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Gender Differences in Psychophysiological Responses to Herbal Plant Olfactory Stimuli: An Electroencephalogram Study

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Abstract. **This study measured and compared the psychophysiological and psychological differences in the responses of men and women to olfactory stimuli from herbal plants. A total of 30 adult participants (mean age, 27.4 years; *SD*, ±8.97 years; 15 men and 15 women) were included and five different herbs were used: lavender, rosemary, sage, apple mint, and pelargonium. During olfactory activity, participants smelled each herb for 90 seconds while relying solely on their sense of smell and electroencephalography was used to measure brain wave changes. Subsequently, participants' emotional states were assessed using the semantic differential method (SDM). The results indicated significant differences in the relative alpha, relative slow alpha, and relative low alpha frequencies in the prefrontal lobe (Fp1 and Fp2) for both genders ($P < 0.05$). Significant gender differences were observed in the relative beta, relative middle beta, ratio of sensorimotor rhythms-mid beta to theta frequencies in the occipital lobe (O1 and O2) ($P < 0.05$). The SDM results showed significant natural emotional responses in both genders after olfactory stimulation with herbal plants. Furthermore, compared with men, women exhibited more natural emotions to sage, apple mint, and pelargonium olfactory stimulation. These findings affirm the calming effects of olfactory stimulation with herbal plants for both genders, thus underscoring gender differences in preferences and psychological responses.**

Fragrances have been used in various ways in everyday life since ancient times because of their psychological effects on mood, stress, and the work environment. Several experimental studies have shown that nature-based scents are an important sensory stimulus that supports stress reduction (Fujita et al. 2010; Pálsdóttir et al. 2021; Toda and Morimoto 2008). When comparing visual, auditory, and natural olfactory stimuli, olfactory stimuli appear to induce a greater sense of calmness and comfort, thereby having a more profound effect on stress reduction than visual and auditory stimuli (Hedblom et al. 2019). A 2-week study of participants' perceptions of nature-based garden smells and a longitudinal case study conducted over 5 years (Pálsdóttir et al. 2021) found that natural olfactory stimuli (soil, wood, dried hay, and plants) reduce stress and have a positive impact on mental recovery.

Increasing research has focused on the restorative effects of garden plants on human health, including the effects of the smell and visual landscapes associated with plants in garden environments (Hassan et al. 2019; Lehrner et al. 2005; Liu et al. 2018). Porteous (1990) formally introduced the concept of "smellscape," which pertains to the comprehensive olfactory experience of a location, akin to a visual landscape. This term serves as the cornerstone for understanding the contextual landscape associated with the sense of smell. Recent virtual reality research has shown that olfactory stimulation has a more positive therapeutic effect than visual and auditory stimuli on patients with post-traumatic stress disorder (Aiken and Berry 2015). Among the various natural elements of these smellscapes, plant density, height, location, and spatial range are directly related to the concentration and diffusion of fragrances (Song and Wu 2022). Additionally, there is evidence that natural exposure to certain volatile natural compounds via inhalation may reduce inflammatory states (Andersen et al. 2021).

Aromatic oils have been used for thousands of years to provide various benefits for human physical and mental well-being. These volatile organic compounds with a distinctly pleasant smell also play an important role in psychophysiological functions (Ali et al. 2015).

Lee and Ro (2002) acknowledged that plant substitutes, including herbal scents, have the potential to be introduced in horticultural therapy programs. Lee (2003) investigated perceptions of and preferences for herbal scents using aroma oils and found that herbal scents can help reduce depression. Additionally, olfactory stimulation from herbs results in immediate physiological changes, such as changes in blood pressure, muscle tension, pupil dilation, skin temperature, pulse rate, and brain activity (Angelucci et al. 2014; Diego et al. 1998; Field et al. 2005). Recently, olfactory stimulation in adult women resulted in stress-relieving effects by stabilizing brain activity in the prefrontal cortex and reducing systolic blood pressure (Choi et al. 2022).

Most herbal olfactory studies have investigated how aroma oils affect human psychology and psychophysiology. However, herbal plants are used instead of aroma oils for agro-healing and horticultural therapies. Therefore, it is necessary to focus attention on the restorative effects of olfactory stimuli from herbs that can be felt in the natural environment.

The olfactory organ is the only sensory system in our body that is directly connected to the outside world, and the olfactory system is described as having a relatively direct connection to brain structures involved in memory and emotion, such as the hippocampus, thalamus, and prefrontal cortex (Benarroch 2010; Mackay-Sim and Royet 2006; Strous and Shoenfeld 2006). Smell plays an important role in the physiological effects of mood, stress, and work capacity. The conventional method of assessing the effects of olfactory stimuli on brain activity and the autonomic nervous system typically involves elucidating the pharmacological effects of aroma by examining the direct association between scent components and receptors and uncovering the psychological effects of subjective scent perception. However, these approaches struggled to objectively measure and quantify the brain's response to olfactory stimuli. In this context, electroencephalogram (EEG) has emerged

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as an independent and noninvasive method capable of continuously expanding our understanding. Furthermore, EEG enables the measurement and transmission of electrical activity of neurons in the cerebral cortex, thus providing valuable insights into various human brain responses (Kim and Choi 2009). Therefore, EEG holds great promise for advancing our understanding of the central nervous system activity in humans regarding the effects of fragrances on brain function (Lorig 1989; MacDonald 2015). Previous studies have reported that EEG can be used to effectively understand spontaneous brain activity and cognitive function during scent inhalation (Skoric et al. 2015; Sowndhararajan et al. 2015).

Therefore, this study aimed to observe changes in human brain activity regarding the natural olfactory stimuli of herbal plants rather than aroma using EEG in adult men and women as well as to study the psychological and psychophysiological effects on human moods and emotions. Although previous research used the term “sex,” this study employs “gender” to align with current perspectives on social and cultural identity. All references to “sex” in the previous studies have been updated to “gender” to reflect this shift. The rationale behind this change is to better address the concepts of identity and social roles as they pertain to the research questions.

Materials and Methods

Participants. Thirty adults (15 men and 15 women) between the ages of 20 and 60 years participated in the study. The recruitment method was primarily used to recruit students and adults at Konkuk University in Seoul. Online sites and flyers were distributed for recruitment. Participants were recruited based on criteria such as the absence of psychopathological disorders, nonusage of related medications, and right-hand dominance. Exclusion criteria comprised olfactory dysfunction, cardiovascular disease, and pregnancy. As a prerequisite for participation, participants were instructed to abstain from alcohol consumption the day before the experiment, refrain from drinking and smoking for 3 hours before the experiment, and avoid using perfumes and cosmetics with strong fragrances on the day of the experiment. Before commencing the experiment, participants were briefed about the study and its precautions, and written informed consent was obtained. Demographic information, including age, gender, height, weight, and body mass index (IOI 353; Resource Medical, Gyeongsan, South Korea), was collected. Each participant received US$8 compensation upon completion of the experiment. This study was approved by the Bioethics Committee of Konkuk University (approval no. 7001355-202310-HR-709).

Experimental environment. This study was conducted in an experimental space (180 cm × 160 cm) at Konkuk University. To minimize external visual stimuli, a white hardboard was placed in front of the desk and ivory-colored curtains were installed on both sides. To maintain a constant indoor temperature and humidity, the environmental conditions of the experimental space were as follows: temperature, 26.7 ± 3.2 °C; humidity, 36.4 ± 14.4% (O-257; DRETEC Korea Co., Seoul, Korea); and illuminance, 10,327.9 ± 7986.2 lx.

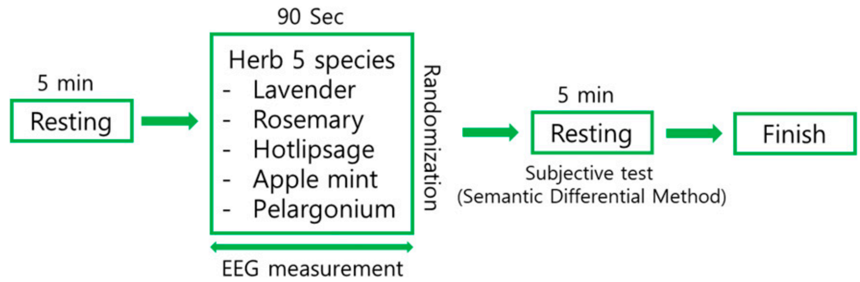

Fig. 1. Experiment protocol. EEG = electroencephalogram.

Experimental protocol. The five herbs used for olfactory stimulation were lavender (*Lavendula* sp.), rosemary (*Rosmarinus officinalis* L.), sage (*Salvia microphylla* Kunth), apple mint (*Mentha suaveolens*), and pelargonium (*Pelargonium graveolens*). Herbal pots were arranged by placing two herbs (20 cm × 18 cm) in a 15-cm square pot. Flowers were omitted because of seasonal variations, and fragrances from the leaves and stems of the herbs were used. The participants were seated at desks, and the changes in brain waves of the frontal and occipital cortices were measured during olfactory stimulation. While smelling the herbal scents, they kept their hands on their knees to avoid contact with the herbs, wore earplugs, and sat with their eyes closed to eliminate other sensory inputs.

The fragrances of herbal plants are emitted mainly when they are shaken or touched. A preliminary test involving 10 adults (5 men and 5 women) was conducted to measure the duration of scent emission by shaking a soft cloth wrapped around a long stick one to five times for each type of herb. The distance between the herb plant and the participant was 10 cm. Preliminary test results showed a difference in the response duration of subjective olfactory stimuli by herbal plants. Apple mint provided the longest olfactory stimulation, on average, for both male and female participants. Lavender was found to have the shortest scent duration. The average scent duration of the five herbs was 56 s, whereas the longest duration was 72 s for apple mint. Thus, the total time of olfactory stimulation with herbal plants was 90 s, considering a reaction time of 10 s before and after each herb.

Based on these preliminary tests, the five herbal plants were shaken five times, and EEG measurements were taken for 90 s under random treatment conditions. To account for potential differences in shaking behavior among individuals, the same researcher conducted a preliminary test, underwent continuous training, and maintained consistent shaking intensity. Additionally, considering that the scent of each herb may be absorbed into the fabric of the long stick during shaking, a new stick was used for each of the five herbs. Participants wore EEG equipment and were instructed to smell the five herbal plants randomly for 90 s while seated; visual, tactile, and auditory senses were excluded (Fig. 1).

Measurements. The EEG levels were analyzed to measure the psychophysiological indicators of adult men and women following olfactory stimulation with five types of herbal plants. A wireless dry EEG device (Quick-20; Cognionics, Inc., San Diego, CA, USA) was used. During EEG, electrical signals in the human brain are recorded at the scalp level (Lina and Karwowski 2020). These recordings are relatively simple, noninvasive, and can be used to objectively evaluate olfactory systems (Fig. 2A). Brain waves appear naturally in both the active and stable states. Electrophysiological signals generated by brain activity are recorded by attaching sensors to the surface of the scalp. In the present study,

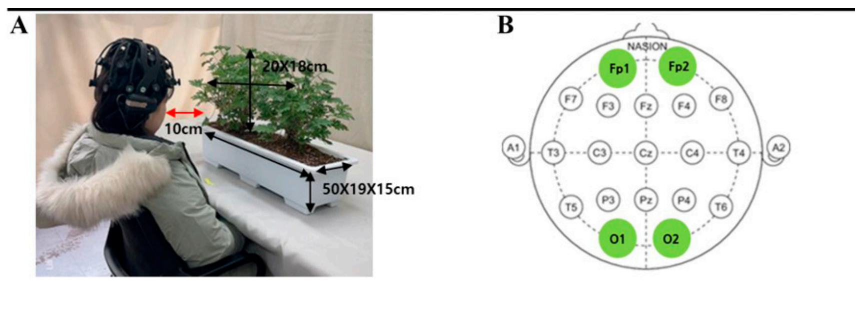

Fig. 2. (**A**) Experimental space layout (50 cm × 19 cm × 15 cm) and herb size (20 cm × 18 cm). (**B**) International electrode arrangement.

Table 1. Electroencephalogram index and corresponding frequency band and psychological state (Constant and Sabourdin 2012; Nafea et al. 2018).

Parameter	Indicator estimate (ratio)	State of mind
Relative alpha	Alpha (8–13 Hz)/total frequency (4–50 Hz)	Relaxation, calm, state, light hypnotic, depressed
Relative fast alpha	Higher alpha (11–13 Hz)/total frequency (4–50 Hz)	Calming, concentration, creative, states
Relative slow alpha	Slow alpha (8–11 Hz)/total frequency (4–50 Hz)	Relaxation, rest, pre-dormancy
Relative beta	Beta (13–30 Hz)/total frequency (4–50 Hz)	"Active" state, awareness
Relative mid beta	Middle beta (15–20 Hz)/total frequency (4–50 Hz)	Thinking, aware of self and surroundings
Ratio of sensorimotor rhythms∼mid beta to theta	(12–20 Hz)/(20–300 Hz)	Attention, vigilance

the electrodes were attached to the left earlobe (A1) according to the International 10–20 Electrode Placement System (Klem et al. 1999). Brain waves were measured in the left frontal lobe (Fp1), right frontal lobe (Fp2), left occipital lobe (O1), and right occipital lobe (O2) (Fig. 2B). The occipital cortex was selected and analyzed to determine the difference between the prefrontal cortex and gender to determine the effect of olfactory stimulation on emotional mood and physiological changes in humans. The semantic differential method (SDM) was used to subjectively evaluate an individual's emotional state through herbal stimulation. The SDM was developed by Osgood (1952) and is commonly used to measure an individual's emotional state. These metrics included three questions consisting of the following three categorized explanatory scales: "comfortable–uncomfortable," "natural–artificial," and "relaxed–awaken." Responses were measured using a 13-point Likert scale.

Data analysis. The EEG data were analyzed using the Bioteck Analysis Program (Bioteck, Daejeon, South Korea). Electrical signals in the cerebral cortex correspond to the delta (0–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), and beta (12–30 Hz) spectral frequency bands (Sowndhararajan et al. 2015). These frequencies are interpreted as follows: theta waves indicate light sleep; alpha waves indicate relaxation; beta waves indicate mental activity; and gamma waves indicate anxiety or excitement (Marzbani et al. 2016). Human behaviors, thoughts, and emotions can alter brainwave activity at various frequencies. Alpha and beta waves are believed to be closely related to human emotions; alpha waves are associated with reduced mental stress, increased relaxation, and improved memory, whereas beta waves correspond to clear and fast thinking (Alarcao and Fonseca 2017; Lagopoulos et al. 2009).

The raw EEG data collected were analyzed using the main alpha waves of relative alpha (RA), relative fast alpha (RFA), relative slow alpha (RSA), relative beta (RB), relative mid beta (RMB), and the ratio of sensorimotor rhythms (SMR)∼mid beta to theta (RSMT) during the comparison between genders (Table 1).

We used SPSS (version 25 for Windows; IBM, Armonk, NY, USA) to compare the cortical activity of the frontal and occipital lobes following olfactory stimulation and the state-detecting algorithm data. During the demographic analysis, Microsoft Excel (Office 2007; Microsoft Corp., Redmond, WA, USA) was used for descriptive statistics of the mean, *SD*, and percentage of each collection item. A one-way analysis of variance (ANOVA) was performed to investigate the effects of EEG parameters and SDM scores. To distinguish differences in the means, we used Duncan's post hoc analysis (Duncan's post hoc test). Independent t tests for gender differences were performed. Differences between all treatment groups were analyzed with a significance level of $P < 0.05$.

Results

Demographic information. A total of 30 participants (15 men and 15 women) participated in this study (mean age, 27.4 years; *SD*, ±10.49 years (Table 2). Participants had an average weight of 64.65 kg (*SD*, ±13.99 kg) and an average body mass index of 22.82 kg/m^2 (*SD*, ±3.5 kg/m^2), which were within the normal ranges according to the World Health Organization criteria. Participants completed the Sense Survey for Screening (SSS) test for olfactory evaluation. The SSS test consists of questions regarding 20 different odor substances, with each rated using a 5-point scale (Kim et al. 2014). The cutoff value for the SSS test is 74 points, which indicates a level at which olfactory decline should be considered. In this study, participants had an average score of 83.03 points on the SSS test, which was within the normal range.

Electroencephalography. Significant differences were observed in the prefrontal cortex of both men and women for key alpha (RA, RSA, and RFA) spectral frequencies during all herbal olfactory stimulation (lavender, rosemary, sage, apple mint, and pelargonium) (Table 3) ($P < 0.05$).

Olfactory stimulation with five herbal plants (lavender, rosemary, sage, apple mint, and pelargonium) showed significant increases in the relative alpha (RA) power spectrum and relative fast alpha (RFA) power spectrum frequencies in Fp1 and Fp2 channels compared with those at rest ($P < 0.05$) (Table 3).

Olfactory stimulation with four herbal plants (rosemary, sage, apple mint, and pelargonium) showed significant increases in the relative slow alpha (RSA) power spectrum frequencies in Fp1 and Fp2 channels compared with those at rest ($P < 0.05$) (Table 3).

Gender brainwave responses. Significant gender differences were observed in the RB, RMB, and RSMT frequencies of the occipital lobe (O1, O2) channels before and after olfactory stimulation with the five herbal plants (Table 4, Fig. 3) ($P < 0.05$). The RB frequency showed significant gender differences in sage, and the RSMT frequency showed significant gender differences for rosemary, with women exhibiting higher activity than that of men in both cases ($P < 0.05$) (Table 4, Fig. 3). The RMB frequency was significantly higher in women than it was in men with all five herbal plants ($P < 0.05$) (Table 4, Fig. 3).

Emotional response (semantic differential method). To assess the subjective evaluation of personal emotional states through herbal olfactory stimulation, the SDM ("comfort and discomfort," "nature and artificial" and "relaxation and arousal") was performed and scores were measured using a Likert scale (13 points). The results showed that participants considered that apple mint was more artificial than the other four herbal plants ($P < 0.05$) (Table 5).

Regarding gender differences, women evaluated the scents of sage, apple mint, and pelargonium as more natural and reported feeling more relaxed when smelling sage ($P < 0.05$) (Table 6).

Discussion

During this study, men and women were exposed to the fragrances of five types of herbs, and we investigated the psychological and psychophysiological effects of olfactory

Table 2. Demographic information of participants.

Variance	Men (n = 15)	Women (n = 15)	Total (N = 30)
	Mean ± *SD*		
Age, year	27.33 ± 8.97	27.47 ± 7.54	27.4 ± 10.49
Height, cm[i]	174.87 ± 3.46	160.83 ± 5.85	167.85 ± 8.56
Weight, kg[ii]	75.85 ± 10.03	53.05 ± 5.16	64.65 ± 13.99
Body mass index, kg/m^2[iii]	24.89 ± 3.26	20.76 ± 2.38	22.82 ± 3.5

[i] Height was measured using an anthropometer without shoes (Ok7979 software; Samhwa, Seoul, South Korea).

[ii] Weight was measured using a body fat analyzer (ioi 353; Jawon Medical, Seoul, South Korea).

[iii] Body mass index was calculated using the following formula: [weight (kg)]/[height (cm)].

Table 3. Comparison of the prefrontal cortex during olfactory stimulation with five herbal plants.

		RA[i]		RSA[i]		RFA[iii]	
		FP1[iv]	Fp2[v]	FP1	Fp2	FP1	Fp2
Olfactory stimuli		Mean ± *SD*					
Lavender	Resting	0.215 ± 0.067	0.213 ± 0.058	0.160 ± 0.059	0.158 ± 0.051	0.055 ± 0.013	0.055 ± 0.012
	Treatment	0.253 ± 0.061	0.248 ± 0.052	0.186 ± 0.056	0.180 ± 0.050	0.066 ± 0.018	0.068 ± 0.015
	t	2.277	2.457	1.747	1.707	2.871	3.564
	P value	0.026*	0.017*	0.085^{NS}	0.093^{NS}	0.006*	0.001**
Rosemary	Treatment	0.262 ± 0.049	0.255 ± 0.048	0.196 ± 0.049	0.188 ± 0.046	0.066 ± 0.015	0.066 ± 0.015
	t	3.081	3.034	2.545	2.441	3.000	3.086
	P value	0.003**	0.004**	0.014*	0.018*	0.004**	0.003**
Sage	Treatment	0.258 ± 0.054	0.254 ± 0.048	0.191 ± 0.049	0.186 ± 0.044	0.067 ± 0.019	0.067 ± 0.017
	t	2.743	2.964	2.227	2.316	2.787	3.128
	P value	0.008*	0.004**	0.030*	0.024*	0.007*	0.003**
Apple mint	Treatment	0.263 ± 0.045	0.255 ± 0.042	0.193 ± 0.045	0.186 ± 0.041	0.070 ± 0.017	0.068 ± 0.016
	t	3.229	3.159	2.419	2.350	3.708	3.475
	P value	0.002**	0.003**	0.019*	0.022*	0.000***	0.001**
Pelargonium	Treatment	0.258 ± 0.055	0.249 ± 0.054	0.191 ± 0.051	0.183 ± 0.049	0.067 ± 0.016	0.066 ± 0.016
	t	2.711	2.490	2.151	1.945	3.131	2.883
	P value	0.009*	0.016*	0.036*	0.057*	0.003**	0.006**

[i] Relative alpha (RA) power spectra were calculated as [alpha (8–13) power]/[total frequency (4–50 Hz) power].
[ii] Relative slow-alpha (RSA) power spectra were calculated as [alpha (8–11) power]/[total frequency (4–50 Hz) power].
[iii] Relative fast-alpha (RFA) power spectra were calculated as [fast-alpha (11–13) power]/[total frequency (4–50 Hz) power].
[iv] Fp1 denotes the left prefrontal lobe.
[v] Fp2 denotes the right prefrontal lobe.
NS, *, **, *** nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively, according to paired *t* tests.

Table 4. Comparison of the occipital cortex in men and women during olfactory stimulation with five herb plants.

Spectrum	Olfactory stimuli	Electrode	Men (n = 15)	Women (n = 15)	*t*	*P* value
			Mean ± *SD*			
Relative beta spectrum[i]	Lavender	O1[iv]	0.315 ± 0.304	0.332 ± 0.413	1.319	0.198^{NS}
		O2[v]	0.311 ± 0.028	0.331 ± 0.038	1.597	0.121^{NS}
	Rosemary	O1	0.315 ± 0.034	0.323 ± 0.042	0.587	0.562^{NS}
		O2	0.312 ± 0.289	0.326 ± 0.368	1.155	0.258^{NS}
	Sage	O1	0.313 ± 0.029	0.342 ± 0.043	2.150	0.040*
		O2	0.313 ± 0.285	0.332 ± 0.383	1.555	0.131^{NS}
	Apple mint	O1	0.315 ± 0.025	0.331 ± 0.038	1.327	0.195^{NS}
		O2	0.320 ± 0.035	0.329 ± 0.0383	0.723	0.476^{NS}
	Pelargonium	O1	0.315 ± 0.031	0.336 ± 0.042	1.540	0.135^{NS}
		O2	0.315 ± 0.030	0.333 ± 0.040	1.310	0.201^{NS}
Relative mid beta spectrum[ii]	Lavender	O1	0.102 ± 0.155	0.004 ± 0.188	1.810	0.081^{NS}
		O2	0.101 ± 0.144	0.114 ± 0.135	2.409	0.023*
	Rosemary	O1	1.138 ± 0.256	1.428 ± 0.381	2.441	0.021*
		O2	1.161 ± 0.251	1.375 ± 0.304	2.095	0.045*
	Sage	O1	0.102 ± 0.012	0.118 ± 0.022	2.527	0.017*
		O2	0.102 ± 0.011	0.116 ± 0.018	2.512	0.018*
	Apple mint	O1	0.102 ± 0.010	0.115 ± 0.017	2.487	0.019*
		O2	0.105 ± 0.013	0.113 ± 0.015	1.562	0.130^{NS}
	Pelargonium	O1	0.102 ± 0.012	0.115 ± 0.015	2.598	0.015*
		O2	0.104 ± 0.014	0.117 ± 0.012	2.680	0.012*
Relative SMR∼mid beta to theta spectrum[iii]	Lavender	O1	1.128 ± 0.214	1.326 ± 0.336	1.923	0.065^{NS}
		O2	1.141 ± 0.221	1.347 ± 0.340	1.964	0.060^{NS}
	Rosemary	O1	0.103 ± 0.149	1.113 ± 0.199	2.441	0.021*
		O2	0.102 ± 0.129	0.116 ± 0.018	2.095	0.045*
	Sage	O1	1.128 ± 0.243	1.385 ± 0.440	1.976	0.058^{NS}
		O2	1.174 ± 0.225	1.325 ± 0.268	1.666	0.107^{NS}
	Apple mint	O1	1.122 ± 0.229	1.382 ± 0.443	2.018	0.053^{NS}
		O2	1.180 ± 0.230	1.332 ± 0.281	1.625	0.115^{NS}
	Pelargonium	O1	1.127 ± 0.296	1.365 ± 0.445	1.726	0.095^{NS}
		O2	1.181 ± 0.246	1.360 ± 0.352	1.607	0.119^{NS}

[i] Relative beta (RB) power spectra were calculated as [beta (13–30) power]/[total frequency (4–50 Hz) power].
[ii] Relative mid beta (RMB) power spectra were calculated as [alpha (15–20) power]/[total frequency (4–50 Hz) power].
[iii] Relative sensorimotor rhythms (SMR)∼mid beta to theta power spectra (RSMT) were calculated as [(12–20) power]/[total frequency (20–300 Hz) power].
[iv] Fp1 denotes the left prefrontal lobe.
[v] Fp2 denotes the right prefrontal lobe.
NS, *, **, *** nonsignificant or significant at $P < 0.05$, 0.01, and 0.001, respectively, according to independent *t* tests.

stimuli while excluding other senses. Although many existing studies have used aromas and herbal extracts and most have reported psychological and physiological effects, there has been limited research of natural olfactory stimulation using herbal plants. Following olfactory stimulation with the herbal plants, both men and women exhibited significant differences in key relative alpha spectra (RA, RSA, and RLA), which are indicators of relaxation, in the prefrontal cortex (Fp1 and Fp2) ($P < 0.05$) (Table 3).

The prefrontal cortex refers to the cerebral cortex located just below the forehead and covers the front part of the frontal lobe. This area comprises various functional areas, such as the primary motor areas, premotor areas, and prefrontal cortex (Schoenemann 2006). Overall, the frontal lobe area is associated with several functions, including reasoning, planning, problem solving, intelligence, behavior, attention, and smell (Bush and Allman 2004; Siddiqui et al. 2008).

During EEG studies, the activation of alpha waves is the most important parameter, and it occurs in a state of temporary rest and during a moderate level of brain activity; furthermore, this activation is found in the prefrontal cortex, occipital lobe, and thalamus region (Palva and Palva 2007). Alpha waves observed in the prefrontal cortex are associated with rapid eye movement sleep, meditation, inner peace, and quiet, which are semi-arousal states (Kim 2018) linked to states of mental harmony, calmness, attention, integration, and learning (Basar 2012; Kim et al. 2013).

Among the psychophysiological properties of aromas extracted from herbal plants, lavender has been the most frequently studied. Previous studies have shown that lavender has anxiolytic, mood-stabilizing, sedative, analgesic, and other neuroprotective properties (Malcolm and Tallian 2017; Sayorwan et al.

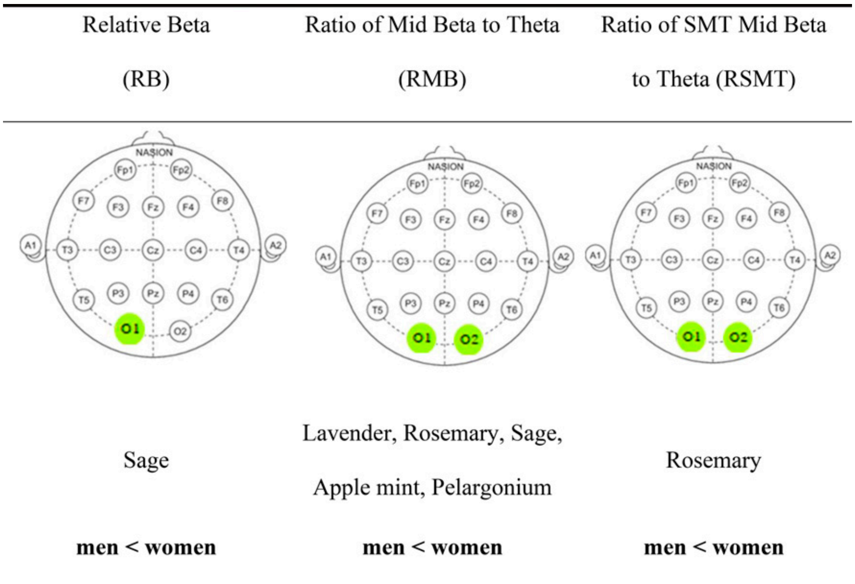

Fig. 3. Changes in brain waves, relative beta (RB), relative mid beta (RMB), ratio of sensorimotor rhythms∼mid beta to theta (RSMT), of olfactory stimuli with five herb plants according to gender.

2012) and demonstrated that lavender oil inhalation significantly increases alpha power spectral values. Studies of pelargoniums have shown that the inhalation of essential oils reduces anxiety (Morris et al. 1995). Additionally, studies have shown that the inhalation of lavender, peppermint, rosemary, and sage essential oils significantly reduces anxiety and stress on brain function (Haze et al. 2002). This suggests that higher alpha wave activity, which is generally associated with olfactory stimulation, is highly correlated with brain relaxation, which decreases stress states (Sowndhararajan et al. 2015). In the present study, olfactory stimulation with the five herbs also showed a significant increase in RA, RSA, and RLA spectra, concomitant with the results of previous studies of aromatic oils. Natural olfactory stimulation with herbal plants has a restorative effect that reduces stress by providing psychological stability and relaxation to both men and women.

Brainwave parameters (RB, RMB, and RSMT) related to concentration and brain activation were activated in the left and right occipital lobes upon olfactory stimulation and differed by gender ($P < 0.05$) (Table 4). During olfactory stimulation with the five herbs, compared with men, women showed greater increases in RB and RLB, which are indicators of brain activity during stress-free resting states (Fig. 3). In addition, RSMT frequencies, which indicate cognitive function and concentration, were higher in women than in men with rosemary olfactory stimulation, thus showing distinct gender differences (Fig. 3). This is consistent with previous studies that showed different EEG power spectral changes in men and women when inhaling fragrances (Kim et al. 2018; Kim et al. 2020).

The occipital region is the rearmost part of the human cerebral cortex that is mainly involved in the processing of visual information and the transmission of signals to and from the cerebral cortex (Li et al. 2013; Schoenemann 2006). Alpha waves observed in a restful state are associated with a relaxed state; however, olfactory stimulation, particularly with the eyes closed, has been proven to activate the occipital region (Cahn and Polich 2006; Kupers et al. 2011; Sayorwan et al. 2012).

The aroma of herbal plants comprises a variety of natural complex compounds that primarily consist of volatile terpenes and oxygenation derivatives (Bakkali et al. 2008). Of these, (+)-limonene and terpinolene inhalation showed significant differences in EEG power spectral values (RB, RHB, RMB, RAHB, and SEF90) between genders (Sowndhararajan et al. 2015). During the physiological process of olfactory stimulation, scent molecules first interact with olfactory receptors and send signals to the brain through analysis, which is the process by which a particular smell is recognized. Here, the olfactory receptors respond differently depending on the composition of the scent (Laska and Teubner 1999). Additionally, people can perceive the same scent differently. The chemical and physical properties of smell molecules, or an individual's memory of smell, can influence the brain's response through EEG (Thomas-Danguin et al. 2014).

Beta waves, characterized by a frequency range of 13 to 30 Hz, represent fast wave activity associated with heightened consciousness. They typically occur during periods of focused mental activity, problem-solving, and decision-making (Neuper and Pfurtscheller 2001). Jung and Choi (2012) observed that the scent of

Table 5. Comparison performed using the semantic differential method during olfactory stimulation.

	Being pleasant	Being natural	Being relaxed
Olfactory stimuli		Mean ± *SD*	
Lavender	9.73 ± 2.54	10.07 ± 2.46 a	9.70 ± 2.23
Rosemary	10.27 ± 2.08	10.43 ± 2.14 a	10.30 ± 2.21
Sage	9.53 ± 2.82	10.47 ± 2.22 a	9.60 ± 2.31
Apple mint	9.20 ± 2.72	8.57 ± 2.59 b	9.17 ± 2.16
Pelargonium	10.13 ± 1.97	9.80 ± 2.12 a	9.97 ± 2.02
F	0.947	3.373	1.115
P value	0.439^{NS}	0.011*	0.352^{NS}

The statistical method used Duncan's post hoc analysis (a > b). The lowercase letters indicate the group to which the activities belong when performing analysis using Duncan.

NS, * nonsignificant or significant at $P < 0.05$ respectively, according to the one-way analysis of variance.

Table 6. Comparison of responses of men and women using the semantic differential method.

		Men (n = 15)	Women (n = 15)		
Evaluation	Olfactory stimuli	Mean ± *SD*		*t*	*P* value
Being pleasant	Lavender	9.20 ± 2.30	10.27 ± 2.73	1.154	0.258^{NS}
	Rosemary	9.60 ± 1.80	10.93 ± 2.18	1.821	0.079^{NS}
	Sage	8.53 ± 2.82	10.53 ± 2.53	2.042	0.051^{NS}
	Apple mint	8.67 ± 2.71	9.73 ± 2.71	1.076	0.291^{NS}
	Pelargonium	9.87 ± 1.92	10.40 ± 2.06	0.732	0.470^{NS}
	F	0.902	0.471		
	P value	0.467^{NS}	0.757^{NS}		
Being natural	Lavender	9.40 ± 2.50	10.73 ± 2.31	1.516	0.141^{NS}
	Rosemary	9.73 ± 1.66	11.13 ± 2.38	1.862	0.073^{NS}
	Sage	9.53 ± 2.41	11.40 ± 1.59	2.497	0.019*
	Apple mint	7.60 ± 2.23	9.53 ± 2.64	2.166	0.039*
	Pelargonium	8.93 ± 2.12	10.67 ± 1.79	2.414	0.023*
	F	2.263	1.607		
	P value	0.071^{NS}	0.182^{NS}		
Being relaxed	Lavender	9.07 ± 2.15	10.33 ± 2.19	1.596	0.122^{NS}
	Rosemary	9.87 ± 1.68	10.73 ± 2.63	1.074	0.292^{NS}
	Sage	8.67 ± 2.28	10.53 ± 1.99	2.381	0.024*
	Apple mint	8.80 ± 2.30	9.53 ± 2.03	0.924	0.363^{NS}
	Pelargonium	9.53 ± 1.88	10.40 ± 2.13	1.180	0.248^{NS}
	F	0.883	0.647		
	P value	0.478^{NS}	0.631^{NS}		

NS, * nonsignificant or significant at $P < 0.05$, respectively, according to paired *t* tests.

Lavandula angustifolia (*L. angustifolia*) decreased alpha power in the occipital and parietal lobes but increased beta power in the frontal and occipital lobes of women with sleep disorders. Similarly, a study of college students found that the lavender scent increased beta wave activity. In our study, during which other sensory inputs were restricted, olfactory stimulation led to greater activation of beta waves in the occipital lobe of women than that of men, suggesting heightened sensitivity mediated by olfactory receptors in women.

The RSMT represents the ratio of brain waves in the SMR~mid beta frequency band divided by the brain waves in the theta frequency band. This ratio can be used to analyze activity patterns and may be related to cognitive functions such as concentration and stability (Lubar 1991). Although the subjects were different, studies by Kim et al. (2021) have shown that the RSMT index is significantly higher in the right prefrontal cortex during children's horticultural activities (harvesting, planting, sowing seeds, mixing soil). The RSMT during harvesting activities indicated an increase in the child's concentration. As such, SMRs from intermediate beta to theta (RSMT) are associated with mental activity, problem-solving, and decision-making, which are associated with concentration and cognitive function (Sauseng and Klimesch 2008). This occurs naturally during intensive activities such as deep conversations, sports, and speech (Hassan et al. 2018a). Therefore, the RSMT and RMB power spectral indices are indicators of concentration.

Rosemary has a distinct effect on the brain and central nervous system that increases awareness by clearing the mind, providing excellent brain-stimulating properties, and helping to improve memory (Faixova and Faix 2008). During a previous study, adults experienced increased blood pressure and an increased respiratory rate after receiving a massage with rosemary oil and felt alert and cheerful (Hongratanaworakit 2009). In another study, after exposure to rosemary oil, mood state changes resulted in feeling refreshed and active (Cahn and Polich 2006). In our study, olfactory stimulation by rosemary was higher in women than it was in men. This was evidenced by previous research that found that rosemary provides a sense of refreshment and enhances psychological stability, and that women have a better olfactory sense than that of men and are more sensitive to these stimuli.

Since the beginning of the studies of olfactory stimuli in humans, the ability of women to detect and identify smell has been found to be better than that of men (Cain 1982; Doty et al. 1984; Schleidt et al. 1981; Toulouse and Vaschide 1899). A recent meta-analysis also found that women generally have better olfactory abilities than men (Sorokowski et al. 2019).

Regarding this view, research of the cause and identification of differences in olfactory stimuli between genders has been conducted (Brand and Millot 2001; Doty and Cameron 2009). The results have shown the association of neuroendocrine agonists and complex interactions between hormones and the olfactory system (Doty and Cameron 2009; Koelega 1994), and the performance of memory-related olfactory tasks, such as smell identification, is associated with prior exposure to the target smell and familiarity (Öberg et al. 2002). According to Cornell Kärnekull et al. (2015), some olfactory abilities, such as smell identification, are associated with semantic memory and general semantic knowledge or verbal fluency (Hedner et al. 2010; Larsson et al. 2000). It was found that threshold-level olfactory sensitivity was susceptible to the influence of gender hormones (Good et al. 1976; Ochsenbein-Kölble et al. 2007), suggesting that there are gender differences attributable to olfactory receptor sensitivity.

Changes in mood after smell stimulation with the herb plant are described as "pleasant, natural, soothing." In the present study, the olfactory stimuli from the five herbs were natural and comfortable for both men and women (Table 5). Differences in mood states according to gender were significant in women, with sage, apple mint, and pelargonium inducing a more natural mood in women than that in men (Table 6). Differences in apple mint were also significantly higher in women in the sedative mood group (Table 6).

No other human senses are as strongly associated with emotion as smell. Olfactory stimulation often affects mood (de Wijk and Zijlstra 2012; Villemure and Bushnell 2007), and the experience of nature-based plant scents reduces stress (Pálsdóttir et al. 2021). Various EEG studies have shown that the smell of aromatic oils from various plant species affects voluntary EEG activity and produces positive psychophysiological effects in humans (Angelucci et al. 2014; Sowndhararajan and Kim 2016).

In our study, natural olfactory stimulation with herbal plants also improved positive functions, such as psychological stability and relaxation in adults. However, gender differences were observed in mood and emotion.

Conclusion

In this study, olfactory stimulation with five herbal plants elicited changes in alpha and beta frequencies in the prefrontal and occipital lobes of men and women. Natural olfactory stimulation with the herbal plants activated alpha waves in the prefrontal cortex, indicative of a relaxed and calm state, reflecting natural and relaxed emotions. In the occipital lobe, gender differences were observed in the parameters related to concentration and cognitive function (RT, RMB, and RSMT). These findings align with those of previous studies, highlighting gender differences in response to herbal olfactory stimuli.

The participants in this study were primarily between 20 and 40 years of age. Further research of the psychological and psychophysiological aspects of other age groups is needed. Additionally, to gain a better understanding of the holistic sensory experiences in natural environments, integrated effects of sight and touch senses and the olfactory sense associated with herbal plants should be researched.

The findings of this study underscore the healing potential of herbal plants and demonstrate their capacity to induce relaxation through natural olfactory stimulation in therapeutic environments such as healing farms or areas abundant in herbal flora. Moreover, by identifying gender-based disparities in preferences and psychological reactions to herbal scents, this research provides a foundational framework for tailored interventions in such settings.

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