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The effect on emotions and brain activity by the direct/indirect lighting in the residential environment

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HIGHLIGHTS

- We examined the influence of lighting environment on emotion and physiology.
- A direct/indirect lighting environment produces higher valence and cool ratings.
- A direct/indirect lighting environment increases the theta frequency band on EEG.
- An EEG signal can be a biological marker of environmental alteration.

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ABSTRACT

This study was performed to explore how direct/indirect lighting affects emotions and brain oscillations compared to the direct lighting when brightness and color temperature are controlled. Twenty-eight subjects (12 females; mean age 22.5) participated. The experimental conditions consisted of two lighting environments: direct/indirect lighting (400 lx downlight, 300 lx uplight) and direct lighting (700 lx downlight). On each trial, a luminance environment was presented for 4 min, followed by participants rated their emotional feelings of the lighting environment. EEG data were recorded during the experiment. Spectral analysis was performed for the range of delta, theta, alpha, beta, and gamma ranges. The participants felt cooler and more pleasant and theta oscillations on the F4, F8, T4, and TP7 electrodes were more enhanced in the direct/indirect lighting environment compared to the direct lighting environment. There was significant correlation between the "cool" rating and the theta power of the F8 electrode. The participants felt more pleasant in the direct/indirect lighting environment, indicating that space with direct/indirect lighting modulated subjective perception. Additionally, our results suggest that theta oscillatory activity can be used as a biological marker that reflects emotional status in different lighting environments.

1. Introduction

Ambient lighting affects human psychophysiology, and interest in the effects of lighting has increased as we spend most of our time surrounded by environments filled with artificial light in which sunlight is often blocked [1,2]. Kruithof, a pioneer in this field of research, reported the psychological effect of light and proposed a curve for a comfort zone of the combination of illumination and color temperature [3]. Indoor lighting can influence affective and cognitive processes [4–7], and physiological functions [1]. Indeed, there is ample evidence to support the hypothesis that lighting environment affects human emotion.

Despite many studies on lighting environments that have assessed "subjective feelings," few reports have described the influence of lighting on objective "biological activity" in the brain. In the 1990s, some studies investigated physiological changes induced by different lighting conditions (brightness and color), but these studies are limited by small number of subjects (7–15) that may be due to the difficulty with control of lighting variables with older technology [8–12].

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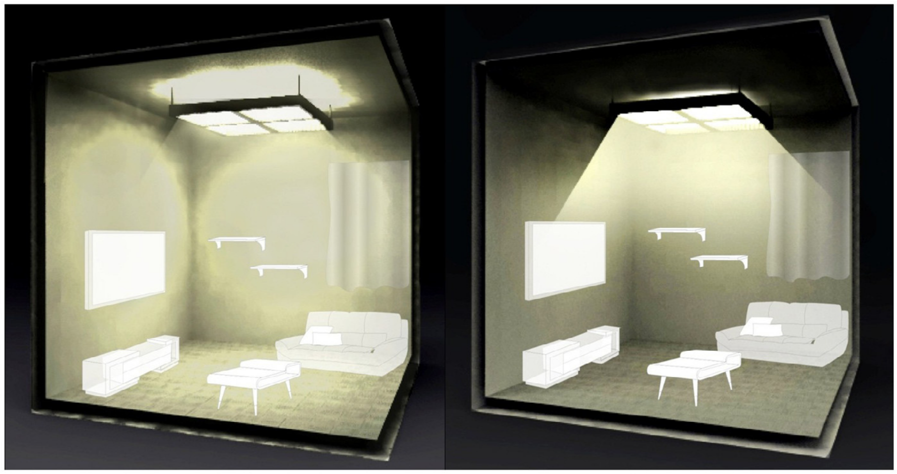

Direct/Indirect Lighting Environment Direct Lighting Environment

Fig. 1. Schematic depicting the experimental room showing direct and indirect lighting environment and direct lighting environment, and furniture.

Recently, there has been a growing interest in the potential of using highly energy-efficient light-emitting diodes (LEDs). LED technology enables more accurate and precise study of the effects of different wavelengths, and it is also useful in the treatment of seasonal affective disorder [13,14]. Moreover, LED technology allows for the design of standardized and elaborate lightings conditions, such as illuminance and color temperature. We have previously used LED technology to successfully evaluate the effects of lighting on emotion and electroencephalography (EEG) [2,15,16].

Most studies of lighting environments, including our previous work, evaluated luminance and color temperatures based on Kruithof's study [3]. Besides source light brightness and color temperature, other factors also used to provide high-quality environments. One crucial factor is how to arrange lighting sources. Indirect and direct lighting designs elicit different feelings, and this property is widely exploited in artificial environments. In the fields of architecture and interior design, it is generally accepted that the perception of room size is an important property, as environments that do not provide sufficient space produce feelings of threat and can act as ambient stressors. In addition, increasing population densities have revealed the need for adequate individual space [17]. Therefore, there have been many studies to identify factors that provide the impression of more room within a given volume of space. With respect to artificial lighting, the use of uniform and peripheral lighting was recommended [18]. For overhead central lighting, it was reported that the ratio of direct/indirect lighting modulated spacious perception [19]; the room appeared larger when more light was supplied indirectly.

The present study explored the influence of direct/indirect lighting on subjects' affective and neurophysiological responses in a residential environment. We investigated EEG activity and emotional scores (dimensional affect and subjective feelings) in subjects exposed to different lighting conditions in an ecologically valid living room setting.

2. Methods

2.1. Participants

Twenty-eight subjects participated in this study (12 females, mean age 22.5). Written informed consent was obtained after a complete description of the study was provided to the participants. Our study was carried out under the guidelines for the use of human subjects established by the Institutional Review Board (IRB) at Gangnam Severance Hospital, Yonsei University.

2.2. Environmental setting

The experiment was conducted in a furnished living room with dimensions of 4.7 m $\times$ 4.4 m and a height of 3.1 m. It contained a TV, an entertainment center, sofas, a coffee table, a side table with flowers, wall shelves, and a rug (Fig. 1). Daylight was excluded by shielding the windows. The temperature and relative humidity of the experimental room were 23.3° (SD = 0.3°) and 21.3% (SD = 1.0%), respectively.

Eight LED lighting panels (600 cm $\times$ 600 cm; LG Electronics, Seoul, Republic of Korea) were suspended above the room; four faced up and four faced down (1 panel: 53 W, 4694 lm, 3000 n, 5000 K). A controller (WE7000, Yokogawa, Japan) regulated the illuminance (700 lx) and color temperature (5000 K) of the LEDs. The luminance was measured at table level (0.75 m).

2.3. Design and procedure

A counterbalanced within-subject design was employed. The experiment consisted of two different lighting conditions: direct/indirect lighting (400 lx downlight, 300 lx uplight) and direct lighting (700 lx downlight) (Fig. 1). In each trial, following a 4-min dark condition (0 lx) to allow subjects to equilibrate to the surroundings, a luminous environment was presented for 4 min. Immediately following luminous environment presentation, the participants were required to complete self-report questionnaires to measure light-induced emotional responses. The same lighting condition was continued while participants completed the questionnaires.

The self-report questionnaires included 100-mm pen-and-paper visual analog scales (VAS) and the Self-Assessment Manikin (SAM) [20]. The VAS consisted of a list of three emotion adjectives (cool, refresh, comfortable). The terms "not at all" and "strongly" were written under the left and right ends of the scale, respectively. The SAM was comprised of two nine-point graphical rating scales measuring the valence and arousal dimensions. For the valence dimension, SAM ranged from a happy to unhappy figure. For the arousal dimensions, the SAM figure ranged from excited and aroused to relaxed.

Upon arrival, participants were comfortably seated in the experiment room and received instructions. They were only informed about the purpose of the study and were uninformed about the hypothesis. The experimenter instructed participants to focus on and evaluate the overall appearance created by the lighting conditions and stressed that they should maintain the

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