Light Attenuation by the Human Eyelid

Katsuhisa Ando and Daniel F. Kripke

Although it has been reported that light treatment during sleep can modify biological rhythms, the amount of light that is transmitted through the human eyelid has not been established. We evaluated eyelid transmission with a visual threshold response. Estimated light transmission through the eyelids was 0.3% for blue, 0.3% for green, and 5.6% for red light. The eyelid was an effective attenuator and acted as a red-pass filter. Illumination intensity and color balance after passing through the eyelid should be considered in evaluating the effects of light treatments during sleep.

Key Words: Light, eyelid, transmission, color, human, eye

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Introduction

Recent studies have shown that light treatment during sleep can influence several parameters of body physiology, including seasonal mood swings (Terman et al 1990; Avery et al 1992, 1993), sleep-wake cycles (Jacobsen 1990), and the length of the menstrual cycle (Dewan 1967; Lin et al 1990; Kripke 1993). The amount of light necessary to achieve these effects has been partly characterized by the illumination presented to the closed eyelid; however, the extent to which light is attenuated by the eyelid has not been established. This study defined the illumination necessary to yield a visual threshold response, both with the eyelids open and the eyelids closed. By comparing the respective thresholds, we determined the light attenuation by the eyelid.

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Method

Visual thresholds were determined for large fields and short exposure without fixation.

Apparatus and Stimulus Conditions

The light source was a tricolor light-emitting diode (LED) (LEDtronics DIS-1018-004), which generated blue light (spectral peak 470 nm, half-peak bandwidth 400–510 nm), green light (555 nm, 540–565 nm) and red light (630 nm, 615–635 nm). A colorless optical diffusing glass (opal glass #43719, thickness 6.25 mm), set 2 cm distant from the subject's right eye, was illuminated by the LED. The subject viewed the opal glass from the side opposite the light source. The LED was mounted on a movable base on a straight rail. Several specific illumination intensities were obtained by changing the distance (3.0–87.5 cm) between the opal glass and the LED. Neutral density filters (Kodak Wratten gelatin filters ND 0.30, 1.00, 2.00, and 3.00) were placed over the LED to adjust intensities as necessary. The subject's head was immobilized by a head-holder and draped with black cloth to exclude background light coming from other directions. The left eye was covered. We did not fix the subject's visual axis and

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did not control pupil size; that is, no mydriatic drugs or artificial pupils were used.

Subjects

Eleven volunteers (6 men and 5 women, 8 white and 3 Asian) gave verbal consent approved by our Institutional Review Board (IRB). They ranged in age from 22–43 years and had normal or corrected normal visual acuity in the test eye. There was no significant difference in age between men and women.

Protocol

The experiment was performed in a completely darkened room after the subjects were dark-adapted for at least 20 minutes. For the yes-no detection paradigm, real or dummy flashes accompanied by a brief tone were randomly presented every 1.5 sec until 30 real flashes had been presented. Consequently, each trial consisted of about 50–70 real and dummy flashes. Flashes had 9.8 msec durations. Subjects were instructed to press a key if they could perceive a flash. The numbers of real and dummy flashes and of true and false subject responses were recorded. To find the approximate distance setting for the threshold, the experimenter gradually varied the position of the LED to grossly locate the threshold of perception. Then four to eight trials at intensities around the presumed threshold were completed. Flashes were presented in six series consisting of each of the three colors under both the eyes-open and eyes-closed conditions. We counterbalanced the order of presentation of eyes-open and eyes-closed between subjects, and we randomized the orders of light color and intensity presentations.

Data Analysis

The following calculations were carried out for eyes-open and eyes-closed for each color, respectively. The true proportion of perceptions was estimated by

$$\text{True proportion of perceptions} = \frac{T/R - F/D}{1 - F/D}$$

where T was true responses, F was false positive responses, R was real presentations ($R = 30$) and D was dummy presentations. Next, we measured the illumination intensity on the surface of the opal glass opposite the LED, using a precision photometer (United Detector 351 power meter) with photometric spectral sensitivity. We estimated illumination by weighing and making corrections for distance and filters. To each set of points relating the proportion of perception to the illumination intensity, a logistic curve was fit by least squares methods. The equation of the logistic curve was

$$\ln\left(\frac{P}{1 - P}\right) = \alpha + \beta * \ln(I)$$

where P was the proportion of perception, I was the illumination intensity, and α and β were constants. The threshold 50% detection level ($P = 0.5$) was then estimated from the best-fitting logistic curve. Figure 1 demonstrates observed data points and best-fitting curves of one subject. Finally, to estimate the attenuation of the eyelid, the threshold in the open-eye (O) condition was divided by the closed-eye (C) threshold (O/C ratio), presented as a percentage.

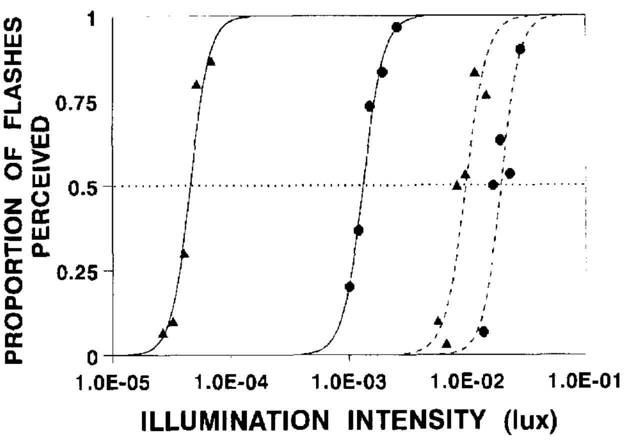

Figure 1. Example of estimations of threshold illumination intensity for a 28-year-old woman. *Circles* = observed data with red light. *Triangles* = observed data with green light. *Lines* = the best-fitted logistic curve for open-eye condition. *Dashed lines* = best-fitted logistic curves for closed-eye condition. Illumination is plotted on a log-scaled abscissa.

Results

Results are illustrated in Figure 2. Means ± SD of O/C ratios were 0.3% ± 0.2%, 0.3% ± 0.4%, and 5.6% ± 3.4% for blue, green, and red light, respectively. Significant overall group differences by color were found by analysis of variance (ANOVA, $F(2, 20) = 28.13$, $p < 0.001$). Between color-pairs, differences between red and the other colors were statistically significant (red vs. blue: $t(10) = 5.39, p < 0.001$; red vs. green: $t(10) = 5.25, p < 0.001$). A significant interaction between color and gender was found (ANOVA, $F(2, 18) = 4.15$, $p < 0.05$). O/C ratios for green were significantly larger for females ($t(9) = 2.37, p < 0.05$), and there were similar trends for blue ($t(9) = 2.18$, $p < 0.10$) and red ($t(9) = 2.23$, $p < 0.10$). No significant differences were found by age (under 30 vs. over 30) or race (white vs. Asian).

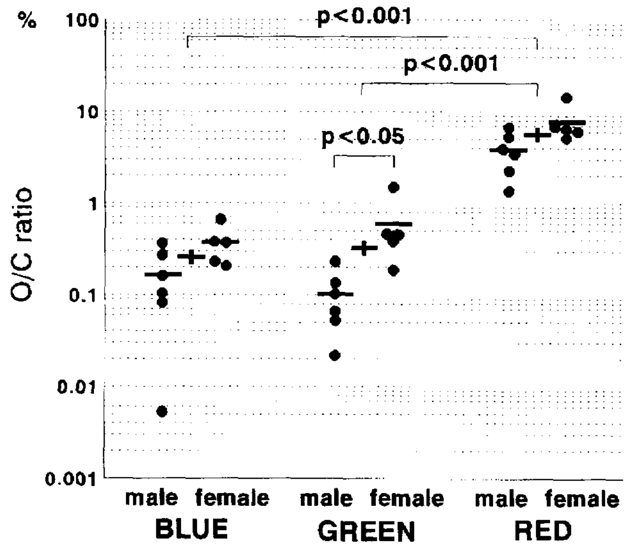

Figure 2. *Circles* = O/C ratios of individual subjects (i.e., the threshold of the open-eye condition divided by the closed-eye threshold). *Plus signs* = means for each color. *Solid lines* = means for each gender for each color.

Discussion

Regarding the optical characteristics of the skin, many studies have discussed reflection by the skin (Kuppenheim 1954), but transillumination studies are very few (Sisson et al 1973). Only two studies from the same group have previously estimated light transmission through the living human eyelid (Moseley et al 1988; Robinson et al 1991). Measurements were made by transilluminating closed eyelids with an embedded optic fiber in an optically opaque contact lens. These two studies, with somewhat different measurement techniques, reported rather different values for transmission. In each study, either the detector or the light source was so small that it encompassed only a part of the eyelid, and measurement of scattered light was variable. It would be hard to exclude stretching of the eyelid by such a special apparatus. In contrast, our method examined that light from a wide visual field that actually struck the retina. Presumably, our method included scattered light entering the pupil and assessed light actually sensed by the retina. The visual threshold method may be more relevant to the actual effects of light during sleep.

In our data, red light was attenuated to about 1/20, and blue and green were reduced to less than 1/100, so that the eyelid was quite an effective attenuator. In addition, the eyelid acted as a red-pass filter, such that approximately 20 times as much red light passed through the closed eyelid as blue or green light. Our results were similar to one of the prior studies (Moseley et al 1988) but demonstrated less transmission of blue and green than the other study (Robinson et al 1991).

Light attenuation by other parts of eye (cornea, aqueous, lens, and vitreous) are definitely important factors in visual thresholds. The absorption characteristics of the lens change markedly with age (Sample et al 1988; Barker et al 1992). Fortunately, in this study, intraocular factors did not have to be considered, because they would be balanced within subjects between open and closed-eye conditions as a result of O/C calculations. Although skin pigmentation and eyelid thickness should be considered as variables which affect the attenuation by the eyelid, we did not evaluate these factors in this study, because objectification would be difficult. Instead, we examined differences between genders and two races. Female eyelids transmitted a higher percentage of the light, but we could not find any difference between whites and Asians in this small sample.

The color filtering of the eyelid may be important in considering potential applications of illumination during sleep for antidepressant treatment, reproductive endocrinology, or circadian phase shifting. After passing through the eyelid, the red light previously used as a placebo may not be as much dimmer than white light as photometric measurement had suggested (Lin et al 1990). Whether it would be therapeutically more efficient to use red light (to gain greater transmission), or to emphasize blue-green (to produce more balanced transmission) remains to be tested.

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References

Avery DH, Bolte MAP, Cohen SA, Millet MS (1992): Gradual versus rapid dawn simulation treatment of winter depression. *J Clin Psychiatry* 53:359–363.

Avery DH, Bolte MA, Dager SR, et al (1993): Dawn simulation treatment of winter depression: A controlled study. *Am J Psychiatry* 150:113–117.

Barker FM, Brainard GC, Dayhaw-Baker P, Hanifin P (1992): Age-related changes in human lenticular transmission (abstract). *Proc 4th Meeting of Society for Light Treatment and Biological Rhythms* 4:11.

Dewan EM (1967): On the possibility of a perfect rhythm method of birth control by periodic light stimulation. *Am J Obstet Gynecol* 99:1016–1018.

Jacobsen FM (1990): Walking in a lighted room. *Biol Psychiatry* 27:372–374.

Kripke DF (1993): Light regulation of the menstrual cycle. In Wetterberg L (ed), *Light and Biological Rhythms in Man.* Oxford: Pergamon Press, pp 305–312.

Kuppenheim HF (1954): Spectral reflectance of the human skin in the ultraviolet, visible and infrared range and its interpretation. *Proceeding of the First International Photobiological Congress.* Wageningen: H Veenman & Zonen, pp 228–232.

Lin MC, Kripke DF, Parry BL, Berga SL (1990): Night light alters menstrual cycles. *Psychiatry Res* 33:135–138.

Moseley MJ, Bayliss SC, Fielder AR (1988): Light transmission through the human eyelid: in vivo measurement. *Ophthalmic Physiol Opt* 8:229–230.

Robinson J, Bayliss SC, Fielder AR (1991): Transmission of light across the adult and neonatal eyelid. *Vision Res* 31: 1837–1840.

Sample PA, Esterson FD, Weinreb RN, Boynton RM (1988): The aging lens: In vivo assessment of light absorption in 84 human eyes. *Invest Ophthalmol Vis Sci* 29:1306–1311.

Sisson TRC, Wickler M (1973): Transmission of light through living tissue. *Pediatr Res* 7:316–388.

Terman M, Schlager DS (1990): Twilight therapeutics, winter depression, melatonin, and sleep. In Montplaisir J, Godbout R (eds), *Sleep and Biological Rhythms.* New York: Oxford University Press, pp 113–128.