45 minutes and 11:30 PM ± 60 minutes, respectively. A survey using the Japanese version of the Morningness-Eveningness Questionnaire (32) for adults was conducted. Mean ± SD of the morningness-eveningness score (M-E score) was 54.69 ± 5.95 (two morning types and 11 neither types). None of the participants had any sleep complaints, and none were taking medications.

The experiment was conducted for two consecutive nights in August and September at a meeting room in an accommodation facility in Japan. On the first night, the experiment started at 7:00 PM, and the participants spent time in a sitting position under a dim light condition (<30 lux in angle of gaze) (dim) until their individual habitual bedtimes (or until the end of the experiment at midnight). Saliva samples were collected every hour using a plain cotton plug (Salivette) to analyze melatonin concentration using a RIA (RK-DSM; Bühlmann Laboratories). Pupil diameters were measured by using an electronic pupillometer (FP-10000; TMI). During the experiment, the participants were allowed to read a book, listen to music, watch a movie with a small and dark screen, and have a chat. The participants moved to a bedroom at their own habitual bedtimes and slept until their habitual wake times. Saliva samples at bedtime were not collected from three adult participants who had habitual bedtime later than midnight because the use of the experimental room was limited until midnight.

On the second day, the participants woke up at individual habitual wake times. In the day time, they were asked to refrain from extreme exercise and bright sunlight. On the second night, the protocol and measurements were almost the same as those for the first night of the experiment, except for the lighting condition. The illuminance level was 580 lux in angle of gaze (bright). White fluorescent lamps placed on the ceiling were used for light sources. The percentage of melatonin suppression just before bedtime was calculated on the basis of the data under the dim light condition. The percentage of suppression of melatonin by the light was defined as [(melatonin concentration under dim light at bedtime − melatonin concentration under bright light at bed time)/melatonin concentration under dim light at bedtime] × 100.

Experimental conditions and procedures in experiment 2

The aim of the second experiment was to determine the effects of room light at home on melatonin concentration in children. Twenty healthy children (mean age, 9.7 ± 1.4 y; seven males and 13 females) and 17 of their parents (mean age, 41.9 ± 4.7 y; three men and 14 women) participated in experiment 2. Twelve of the participants (six children and six adults) were the same as those in experiment 1. The habitual bedtimes for children and adults were 9:33 PM ± 45 minutes and 11:22 PM ± 66 minutes, respectively. Mean ± SD of M-E score was 56.8 ± 7.2 in adults (nine morning types, 11 neither types, and one evening type). The experiment on the first night was conducted at the same place and using the same protocol as experiment 1. The experiment started at 7 PM, and the saliva samples were collected under a dim light condition (<30 lux in angle of gaze) (dim) until individual habitual bedtime. The next day, the participants returned home, and they were asked to collect saliva samples within 1 week by themselves at home under a room light (home) condition every hour until individual habitual bedtime. Saliva samples were frozen at home and sent to our laboratory.

The illuminance level and color temperature were measured (CL-200; Konica Minolta Holdings, Inc) in the dining room,

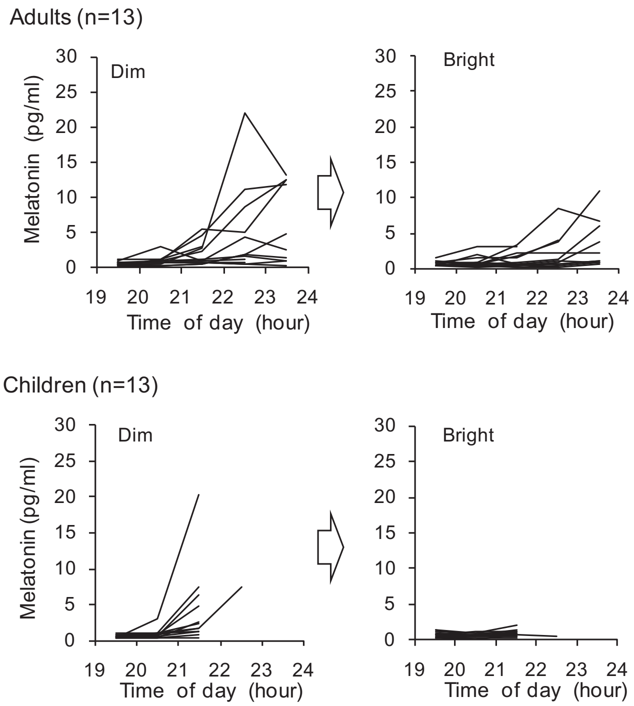

Figure 1. Changes in salivary melatonin concentrations in adults (top) and children (bottom) in experiment 1. Melatonin concentration increased during the night under dim light (left) and was reduced by exposure to bright light (right). In children, melatonin secretion was completely suppressed by light or had not yet risen by bedtime (right, bottom).

living room, and/or private rooms where the participants spent much time at night. This was done in their homes by themselves. The average ± SD of vertical illuminance at eye level for adults and children were 144.7 ± 82.5 lux and 121.8 ± 84.6 lux, respectively. The average color temperatures of light for adults and children were 3812.3 ± 1041.5 K and 4019.6 ± 925.7 K, respectively. No significant difference between adults and children was found for illuminance level or color temperature.

Statistical analysis

Wilcoxon signed-rank test and nonpaired *t* test were used to assess the statistical significance of differences.

Results

Effects of moderately bright light (experiment 1)

Melatonin concentrations under a dim light and under a bright light in experiment 1 are shown in Figure 1. Melatonin secretion in children was completely suppressed by exposure to bright light or had not yet risen by bedtime. There were interindividual differences in the increase in melatonin concentration during the night. Because melatonin concentration did not increase in some children (n = 8) and adults (n = 7), data for these participants were excluded from further analysis. For the remaining participants, the melatonin concentration under bright light was significantly lower than that under dim light in both adults and children ($P < .05$; Wilcoxon signed-rank test) (Figure 2). The percentage of melatonin suppression at bedtime (0 hours) in children was 88.2%, which was significantly larger than that in adults (46.3%) ($t = -3.35$; $P < .01$).

Pupil diameters were significantly decreased by exposure to light in both children and adults. The pupil diameters in children were significantly larger than those in adults under dim light ($t = 5.20$; $P < .01$) and bright light ($t = 4.18$; $P < .01$) (Figure 3). No significant difference was found for constriction rate of pupil size between adults and children ($t = 0.51$; $P = .61$).

Effect of room light at home (experiment 2)

Melatonin concentrations under dim light in the experimental room and room light at home in experiment 2 are shown in Figure 4. The data from six adults and five children were not included because their melatonin concentrations had not yet risen during our collection period. For the remaining participants, there was no significant difference in melatonin concentrations under dim light and under room light in adults. On the other hand, melatonin concentration in children at bedtime was significantly

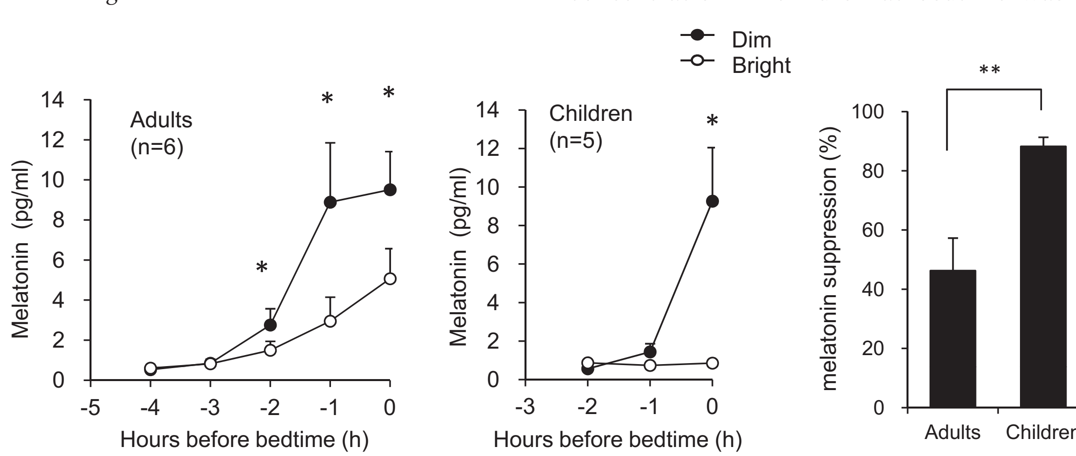

Figure 2. Average melatonin concentrations and percentages of melatonin suppression (mean + SE) in experiment 1. Zero hours means the bedtime of each participant. The data for some participants were excluded because their melatonin concentration did not increase before bedtime. The melatonin concentration under bright light was significantly lower than that under dim light. The percentage of melatonin suppression before bedtime in children (88.2%; n = 5) was significantly larger than that in adults (46.3%; n = 6). **, $P < .01$; *, $P < .05$.

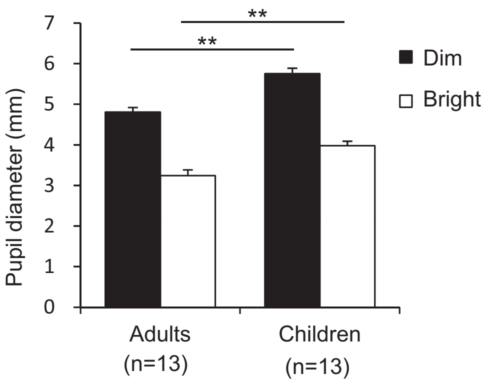

Figure 3. Pupil diameters (mean + SE) in adults and children in experiment 1. The pupil diameter in children was significantly larger than that in adults under both dim light and bright light. **, $P < .01$.

lower under room light than under dim light ($P < .05$; Wilcoxon signed-rank test). The percentage of melatonin suppression in children was 51.6% and tended to be higher than that in adults (26.7%) (t = 1.90; $P = .069$).

Discussion

We found that light-induced melatonin suppression in children was significantly greater than that in adults. Surprisingly, melatonin secretion in children had not yet risen by bedtime or was completely suppressed by light at 580 lux at eye level (Figures 1 and 2). The percentage of melatonin suppression in children was 88.2%, which was almost twice that in adults (46.3%). This percentage is consistent with the estimation of age-dependent circadian photosensitivity by Turner and Mainster (33). They estimated that circadian photoreception of 10-year-old children is twice that of 45-year-old adults due to age-related losses in crystalline lens transmittance and pupillary area.

In the present study, pupil size in children was significantly larger than that in adults (Figure 3), which is consistent with the results of previous studies (13). Large pupil size in children might be a cause of large melatonin suppression. In experiment 1, the average pupil area under bright light in children (49.7 mm^2) was 1.5 times that in adults (33.0 mm^2). On the other hand, the percentage of melatonin suppression in children (88.2%) was 1.9 times that in adults (46.3%). These findings suggest that more than half of the difference in melatonin suppression in children and adults would be explained by pupil area. Although the high transmission rate of a short wavelength of light in the crystal lens of a child (14, 33) might be another reason for the large melatonin suppression in children, further studies are needed to test this hypothesis.

Unfortunately, the percentage of melatonin suppression by light in half of the participants was not calculated because melatonin concentration did not increase before habitual bedtime. This means our data might be limited to subjects with early chronotype. Because some studies have suggested a correlation between delayed sleep phase and higher light sensitivity (34, 35), we might have underestimated or overestimated the amount of melatonin suppression in the present study. We need to clarify this limitation in further study.

In the present study, melatonin concentration at home under artificial light was measured. We found that melatonin was significantly suppressed in children but not in adults. The percentages of melatonin suppression in children and adults were 51.6 and 26.7%, respectively (Figure 4). Melatonin suppression in children was almost twice that in adults. This was consistent with the results of the experiment 1. We obtained reproducible results and confirmed that melatonin in children is more sensitive than

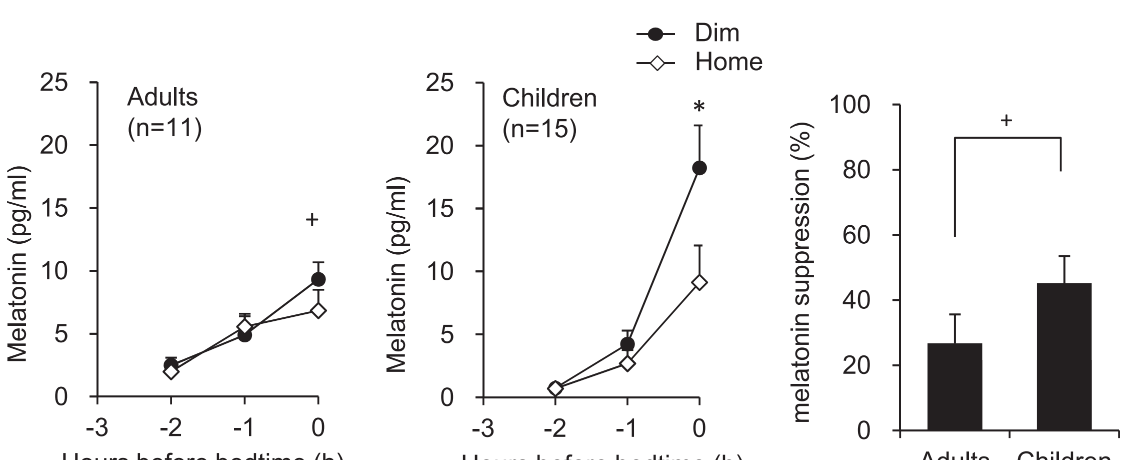

Figure 4. Melatonin concentrations (mean + SE) under dim light in the experimental facility and under room light at home in adults and children in experiment 2. Zero hours means the bedtime of each participant. Melatonin concentration in children was significantly lower under room light at home than under dim light in the experimental facility. The percentage of melatonin suppression in children (51.6%; n = 15) tended to be higher than that in adults (26.7%; n = 11). *, $P < .05$; +, $P < .10$.

that in adults to light at night, even light of several hundred lux like an ordinary room light.

It has been reported that melatonin in almost all adults is suppressed by exposure to room light at 200 lux (2). However, we did not find significant melatonin suppression in adults at home. This inconsistent result may be caused by the difference in ethnicity of subjects. It has been reported that light-induced melatonin suppression was larger in a European population than in an Asian population (11). The fact that the participants in the present study were all Japanese might be the reason why no significant melatonin suppression was found with exposure to room light.

Furthermore, the lighting condition during daytime might be another reason. It has been reported that less exposure to light during daytime can increase sensitivity to light, which results in large melatonin suppression by light at night (9, 10, 36). Because we did not strictly control the lighting condition during daytime in the present study, exposure to natural bright light such as sunlight during the daytime might have diminished sensitivity to light at night. There might also have been some bias in the home condition as discussed below.

We did not strictly control the posture in the home condition. It has been shown that posture can influence melatonin concentration in some studies (37, 38) but not in other studies (39). Although the effect of posture on melatonin concentration remains controversial (40), illuminance at eye level varies depending on posture. Although it has been reported that there was a significant correlation between dim light melatonin onset measured in the laboratory and that at home without posture control (41), posture control and/or continuous monitoring of illuminance at eye level may be desirable when examining the effect of room light on melatonin concentration.

In modern society, many studies have shown relationships between sleep problems in children and media use such as watching TV and playing computer games (22, 24–26). Recently, the influence of light from these devices on melatonin secretion has been examined in young adults and adolescents (27–31). In the present study, we found that melatonin suppression in primary school children was more sensitive to light than that in adults. Furthermore, melatonin concentration in some children had not yet risen by bedtime. One study showed that adolescents living in homes without electric lighting have earlier sleep times (42). Although there is room for discussion on the relationships of melatonin suppression by light exposure at night with sleep and health in children (43), more attention should be paid to the lighting environment at night for children. Furthermore, it would be important to know about homeostatic and circadian components in children of this age (44).

Conclusions

We found that the percentage of melatonin suppression by light in children was almost twice that in adults, suggesting that melatonin in children is more sensitive than that in adults to light at night.

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