Non-visual biological effect of monochromatic light on human circadian rhythm of physiological and psychological parameters

Jinghua Huang, Ming An, Yoshihiro Shimomura, Tetsuo Katsuura

Chiba University, Department of Design & Architecture
Japan, huangjinghua@faculty.chiba-u.jp

Abstract: In order to design good and healthy lighting environment, it is very important to understand the knowledge about the non-visual effects of light. We report the time-of-day-dependent effects of two different wavelength monochromatic light at 458 nm and 550 nm on human physiological and psychological parameters under the same irradiance density (9.8 μW/cm^2 at eye level). We found that 458 nm light exposure caused significantly larger P300 amplitude, higher HF/(HF+LF) component, larger changes of body temperature, shorter 180-s time production, and lower fatigue scores than occurred with 550 nm light. We also found that monochromatic light exposure at nighttime induced a larger P300 amplitude, shorter 180-s time production and lower changes of body temperature than in the daytime. Our findings suggest that short wavelength monochromatic light had time-of-day dependent effects on human physiological and psychological functions. The implications of these findings may be significant for designing novel light devices.

Key words: Monochromatic Light, Circadian Rhythm, Cognitive Function, Time Production, Body Temperature, Heart Rate Variability.

1. Introduction

There is no doubt that the sun plays a very important role in our daily lives. The primary concern in the lighting of buildings has generally been to allow for vision, suited to the room or building usage. However, light also exerts other biological effects that influence human physiology, behavior and mood. Previous studies showed that ocular light exposure elicits acute physiological effects in humans such as an increase in core body temperature at night (Rüger et al., 2006), reduces sleepiness (Cajochen et al., 2005), and enhances the arousal level (Lockley et al., 2006), affects autonomic system (Schäfer and Kratky, 2006), and time production (Katsuura et al., 2007). Therefore, it is very important to understand the non-visual effects of light to design healthy lighting environments. In chronobiological studies, several reports showed that core body temperature (Waterhouse et al., 2005), human cognitive function (Huang et al., 2006), autonomic system (Aoyagi et al., 2003), and time production (Kuriyama et al., 2005) under ordinary lighting environment exhibit circadian variations. However, the circadian rhythms of human cognitive function, autonomic nerve function, body temperature, and time sense under monochromatic light exposure remain unknown. Therefore, in the present study, we aimed to explore the time–of–day–dependent effects of two different wavelengths of light, 458 nm and 550 nm on these functions.

2. Methods

2.1 Subjects and Prestudy Conditions

A total of 12 healthy male undergraduate students (mean age=21, SD=1.1 yrs) participated in the present study. To minimize inter-individual variation in circadian phase, we selected only subjects who were neither morning-type nor evening-type persons (average scores=49.67±4.65), as assessed by a translated version of the morningness/eveningness questionnaire (Horne and Ostburg, 1976). Subjects were instructed to keep a regular sleep-wake schedule during the week (baseline days) before entering the study to synchronize their sleep-wake rhythm, and were asked to abstain from the use of any prescription or recreational drugs until the completion of this study. Subjects gave written informed consent to participate in the study and were paid for their participation.

2.2 Study Protocol

The experiment consisted of two monochromatic light exposure sessions with different light wavelengths: 458 nm and 550 nm. In each session, after 5 min of incandescent light exposure (19 lx when measured vertically and 96 lx when measured horizontally at eye level), subjects were dark adapted (<1 lx) for 5 min, followed by monochromatic light exposure at either 458 nm or 550 nm under the same irradiance density ($9.8\mu W/cm^2$ at eye level). During monochromatic light exposure, after 6 min of Alpha Attenuation Test for 6 min, subjects performed approximately 20–min oddball task to extract P300 event-related potentials, followed by a time–production task for 6 min. The session interval was 30 min, while the order of monochromatic light exposure was counterbalanced by subjects. In order to compare the circadian changes of physiological and psychological parameters, we tested two times (daytime and nighttime) on 2 separate days, 12 h out of phase with each other. Nighttime light exposure occurred approximately 9.25 hours before the respective averaged wake time observed during each subject's baseline days. Subjective alertness scores (KSS; Ishihara et al., 1982) were collected at the beginning of each session. Oral temperature (Tor) was measured at the beginning and the end of each session. Subjective status was assessed using visual analogue scales (VAS) at the end of each session. Electroencephalogram, electrocardiogram were measured continuously throughout each session.

2.3 Data Analysis

Repeated measures ANOVA and paired t-tests were used to analysis the values of subjective assessment of feelings, the mean values of time-production, P300 amplitude, heart rate variability, and the changes of body temperature (ΔTor). The level of statistical significance for all of these analyses was set at 0.05.

3. Results and Discussion

We found that there were no significant main effects in KSS ratings among the experimental sessions ($p>0.05$). These results suggest that the subjective sleepiness before monochromatic light exposure was almost at the same level for all of the experimental sessions. We found that the feeling of fatigue in the 458 nm condition had a tendency to be lower than that in the 550 nm condition.

Using event-related potential-P300, we found that a greater P300 amplitude was elicited following exposure to

458 nm light than to 550 nm light (p<0.01). Because the experimental design contrasted two narrow-band monochromatic lights, and we used 458 nm and 550 nm light with an equal level of irradiance density, our findings suggest that the melanopsin-dependent photoreception system contributed the mediation of these responses relative to the rod and cone visual photopic system. In terms of time–of–day effects on cognitive function, we found that exposure to 458 nm light induced a larger P300 amplitude at the Fz electrode site at nighttime than in the daytime (p<0.05) (Fig. 1). Because P300 amplitude is believed to be related to the amount of cognitive resources available for the evaluation of stimuli (Gaillard, 1988), this result suggests that during 458 nm light exposure, a relatively larger allocation of attention resources had been provided to perform the oddball task at nighttime than in the daytime.

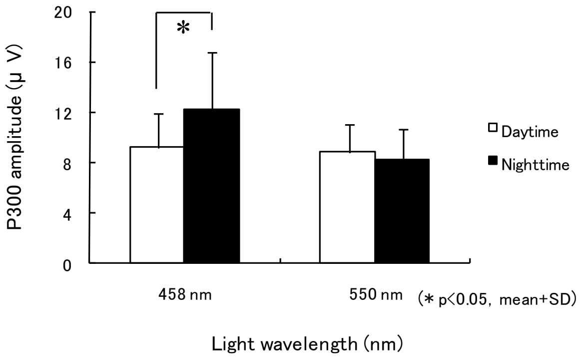

Fig. 1 Mean P300 amplitude at 458 nm and 550 nm light exposure for each time of day.

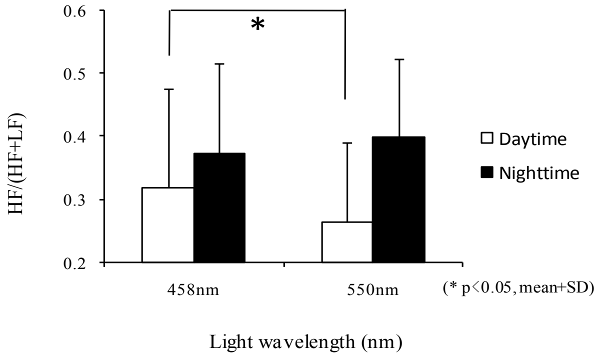

Fig.2 Mean HF/(HF+LF) at 458 nm and 550 nm light exposure for each time of day.

Katsuura et al. (2007) suggested that higher activity in the central nervous system is related to the acceleration of the time sense. Our findings that exposure to 458 nm light caused a shorter time production and larger P300 amplitude compared with 550 nm light (p<0.05) support this theory. In terms of time–of–day effects on time production, we found that time production at nighttime was shorter compared with that in the daytime (p<0.05). This result is very similar to that of Kuriyama et al. (2005), who reported that short-term time production tended to be shorter than the actual time interval during the nighttime, and it became longer toward the morning time.

With regards to the effect of light wavelength on the changes of body temperature, we found that the acute ΔTor elevation induced by daytime 458 nm light was larger than that at nighttime (p<0.05). This result suggests that the effect of 458 nm light exposure on body temperature is time-of-day dependent. We also found that ΔTor was larger at 458 nm light exposure than at 550 nm light exposure in the daytime (p<0.05). The melanopsin-dependent photoreception system might be contributed the mediation of this response as well as the result of P300 amplitude.

Our current study showed an additional novel findings; that exposure to 458 nm light caused a higher HF/(HF+LF) component compared with exposure to 550 nm light in the daytime (p<0.05) (Fig. 2). Because blue is known to be associated with being calming and relaxing (Yousuf Azeemi and Mohsin Raza, 2005), the color effect of light might be one of regulators of the non-visual biological effect of monochromatic light in human autonomic responses.

4. Conclusions

In conclusion, cognitive function, autonomic responses, body temperature, and time sense showed circadian rhythm and were influenced by monochromatic light exposure in a wavelength-dependent manner. 458 nm light exerts its non-visual effects on human cognitive function, body temperature and time sense, while plays its psychological effect on autonomic responses. The implications of these findings may be significant for designing novel light devices. Further study needs to be extended to individual difference.

5. Acknowledgment

This work was supported in part by the Grant-in-Aid for Science Research (B) (grant No. 20370098) from the Japan Society for the Promotion of Science.

6. References

[1] Aoyagi, N., Ohashi, K., Yamamoto, Y. (2003) Frequency characteristics of long-term heart rate variability during constant-routine protocol, *Am J Physiol Regul Integr Comp Physiol*, vol. 285, pp 171-176.

[2] Cajochen, C., Munch, M., Kobialka, S., Krauchi, K., Steiner, R., Oelhafen, P., Orgul, S., Wirz-Justice, A. (2005) High sensitivity of human melatonin, alertness, thermoregulation, and heart rate to short wavelength light, *J Clin Endocrinol Metab*, vol. 90, pp 1311-1316.

[3] Gaillard, A.W. (1988) Problems and paradigms in ERP research, *Biol Psychol*, vol. 26, pp 91-109.

[4] Horne, J.A., Östberg, O. (1976) A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms, *Int J Chronobiol*, vol. 4, pp 97-100.

[5] Huang, J., Katsuura, T., Shimomura, Y., Iwanaga, K. (2006) Diurnal Changes of ERP Response to Sound Stimuli of Varying Frequency in Morning-Type and Evening-Type Subjects, *J Physiol Anthropol*, vol. 25, no. 1, pp 49-54.

[6] Ishihara, K., Saito, T., Miyata, Y. (1982) Sleepiness scale and an experimental approach, *Jpn J Psychol*, vol. 52, pp 362-365 (in Japanese).

[7] Katsuura, T., Yasuda, T., Shimomura, Y., Iwanaga, K. (2007) Effects of Monochromatic Light on Time Sense for Short Intervals, *J Physio Anthropol*, vol. 26, no. 2, pp 95-100.

[8] Kuriyama, K., Uchiyama, M., Suzuki, H., Tagaya, H., Ozaki, A., Aritake, S., Shibui, K., Xin, T., Lan, L., Kamei, Y., Takahashi, K. (2005) Diurnal fluctuation of time perception under 30-h sustained wakefulness, *Neurosci Res*, vol. 53, pp 123-128.

[9] Lockley, S.W., Evans, E.E., Scheer, F.A., Brainard, G.C., Czeisler, C.A., Aeschbach, D. (2006) Short-wavelength sensitivity for the direct effects of light on alertness, vigilance, and the waking electroencephalogram in humans, *Sleep*, vol. 29, pp 161-168.

[10] Rüger, M., Gordijn, M.C., Beersma, D.G., de Vries, B., and Daan, S. (2006) Time-of day dependent effects of bright light exposure on human psychophysiology: comparison of daytime and nighttime exposure, *Am J Physiol Regul Integr Comp Physiol*, vol. 290, pp R1413-R1420.

[11] Schäfer, A., Kratky, K.W. (2006) The Effect of Corlored Illumination on Heart Rate Variability, *Forsch Komplementämed*, vol. 13, pp 167-173.

[12] Waterhouse, J., Drust, B., Weinert, D. (2005) The circadian rhythm of core temperature: origin and some implications for exercise performance, Chronobiol Int, vol. 22, pp 207-225.

[13] Yousuf Azeemi, S.T., Mohsin Raza, S. (2005) A critical analysis of chromotherapy and its scientific evolution, *eCAM*, vol. 2, pp 481-488.