Effect of intensity of short-wavelength light on human alertness

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ABSTRACT

Short-wavelength light is known to have an alerting effect on human alertness. This study evaluates the acute alerting ability of short-wavelength light of three different intensities (40 lx, 80 lx and 160 lx). Eight subjects participated in a 60-minute exposure protocol for four evenings, during which electroencephalogram (EEG) as well as subjective sleepiness data were collected. EEG power in the beta range was significantly higher after subjects were exposed to 160 lx light than after they were exposed to 40 lx, 80 lx light or remained in darkness. Also, the alpha theta was significantly lower under 160 lx light then in darkness. These results show that the effect of intensity on alertness is not linear and further work should be done to investigate the threshold intensity that is required to produce an alerting effect.

Keywords: *short-wavelength light, alertness, EEG*

INTRODUCTION

Light has been shown to exert strong non-visual effects on a range of biological functions such as the regulation of human circadian system. Exposure to light in the evening and nighttime, especially of short-wavelength (but not necessarily limited to short wavelengths), has been shown to lead to an increase in alertness in humans. This effect is suggested to be related to circadian disruption. Circadian disruption is associated with reduced levels of the hormone melatonin and is primarily mediated by activation of the intrinsically photosensitive retinal ganglion cells which respond to short-wavelength light most strongly. Exposure to light in the evening can inhibit the production of melatonin which otherwise would naturally build-up in the body during the late-evening hours.

Short-wavelength light is becoming a critical safety concern. For example, there has been concern about home lighting in the evening, where warm tungsten light is increasingly being replaced by cooler solid-state lighting; the use of emissive electronic displays may also be responsible for the increasing sleep problem (Chang et al. 2015). Differences in the properties of lighting were shown to affect individuals in various ways. Past studies have tried to define and quantify the timing, illuminance levels, exposure duration and wavelength distribution of the light required to evoke alerting responses (Cajochen 2007).

A study has looked at how three different illuminances ranging from 3 lx to 9100 lx affect EEG activity over 6.5 hours of exposure, and a dose-response relationship was found in subjective alertness and EEG power (Cajochen et al. 2000). Some other such studies have also demonstrated a non-linear relationship between light intensity and circadian shifts (Zeitzer et al. 2000). It is generally agreed that brighter light has a stronger alerting ability than dimmer light. However, there is no consensus yet about the threshold of light intensity needed to produce these effects.

EXPERIMENTAL DESIGN

The alerting effect of intensity of light in humans has so far received little attention. This work is concerned with exploring the threshold intensity of light needed to evoke acute alertness responses in humans at nighttime. The objective, specifically, is to investigate the effect of three intensities (40 lx, 80 lx and 160 lx) of a short-wavelength light (λmax = 475 nm), compared to remain in darkness (< 1 lx), on human alertness during the evening.

Eight participants (28 ± 3.6 years, including five females) were recruited for the within-subject, four-session study. All of them went through a pre-screening procedure where individual sleep/rise time was collected and the daily consumption of nicotine, caffeine and alcohol was reported. An information sheet was given and participants were asked to refrain from caffeine and alcohol intake 3 hours prior to the experiment, and to try to maintain a regular, constant sleep schedule during the entire experimental period.

Light was delivered through 12 mounted in the ceiling of a room with white walls and grey carpets. Participants were asked to sit under the light whilst reading, with a white table in front of them. Four light settings were used: a dim (2000 K, < 1 lx) and three short-wavelength lighting conditions. The short-wavelength condition had a peak at about 480 nm and was approximately Gaussian with a half-width half-height of 35 nm. Three intensities were 40 lx, 80 lx and 160 lx (± 1 lx).

Each participant completed four sessions over four nights, all starting at the same time (8 pm). Participants were fitted with EEG electrodes prior to the start of the exposure. During each evening study EEG was continuously recorded over 60 minutes. Under the dim condition, participants were kept in the dim light for 60 minutes. Under the blue condition, test lights were energized for 40 minutes, preceded by a 20-min dim (< 1 lx) period. Subjective was rated every 20 minutes. Participants were reminded to write down their scores on the Karolinska sleepiness scale (KSS) questionnaire at the 20th, 40th and 60th minute of each session (Figure 1).

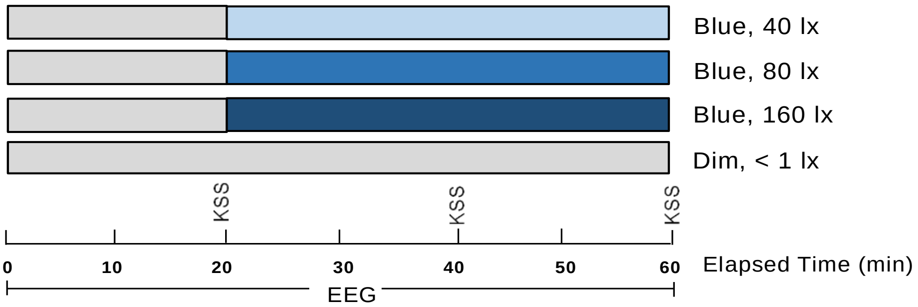

Figure 1: Experimental design.

RESULTS

EEG measures collected were averaged to produce overall EEG PSD, and then grouped into the following frequency bins: 5-9 Hz (theta alpha), 8-9 Hz (lower alpha), 11-13 Hz (higher alpha), and 13-30 Hz (beta). In each frequency range, EEG power averaged over the 40 minutes under test lighting was normalized to the initial 20 minutes of dim light period. One-way analysis of variance (ANOVA) was performed using the normalized power in each of the frequency ranges studied. Post-hoc t-tests (with Bonferroni corrections) were used to further compare the significance between lighting conditions.

One-way ANOVA revealed a close to significant main effect of lighting condition in the normalized theta alpha ($F3, 28 = 2.785$; $p = 0.059$) and a significant main effect of lighting condition in beta ($F3,28=7.571$; $p=0.001$). No significant difference was observed in lower alpha ($F3, 28 = 0.477$; $p = 0.701$) or higher alpha ($F3, 28 = 0.385$; $p = 0.765$) ranges. Post-hoc pairwise comparisons found significant differences between dim and 160 lx, 40 lx and 160 lx, 80 lx and 160 lx in beta range. Power in theta alpha was lower after exposure to 40 lx and 160 lx blue lights than after remaining in the dim condition. Power in beta range was significantly higher after exposure to 160 lx blue lights than after exposure to the other three lighting conditions. Compared to dim, exposure to 160 lx blue light has also reduced lower alpha power and increased high alpha power, although these differences did not reach statistical significance ($p > 0.05$).

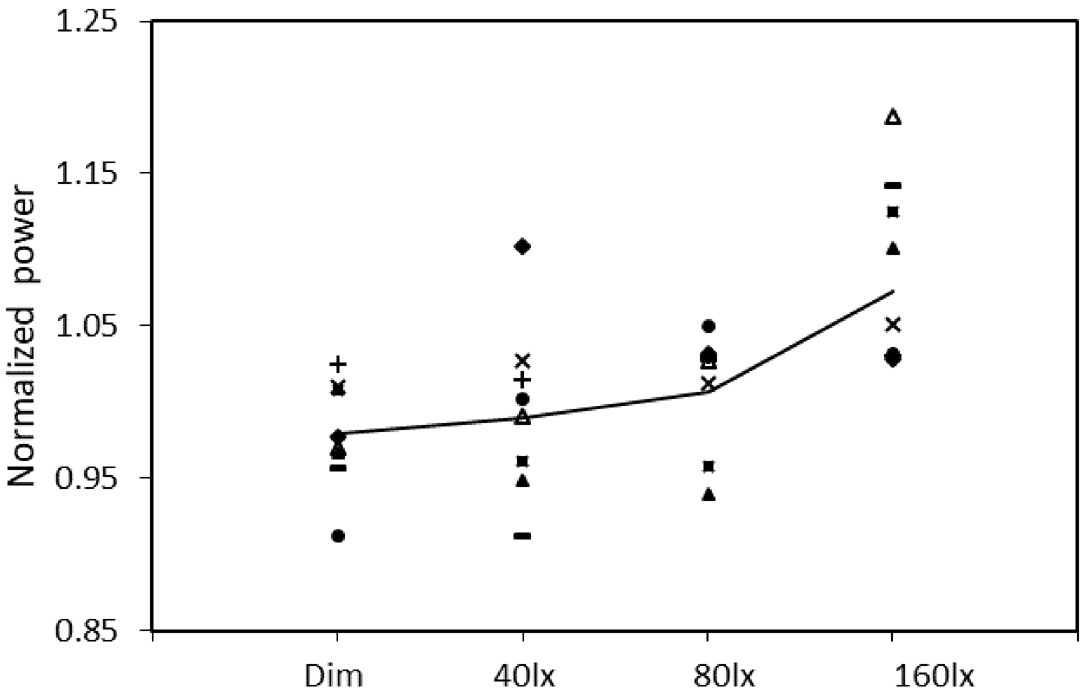

Figure 2: Individual EEG power values in beta range (the same symbol indicates the values obtained from the same participant).

Subjective sleepiness was evaluated using the Karolinska sleepiness scale (KSS), a self-reporting scale that ranges from 1 ('extremely alert') to 9 ('very sleepy, fighting sleep') (Shahid et al. 2012). This scale has previously been shown to be sensitive to changes in sleepiness and the alerting effects of lights (Lockley et al. 2006).

The KSS was rated three times (at the 20th, 40th, and 60th min) during each session. Subjects were asked to rate themselves from 1 to 9, according to their sleepiness. Mean scores over the experimental condition were normalized to the initial dim session.

ANOVA revealed a significant difference between dim and 160 lx conditions. Mean score in 160 lx condition was significantly lower than score in dim condition (a lower KSS score means more alertness). Mean scores under 40 lx and 80 lx conditions were lower than score under the dim, and higher than score under the 160 lx condition, although these differences did not reach statistical significance ($p > 0.05$).

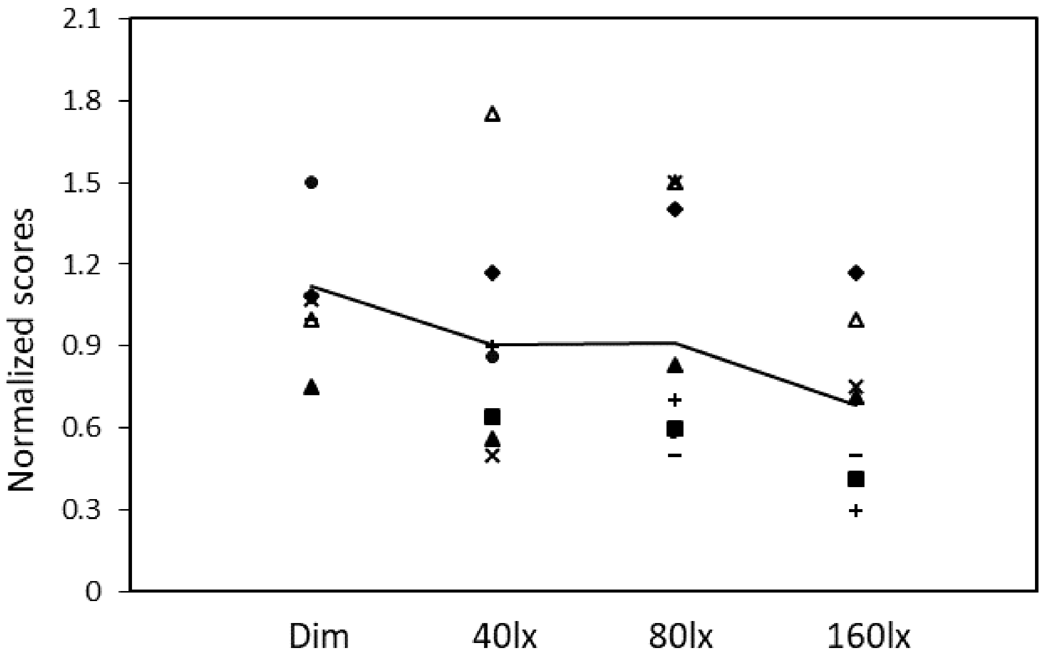

Figure 3: Individual KSS scores (the same symbol indicates the values obtained from the same participant).

CONCLUSIONS

This study provides some evidence that short-wavelength light exposure in the evening can increase human alertness and that this can occur relatively quickly (even though some other studies have suggestion that melatonin inhibition, for example, may have a longer time course). Both objective and subjective results also suggest that for the lighting conditions tested in the present study, light of higher intensity has a stronger alerting effect than light of lower intensity. These findings, in themselves, do not enable a threshold effect to be identified. However, the methodology described in this study may provide a basis for future on-going work to address this question explicitly.

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