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Effects of Leaf Shape of Foliage Plants on Human Psychophysiological Responses

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Keywords. EEG, leaf shape, parietal cortex, plant form, visual stimulus

Abstract. **Visual characteristics of foliage plants are increasingly recognized as important factors influencing human psychological and physiological responses; however, empirical evidence regarding the effects of specific leaf shapes remains limited. This study investigated humans' psychophysiological and psychoemotional responses to visual stimuli from foliage plants of various shapes to address this research gap using objective and subjective measures. Thirty adults (24.86 ± 2.68 years old) participated in the experiment conducted at a laboratory in Konkuk University designed explicitly for this study. The foliage plants used in the experiment were classified into five groups based on leaf shape and plant shape: round (*Ficus elastica; Peperomia obtusifolia*), upward linear (*Sansevieria trifasciata; Sansevieria stuckyi*), downward linear (*Dracaena draco; Dracaena marginata*), palmate (*Fatsia japonica; Schefflera arboricola*), and downward compound (*Nephrolepis exaltata; Adiantum raddianum*). Participants took a 3-minute rest before the experiment began, and their brain waves were measured while they observed each plant for 90 seconds. Ten plants were presented randomly. Immediately after observing each plant, the Semantic Differential Method (SDM) assessed psychoemotional responses. The collected data were analyzed using a one-way analysis of variance (ANOVA) and Duncan's post hoc test. Comparisons among the five plant groups revealed that observing palmate and downward compound plants significantly increased relative gamma and spectral edge frequency 90% in the left parietal lobe, indicating improved concentration ($P < 0.05$). In addition, observing plants compared with empty spaces significantly activated the relative high-beta power spectrum in the left and right parietal lobes ($P < 0.05$), with no differences observed among plant shapes. The SDM analysis showed that participants felt most comfortable and stable when viewing round-shaped plants ($P < 0.001$) and experienced the most enjoyment when viewing palmate-shaped plants ($P < 0.001$). These findings demonstrate that foliage plant leaf shape differentially influences human psychophysiological and psychoemotional responses and provide evidence for shape-based indoor green design.**

Natural environments have been widely recognized for their beneficial effects on human physiological and psychological health. Several studies have shown that exposure to nature improves mental well-being and stress-coping ability (Jimenez et al. 2021; Russell et al. 2013). Urban residents who spend time in natural environments experience enhanced concentration and reduced fatigue and irritability (Herzog et al. 2003), and natural settings are consistently reported to be more restorative than built environments (Menardo et al. 2019). Spending time in green environments has been associated with improved subjective well-being (Scopelliti et al. 2019) and reduced stress levels (Payne et al. 2020).

Two prominent theoretical frameworks explain the restorative effects of nature: Stress Recovery Theory (SRT) (Ulrich 1983, 1984) and Attention Restoration Theory (ART) (Kaplan and Kaplan 1989; Kaplan 1995). SRT proposes that exposure to natural environments facilitates recovery from stress responses, a proposition supported by clinical and experimental evidence. A seminal hospital study demonstrated that surgical patients with views of trees recovered faster and required less pain medication than those with views of brick walls (Ulrich 1984), highlighting the positive influence of natural views on physical and emotional recovery. ART, in contrast, suggests that prolonged cognitive effort leads to attentional fatigue and that environments affording effortless attention, such as nature, restore depleted attentional resources. Supporting this theory, individuals with views of nature from their windows report greater effectiveness and comfort (Kaplan 2001), and students exposed to natural views show improved attentional performance (Tennessen and Cimprich 1995).

As modern societies increasingly confine daily activities indoors, the importance of incorporating natural elements into indoor environments has gained attention. Individuals now spend ∼80% to 90% of their time indoors (Hassan et al. 2020), prompting efforts to improve indoor environmental quality through natural elements. Studies have shown that indoor spaces containing plants promote greater relaxation and task efficiency compared with spaces without plants (Shibata and Suzuki 2002). Even a minimal green view index (∼5%) has been shown to induce physiological stabilization (Choi et al. 2016; Ikei et al. 2014), and visual exposure to green plants positively affects psychological states and brain activity (Song et al. 2015).

Physiological indicators such as heart rate variability (HRV) and blood pressure variability are widely used to assess autonomic regulation associated with perceived comfort in indoor environments (Oh and Park 2022; Vanderlei et al. 2009). Consistent with these findings, ∼80% of office workers report enhanced comfort in workplaces with indoor plants (Miyak 2001). Empirical studies further demonstrate that indoor plant exposure stabilizes autonomic and parasympathetic nervous system activity (Ikei et al. 2014). Moreover, visual stimuli from real plants, compared with artificial plants, plant photographs, or empty spaces, have been shown to increase relative theta power and decrease high beta activity in the occipital cortex, indicating reduced stress and anxiety (Jeong et al. 2021).

Although the beneficial effects of indoor plants are well documented, relatively little attention has been paid to the role of plant morphology, particularly leaf shape, in shaping psychophysiological responses. Leaf shape is a key visual characteristic influencing aesthetic preference and perceptual responses to plants (Berger 2022). In South Korea, the concept of "plant interiors" (planterior), which integrates plants as central visual elements in interior design, has rapidly expanded (KIPA IPEC 2024). Planterior spaces function not merely as decorative environments but as spaces that mediate psychological and physiological well-being through visual stimuli (Jo et al. 2019). Despite the growing popularity of such environments, most psychophysiological studies have focused on the presence or absence of plants rather than systematically examining shape-specific visual effects.

To address this research gap, the present study aimed to investigate adults' psychophysiological and psychoemotional responses to visual stimuli from foliage plants with different leaf shapes. Using electroencephalography (EEG), HRV, and subjective emotional

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assessments, this study examined whether distinct leaf shapes elicit differential cognitive and emotional responses, thereby providing empirical evidence to inform evidence-based indoor green design.

Methods

Participant recruitment and research conditions

Recruitment. This study was conducted with voluntary participants aged 20 and older. Based on previous psychophysiological studies using EEG, a sample size of 30 participants was determined to be sufficient to ensure stable distribution characteristics and reliable statistical analysis (Kim et al. 2020). In addition, the within-subject experimental design reduced interindividual variability and increased statistical sensitivity, allowing reliable detection of differences across foliage plant shape conditions with this sample size. Recruitment announcements were posted on online agricultural and horticultural SNS platforms and bulletin boards at Konkuk University's library and student center with institutional cooperation. The selection criteria for participants were adults aged 20 to 65 years without visual impairment and with standard or corrected vision. Individuals with plant-related allergies, psychiatric disorders, or those taking medications were excluded from the study (Choi et al. 2016). Participants were instructed to abstain from food and beverages containing caffeine for at least 3 h before the experiment to minimize its potential effects on brain activity (Heckman et al. 2010). The study's purpose, procedures, and measurement instruments were explained to the potential participants, and those who voluntarily expressed their willingness to participate and submitted a consent form were selected. This study was approved by the institutional review board of Konkuk University (7001355-202302-HR-653).

Experimental condition. The experiment was conducted in a laboratory at Konkuk University appropriately set up for this study. To minimize external auditory and visual interference, environmental conditions were strictly controlled throughout the experiment. The laboratory environment was controlled to maintain an average temperature of 23.16 °C, an average humidity of 63.2%, and an average illuminance of 1197 lx, ensuring a comfortable setting for participants. Three sides of the laboratory were enclosed with curtains (270 × 230 cm) to block extraneous visual stimuli. All observations were conducted at a white table (180 × 89 cm, height 70 cm) and adjustable chairs were provided to allow participants to maintain a comfortable seated posture throughout the experiment.

Experimental procedure. Participants were briefed on the study's details and provided informed consent before the experiment. Demographic information was collected through questionnaires, and participants' height, weight, and body mass index (BMI) were measured using an Ioi 353 device (Jawon Medical, Gyeongsan, South Korea).

Before the visual stimulus experiment with plants began, participants rested for 3 min while gazing at an empty space without plants. Subsequently, each participant was exposed to 10 different types of plants in a random order for 90 s each, during which their brain waves were measured. This observation duration was selected based on previous EEG-based visual stimulation studies indicating that short-term exposure within this time range is sufficient to elicit stable neural responses while minimizing participant fatigue and motion artifacts. Participants were instructed to remain still and silent, focusing on the foliage plants placed directly in front of them. After each 90-s observation period, participants completed a questionnaire to evaluate their subjective emotions. This procedure was repeated for all 10 types of plants, with a 3 min rest period before each new plant observation. After the brain wave measurements for all plants were completed, participants' subjective plant preferences were assessed, and the experiment was concluded (Fig. 1).

Foliage plant classification

The indoor foliage plants used in this experiment were selected based on leaf and plant shape. A total of 10 plant species were classified into five shape categories, with two species representing each category, as shown in Table 1.

Measurements

Electroencephalography. Brain waves were measured using a wireless dry EEG device (Quick-20l; Cognionics, San Diego, CA, USA) while participants observed the plants as visual stimuli. This EEG device employs a dry electrode system rather than traditional wet electrodes with an electrolyte gel, reducing the risk of electrical shock and enhancing portability and setup efficiency (Guger et al. 2012). The wireless dry EEG device is noninvasive and can collect data in a short period without exposing participants to external energy stimuli such as radiation or magnetic fields. The medical electrodes used in this study (HR-OP42; Hurev, Wonju, South Korea) have been certified safe by the Food and Drug Administration (FDA), Conformité Européenne (CE), and the Korea Drug Administration (KDA).

The electrodes were attached according to the international 10–20 electrode placement system (Klem et al. 1999). The reference electrode was placed on the left earlobe (A1), and brain activity was recorded from the left prefrontal cortex (Fp1), right prefrontal cortex (Fp2), left frontal cortex (F3), right frontal cortex (F4), left parietal cortex (P3), right parietal cortex (P4), left occipital cortex (O1), and right occipital cortex (O2) (Flores 2002). These regions were selected to capture neural activity related to attention, cognitive processing, and visual perception during plant observation.

EEG signals were continuously recorded throughout each 90 s observation period and analyzed using a brain mapping program (BioTek Analysis Software, Daejeon, Korea). Relative power spectra (theta, beta, high-beta, and gamma bands) and spectral edge frequency 90% (SEF90) were calculated as indicators of attentional state, cognitive engagement, and mental arousal.

HRV was measured simultaneously using sensors connected to the EEG device. HRV reflects variation in the time intervals between consecutive heartbeats and is commonly used to assess autonomic nervous system regulation. Higher variability is associated with parasympathetic dominance and physiological relaxation, whereas reduced variability reflects

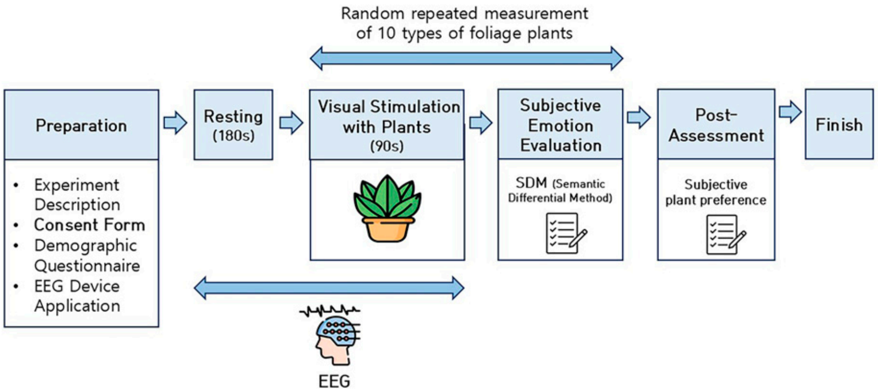

Fig. 1. Experimental procedure. EEG = electroencephalogram.

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Table 1. Classification of indoor foliage plants according to shape.

Classification	Round	Upward linear	Downward linear	Palmate	Downward compound
10 plants					
	Rubber plant (*Ficus elastica*)	Snake plant (*Sansevieria trifasciata*)	Dragon tree (*Dracaena draco*)	Japanese aralia (*Fatsia japonica*)	Boston fern (*Nephrolepis exaltata*)
					
	Baby rubber plant (*Peperomia obtusifolia*)	Stucky's snake plant (*Sansevieria stuckyi*)	Madagascar dragon tree (*Dracaena marginata*)	Umbrella tree (*Schefflera arboricola*)	Maidenhair fern (*Adiantum raddianum*)

increased sympathetic activation (Vanderlei et al. 2009).

SDM. The SDM developed by Osgood (1952) was used and included five items: "anxious-relaxed," "tense-calm," "busy-at leisure," "depressed-happy," and "stimulated-soothed." The scores range from 1 to 7, with higher scores indicating more positive emotional states.

Subjective plant preference. A subjective plant preference evaluation assessed participants' preferences for the plants used in the experiment. The evaluation comprised items assessing preference for the shape of individual leaves and the plant's overall shape. A questionnaire was specifically designed by the researcher for the plants used in this study.

Data analysis

The collected EEG, HRV, and SDM data were analyzed using SPSS (version 25 for Windows; IBM, Armonk, NY, USA). Because the primary objective of this study was to compare mean psychophysiological and psychoemotional responses across foliage plant shape categories defined by a single independent variable (plant shape), one-way ANOVA was used. When significant differences were detected, Duncan's post hoc test was applied to identify pairwise differences among plant shape groups. This analytical approach was considered appropriate given the within-subject experimental design and the focus on shape-based group comparisons. Independent sample *t* tests were conducted to examine gender differences. All statistical analyses were performed at a significance level of $P < 0.05$. Demographic characteristics were summarized using descriptive statistics, including means, standard deviations, and percentages, calculated with Microsoft Excel (Microsoft Excel 2016; Microsoft Corporation, Redmond, WA, USA).

Results

Participants

In total, 30 individuals (15 men and 15 women) participated in this study. The average age, height, weight, and BMI of the participants were 24.86 years, 167.34 cm, 61 kg, and 21.58 kg/m^2, respectively (Table 2).

EEG analysis results

Comparing the five groups according to plant shapes. Comparing the five groups of plants (round, upward linear, downward linear, palmate, and downward compound) based on their shapes revealed that the relative delta (RD) power in the left parietal lobe (P3) was higher when viewing round and upward linear plants compared with downward linear, palmate, and downward compound plants ($P < 0.05$). Conversely, the elative gamma (RG) power and spectral edge frequency 90% (SEF90) in the left parietal lobe (P3) were higher when viewing palmate and downward compound plants compared with round, upward linear, and downward linear plants ($P < 0.05$) (Fig. 2).

Comparing the five plant groups and resting state. The brainwaves observed when looking at an empty space were compared with those observed when viewing plants. Compared with the resting state, the spectral edge frequency 50% (SEF50) in the left and right occipital regions (O1, O2) was significantly higher when viewing plants ($P < 0.05$, $P < 0.01$), with no differences observed among the different plant shapes (Fig. 3).

Comparing brain waves between genders according to plant shapes (RA). When comparing the five plant groups according to shape, men had a higher relative alpha power spectrum (RA) in the frontal regions (F3 and F4) than women when viewing round plants ($P < 0.01$). When viewing palmate-shaped plants, men had a higher RA in both the left and right frontal regions (F3 and F4) ($P < 0.01$) and in the right occipital region (O2) ($P < 0.05$). When viewing downward compound plants, men exhibited higher RA in the left and right frontal regions (F3 and F4) ($P < 0.01$, $P < 0.05$) and the right occipital region (O2) ($P < 0.01$) than women. While observing downward linear plants, men also showed a higher RA in the right frontal region (F4) than women ($P < 0.01$), with no gender differences in the occipital regions (O1, O2). For palmate-shaped plants, men had a higher RA in both the left and right frontal regions (F3 and F4) ($P < 0.01$) and in the right occipital region (O2) ($P < 0.05$). When viewing downward compound plants, men exhibited higher RA in the left and right frontal regions (F3 and F4) ($P < 0.01$, $P < 0.05$) and the right occipital region (O2) ($P < 0.01$) than women (Table 3).

Comparing brain waves between genders according to plant shapes (RB). When comparing the five plant groups by shape, women exhibited a higher relative beta power spectrum (RB) in the left parietal region (P3) than men when viewing round plants ($P < 0.01$). When viewing palmate-shaped plants, women had higher RB in the left parietal region (P3) ($P < 0.01$) and right occipital region (O2) ($P < 0.05$) than men. When viewing downward compound plants, women showed a higher RB in the left parietal region (P3) ($P < 0.001$) and right occipital region (O2) ($P < 0.01$) than men (Fig. 4). When viewing upward linear plants, women showed a higher RB in the left parietal region (P3) than men ($P < 0.001$), with no gender differences in the left and right occipital regions (O1 and O2). For downward linear plants, women had a higher RB in the left

Table 2. Participants' demographic information.

	Male (n = 15)	Female (n = 15)	Total (N = 30)
Variable	Mean ± standard deviation		
Age (years)	24.80 ± 2.33	23.93 ± 3.08	24.86 ± 2.68
Height (cm)	173.57 ± 6.68	161.12 ± 4.97	167.34 ± 8.58
Body weight (kg)	70.52 ± 17.06	51.65 ± 8.49	61.08 ± 16.35
BMI (kg/m^2)	23.26 ± 4.17	19.91 ± 2.60	21.58 ± 3.82

BMI = body mass index = weight/height^2.

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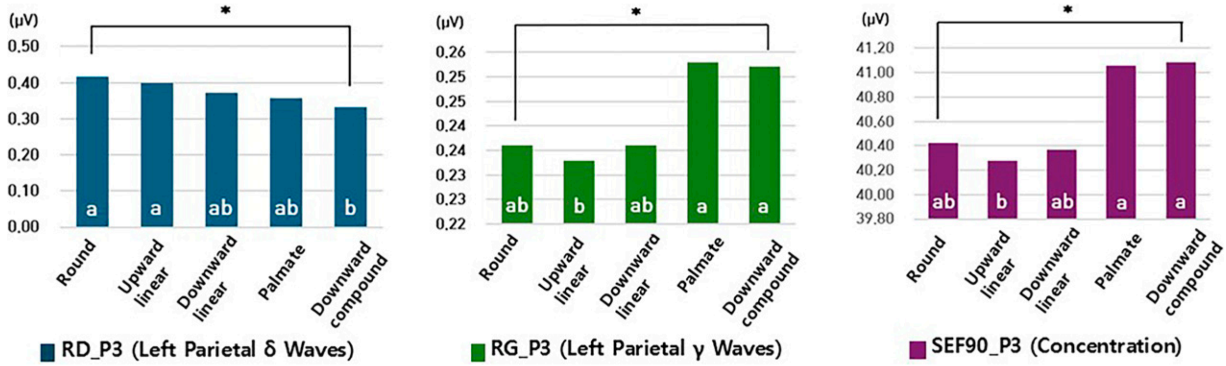

Fig. 2. Comparison among five groups according to plant shapes (N = 30). Note. *Significant at $P < 0.05$, one-way analysis of variance. Post hoc analysis: a > b > c > d using Duncan's multiple range test; P3 = left parietal lobe; RD = relative delta power spectrum; PS = 1–4 (Hz); RG = relative gamma power spectrum; PS = 30–50 (Hz); SEF90 = spectral edge frequency 90%, 4–50 (Hz) (percentage 90).

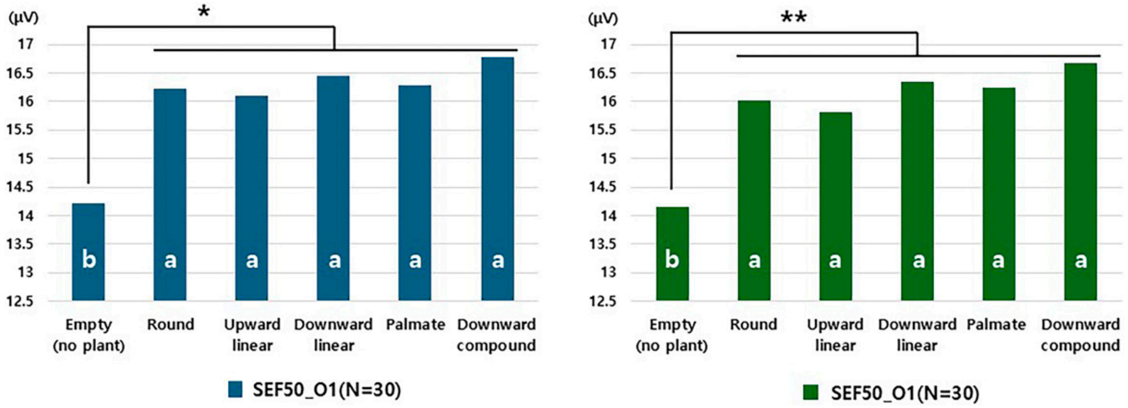

Fig. 3. Comparison of brain waves in five groups according to plant shapes and without plants (N = 30). Note. *, ** significant at $P < 0.05$, $P < 0.01$ using one-way analysis of variance. Post hoc analysis: a > b > c > d using Duncan's multiple range test; SEF50 = spectral edge frequency 50% = Median Frequency, 4–50 (Hz) (percentage 50).

parietal region (P3) than men ($P < 0.05$), with no gender differences in the occipital regions (O1 and O2). When viewing palmate-shaped plants, women had higher RB in the left parietal region (P3) ($P < 0.01$) and right occipital region (O2) ($P < 0.05$) than men. When viewing downward compound plants, women showed a higher RB in the left parietal region (P3) ($P < 0.001$) and right occipital region (O2) ($P < 0.01$) than men (Table 4).

Comparing HRV between genders according to plant shapes. Comparing the five plant groups (round, upward linear, downward linear, palmate, and downward compound) by shape revealed that women had higher heart

Table 3. Comparison of brain waves between men and women according to plant shapes (RA) (N = 30).

		RA			
		F3	F4	O1	O2
Classification		Mean ± standard deviation			
Round	Male (n = 15)	0.197 ± 0.026	0.195 ± 0.028	0.208 ± 0.039	0.214 ± 0.036
	Female (n = 15)	0.177 ± 0.028	0.168 ± 0.039	0.196 ± 0.033	0.194 ± 0.032
	t	2.853	3.052	1.215	2.299
	P value	0.006**	0.003**	0.229^{NS}	0.025*
Upward linear	Male (n = 15)	0.194 ± 0.031	0.193 ± 0.032	0.213 ± 0.040	0.219 ± 0.039
	Female (n = 15)	0.182 ± 0.027	0.169 ± 0.038	0.206 ± 0.039	0.207 ± 0.036
	t	1.675	2.591	0.717	1.293
	P value	0.099^{NS}	0.012*	0.476^{NS}	0.201^{NS}
Downward linear	Male (n = 15)	0.193 ± 0.033	0.198 ± 0.032	0.205 ± 0.049	0.212 ± 0.042
	Female (n = 15)	0.183 ± 0.032	0.179 ± 0.038	0.201 ± 0.040	0.205 ± 0.038
	t	1.195	2.117	0.285	0.67
	P value	0.237^{NS}	0.039*	0.777^{NS}	0.506^{NS}
Palmate	Male (n = 15)	0.196 ± 0.028	0.198 ± 0.026	0.209 ± 0.045	0.216 ± 0.039
	Female (n = 15)	0.175 ± 0.032	0.174 ± 0.040	0.199 ± 0.049	0.194 ± 0.028
	t	2.704	2.683	0.762	2.542
	P value	0.009**	0.009**	0.449^{NS}	0.014*
Downward compound	Male (n = 15)	0.199 ± 0.032	0.194 ± 0.031	0.207 ± 0.048	0.219 ± 0.051
	Female (n = 15)	0.175 ± 0.025	0.171 ± 0.037	0.193 ± 0.032	0.188 ± 0.025
	t	3.347	2.623	1.39	3.014
	P value	0.001**	0.011*	0.17^{NS}	0.004**

NS = nonsignificant, * significant at $P < 0.05$, ** significant at $P < 0.01$ using an independent *t* test; RA = relative alpha power spectrum, PS: 8–13 (Hz); F3 = left frontal lobe; F4 = left frontal lobe; O1 = left occipital lobe; O2 = right occipital lobe.

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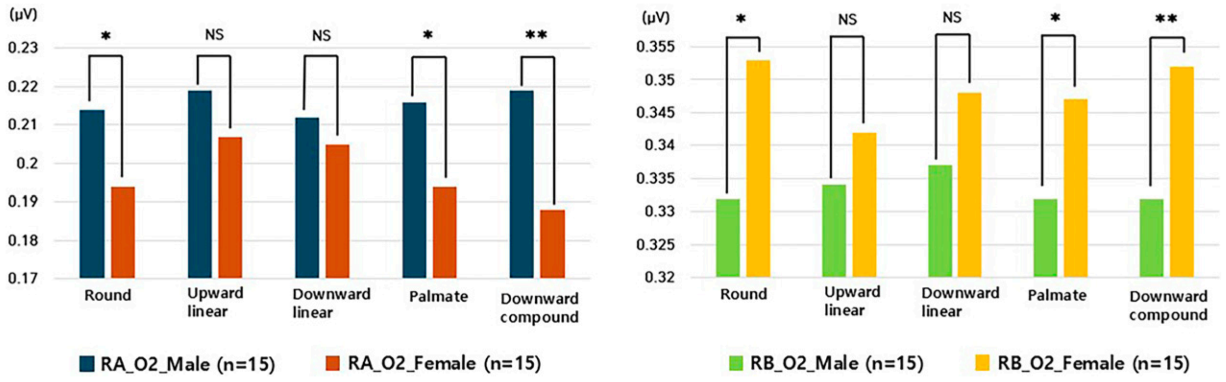

Fig. 4. Comparison of brainwaves between genders according to plant shapes (N = 30). Note. *, ** significant at $P < 0.05$, $P < 0.01$ using independent t tests. RA = relative alpha power spectrum; PS = 8–12 (Hz); RB = relative beta power spectrum; PS = 15–30 (Hz); O2 = right occipital lobe.

rates, with a significant difference observed when viewing palmate-shaped plants ($P < 0.05$). The standard deviation of the NN interval (SDNN) showed no difference when viewing upward linear plants; however, significant differences were found between the genders for other plant shapes ($P < 0.05$, $P < 0.01$). Low frequency (LF) showed significant gender differences for all plant shapes ($P < 0.001$). High frequency (HF) also showed significant gender differences for all plant shapes ($P < 0.001$) (Table 5).

Emotional differences according to plant shapes. The SDM was used to explore emotional differences elicited by visual stimuli from different plant shapes. Participants reported feeling more relaxed when viewing round, palmate, and downward compound plants compared with other shapes, with *Ficus elastica* and *Peperomia obtusifolia* (round plants) being the most relaxed ($P < 0.001$). These shapes also made the participants feel more stable, with round-shaped plants again providing the highest sense of stability ($P < 0.001$). Round-shaped plants, such as *F. elastica* and *P. obtusifolia*, made participants feel more at leisure than other shapes ($P < 0.01$). Palm-shaped and downward-compounded plants evoked the most enjoyment, particularly *Fatsia japonica* and *Schefflera arboricola* ($P < 0.001$). Finally, round plants induced a greater sense of calmness than other plant shapes ($P < 0.01$) (Fig. 5).

Emotional responses to plant shape differed by gender, with women typically expressing stronger feelings than men. Both men and women felt most relaxed, stable, and at leisure when viewing round-shaped plants; however, women reported these emotions more intensely than men. There were no significant differences in feelings between men and women when viewing upward linear plants (Table 6).

Plant shape preferences. The subjective plant preference evaluation indicated that participants showed a preference for plant shapes in the following order: downward compound, round, palmate, upward linear, and downward linear ($P < 0.001$) (Fig. 6). In addition, the SDM evaluation results revealed that participants felt more relaxed and stable when viewing downward compound, round, and palmate plants, which may account for their stronger preference for these shapes.

Discussion

This study highlights the distinct psychophysiological responses elicited by different foliage plant shapes, emphasizing the potential role of specific plant forms in promoting either relaxation or concentration. Specifically, palmate and downward compound plants were associated with increased relative gamma (RG) power and spectral edge frequency 90% (SEF90) in the left parietal lobe, suggesting enhanced attentional engagement and cognitive activation, whereas round-shaped plants were more strongly associated with relaxation-related responses. These findings align with previous research on the parietal lobe's

Table 4. Comparing brain waves between men and women according to plant shapes (RB) (N = 30).

		RB			
		P3	P4	O1	O2
Classification		Mean ± standard deviation			
Round	Male (n = 15)	0.323 ± 0.031	0.337 ± 0.023	0.332 ± 0.030	0.332 ± 0.030
	Female (n = 15)	0.356 ± 0.044	0.349 ± 0.033	0.345 ± 0.038	0.353 ± 0.037
	t	−3.369	−1.606	−1.42	−2.447
	P value	0.001**	0.114^{NS}	0.161^{NS}	0.017*
Upward linear	Male (n = 15)	0.325 ± 0.019	0.333 ± 0.018	0.335 ± 0.023	0.334 ± 0.024
	Female (n = 15)	0.353 ± 0.036	0.343 ± 0.044	0.340 ± 0.041	0.342 ± 0.039
	t	−3.737	−1.174	−0.534	−0956
	P value	0.000***	0.245^{NS}	0.596^{NS}	0.343^{NS}
Downward linear	Male (n = 15)	0.331 ± 0.022	0.339 ± 0.022	0.334 ± 0.027	0.337 ± 0.027
	Female (n = 15)	0.352 ± 0.039	0.344 ± 0.035	0.344 ± 0.034	0.348 ± 0.029
	t	−2.488	−0.734	−1.319	−1.434
	P value	0.016*	0.466^{NS}	0.193^{NS}	0.157^{NS}
Palmate	Male (n = 15)	0.329 ± 0.018	0.333 ± 0.022	0.333 ± 0.021	0.332 ± 0.024
	Female (n = 15)	0.351 ± 0.036	0.343 ± 0.047	0.342 ± 0.041	0.347 ± 0.031
	t	−3.124	−1.106	−0.998	−2.067
	P value	0.003**	0.273^{NS}	0.322^{NS}	0.043*
Downward compound	Male (n = 15)	0.332 ± 0.021	0.334 ± 0.021	0.334 ± 0.025	0.332 ± 0.023
	Female (n = 15)	0.359 ± 0.033	0.345 ± 0.037	0.341 ± 0.035	0.352 ± 0.025
	t	−3.713	−1.415	0.984	−3.436
	P value	0.000***	0.162^{NS}	0.329^{NS}	0.001**

NS = nonsignificant, * significant at $P < 0.05$, ** significant at $P < 0.01$, *** significant at $P < 0.001$, using an independent t test; RB = relative beta power spectrum, PS: 13–30 (Hz); P3 = left parietal lobe; P4 = right parietal lobe; O1 = left occipital lobe; O2 = right occipital lobe.

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Table 5. Comparing heart rate variability between genders according to plant shapes (N = 30).

Classification		Male (n = 15)	Female (n = 15)	*t*	*P* value
		Mean ± standard deviation			
Heart rate	Round	66.115 ± 9.442	70.012 ± 8.592	−1.672	0.100^{NS}
	Upward linear	66.138 ± 8.482	70.382 ± 8.572	−1.927	0.059^{NS}
	Downward linear	67.258 ± 9.091	71.644 ± 11.303	−1.656	0.103^{NS}
	Palmate	65.875 ± 8.576	70.579 ± 8.705	−2.109	0.039*
	Downward compound	65.905 ± 8.181	69.981 ± 8.179	−1.93	0.059^{NS}
SDNN	Round	56.962 ± 20.695	45.705 ± 13.925	2.472	0.016*
	Upward linear	58.756 ± 21.049	47.908 ± 20.978	1.999	0.05^{NS}
	Downward linear	66.773 ± 28.381	46.657 ± 17.373	3.311	0.002**
	Palmate	58.955 ± 28.017	44.927 ± 15.653	2.394	0.020*
	Downward compound	56.473 ± 21.766	43.731 ± 12.356	2.788	0.007**
LF	Round	0.519 ± 0.081	0.427 ± 0.096	4.023	0.000***
	Upward linear	0.524 ± 0.083	0.431 ± 0.089	4.166	0.000***
	Downward linear	0.534 ± 0.111	0.429 ± 0.089	4.048	0.000***
	Palmate	0.53 ± 0.088	0.439 ± 0.094	3.913	0.000***
	Downward compound	0.523 ± 0.091	0.419 ± 0.094	4.340	0.000***
HF	Round	0.481 ± 0.081	0.573 ± 0.096	−4.023	0.000***
	Upward linear	0.476 ± 0.083	0.569 ± 0.089	−4.166	0.000***
	Downward linear	0.466 ± 0.111	0.571 ± 0.089	−4.048	0.000***
	Palmate	0.468 ± 0.088	0.561 ± 0.094	−3.913	0.000***
	Downward compound	0.477 ± 0.091	0.581 ± 0.094	−4.340	0.000***
LF/HF ratio	Round	1.136 ± 0.358	0.792 ± 0.298	4.048	0.000***
	Upward linear	1.170 ± 0.423	0.803 ± 0.296	3.900	0.000***
	Downward linear	1.285 ± 0.624	0.792 ± 0.270	3.979	0.000***
	Palmate	1.228 ± 0.525	0.832 ± 0.303	3.573	0.001**
	Downward compound	1.146 ± 0.444	0.765 ± 0.296	3.773	0.000***

NS = nonsignificant, * significant at $P < 0.05$, ** significant at $P < 0.01$, *** significant at $P < 0.001$ using independent *t* test; SDNN = the standard deviation of the NN interval; LF = power in low frequency range (0.04–0.15 Hz); HF = power in high frequency range (0.15–0.4 Hz); LF/HF ratio = sympathovagal balance.

role in sensory integration, attention, and cognitive processing (Culham et al. 2006).

Compared with the resting condition, SEF50 values in the occipital regions were significantly elevated during plant observation regardless of plant shape (Fig. 3). This result indicates that viewing foliage plants, as opposed to an empty visual field, generally increases visual and cognitive engagement. Because the occipital lobe primarily processes visual information, increased visual complexity and salience provided by plants likely contributed to the observed shift toward higher-frequency brain activity. This finding is consistent with previous studies reporting increased occipital activation during exposure to natural visual stimuli (Choi et al. 2022; Song et al. 2015).

Among the five plant shapes, men displayed significantly higher RA power in frontal and occipital regions than women when viewing round, palmate, and downward compound plants (Table 3). Because RA power is commonly associated with relaxation and calm attentional states, this pattern suggests that male participants may experience stronger visually mediated relaxation responses to certain plant shapes. This finding is consistent with prior neurophysiological studies indicating sex-related differences in visual information processing and resting-state neural activity (Cahill 2006; Gur and Gur 1990).

Conversely, women exhibited significantly higher RB power in the left parietal region across several plant shapes (Table 4). RB power is typically linked to active attention, cognitive processing, and mental engagement, suggesting that women may experience heightened cognitive responsiveness during plant observation. This interpretation aligns with previous research indicating that women often show stronger neural activation in tasks requiring detailed visual analysis and sustained attention (Cahill 2006; Kimura 1999).

HRV analysis indicated that autonomic nervous system activity remained stable across all plant observation conditions (Table 5). Although HRV indices did not differ significantly among plant shapes, the overall stability of HRV values suggests that plant observation did not induce physiological stress and provided a balanced autonomic state while allowing shape-specific neural modulation. Similar patterns have been reported in previous HRV studies examining visual exposure to natural elements (Agelink et al. 2001; Jung et al. 2015).

Subjective emotional evaluations further supported the physiological findings. Participants reported greater comfort and stability

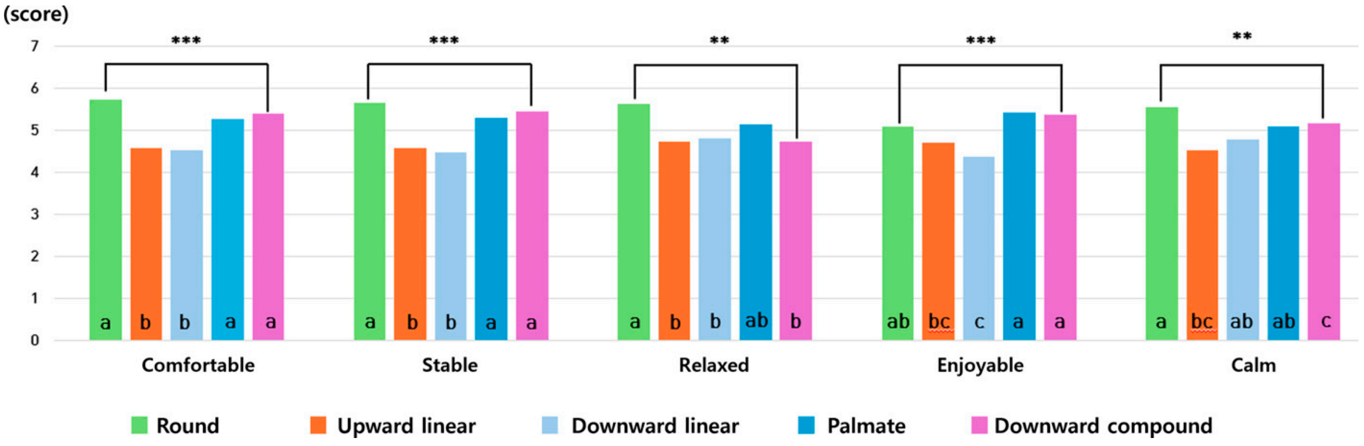

Fig. 5. Emotional differences according to plant shapes (N = 30). Note. **, *** significant at $P < 0.01$, $P < 0.001$ using one-way analysis of variance, respectively. Post hoc analysis: a > b > c > d using Duncan's multiple range test.

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Table 6. Emotional differences between genders according to plant shapes (N = 30).

Classification		Comfortable	Stable	Relaxed	Enjoyable	Calm
		Mean ± standard deviation				
Round	Male (n = 15)	5.37 ± 1.32	5.27 ± 1.20	5.23 ± 1.35	4.77 ± 1.04	5.23 ± 1.07
	Female (n = 15)	6.10 ± 0.96	5.27 ± 1.20	6.00 ± 1.01	5.40 ± 1.13	5.87 ± 1.00
	t	−2.894	−2.841	−2.538	−2.283	−2.218
	P value	0.007**	0.008**	0.017*	0.030*	0.035*
Upward linear	Male (n = 15)	4.17 ± 1.70	4.17 ± 0.31	4.57 ± 1.30	4.43 ± 1.00	3.97 ± 1.71
	Female (n = 15)	5.00 ± 1.57	4.97 ± 1.47	4.90 ± 1.34	4.97 ± 1.42	5.10 ± 1.68
	t	−1.831	−1.795	−0.874	−1.811	−2.391
	P value	0.077$^{\text{NS}}$	0.083$^{\text{NS}}$	0.390$^{\text{NS}}$	0.081$^{\text{NS}}$	0.024*
Downward linear	Male (n = 15)	4.07 ± 1.50	4.17 ± 1.23	4.57 ± 1.22	3.77 ± 0.97	4.30 ± 1.34
	Female (n = 15)	4.97 ± 1.37	4.77 ± 1.40	5.03 ± 1.56	4.97 ± 1.15	5.27 ± 1.23
	t	−2.619	−1.814	−1.328	−5.174	−2.838
	P value	0.014**	0.080$^{\text{NS}}$	0.195$^{\text{NS}}$	0.000***	0.008**
Palmate	Male (n = 15)	5.07 ± 0.94	5.03 ± 1.06	5.07 ± 1.337	5.20 ± 1.09	4.80 ± 1.09
	Female (n = 15)	5.47 ± 1.47	5.57 ± 1.30	5.23 ± 1.56	5.63 ± 1.24	5.40 ± 1.40
	t	−1.235	−1.887	−0.434	−1.557	−2.127
	P value	0.227$^{\text{NS}}$	0.069$^{\text{NS}}$	0.667$^{\text{NS}}$	0.130$^{\text{NS}}$	0.042*
Downward compound	Male (n = 15)	5.10 ± 1.49	5.10 ± 1.32	4.40 ± 1.95	4.90 ± 1.12	4.77 ± 1.61
	Female (n = 15)	5.70 ± 1.23	5.80 ± 1.24	5.03 ± 1.88	5.83 ± 0.95	5.60 ± 1.24
	t	−1.694	−2.276	−1.345	−3.979	−2.363
	P value	0.101$^{\text{NS}}$	0.030*	0.189$^{\text{NS}}$	0.000***	0.025*

NS = Nonsignificant, * significant at $P < 0.05$, ** significant at $P < 0.01$, *** significant at $P < 0.001$, using an independent *t* test.

when viewing round-shaped plants and greater enjoyment when viewing palmate-shaped plants. The convergence between EEG indicators and subjective emotional responses suggests that foliage plant shape simultaneously influences cognitive states and affective experience. These findings are consistent with previous research demonstrating that round and visually rich plant forms are perceived as more comforting and aesthetically pleasing (Berger 2022).

Taken together, the present findings indicate that foliage plant shape is not merely an aesthetic feature but a functional visual factor that modulates psychophysiological and psychoemotional responses in indoor environments. These results provide empirical support for evidence-based selection of plant shapes in restorative, therapeutic, and work-related indoor settings.

Conclusion

This study investigated humans' psychophysiological and psychoemotional responses to visual stimuli from different foliage plant shapes. Plants were categorized into five shape types: round, upward linear, downward linear, palmate, and downward compound. Participants' brain waves, HRV, and subjective emotional responses were measured during visual observation.

The results demonstrated that foliage plant shape differentially influenced neural activity related to relaxation and concentration. Specifically, observing round and upward linear plants was associated with increased RD activity in the left parietal lobe, indicating relaxation-related responses, whereas palmate and downward compound plants elicited higher RG power and spectral edge frequency 90%, suggesting enhanced concentration. In addition, viewing plants regardless of shape produced higher occipital spectral edge frequency values than viewing empty spaces, indicating increased visual and cognitive engagement.

HRV results indicated that autonomic nervous system activity remained stable across all plant observation conditions. However, sex-related differences were observed in EEG responses, suggesting that men and women may differ in how they cognitively and emotionally respond to specific plant shapes. Subjective emotional evaluations further supported the physiological findings, with round and palmate plants evoking greater comfort, stability, and enjoyment.

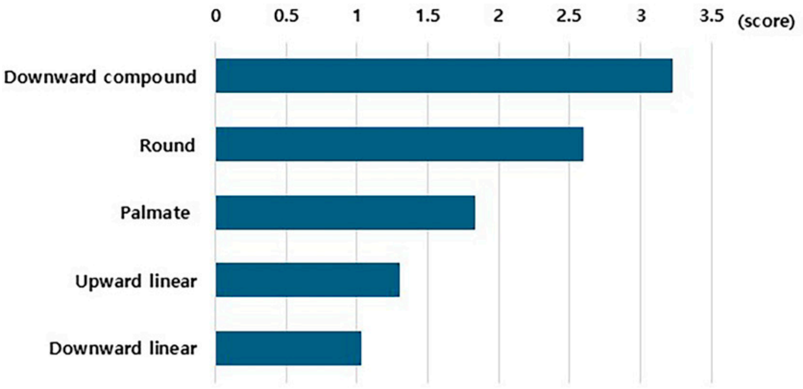

Fig. 6. Preferences ranking according to plant shapes (N = 30).

Overall, these findings confirm that foliage plant shape functions as a meaningful visual factor influencing human psychological stability and concentration in indoor environments. The results provide empirical support for selecting specific plant shapes in restorative, therapeutic, and work-related settings. Future studies should expand participant characteristics and contextual factors to further refine personalized plant-mediated interventions and evidence-based interior plant design.

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