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Physiological and psychological responses of humans to the index of greenness of an interior space

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ABSTRACT

The objective of this study was to identify the optimal index of greenness in terms of psychophysiological responses and subjective preference. We recruited 103 adult (51 male, 52 female) participants, who were examined individually in an interior space (lab) setting at Konkuk University, Seoul, South Korea. Participants observed plants in the space for 3 min per experimental index of greenness (5%, 20%, 50%, and 80%). During this period, heart rate variability (HRV) and electroencephalographic (EEG) physiological responses were measured, and the participant's preference for index of greenness and subjective index of greenness was determined via surveys. HRV values were normal, and not significantly different, except that male participants showed higher mean variability between cardiac NN intervals and greater autonomic activity than female participants ($P < 0.05$). EEG data were not significantly different, except that female participants had a significantly higher mean amplitude at the left occipital (O1) electrode than male participants ($P < 0.01$). Subjectively, participants preferred the 50% index of greenness the most, though they consistently reported the subjective index of greenness to be ~15% higher than the actual level. We conclude that given a limited interior space, even a small amount of greenery may exert a relaxing effect on people.

1. Introduction

Urbanites in today's modern society spend more than 80% of their time indoors.[1,2] Because of this, the need for green space is on the rise for those who have limited opportunities to access nature.[3] To this end, green plants are being placed in interior spaces,[4] which increase the index of greenness[5] of the space.

Ulrich[6] reported that stress-related negative emotions and autonomic nervous system activation are suppressed when humans access the natural environment. In fact, one study revealed that patients exposed to nature after surgery recovered faster;[7] Ulrich's group also noted similar results in recovering from stress.[8] Kaplan and Kaplan[9] hypothesized that nature and green landscaping induce a natural focus which is neither burdensome to nor consciously recognized by humans, but which relieves mental fatigue in everyday life. Indeed, a window with a view of nature has positive benefits such as stabilizing the mind and enhancing satisfaction of life.[10] Ikei et al.[11] measured changes in heart rate variability (HRV) in people between an internal space with and without plants, and found that green plants induced parasympathetic activity and greater stabilization of the autonomic nervous system. In addition, Son et al.[12] have noted increased electroencephalographic (EEG) activity when plants were included in an interior space. These data support the possibility of a genetically programmed sense of relief and comfort one would feel in the natural environment, which Wilson proposed[13] as the concept of "biophilia" (the tendency to place value on life and process similar to life).

The index of greenness refers to the percentage of a streetscape or interior space in which green leaves occupy the visual field of a person[14,15]; it replaced the ratio of greenness and more directly represents what humans experience.[14] Several studies have shown that the index of greenness has a significant impact on preference and satisfaction of a perceived scene.[5,16] In particular, it influences the satisfaction level[2] and visual preference of uses of a space[15]; and enhances performance[17] and psychological stability.[18] Furthermore, Lee[3] further noted improved concentration and greater

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positive emotions in urbanites given a greater index of greenness. However, the correlation between the index of greenness and its restorative ability is still unclear, as is the optimal index for indoor spaces. In fact, very high indices were found to have low viewing preference, suggesting a balance is needed.[19] Therefore, this study was designed to identify the preferred index of greenness of urbanites through subjective and physiological measures, and to identify possible sex differences in these psychophysiological responses.

2. Materials & methods

2.1. Research subjects

We recruited a total of 103 males and females in their twenties (male 51, female 52) (Table 1) via the Konkuk University website. Informed consent was obtained by the primary researcher through individual contact with all participants. Inclusion criteria were acknowledgment of consent and currently not suffering from specific diseases. Participants were told to abstain from alcohol for the 2 days before the experiment, and from caffeine and smoking for the 2.5 h prior to the experiment, based on previous research.[20,21]

2.2. Experimental environment

The interior space was prepared in a lab at Konkuk University, and based on the US standard workspace area of the IFMA (International Facility Management Association) of 11.5-15.0 m^2. For this study, a space of 1.5 m x 1.5 m was set apart,[2,22] and an ivory colored blackout curtain was hung to block external visual elements and create a closed workspace (Fig. 1). The interior environment was set at 23.0-26.0 °C, relative humidity of 30 ± 10%, and illumination of 700 lx (fluorescent light), according to the recommendations of ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.).

2.3. Index of greenness

The index of greenness was first calculated by using a photo that was taken within the general range of vision, and determining the percentage of leaves of living plants in the total area of the photo.[14] Based on Yoo and Lee's research,[2] the index of greenness focal point was set at 1.5 m horizontally from the participant's chair, and within the visual angle of 20° up and down from that point. The index of greenness was then obtained by calculating the plant leaf area as a percent of the total area using Auto CAD 2012 (Autodesk Inc., CA, USA). Because preference differences were not statistically significant unless indices of greenness were over 5% different,[16] we set the treatment levels at 5%, 20%, 50%, and 80% (Fig. 2). In addition, since design elements such as shape and color could stimulate vision,[22] the plants were arranged in a mosaic to minimize such effects. The same plant, *Epipremnum aureum*, and same pots (20–30 cm size) were used in all cases to control for preference of plant shapes.[23]

2.4. Experimental procedure

After explaining the procedure in detail to the subjects before the experiment, the body composition and height of the subjects were measured using a fat analyzer (ioi 353; Jawon Medical, Gyeongsan, South Korea) and anthropometer (Ok7979; Samhwa, Seoul, South Korea). Demographic information such as age, gender, and smoking history and current disease state was collected using a survey. Physiological responses were measured using an MP150WSW (BIOPAC system Inc., Goleta, California, USA) device attached to the relevant body parts. Subjects were told to close their eyes and rest for 3 min[24] to acclimatize them and stabilize physiological measurements. Then subjects were randomly shown plants according to that trial's index of greenness for 3 min.[21] During the time interval needed to treat the index of greenness (2 min), subjects closed their eyes and rested comfortably (Fig. 1).[21] The physiological responses for the four different index of greenness while the subjects were in a stable condition were also measured and saved. After measuring the physiological responses to each index of greenness treatment, the subjects answered the survey to examine their subjective psychological responses.

2.5. Measurement items

Electrocardiography (ECG) and electroencephalography (EEG) were utilized. For ECG, after attaching the biopotential module (ECG 100C, BIOPAC system Inc., Goleta, California, USA) to the physiological data acquisition system (MP150WSW, BIOPAC system Inc., Goleta, California, USA), electrodes were placed on each end of the collarbones, and ground electrodes were attached to the area of the left rib bones (Fig. 3). For EEG recording, a different biopotential module (EEG 100C, BIOPAC system Inc., Goleta, California, USA) was attached to the physiological data acquisition system (MP150WSW, BIOPAC system Inc., Goleta, California, USA). An electrode cap (Electro-Cap, Electro-Cap International, Inc., Eaton, Ohio, USA) using the 10–20 electrode system of the International Federation[25] was placed on the subject's head, and recordings of Fp1 (left frontopolar), Fp2 (right frontopolar), O1 (left occipital lobe), and O2 (right occipital lobe) were made (Fig. 3). These were chosen because cognition and thinking are regulated by the frontopolar region,[26] whereas visual processing is represented by occipital EEG.[27] Eye movements were measured by electrooculogram (EOG) to control for eye movement artifacts.

For subjective psychological measures, we utilized a semantic differential scale (SD scale)[28] and a survey on the characteristics of the visual images.[29,30] The subjects were shown four pictures with the index of greenness set to 5%, 20%, 50%, and 80%, respectively, and were then asked to choose a photo with their preferred index of greenness. The subjects then indicated their preferred image on a scale with 7 pairs of opposite words of emotion laid out in 5 levels. Finally, they wrote down the index of greenness they believed was represented in the chosen photo.

2.6. Analysis methods

EEG values were analyzed using Biopac's AcqKnowledge 4.2 analysis software. Power spectrum analysis, in which EEG power in calculated for specific frequency bands, was also performed. Fast Fourier transformation was used to split EEG power into α, β, θ, and δ frequency bands. We focused on α band activity, since it frequently occurs during a stimulated and stable condition, when eyes are closed, and are relevant to a relaxed and stable condition. EOG activity was extracted and removed from the EEG prior to power analyses.

ECG was also analyzed by using Biopac's AcqKnowledge 4.2, and with Kubios 2.2 analysis software (University of Eastern Finland, Finland). Raw ECG data was filtered and converted to HRV data. HRV analysis includes time domain and frequency domain analyses, both of which were conducted by each level of the index of greenness using Kubios 2.2. The RR interval, i.e., the gap between successive R peaks on the ECG, and the rate of change in RR intervals were quantified to assess activities of the sympathetic and parasympathetic nervous systems.[31] Time domain measures included 1) RMSSD (root mean square of successive differences), which represents the stability of the heart rate and parasympathetic nervous system activity[32]; 2) SDNN (standard deviation of

Table 1
Descriptive information of subjects who participated in the study to measure psychophysiological response according to the index of greenness of interior space (N = 103).

Variable	Male (n = 51) Mean ± SD	Female (n = 52)	Total (n = 103)	P
Age (years)	22.6 ± 2.6	20.7 ± 1.5	21.6 ± 2.3	***
Height (cm)	173.8 ± 5.9	159.7 ± 4.7	166.7 ± 8.8	***
Body weight (kg)	69.6 ± 10.8	55.0 ± 8.0	62.2 ± 11.9	***
Body mass index (kg m^{-2})	23.0 ± 2.7	21.6 ± 3.0	22.3 ± 2.9	*
	N (%)			
Smoking	12 (23.5)	2 (3.8)	14 (13.6)	**
Nonsmoking	39 (76.5)	50 (96.2)	89 (86.4)	
Disease				
Yes	11 (21.6)	6 (11.5)	17 (16.5)	ns
No	40 (78.4)	46 (88.5)	86 (83.5)	

Note: Height = without shoes was measured by an anthropometer (Ok7979; Samhwa, Seoul, South Korea).
Body weight = measured by a body fat analyzer (ioi 353; Jawon Medical, Gyeongsan, South Korea).
Body mass index = [weight (kg)]/[height (m)^2].
ns, *,**,*** = Nonsignificant or significant by independent *t*-test or chi square test at *P* < 0.05, 0.01, or 0.001, respectively.

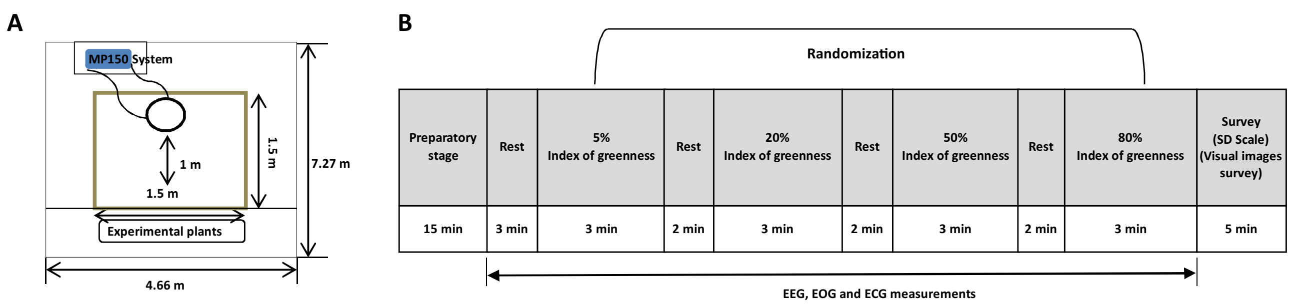

Fig. 1. A: Room arrangement for the experiment. B: Study procedures.
SD Scale = Semantic differential scale.[28]
Visual images survey.[29,30]
EEG = Electroencephalography.
EOG = Electrooculogram.
ECG = Electrocardiography.

NN intervals), which reflects cardiovascular stability and the ability of the autonomic nerve system to regulate the heart[33]; and 3) mean RR (the mean duration of RR intervals), which identifies bradycardia.[32] Frequency domain analyses assess the activity of the sympathetic and parasympathetic autonomic systems. The following frequency domain measures were analyzed: VLF (very low frequency) oscillatory power (0.003–0.04 Hz), a measure of autonomic nerve system function[32]; LF (low frequency) oscillatory power (0.04–0.1 Hz), an indicator of sympathetic activity; HF (high frequency) power (0.15–0.4 Hz), an indicator of parasympathetic activity; and the LF/HF ratio, which shows the balance between the sympathetic and parasympathetic systems, though mainly reflecting sympathetic activity. Frequency domain measures were converted to log values prior to analysis.

Subjects whose recordings included excessive artifacts were excluded, so 97 (male 49, female 48) and 93 (male 50, female 43) subjects were used for EEG and ECG analyses, respectively. SPSS (Version 22 for Windows; IBM, Armonk, NY) was used to conduct one-way analysis of variance and two-way analysis of variance using a significance level of P < 0.05. For the demographic information Microsoft Excel (Office 2007; Microsoft Crop., Redmond, WA) was used to generate descriptive statistics, and SPSS (Version 22) for an independent *t*-test and Chi-square tests.

3. Results and discussion

3.1. Demographic characteristics

The average age of the subjects was 21.6 ± 2.3 years old (male 22.6 ± 2.6, female 20.7 ± 1.5). Although there were sex differences in the mean age and smoking condition, there were no differences in whether they currently had a disease (Table 1).

3.2. Heart rate variability (HRV) according to the index of greenness

HRV quantifies fluctuations in heart rate related to internal or external environmental changes, especially changes due to autonomic nervous system activity.[31] It acts as an indirect measure of mental stress.[34] and is a key indicator of physiological stability. We found no significant differences between HRV values according to the index of greenness treatments (Table 2). In addition, there were no significant sex differences in HRV for any given index of greenness treatment; however, male subjects had significantly higher SDNN, VLF, LF, and LF/HF ratio values (Table 2). SDNN values were within the standard range (30–60 ms, stable condition) for both sexes, though the male SDNN averaged about 2.2% higher than the female SDNN. This is consistent with previous studies, whose authors suggest that a lower SDNN in females relates to higher degrees of emotional sensitivity and stress susceptibility.[35,36] The other values were all also within the standard range (VLF: 5.0–7.2 ms^2, LF: 4.7–7.0 ms^2, stable condition); male values were an average of 4.7%, 5.5%, and 23% higher than female values, respectively. These findings are also consistent with those of previous studies, which suggest that male autonomic nervous system activity is tonically higher than that in females.[37,38]

Of all the HRV measures, only RMSSD was significantly different. It was higher with an index of greenness of 50%, but was only significantly higher for male subjects (Table 2). A greater RMSSD indicates increased parasympathetic nervous system activity, and

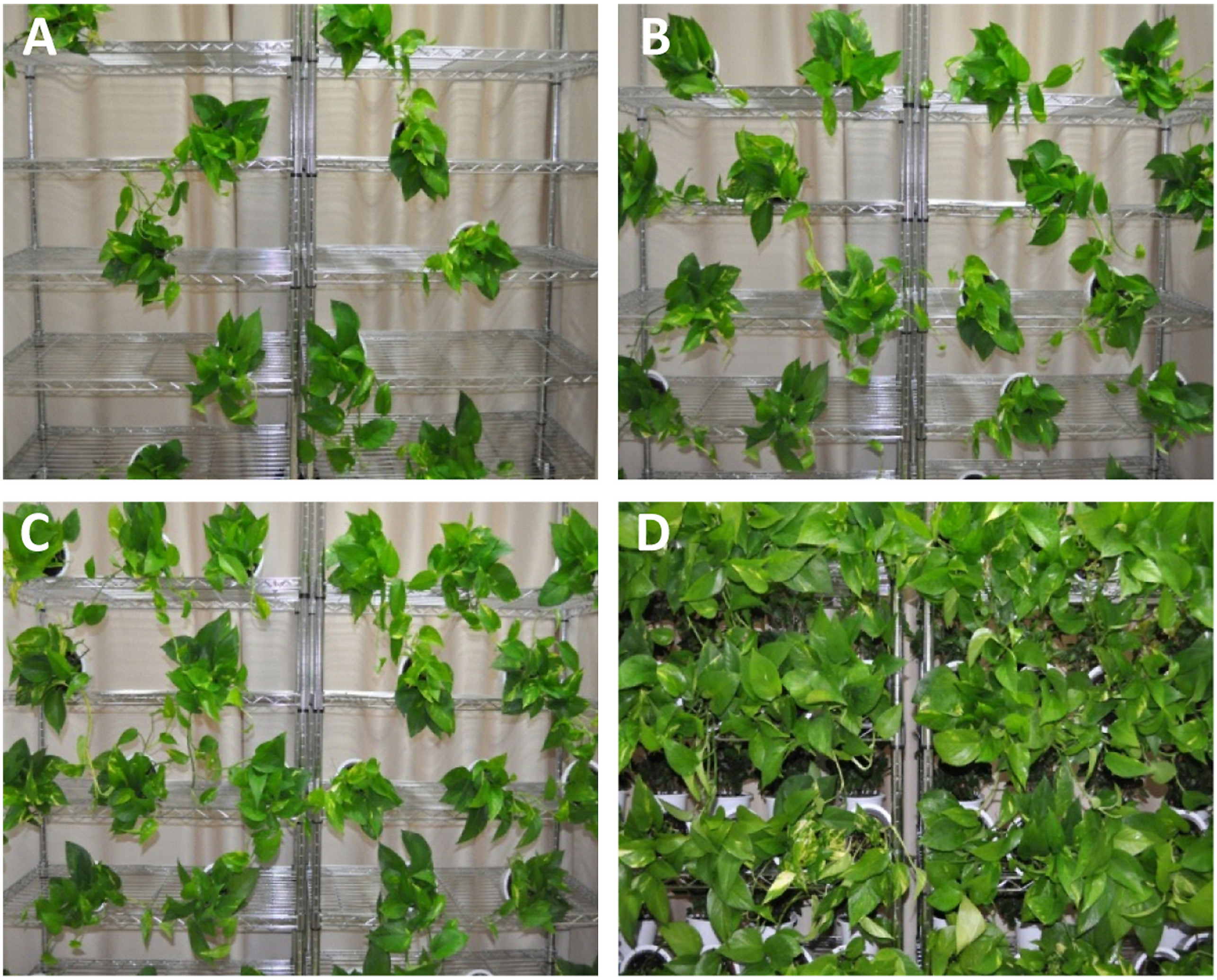

Fig. 2. Index of greenness photos. (A) 5% Index of greenness, (B) 20% Index of greenness, (C) 50% Index of greenness, and (D) 80% Index of greenness.

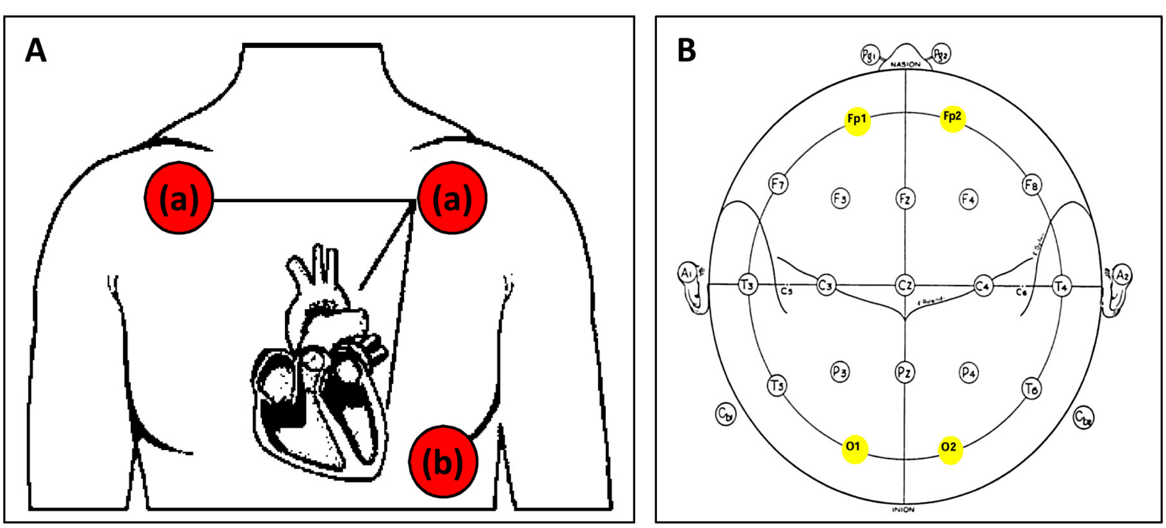

Fig. 3. A: Electrocardiography lead placement. (a) Measuring electrode (b) Ground electrode. B: The 10–20 electrode system.

frequently demonstrates sex differences.[37] Given the limited number of significant differences in HRV measures in this study, we cannot decisively conclude that an index of greenness of 50% is the most effective in stabilizing the physiological state, even in males.

3.3. *Electroencephalography (EEG)*

No significant differences related to index of greenness were found in any EEG activity measures; the only significant difference

Table 2
Results of heart rate variability (HRV) according to the index of greenness of interior space.

HRV	%	Time domain measures of HRV			Frequency domain measures of HRV			
		RMSSD (ms) Mean ± SD	SDNN (ms)	Mean RR (ms)	Ln(VLF) (ms^2)	Ln(LF) (ms^2)	Ln(HF) (ms^2)	LF/HF ratio (ms^2)
Total (n = 93)	5	32.6 ± 17.1	44.0 ± 16.6	779.9 ± 103.2	6.2 ± 1.0	6.0 ± 0.9	5.8 ± 1.0	1.8 ± 1.7
	20	32.7 ± 19.2	42.8 ± 16.9	779.9 ± 103.2	6.1 ± 1.0	6.0 ± 0.9	5.8 ± 0.9	1.6 ± 1.3
	50	33.2 ± 19.7	43.9 ± 16.2	780.1 ± 104.8	6.2 ± 1.0	6.0 ± 0.9	5.8 ± 1.0	1.8 ± 1.8
	80	33.2 ± 19.1	43.8 ± 17.6	778.0 ± 103.7	6.2 ± 1.0	5.9 ± 1.0	5.8 ± 1.1	1.8 ± 1.7
	P[a]	ns	ns	ns	ns	ns	ns	ns
Male (n = 50)	5	32.0 ± 16.0 a[c]	46.1 ± 16.6	788.4 ± 99.1	6.4 ± 1.0	6.2 ± 0.8	5.8 ± 1.0	1.8 ± 1.7
	20	32.5 ± 18.3 a	45.2 ± 18.0	789.2 ± 100.4	6.2 ± 1.1	6.2 ± 0.9	5.8 ± 0.9	1.6 ± 1.3
	50	43.9 ± 14.1 b	43.9 ± 14.1	786.8 ± 101.0	6.3 ± 0.8	6.2 ± 0.7	5.8 ± 1.0	1.8 ± 1.8
	80	33.0 ± 18.7 a	45.9 ± 17.1	785.0 ± 100.2	6.3 ± 1.0	6.1 ± 1.0	5.8 ± 1.0	1.8 ± 1.7
	P	***	ns	ns	ns	ns	ns	ns
Female (n = 43)	5	33.3 ± 18.4	41.5 ± 16.6	769.9 ± 108.2	6.1 ± 1.1	5.9 ± 0.9	5.8 ± 1.1	1.6 ± 1.5
	20	33.0 ± 20.5	40.0 ± 15.2	769.1 ± 106.5	5.9 ± 1.0	5.7 ± 0.8	5.7 ± 0.9	1.3 ± 1.1
	50	35.0 ± 22.6	43.9 ± 18.6	772.2 ± 109.8	6.1 ± 1.1	5.9 ± 1.0	5.8 ± 1.1	1.6 ± 2.1
	80	33.4 ± 19.7	41.4 ± 18.1	769.8 ± 108.4	6.0 ± 0.9	5.8 ± 1.1	5.8 ± 1.2	1.6 ± 1.7
	P	ns	ns	ns	ns	ns	ns	ns
Analysis of variance[b]								
Gender		ns	*	ns	**	***	ns	**
Index of greenness		ns	ns	ns	ns	ns	ns	ns
Gender × Index of greenness		ns	ns	ns	ns	ns	ns	ns

Note: HRV = Heart rate variability.
RMSSD = Square root of the mean squared differences between successive RR intervals.
SDNN = Standard deviation of RR intervals; Mean RR = The mean of RR intervals.
Ln(VLF) = Log-transformed very low frequency band [0–0.04 Hz].
Ln(LF) = Log-transformed low frequency band [0.04–0.15 Hz].
Ln(HF) = Log-transformed high frequency band [0.15–0.4 Hz].
LF/HF ratio = Ratio between LF and HF band powers.
% = Index of greenness.
[a] ns,*** Nonsignificant or significant by One-way ANOVA at $P \le 0.05$ and 0.001.
[b] ns,*,**,*** Nonsignificant or significant by Two-way ANOVA at $P \le 0.05$, 0.01, or 0.001, respectively.
[c] Means sharing a common letter are not significantly different at $P \le 0.05$ using Tukey's honestly significant difference test.

Table 3
Results of electroencephalography (EEG) according to the index of greenness of interior space.

EEG	%	Fp1 (μV) Mean ± SD	Fp2 (μV)	O1 (μV)	O2 (μV)
Total (n = 97)	5	0.093 ± 0.040	0.097 ± 0.039	0.088 ± 0.025	0.107 ± 0.065
	20	0.094 ± 0.043	0.097 ± 0.039	0.089 ± 0.028	0.108 ± 0.067
	50	0.093 ± 0.043	0.095 ± 0.042	0.091 ± 0.031	0.109 ± 0.067
	80	0.094 ± 0.051	0.097 ± 0.051	0.088 ± 0.036	0.107 ± 0.070
	P[a]	ns	ns	ns	ns
Male (n = 49)	5	0.091 ± 0.035	0.095 ± 0.036	0.085 ± 0.026	0.103 ± 0.064
	20	0.095 ± 0.042	0.099 ± 0.040	0.087 ± 0.027	0.104 ± 0.066
	50	0.090 ± 0.037	0.094 ± 0.037	0.085 ± 0.024	0.103 ± 0.063
	80	0.090 ± 0.037	0.095 ± 0.039	0.084 ± 0.025	0.103 ± 0.064
	P	ns	ns	ns	ns
Female (n = 48)	5	0.096 ± 0.045	0.098 ± 0.042	0.090 ± 0.023	0.111 ± 0.067
	20	0.094 ± 0.045	0.094 ± 0.042	0.091 ± 0.029	0.112 ± 0.068
	50	0.097 ± 0.049	0.097 ± 0.047	0.096 ± 0.037	0.116 ± 0.070
	80	0.099 ± 0.063	0.099 ± 0.061	0.092 ± 0.045	0.111 ± 0.075
	P	ns	ns	ns	ns
Analysis of variance[b]					
Gender		ns	ns	*	ns
Index of greenness		ns	ns	ns	ns
Gender × Index of greenness		ns	ns	ns	ns

EEG = Electroencephalography.
Fp1 = EEG measurement location name; left frontopolar.
Fp2 = EEG measurement location name; right frontopolar.
O1 = EEG measurement location name; left occipital.
O2 = EEG measurement location name; right occipital.
[a] ns,* Nonsignificant or significant by Two-way ANOVA at $P \le 0.05$.
[b] ns Nonsignificant at $P \le 0.05$ by One-way ANOVA.

in any EEG measure was significantly higher EEG power in males relative to females at the O1 (occipital) electrode (Table 3). According to Lee and Son,[39] as well as Jang,[21] seeing green plants have a positive impact on the psychological state and increase physiological activity measures in the cerebrum. Other work demonstrated that seeing actual foliage plants was more relaxing, physiologically (i.e., increased frontal lobe activity) and psychologically, than seeing plants on video screens.[40] Indeed, these studies were confirmed

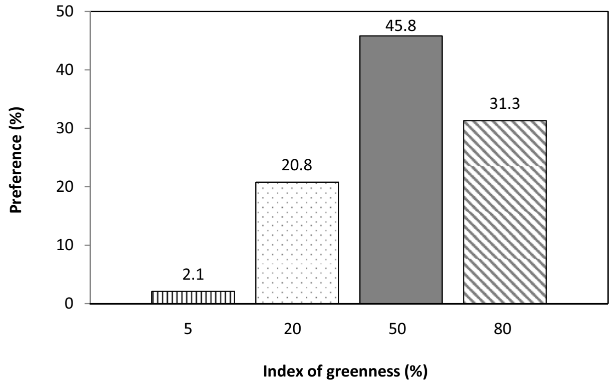

Fig. 4. Preference for index of greenness.

by data on workplace environment preference demonstrating a greater preference towards an environment with plants.[41]

Our EEG data do not support these previous studies; however, they do not refute them either. We chose a specific type of EEG analysis, and one possibility that explains our different results is the need for a different type of analysis given our current experimental paradigm.

3.4. Subjective index of greenness preference and perception

The survey results representing the preferred index of greenness are shown in Fig. 4. The most frequent choice (45.8%) was 50%, whereas very few subjects (2.1%) chose the minimal value of 5%. Our result is different from Lee and Bang,[16] who reported a preferred index of 30%. However, their study used rather burdensome trees and understory planting together, and the different arrangements and study protocol could be the source of the differences. Biological diversity of greenness or planting design may affect to the preference for index of greenness.

On the other hand, the difference could be explained by some of our other results, those of the perceived greenness survey. We asked subjects to indicate the index of greenness that they perceived when looking at the test pictures (i.e., known index of greenness levels of 5%, 20%, 50%, and 80%). As described in Fig. 5, the subjective index of greenness was rated about 15% higher than the actual index of greenness level for all subjects, with no significant sex differences. It is therefore likely that there are differences between how Lee and Bang's multilevel/tree-planting protocol[16] was perceived by their subjects, and how our single-plant, distributed images were perceived by our subjects.

In addition, we utilized a semantic differential scale to identify the evoked feelings/imagery in the subjects. As seen in Fig. 5, for an index of greenness level of 50%, subjects chose only the positive semantic choices, with 'fresh' and 'comfortable' as the most chosen options. According to Yoo,[42] adults in their twenties felt positive mental images described as 'abundant', 'usual', and 'natural', among others, when viewing the plant used in this study (*Epipremnum aureum*). Song et al.[43] and Jang[21] reported similar results with foliage plants such as *Epipremnum aureum*, and their subjects used words such as 'openness', 'tranquil mind', 'bright', and 'luxurious'. Our data and their results support the hypothesis that viewing foliage plants are generally associated with positive images and feelings (Fig. 6).

In conclusion, we found no significant differences in physiological parameters with regard to the index of greenness, though we did not seek to examine whether there was a difference between an index of 0% and other nonzero indices. In previous studies of

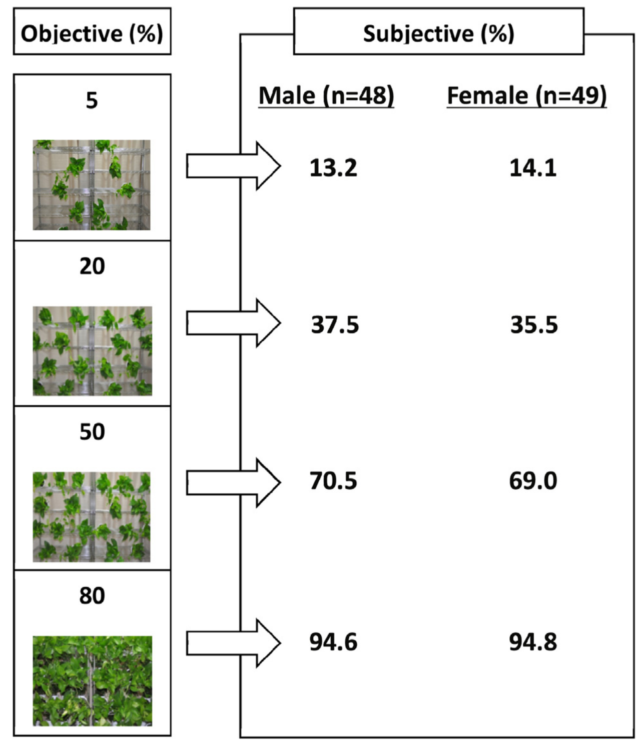

Fig. 5. Subjective index of greenness scale of indoor space in males and females.

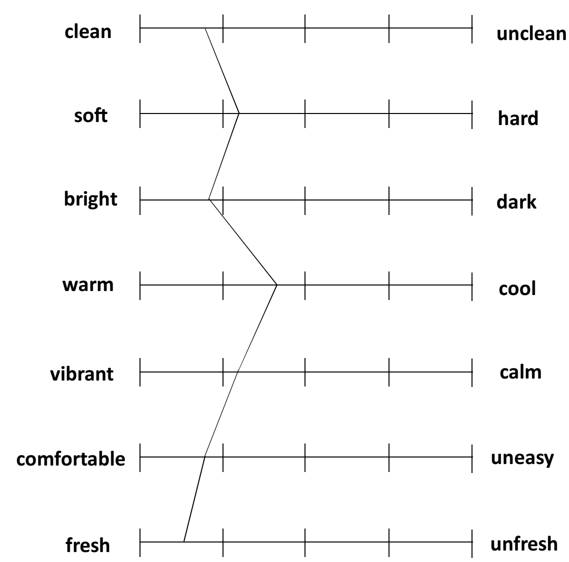

Fig. 6. Means of environment assessment semantic differential scale of indoor space according to index of greenness 50%.

an indoor environment, even using a very low index of greenness, significant improvements in psychophysiological measures of stability were noted.[11,40] In other words, within a limited indoor space, even a small amount of plants can provide benefits in psychophysiological stability, seemingly by stimulating the autonomic nervous system. However, our subjects mostly preferred an index of greenness of 50%, suggesting that more plants in an indoor environment could either enhance the benefit, or provide it to a broader group of people who might not experience the benefits at low indices. Based on this study, follow-up research on psychophysiological stability using a harmonious interior landscape could be conducted to identify synergistic or other enhancing effects; these could then be followed by further studies applying and examining the impacts of emotional stability, alleviation of aggressiveness, improvement of concentration and learning ability in urban workers, especially in stressful jobs.

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