

Foliage Plants Cause Physiological and Psychological Relaxation as Evidenced by Measurements of Prefrontal Cortex Activity and Profile of Mood States

Sin-Ae Park

Department of Environmental Health Science, Konkuk University,
05029, Seoul, South Korea

Chorong Song

Center for Environment, Health and Field Sciences, Chiba University,
277-0882, Chiba, Japan

Ji-Young Choi

Graduate School of Environmental Science, Konkuk University,
05029, Seoul, South Korea

Ki-Cheol Son

Department of Environmental Health Science, Konkuk University, 05029,
Seoul, South Korea; and the Graduate School of Environmental Science,
Konkuk University, 05029, Seoul, South Korea

Yoshifumi Miyazaki¹

Center for Environment, Health and Field Sciences, Chiba University,
277-0882, Chiba, Japan

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Abstract. The study's objective was to investigate the effects of foliage plants on prefrontal cortex activity and subjective assessments of psychological relaxation. In a crossover experimental design, 24 male university students in their 20s observed a container with and without foliage plants for 3 minutes while oxyhemoglobin (oxy-Hb) concentration in the prefrontal cortex was continuously measured with a portable near-infrared (NIR) spectroscopy device. Afterward, subjective evaluations of emotions were obtained via two self-report questionnaires: a modified semantic differential (SD) method and the Profile of Mood State questionnaire (POMS). Oxy-Hb concentration in the right prefrontal cortex was significantly lower in subjects who viewed the foliage plants than in those who did not, indicating a physiologically relaxed state. The subjects also reported in the SD method significantly more positive emotions (e.g., comfortable, natural, and relaxed) associated with viewing the foliage plants. In the POMS, a significant positive effect on psychological relaxation when subjects viewed the foliage plants was shown. Thus, we conclude that foliage plants have both physiological and psychological relaxation effects in males even after only short exposure.

In an urban society, city dwellers spend over 80% of their time in indoor environments (Yoo and Lee, 2014). Therefore, there are limited opportunities to experience nature or green plants (Lee, 2007). Furthermore, many city dwellers in modern society spend most of their time in a stressed state (Herzog et al., 1997; Kim et al., 2013).

Various theories have been proposed to explain the importance of experiencing nature

or green plants for human health and well-being. Kaplan and Kaplan (1989) proposed the attention restoration theory, which states that nature provides environmental stimulation, which alleviates the attention fatigue that occurs while performing cognitive tasks. Ulrich (1983) proposed that nature might allow stress recovery through innate, adaptive responses to the attributes of natural environments. Moreover, interest in the relationships between nature or green plants and human health has been increasing in recent years (Bowler et al., 2010).

Previous studies have reported the impact of visual stimulation by green plants on physiological and psychological relaxation. Ulrich (1983) reported that a natural environment led to the alleviation of stress-related

negative emotions and autonomic nervous system activation. In addition, Ikei et al. (2014a) showed that viewing green plants in an indoor environment was associated with greater stabilization of the autonomic nervous system and parasympathetic activity by measuring heart rate variability. Son et al. (1998) reported that green plants in an interior space increased alpha waves in electroencephalographic activity, which was used as an index of emotional stabilization.

Measurements of brain function are routinely performed using electroencephalography, positron emission tomography, single-photon emission computed tomography, functional magnetic resonance imaging, and magnetoencephalography. However, the experimental environments for these techniques are quite different from normal daily environments, requiring strict motion restriction that may be stressful for the subjects. Furthermore, in vivo determination of the brain activity in humans requires flexible, accessible, and rapid monitoring techniques. Jöbsis (1977) demonstrated that near-infrared spectroscopy (NIRS) can be used as a tool to noninvasively monitor cerebral blood oxygenation. A major advantage of NIRS is better tolerance to head motion because of the temporal resolution of the device (Perrey, 2012) so that NIRS has been used in many studies of activation-induced changes in brain activity over the past 20 years (Perrey, 2012). Near-IR light penetrates tissue to a depth of several centimeters and allows to continuous measure for the noninvasive monitoring of hemodynamics in the prefrontal cortex of the brain (Jöbsis, 1977; Perrey, 2008).

The biological effects of viewing foliage plants on the wellbeing of individuals are not well understood. Because of the advantages of using NIRS to assess brain activity, the objective of this study was to use this technique to investigate the effects of foliage plants on prefrontal cortex activity and associate these effects with subjective assessments of psychological relaxation.

Materials and Methods

Subjects. University male students in their 20s were recruited from Konkuk University, Seoul, South Korea. Researchers contacted students who were on a campus volunteer list by phone or face to face. In total, 24 male university students were recruited. Inclusion criteria were not having rhinitis symptoms (because these can affect the data) and not consuming caffeine or smoking 2 h before testing. Researchers provided the study's purpose, procedures, schedule, and requirements to participants, and the subjects provided written informed consent.

The mean age of the subjects in this study was 24.0 ± 2.7 years. The mean height and weight were 172.9 ± 6.4 cm and 68.6 ± 11.4 kg, respectively. Body mass index (BMI) was 22.8 ± 2.9 kg·m⁻², which is in the normal range (WHO, 2006). After completion of the study, the subjects received \$20 as an

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¹Corresponding author. E-mail: ymiyazaki@faculty.chiba-u.jp.

incentive. The study was approved by the institutional review board (7001355–201508-HR-079).

Experimental procedures. A space (1.5 × 1.7 m) with a table and chair in a laboratory at the Konkuk University campus was used in this study. The experimental space in the laboratory was sectioned off by a curtain to avoid possible barrier factors, such as noise or interruption. The space was maintained at (mean ± SD) 25.4 ± 1.5 °C, 52.5 ± 5.8% relative humidity, and 1645 ± 189 lx illumination.

The experimental procedures are presented in Fig. 1. This study was of a crossover experimental design, which is a repeated measures design. In a crossover design, each experimental group crosses over from one treatment to another, which provides a more efficient comparison of treatments than a parallel design (Piantadosi, 2005). Each subject visited the laboratory once to complete this study.

A container with or without plants was covered by a cardboard box on the desk. After a 30-s resting period, each subject randomly observed either foliage plants (*Epipremnum aureum*) in a container (55 × 19 × 15 cm) or a container without foliage plants for 3 min while maintaining the sitting position (Fig. 2A and B). Before visual stimulation, the container with or without plants was covered by a cardboard box (Ikei et al., 2014a). During the testing procedure, oxy-Hb concentration in the prefrontal cortex was measured continuously with NIRS as an index of the physiological effects of viewing plants on the prefrontal cortex activity. After finishing the 3-min treatment, subjective evaluations of the emotional effects were measured by using surveys for about 1 min.

Before starting the testing, the subjects were provided with a detailed explanation about the procedures of this study. Body weight and height without shoes of each subject were measured by a body fat analyzer (ioi 353; Jawon Medical, Gyeongsan, South Korea) and an anthropometer (Ok7979; Samhwa, Seoul, South Korea). The BMI was calculated with the data for body weight and height $\{BMI = [weight (kg)]/[height (m)]^2\}$.

Measurement for prefrontal cortex activity. Oxy-Hb concentrations in the prefrontal cortex were continuously measured using a portable NIRS (Pocket NIRS Duo; Dynasense, Shizuoka, Japan; Watanabe et al., 2012) while each subject was viewing the containers with or without foliage plants and resting. Moreover, baseline data of oxy-Hb concentration in the prefrontal cortex in each subject was measured by NIRS by sitting on a chair for 3 min. NIRS was worn on the forehead of each subject (Fig. 3), and the oxy-Hb concentrations in the left and right prefrontal cortex were measured at 1 Hz.

Subjective evaluation. A subjective evaluation was conducted using the modified SD method (Osgood et al., 1957). The SD method uses three pairs of adjectives on 13 scales, including “comfortable-uncomfortable,” “natural-artificial,” and “relaxed-awakening.”

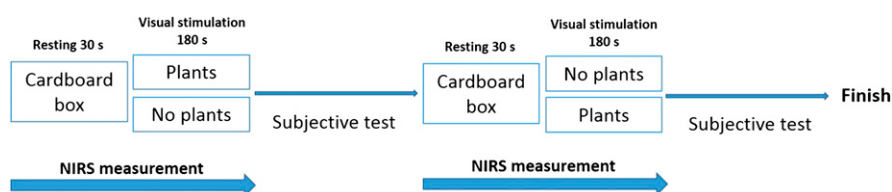


Fig. 1. Study protocol for measuring oxyhemoglobin concentration in the prefrontal cortex. A crossover experimental design is shown for examining the effects of visual stimulation on brain function using near-IR spectroscopy (NIRS) and foliage plants.



Fig. 2. Experimental viewing conditions: (A) foliage plants (*Epipremnum aureum*) condition and (B) no foliage plants condition.

A higher score for each indicates a better emotional condition (Osgood, 1952).

In addition, the POMS, originally developed by McNair et al. (2003) and then translated to Korean by Yeun and Shin-Park (2006), was conducted. The POMS questionnaire consists of 30 questions in six sub-categories, such as tension-anxiety (T-A), depression-dejection (D), anger-hostility (A-H), fatigue (F), confusion (C), and vigor (V). The lower scores for the T-A, D, A-H, F, and C indicate a better emotional condition, but a higher score for the V indicate a better condition. The total mood disturbance (TMD) score is calculated by the formula $[(T-A) + (D) + (A-H) + (F) + (C) - (V)]$ (Baker et al., 2002). A lower score of TMD indicates a better emotional condition. The Chronbach' α was 0.7 (McNair et al., 1992).

Data analysis. Data on the oxy-Hb concentration difference between the control and treatment groups were used for analysis. The measured mean data for the 30-s resting period served as a baseline measure for each subject. This value was deleted from the oxy-Hb concentration data acquired at every second during the testing period.

Statistical analyses were performed using SPSS software (version 20; SPSS Inc., Chicago, IL) for all variables. $P < 0.05$ was considered as statistically significant. The



Fig. 3. The portable near-IR spectroscopy (NIRS). Subject wears the NIRS device on the left and right forehead.

differences between the control and treatment groups of oxy-Hb concentration were analyzed using a paired t test. The results from the SD method and POMS were analyzed by the Wilcoxon signed-rank test.

Results

Prefrontal brain activity measured by NIRS. Changes in oxy-Hb concentration in the right prefrontal cortex over time under the two treatment conditions are shown in Fig. 4. NIRS revealed that the average oxy-Hb concentration in the right prefrontal cortex in the viewing foliage plant condition was

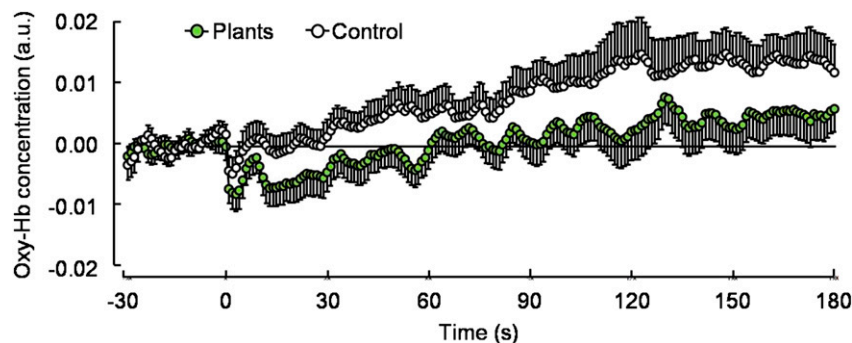


Fig. 4. Changes in oxyhemoglobin (oxy-Hb) concentration in the right prefrontal cortex over time under the two treatment conditions. Values are means \pm SE (N = 24).

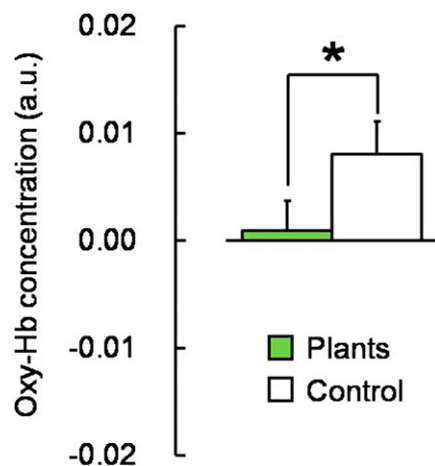


Fig. 5. Comparisons of oxyhemoglobin (oxy-Hb) concentration in the right prefrontal cortex. Near-IR spectroscopy was used to assess brain oxy Hb concentrations between the viewing foliage plants and no foliage plants conditions. Values are means \pm SE * P < 0.05; N = 24.

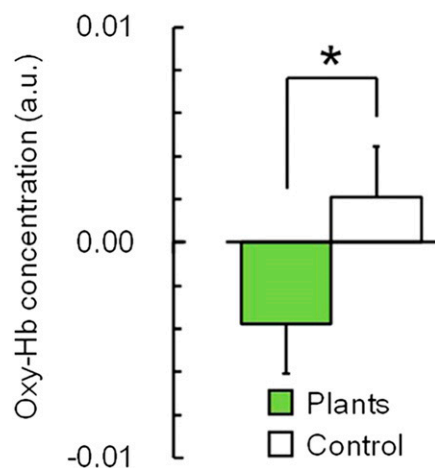


Fig. 6. Comparisons of oxyhemoglobin (oxy-Hb) concentration in the right prefrontal cortex during 1–60 s. Near-IR spectroscopy was used to assess brain oxy Hb concentrations between the viewing foliage plants and no foliage plants conditions. Values are means \pm SE * P < 0.05; N = 24.

significantly lower than that in the “no plants” condition for the 1- to 180-s testing period (P < 0.05; Fig. 5). At the beginning the observation period of 1–60 s, it was lower

than the baseline in the plants group. In the average of 1–60 s, oxy-Hb concentration in the right prefrontal area was significantly decreased in the viewing foliage plant condition than “no plants” condition (P < 0.05; Fig. 6). In contrast, there was no significant difference in oxy-Hb concentration in the left prefrontal cortex between the two treatments (data not shown).

Subjective evaluation. The subjective evaluation of the emotional impact of the foliage plants showed an association with positive effects in this study (Figs. 7–9). By the modified SD method, the subjects reported feeling significantly more comfortable, natural, and relaxed when viewing foliage plants than when they were not (P < 0.01; Fig. 7).

The results of the POMS questionnaire also showed a positive effect on psychological relaxation when subjects viewed the foliage plants (Figs. 8 and 9). Specifically, scores in the T-A, A-H, and F subcategories were significantly lower and scores in the V subcategory were higher when viewing plants than when not viewing plants (P < 0.05; Fig. 8). The TMD score was 1.9 in the group with foliage plants and 4.3 in the group with no foliage plants (P < 0.01; Fig. 9).

Discussion

The subjects showed physiological and psychological relaxation resulting from visual stimulation comprising the viewing of foliage plants for 180 s. The oxy-Hb concentration in the right prefrontal cortex was significantly lower when viewing the container with, than without, foliage plants, and the decrease started from as early as 1–60 s. Thus, the visual stimulation of viewing foliage plants led to a physiological relaxation effect. In addition, the positive physiological responses of humans to foliage plants appeared almost immediately.

Although few studies have previously used NIRS to examine the effects of visual stimulation on relaxation, a recent study reported a physiological relaxation effect associated with decreasing oxy-Hb concentration in the right prefrontal cortex while viewing a 3-dimensional image of a water lily (Igarashi et al., 2014c). In addition, olfactory stimulation with rose and orange oil induced

physiological and psychological relaxation by decreasing the oxy-Hb concentration in the right prefrontal cortex (Igarashi et al., 2014a). Further, Hinoki cypress leaf oil reduced oxy-Hb concentration in the right prefrontal cortex and increased parasympathetic nervous activity (Ikei et al., 2015). The present study led the same results like the previous findings in the physiological and psychological relaxation by decreasing the oxy-Hb concentration in the right prefrontal cortex. When the local brain activity increases, brain blood flow increases (Fox and Raichle, 1986). The level of brain blood flow is consistent with the level of oxy-Hb (Hoshi et al., 2001), and NIRS can detect this activity-related increase in oxy-Hb. Consequently, it is considered that a decrease in the oxy-Hb concentration equates to a physiological relaxation effect (Igarashi et al., 2014a).

In this study, the left and right prefrontal cortices differentially responded to the viewing of foliage plants. Oxy-Hb concentration measured by NIRS significantly decreased in the right prefrontal area but not in the left prefrontal area. These results are consistent with previous findings: most of the NIRS studies on visual stimulation have reported that only one prefrontal area is significantly activated (Igarashi et al., 2014a, 2014b, 2014c, 2015). Moreover, a review of functional NIRS studies reported hemispheric differences in brain activation (Homae, 2014). The prefrontal region is involved in decision-making and emotional processing (Barrash et al., 2000; Tranel et al., 2000). Although it is unknown whether the right and left prefrontal regions make asymmetric contributions, considerable evidence exists that supports a predominant role for the right hemisphere in emotional processing (Damasio, 1994, 1999), with, in particular, a more dramatic effect on autonomic responses (Angrilli et al., 1999; Zahn et al., 1999). More studies are needed using NIRS to investigate the hemispheric differences in the response to sensory stimulation to clarify the functional implications.

The subjective evaluation of the emotional impact of viewing foliage plants also showed a significant positive effect in this study. The subjects felt comfortable, natural, and relaxed by viewing foliage plants. Furthermore, the subjects reported significantly decreased tension, anxiety, and fatigue and increased vigor. In a previous study, high school students also reported on the SD questionnaire that foliage plants led to positive associations, such as feeling comfortable, relaxed, and natural (Ikei et al., 2014a). Moreover, viewing real pansies compared with artificial pansies produced similar positive emotions in the SD method (Igarashi et al., 2015). Further, via the POMS questionnaire, office workers reported psychological relaxing effects when viewing roses, such as decreased tension, depression, anger, fatigue, and confusion and increased vigor (Ikei et al., 2014b).

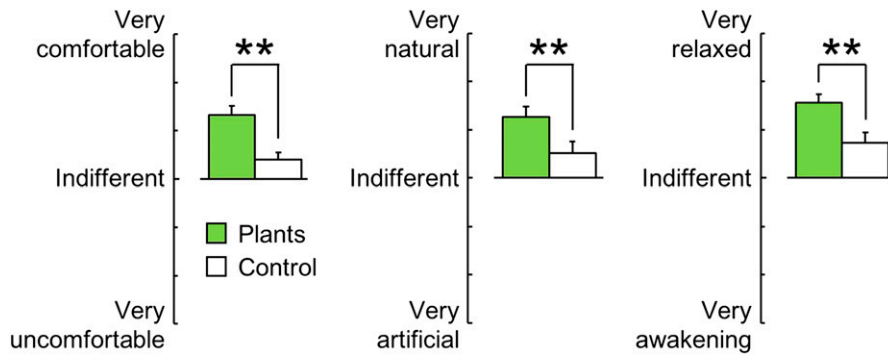


Fig. 7. Comparisons of a modified semantic differential (SD) method under conditions of viewing foliage plants vs. no foliage plants. The SD method uses three pairs of adjectives on 13 scales, including “comfortable-uncomfortable,” “natural-artificial,” and “relaxed-awakening.” A higher score for each indicates better emotional condition. Values are means \pm SE $**P < 0.01$; $N = 24$.

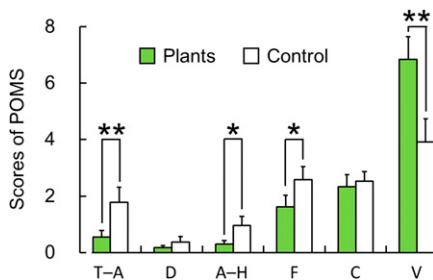


Fig. 8. Comparisons of tension-anxiety (T-A), depression-dejection (D), anger-hostility (A-H), fatigue (F), confusion (C), and vigor (V) in the Profile of Mood State (POMS) questionnaire between conditions of viewing and not viewing foliage plants. The POMS questionnaire consists of 30 questions in the six subcategories of T-A, D, A-H, F, C, and V. Lower scores for T-A, D, A-H, F, and C indicate a better emotional condition, but a higher score for the V category indicates a better condition. Values are means \pm SE $*P < 0.05$ and $**P < 0.01$; $N = 24$.

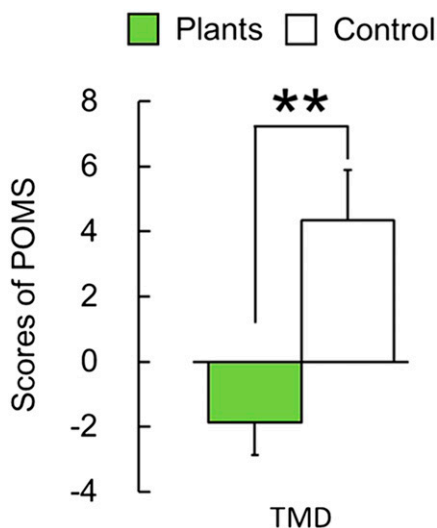


Fig. 9. Comparisons of the total mood disturbance (TMD) score in the Profile of Mood State (POMS) questionnaire between conditions. The POMS questionnaire consists of 30 questions in six subcategories, such as tension-anxiety (T-A), depression-dejection (D), anger-hostility (A-H), fatigue (F), confusion (C), and vigor (V). The TMD score was calculated by the formula $[(T - A) + (D) + (A - H) + (F) + (C) - (V)]$. Values are means \pm SE $**P < 0.01$; $N = 24$.

Previous studies have reported that exposure to environments with plants can have physiological and psychological benefits (Hartig et al., 1991; Ulrich, 1981; Ulrich, 1991; Ulrich and Parsons, 1992). For example, Ulrich (1991) reported that a natural environment led to recovery from stress. In addition, interior spaces with green plants induced stable autonomic nervous system activity (Ikei et al., 2014a) and increased emotional stability as inferred based on increased alpha wave activity in electroencephalographic measurements (Son et al., 1998). Chang and Chen (2005) comprehensively investigated the effects of window views and indoor plants on human psychophysiological responses in workplace environments by measuring electromyography, electroencephalography, blood volume pulse, and state anxiety. The results of this study showed that participants were notably less nervous or anxious when viewing nature or indoor plants. Finally, a review of 21 studies concluded that passive interactions with indoor plants provide psychological benefits, such as stress reduction and increased pain tolerance (Bringslimark et al., 2009).

As our data indicate, even a small number of plants can offer psychophysiological benefits. In accordance with our findings, Ikei et al. (2014a) reported that as few as three foliage plants that were 55–60 cm in height provided significant physiological and psychological relaxation in high school students. Moreover, Choi (2015) reported that an index of greenness equivalent to 5% foliage green plants within an interior space resulted in psychophysiological stability in male university students.

In conclusion, in the current study, viewing foliage plants led to physiological and psychological relaxation in male subjects in their 20s. Future study is needed to investigate the effects on brain function from sensory stimulation for various age groups and gender differences. Furthermore, it would be of interest to determine whether foliage plants could alleviate aggressiveness or emotional instability in individuals with special needs.

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