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Effectiveness of a Red-visor Cap for Preventing Light-induced Melatonin Suppression during Simulated Night Work

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Abstract Bright light at night improves the alertness of night workers. Melatonin suppression induced by light at night is, however, reported to be a possible risk factor for breast cancer. Short-wavelength light has a strong impact on melatonin suppression. A red-visor cap can cut the short-wavelength light from the upper visual field selectively with no adverse effects on visibility. The purpose of this study was to investigate the effects of a red-visor cap on light-induced melatonin suppression, performance, and sleepiness at night. Eleven healthy young male adults (mean age: 21.2±0.9 yr) volunteered to participate in this study. On the first day, the subjects spent time in dim light (<15 lx) from 20:00 to 03:00 to measure baseline data of nocturnal salivary melatonin concentration. On the second day, the subjects were exposed to light for four hours from 23:00 to 03:00 with a nonvisor cap (500 lx), red-visor cap (approx. 160 lx) and blue-visor cap (approx. 160 lx). Subjective sleepiness and performance of a psychomotor vigilance task (PVT) were also measured on the second day. Compared to salivary melatonin concentration under dim light, the decrease in melatonin concentration was significant in a nonvisor cap condition but was not significant in a red-visor cap condition. The percentages of melatonin suppression in the nonvisor cap and red-visor cap conditions at 4 hours after exposure to light were 52.6±22.4% and 7.7±3.3%, respectively. The red-visor cap had no adverse effect on performance of the PVT, brightness and visual comfort, though it tended to increase subjective sleepiness. These results suggest that a red-visor cap is effective in preventing melatonin suppression with no adverse effects on vigilance performance, brightness and visibility. *J Physiol Anthropol 30(6): 251–258, 2011* http://www.jstage.jst.go.jp/browse/jpa2
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Introduction

Humans in modern society benefit from artificial light in various ways. Despite the benefits of artificial light, recent studies have shown that artificial light at night may have negative effects on health in shift workers (Stevens, 2009a). In the field of physiological anthropology, studies on human physiological and cultural adaptation to artificial light and lifestyle are therefore important.

Studies performed in the 1990s showed that bright light at night increases alertness of night workers and shifts their circadian rhythm rapidly (Dawson and Campbell, 1991; Eastman et al., 1995). Some later epidemiological studies, however, showed that shift work can increase the risk of cancer (Davis et al., 2001; Hansen, 2001; Schernhammer et al., 2001). Suppression of melatonin secretion by exposure to light at night is thought to be one of the causes of the risk of cancer in shift workers (Blask et al., 2003; Stevens, 2009b). Therefore, a countermeasure to prevent melatonin suppression by light without a decrease in alertness is needed.

Melatonin secreted from the pineal gland reveals the circadian rhythm. Melatonin is secreted at night and its secretion is suppressed by exposure to light. Recent studies have shown that nocturnal melatonin secretion can be suppressed by exposure to a light of several hundred luces (Aoki et al., 1998; Gooley et al., 2011; Higuchi et al., 2003; Zeitzer et al., 2000). The magnitude of melatonin suppression by light depends on not only the light intensity but also the spectrum of light. Short-wavelength light at around 460 nm (blue light) has been reported to be the most effective for melatonin suppression (Brainard et al., 2001; Thapan et al., 2001). Melanopsin-expressing retinal ganglion cells (mRGCs) were recently discovered as new retinal photoreceptors (Berson et al., 2002; Provencio et al., 2000). mRGCs are most sensitive to short-wavelength light and are involved in light-induced melatonin suppression via the retinohypothalamic tract (RHT) (Lockley and Gooley, 2006).

Some studies have shown that cutting short-wavelength light is an effective way to prevent melatonin suppression by light at night. Wearing orange color (blue blocker) goggles has been suggested to be effective for preventing melatonin suppression by light (Kayumov et al., 2005; Sasseville et al., 2006). A very low color temperature light (2300 K) using a special filter that absorbs the shortwave-length has also been reported to be effective for preventing melatonin suppression by light (Kozaki et al., 2008). These countermeasures, however, have a problem of visibility of color in the visual field that may lead to human error or accidents in the workplace. Another possible problem is that cutting short-wavelength light may increase sleepiness, since some studies have shown that short-wavelength light increases alertness (Cajochen et al., 2005; Lockley et al., 2006; Revell et al., 2006).

In the present study, we focused on the use of a red-visor cap as a possible countermeasure to prevent melatonin suppression. The merits of a red-visor cap are that it is easy to use and is inexpensive and has no adverse effect on visibility. Cutting off short-wavelength light from the upper visual field is an another merit of a visor cap, since previous studies have shown that inferior retinal light exposure is more effective than superior retinal exposure in suppressing melatonin (Glickman et al., 2003; Lasko et al., 1999).

Since light-induced melatonin suppression and increase in alertness share a part of the neural pathway and nucleus involving the non-image forming effects of light (Gooley et al., 2003), it is doubtful whether we can prevent light-induced melatonin suppression with no adverse effect on alertness. However, according to a previous study, light-induced melatonin suppression is not necessarily accompanied by increase in alertness (Ruger et al., 2005). Furthermore, it has been reported that filtering short-wavelength light prevents melatonin suppression without decrease in subjective or objective alertness (Kayumov et al., 2005; Rahman et al., 2011). A recent study showed that even red light can increase alertness at night (Figueiro et al., 2009). Further studies are needed to clarify the relationship between prevention of light-induced melatonin suppression and alertness.

The purpose of the present study was to investigate the effects of a red-visor cap on melatonin suppression, sleepiness, and performance of a vigilance task in a simulated night work environment.

Methods

Subjects

Eleven healthy male students (mean age: 21.2±0.9 yr) volunteered to participate in the present study. None of the subjects had any sleep complaints, and none of the subjects were taking medications or working night shifts. Before the experiment, each subject completed a Japanese version of the Morningness–Eveningness Questionnaire (MEQ) (Horne and Ostberg, 1976) and a questionnaire on sleep habits (habitual bedtime, habitual rising time, sleep quality, etc.). Mean and standard deviation of the morningness–eveningness score (M–E score) was 49.2±5.5. None of the subjects were either extreme morning-type or extreme evening-type. Subjects were instructed not to consume alcohol and not to perform intense exercise 24 hours prior to the experiments. Subjects gave written informed consent for participation in the study, which was approved by the Ethics Research Committee in the Faculty of Design, Kyushu University.

Lighting conditions and visor-cap

White fluorescent lamps (FLR-40S W/M 4200K, Matsushita Electric Industrial Co., Ltd., Osaka, Japan) placed on the ceiling were used for light sources. The iluminance level was set at 500 lx in the direction of gaze at the subject's eye level (nonvisor), which was measured using a light meter (CL-200, KONICA MINOLTA HOLDINGS, INC., Tokyo, Japan). Spectral irradiance at the subject's eye level was also measured (LightSpex, McMahan Research Laboratories, Chapel Hill, NC) (Fig. 1). A commercially available red-visor cap (red visor) was used. Wearing the red visor decreased the illuminance level of the subject's eye level at approximately 160 lx (150–170 lx) and cut the spectrum of the short wavelength of light (Fig. 1). Table 1 shows the irradiance (μW/cm^2) at eye level for 50-nm wavelength blocks in each condition. To determine the effect of spectrum change by the red visor, a blue-visor cap (blue visor) was also used. The

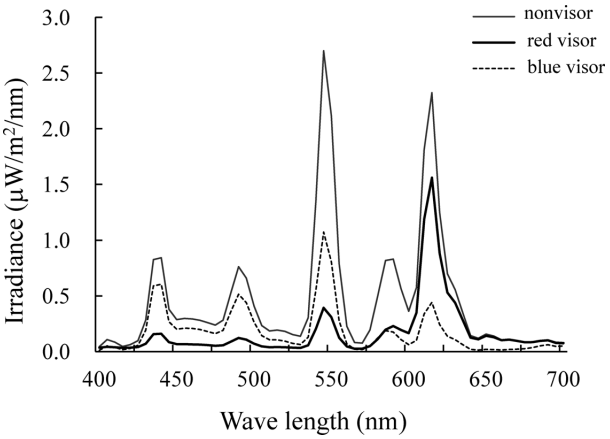

Fig. 1 Spectral irradiance at eye level in each condition.

Table 1 Irradiance (mW/cm^2) at eye level for 50-nm wavelength blocks in each condition

	Nonvisor	Red Visor	Blue Visor
400–450 nm	13.9	3.5	9.3
450–500 nm	19.5	3.8	13.3
500–550 nm	29.3	4.8	13.1
550–600 nm	31.0	6.6	9.2
600–650 nm	40.9	28.2	7.7
650–700 nm	5.2	5.1	1.6
Total	139.8	52.0	54.2

illuminance level of the blue visor was the same as that of the red visor.

The experimental room was set to a dim light (<15 lx) except for the period of exposure to each light condition. During the experiments, room temperature and relative humidity were set at 26°C and 50%, respectively.

Procedure

The study was conducted during the period from June to July in Japan. Beginning one week prior to the start of the experiment, the subjects were instructed to wake up between 07:00 and 08:30 and to go to bed between 23:30 and 01:00 in order to maintain regular sleep-wake cycles. Self-recording of a sleep diary was conducted to confirm each subject's compliance. The average times when the subjects woke up and went to bed were 08:11±36 mins and 0:50±26 mins, respectively. The sleep/wake pattern was also recorded every minute using an accelerometer (Actiwatch-L, Mini-Mitter Co., Inc., USA) that was attached to each subject's nondominant wrist. Although two subjects went to bed after 01:00 and woke up after 08:30, they were not excluded from the analysis because their sleep timing and melatonin onset were stable through the experiments.

On the first night, each subject spent 7 hours (from 20:00 to 03:00) in the experimental room under a dim light condition (<15 lx), and saliva samples were collected every hour to determine nocturnal variation in salivary melatonin concentration. The subjects were allowed to listen to music or read a book but were not allowed to sleep. The subjects slept in the laboratory from 03:00 to 08:00, and saliva samples were collected after they awoke.

On the next night, an experiment was conducted to determine the magnitude of melatonin suppression by light. The subjects visited the laboratory at 20:00 and spent 3 hours in the experimental room under dim light (<15 lx). They were then exposed to each lighting condition for 4 hours (from 23:00 to 03:00). During the exposure to light, each subject sat on a chair and watched an unexciting movie to fix his eyes. A 7-inch liquid crystal display (LCD) display was placed about 50 cm in front of the subject. The light intensity of the LCD display was very small (<5 lx) compared to that of the room light. On the second night, each subject performed a psychomotor vigilance task (PVT) every hour as an index of objective sleepiness (Dinges and Powell, 1985). Subjective sleepiness, fatigue, mood, visual comfort and brightness were also measured every hour using a visual analogue scale (VAS). The experiment was conducted in a randomized crossover manner. The interval between the experiments was at least one week.

Measurements

Saliva samples were collected using a plain cotton plug (Salivette, Sarstedt, Germany). The saliva samples were kept frozen at −30°C until analysis. After centrifugation (for 5 min at 3000 rpm), melatonin concentrations in the saliva samples every two hours were determined using a radioimmunoassay (RK-DSM, Bülmann, Switzerland). The percentage of suppression of melatonin concentration induced by the light was defined as [(melatonin concentration under dim light on the 1st night−melatonin concentration during exposure to light on the second night)/melatonin concentration under dim light on the 1st night]×100.

The PVT was a simple reaction time task to a visual stimulus, presented approximately 10 times/minute (inter-stimulus interval being varied from 2 to 10 s) for 10 min (Dinges and Powell, 1985). The subjects were asked to press the button as quickly as possible after the appearance of the visual stimulus. Mean reaction time (RT) and number of lapses (lapse = response latency exceeding 500 ms) were measured. According to previous studies (Dinges et al., 1997; Kaida et al., 2006), the mean of the RTs was transformed to reciprocal RTs (1/mean RTs) and the numbers of lapses were transformed as sqrt (x)+sqrt $(x+1)$, where x is the concerting number.

Statistical analysis

Two-way ANOVA (visor condition and time of day) with repeated measurements and the paired *t*-test were performed to determine significance.

Results

Melatonin concentration

Salivary melatonin concentration on the first night increased during the night and decreased in the morning in the three conditions (Fig. 2). There was no significant difference among the melatonin concentrations on the first night in the three conditions. On the second night, salivary melatonin concentration in the nonvisor condition was significantly decreased by light exposure. However, no significant melatonin suppression by light exposure was found in the red visor and blue visor conditions. The percentages of melatonin suppression by light are shown in Fig. 3. The percentages of melatonin suppression in the nonvisor, red visor and blue visor conditions at two hours after exposure to light were 57.0±26.6%, 20.3±32.1% and 31.1±41.5%, respectively. A significant difference was found only between the nonvisor and red visor conditions. The percentages of melatonin suppression in the nonvisor, red visor and blue visor conditions at four hours after exposure to light were 52.6±22.4%, 7.7±3.3% and 3.3±67.6%, respectively. The percentages of melatonin suppression in the red visor and blue visor conditions were significantly lower than that in the nonvisor condition.

Results of ANOVA for transformed number of lapses and reciprocal mean reaction time of the PVT showed main effects of time of day, but main effects of visor condition and significant interaction were not found. Although transformed lapses in the PVT (Fig. 4a) and reciprocal mean reaction time significantly increased during the night, significant differences among the visor conditions were not found. Results of ANOVA of subjective sleepiness after light exposure showed main

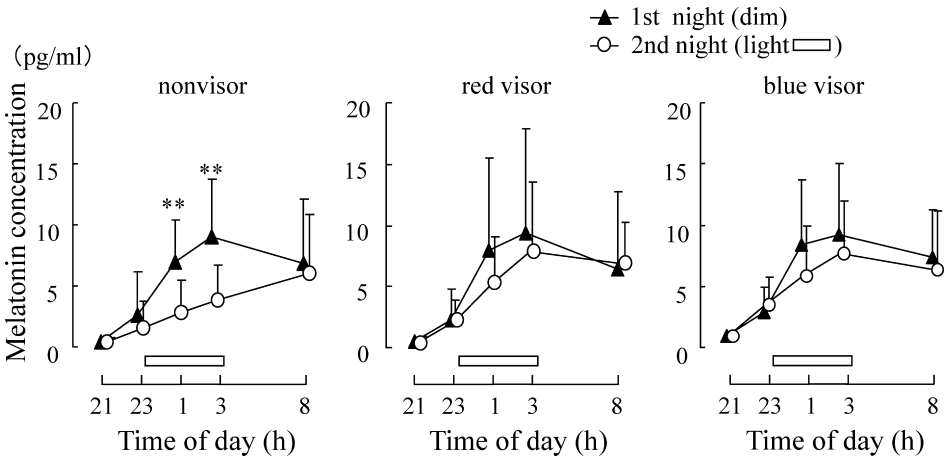

Fig. 2 Salivary melatonin concentration in each condition (means+*SD*). Significant melatonin suppression was found in the nonvisor condition but not in the red visor and blue visor conditions. **: $p<0.01$

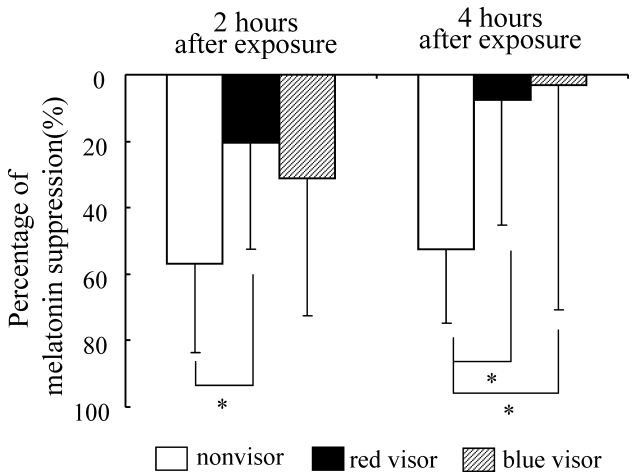

Fig. 3 Percentage of melatonin suppression after exposure to light (means+*SD*). The percentages of melatonin suppression in the red visor and blue visor conditions were significantly lower than that in the enonvisor condition. *: $p<0.05$

effects of time of day ($p<0.01$) and visor condition ($p<0.01$). No significant interaction between time of day and visor condition was found (Fig. 4b). Subjective sleepiness in the red visor condition tended to be higher at 1:00 and 2:00 than that in the nonvisor condition ($p<0.10$). Subjective sleepiness in the blue visor condition was significantly higher at 1:00 and 3:00 than that in the nonvisor condition. No significant difference was found between subjective sleepiness in the red visor condition and that in the blue visor condition.

Although subjectively rated brightness of the visual field significantly increased after light exposure, no significant differences were found among the visor conditions (Fig. 4c). Visual comfort tended to decrease after light exposure and no significant differences were found among the visor conditions. Although increase in subjectively rated mental fatigue and decrease in mood were found during the night, no significant differences were found among the visor conditions.

Pupil area in the nonvisor, red visor and blue visor conditions significantly decreased after exposure to light. Although pupil area after light exposure showed no significant difference among the three conditions, the percentage of pupil constriction in the blue visor condition was significantly higher than that in the red visor. The percentage of pupil constriction in the nonvisor, red visor, and blue visor conditions were 12.9±16.9%, 8.8±13.4%, and 21.4±10.2%, respectively.

Discussion

Use of the red-visor cap significantly prevented melatonin suppression that occurred in the nonvisor condition. Salivary melatonin concentration in the red-visor condition was almost the same as that in the dim light condition. Decrease in illuminance level by wearing the red-visor cap would be one reason for the prevention of melatonin suppression because dose-response relationship exists between illuminance level and magnitude of melatonin suppression (Aoki et al., 1998; McIntyre et al., 1989). It has been shown, however, that even 100 lx of light has the potential to suppress melatonin secretion (Zeitzer et al., 2000). In the red visor condition, no significant suppression was induced even though light of 160 lx was thought to be sufficient to suppress melatonin secretion. This result suggests that there may be other reasons other than illuminance level.

Decrease in short-wavelength light is thought to be one of the other reasons for prevention of light-induced melatonin suppression by wearing the red-visor cap since previous studies have shown that cutting short-wavelength light was an effective way to prevent light-induced melatonin suppression (Kayumov et al., 2005; Kozaki et al., 2008; Sasseville et al., 2006). In the present study, irradiance of short-wavelength light (450–500 nm) at eye level was decreased from 19.5 μW/cm^2 to 3.8 μW/cm^2 by wearing the red-visor cap (Table 1). Two previous studies have demonstrated that inferior

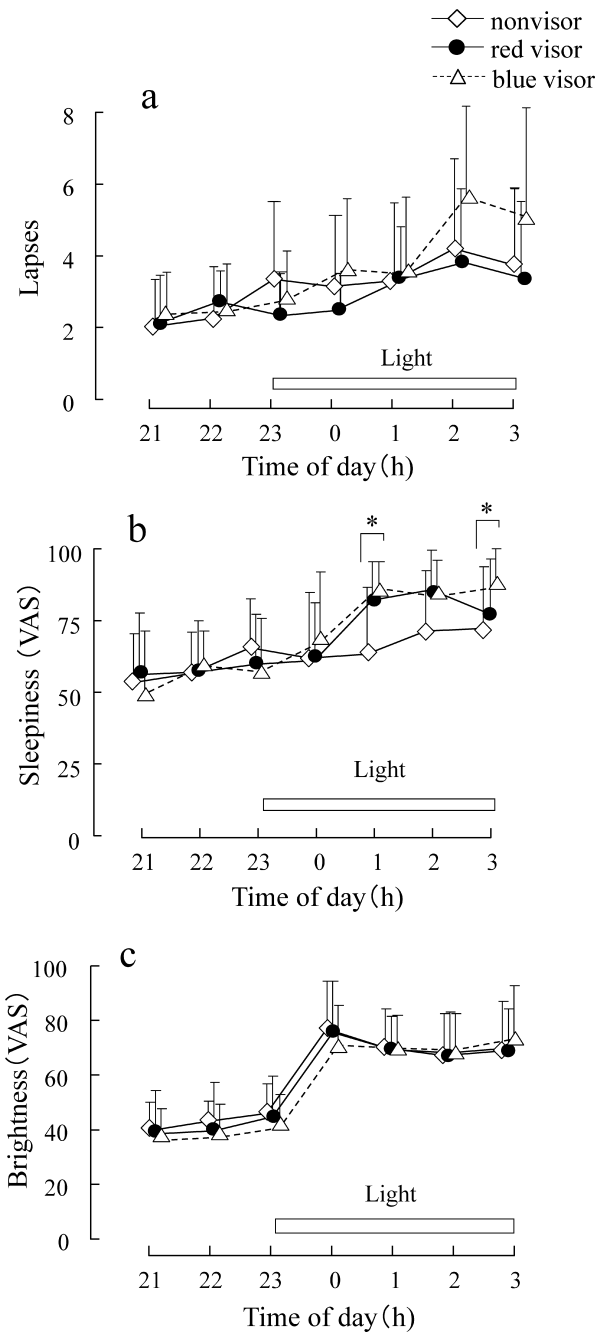

Fig. 4 (a) Transformed of number of lapses (reaction times greater than 500 ms) in the PVT in each condition (means+*SD*). No significant differences were found in number of lapses among the three visor conditions. (b) Subjectively rated sleepiness (VAS) in each condition (means+*SD*). Subjective sleepiness in the blue visor condition was significantly higher than that in the nonvisor condition (*: $p<0.05$). (c) Subjectively rated brightness of the visual field in each condition (means+*SD*). No significant differences were found in brightness among the three visor conditions.

retinal light exposure is more effective than superior retinal exposure in suppressing melatonin secretion in humans (Glickman et al., 2003; Lasko et al., 1999). The red-visor cap is able to selectively cut off the light from the upper visual field. This may be the reason why the red-visor cap can efficiently prevent melatonin suppression by light.

Contrary to our expectation, there was no significant difference between percentages of melatonin suppression in the red visor and blue visor conditions. We found that the blue visor prevented meatonin suppression (Fig. 2). As well as the red visor condition, decrease in illuminance level by wearing the blue-visor cap would be one reason for the prevention of melatonin suppression. Furthermore, even the blue-visor cap decreased irradiance of short-wavelength light (450–500 nm) from 19.5 μW/cm^2 to 13.3 μW/cm^2. A recent study has shown that middle-wavelength light (555-nm light) was as effective as short-wavelength light (460-nm light) for suppressing melatonin at the beginning of light exposure and at low irradiance (Gooley et al., 2010). In the present study, irradiance of middle-wavelength light (500–600 nm) at eye level was decreased from 60.3 μW/cm^2 to 22.3 μW/cm^2 by wearing the blue-visor cap (Table 1). In the comparison of data for percentages of melatonin suppression in the nonvisor condition, a significant difference was found at two hours after light exposure in the red visor condition, but no significant difference was found in the blue visor condition (Fig. 3). These results suggested that cutting short-wavelength light by using a red-visor cap could be more effective than using a blue-visor cap for preventing melatonin suppression.

In the present study, the percentage of pupil constriction in the blue visor condition was significantly larger than that in the red visor condition. This is consistent with the results of a previous study showing that pupil constriction is sensitive to short-wavelength light (Gamlin et al., 2007). Melanopsin-expressing retinal ganglion cells (mRGCs), recently identified retinal photoreceptors, are involved in light-induced pupillary constriction (Gamlin et al., 2007; Tsujimura et al., 2010). The results of the present study suggested that response to mRGCs was lower in the red visor condition than in the blue visor condition. It has been shown that dilated or large pupils increase light-induced melatonin suppression (Gaddy et al., 1993; Higuchi et al., 2008). In the present study, the constriction of pupils in the blue visor condition may have weakened the melatonin suppression by light.

Use of the red-visor cap had no significant adverse effect on performance of the PVT (number of lapses and mean reaction time), though subjective sleepiness tended to be higher in the red visor condition than in the nonvisor condition. In previous studies, there was a discrepancy between subjective sleepiness and performance of a PVT (Belenky et al., 2003; Kaida et al., 2007; Van Dongen et al., 2004). The reason for the discrepancy is that subjective sleepiness can easily be affected by internal and external factors such as mental activity, music, and communication (Kaida et al., 2007). Sleepiness in the red-visor cap conditions is thought to be due to the decrease in illuminance level from 500 lx to 150–170 lx, since it has been reported that one hundred lux of light is sufficient to increase subjective alertness (Cajochen et al., 2000).

As for the effect of color of the visor on subjective

sleepiness and performance, it has been reported that short-wavelength light has more impact on subjective and objective alertness as well as melatonin suppression (Cajochen et al., 2005). Contrary to our expectation, there was no significant difference between alertness in the red visor and that in the blue visor condition. Compared with the nonvisor condition, a significant increase in subjective sleepiness was only observed in the blue visor condition. A recent study has shown that both blue light and red light can increase alertness at night (Figueiro et al., 2009). The effects of color of light on subjective sleepiness seem to involve complicated mechanisms including not only non-visual but also visual pathways.

It has already been demonstrated that wearing goggles with a filter that blocks all short-wavelength light less than 530 nm prevents melatonin suppression with no adverse effect on subjective sleepiness and performance of a vigilance task (Kayumov et al., 2005). In addition to these benefits, the merit of the red-visor cap is that there were no adverse effects on brightness and visual comfort. To clarify the merits of red-visor cap for visibility, visual performance should have been tested in various ways.

This kind of visor cap is thought to be useful for shift workers who are exposed to artificial light in their workplaces. Particularly for shift workers engaged in a rapid rotation system, the visor cap may be useful for preventing light-induced phase delay of circadian rhythm. Since it is difficult to adjust the illuminance level and the spectrum condition in many workplaces, use of the visor cap may be a useful countermeasure on an individual level. Although lowering illuminance level in a workplace may be an effective way for economically preventing light-induced melatonin suppression, it may be difficult to maintain alertness and performance level. To answer this question in the present study, 160 lx of a nonvisor condition should have been added. The combination of other countermeasures such as a nap and caffeine (Schweitzer et al., 2006; Takahashi, 2003) should be considered for retaining alertness in a moderately low illuminance level.

In conclusion, the use of a red-visor cap is a potential countermeasure for preventing melatonin suppression by light with no adverse effect on performance and visibility of night workers. In the field of physiological anthropology, many studies have shown the effects of light on human physiological functions and health (An et al., 2009; Higuchi et al., 2005; Hirota et al., 2010; Kohyama, 2011; Kozaki et al., 2011). Accumulation of scientific data will enable cultural adaptation, including behavioral and instrumental adaptation, to avoid unfavorable effects of artificial light.

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