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ORIGINAL ARTICLE

Effects of Plant Essential Oils on Physiological Changes

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Abstract

This study aimed to investigate whether inhaling the aroma of essential oils could alleviate physiological stress responses and mimic the effects of forest therapy in urban settings. Briefly, 31 participants underwent stress index assessments for two days and inhaled the selected plant essential oils. The effects of this treatment on physiological responses were determined through electroencephalogram (EEG) and heart rate variability (HRV) measurements taken before and after inhaling the aroma of essential oils, extracting results for low frequency (LF) and high frequency (HF) components of HRV, as well as θ and α brainwave activities. The results indicated that lavender oil did not yield significant differences, whereas pine, chamomile, and cypress oils exhibited significant differences in effects. Overall, stress relief was associated with enhanced θ and α brainwave activities, a decrease in the LF component and an increase in the HF component of HRV. Among the essential oils studied, pine oil was the most effective. These findings underscore the potential of plant essential oils in replicating the therapeutic benefits of forest therapy, even in urban environments. Further investigations into their utilization are warranted to better understand and harness their therapeutic potential.

Key words: Sense of smell, Stress, Essential oil

1. Introduction

1.1. Research background and objectives

Smell is the only sense directly connected to the brain through the nose. Unlike other senses, such as vision and hearing, where sensory stimuli are processed through the thalamus and consciously perceived, smell directly influences the limbic system through the olfactory epithelium, making it a powerful and intuitive sense that can affect emotions and feelings without conscious awareness (Choi, 2021). Thus, the olfactory nerve can be considered an extension of the brain, with its fibers reaching deep into the nasal cavity. Olfactory cells relay electrical-chemical reactions to the olfactory bulb, which then transmits them directly to brain regions responsible for vital processes, such as digestion, reproduction, and emotional responses. For instance, individuals with anosmia, the inability to smell, have a significantly higher likelihood of developing depression, and loss of smell also impairs taste function (Cho and Song, 2002). Given this understanding, extensive research has leveraged the aromatic properties of essential oils derived from plants. In forest therapy, the biochemical essence emitted by trees, such as pine and fir, is central to its therapeutic effects. According to previous research (Kang, 2018), among 351 studies (including duplicates) related to stress, 34 different types of essential oils were used, with

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97 studies (27.6%) using lavender oil, and 26 studies (7.4%) using clove oil. On the other hand, aromatherapy using essential oils extracted from herbs and trees is recognized as a national natural therapy in France. Aromatherapy, a compound word combining "aroma," meaning fragrance, and "therapy," meaning treatment, refers to therapy and treatment utilizing fragrances (Cho and Song, 2002). Aromatherapy harnesses essential oils extracted from various plant parts, such as flowers (*Rosa hybrida*), leaves (*Mentha piperascens*), fruits (*Citrus limon*), seeds (*Foeniculum vulgare*), roots (*Armoracia rusticana*), bark (*Cornus kousa*), wood (*Cinnamomum verum*), flowers from tree branches (*Cananga odorata*), garlic (*Allium sativum L.*), and dried flowers (*Syzygium aromaticum*). Thus, the source of essential oils can range from the entire tree of *Pinus densiflora* to flowers of *Rosa hybrida* and roots of *Valerian officinalis*. These oils, housed in specialized plant structures called oil glands, are extracted using distillation and compression techniques to produce potent essential oils.

Research on smell and aroma has been steadily advancing in Europe, revealing that the effects of aroma are far more significant than previously anticipated. Odor molecules reach the lungs through the sense of smell, from where they are transported throughout the body via the bloodstream, or they are absorbed into the capillaries through skin pores, spreading throughout the body along with the flow of bodily fluids, affecting various organs and tissues. Currently, research exploring the potential of plant essential oils is multifaceted. Studies include investigations into the combined effects of essential oil inhalation and aromatherapy education programs on stress and autonomic nervous system activity in female college students preparing for employment (Lee, 2023), the effects of aromatherapy on stress, blood sugar levels, fatigue, and sleep in middle-aged women (Yeo, 2019), and the impact of aromatherapy education and experience programs on depression and stress in middle school girls from a natural healing perspective (Yoon, 2021). Other studies delve into the effects of aromatherapy on adults with COVID-19 symptoms, such as sore throat, nasal congestion, stress, fatigue, and poor sleep quality(Kang, 2023), as well as the effects of aroma blending essential oil inhalation on fatigue, stress, depression, and happiness in nurses (Baek, 2022). However, such studies are often confined to specific locations or environments. Therefore, this study aimed to experimentally investigate whether the physiological benefits observed in forests can also be harnessed in urban settings by utilizing plant essential oils, catering to individuals unable to access forest therapy due to various constraints.

1.2. Study content and composition

The scents extracted from plants are recognized for their diverse effects, including stabilizing emotions, inducing excitement, and effectively regulating mood. Additionally, they can aid in improving concentration and alleviating various neurological disorders caused by stress (Choi, 2021). This study aimed to explore the efficacy of essential oils extracted from plants through theoretical review. Additionally, it sought to verify whether the scent effects of pine, a key component in forest therapy, could be replicated in urban environments without direct forest exposure for therapy.

The experiment was conducted twice, on 4th and 7th Dec 2023, targeting 31 male and female students from G University in Gangwon Province, South Korea. The procedure was as follows:

1) Stress index examination was conducted using the Modified Form of the Stress Response Inventory (SRI-MF) questionnaire;

2) measurements related to the autonomic nervous system, brainwaves, and heart rate variability (HRV) were taken using the OMNIFIT Mindcare device;
3) one drop of essential oil, randomly chosen from pine (*Pinus densiflora*), cypress (*Cupressus sempervirens*), lavender (*Lavandula species*), and chamomile (*Matricaria recutita L.*), known for their stress- relieving effects, was applied to a mask (to prevent errors in the application of the plant's essential oil). Participants wore the mask with the oil and closed their eyes while assuming a relaxed posture, inhaling the scent for 1 min;
4) after removing the mask, participants took a 5-min rest; and
5) measurements related to the autonomic nervous system, brainwaves, and HRV were taken again.

Research parameters, such as measurements related to the autonomic nervous system, brainwaves, and HRV, were obtained using the OMNIFIT Mindcare device, as shown in Fig. 1. The collected data were analyzed using the statistical software SPSS ver24.0. This experiment enabled a practical verification of whether effects similar to forest therapy could be achieved using aromatherapy.

2. Research Subjects and Methods

2.1. Research design

This study employed a fundamental experimental design to analyze the effects of inhaling the aroma of selected essential oils on the autonomic nervous system, brainwaves, and HRV to clarify whether such practices can mimic the effects of forest therapy.

2.2. Research participants

The participants in this study were students from G University in Gangwon Province, South Korea. They were selected based on their voluntary agreement to participate in the study, understanding of the procedures and significance, absence of any illnesses, and non-consumption of medication. A total of 31 participants were selected and subjected to repeated experiments before and after inhaling fragrances.

(A) (B)

Fig. 1. The OMNIFIT Mindcare device (A) and the measurement set-up (B).

Table 1. Homogeneity in the relationship between woody and herbaceous plants in terms of gender and stress index

Variable	Item	Woody plants	Herbaceous plants	χ^2
Gender	Female	5 (27.8)	6 (46.2)	0.449 (0.249)
	Male	13 (72.2)	7 (53.8)	
SRI-MF	Appropriate level	12 (66.7)	10 (76.9)	0.696 (0.417)
	Precautionary force	6 (33.3)	3 (23.1)	
	Possible disease group	-	-	

*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$, determined using analysis.

2.3. Research tools

The research tools employed in this study included:

1) SRI-MF questionnaires for stress assessments;
2) an OMNIFIT Mindcare device for measuring autonomic nervous system parameters, brainwaves, and HRV; and
3) four essential oils, selected based on their frequent usage in stress-related research: lavender oil, chamomile oil, pine oil (containing a high level of phytoncides, a key component of forest therapy), and cypress oil.

2.4. Study procedure

1) Stress assessment

Before the experiment, stress levels were assessed using the SRI-MF questionnaire, comprising a total of 22 items, divided into three subdomains: somatization (9 items), anger (5 items), and depression (8 items). Each item was rated on a 5-point Likert scale. The reliability of this scale, as measured by Cronbach's α, was determined to be 0.93, indicating high internal consistency. This assessment aimed to evaluate the impact of plant-derived essential oils on stress responses.

2) Plant essential oils

In this study, four different essential oils were utilized: pine oil, cypress oil, chamomile oil, and lavender oil. Previous research has often combined 2–3 oils with similar effects, but in this study, each oil was individually tested to assess its specific effects. Pine oil, known for its high content of phytoncides, was chosen due to its reported benefits in alleviating psychological fatigue (Lee, 1995). Cypress oil is recognized for its calming effects and efficacy in treating venous disorders and cellulitis (Cho and Song, 2002). Lavender oil is renowned for its calming properties, aiding in insomnia relief, emotional balance, stress reduction, and wound healing (Cho, 2000; Kwon et al., 2008; Park, 2011; Yoo, 2019). Chamomile oil, rich in esters, possesses soothing properties and has been shown to effectively alleviate mental distress, anxiety, agitation, and depression (Han et al., 2002; Cho, 2011).

Phytoncides are primarily found in coniferous trees like pine (*Pinus densiflora*), Korean pine (*Pinus koraiensis*), larch (*Larix kaempferi*), and hinoki cypress (*Chamaecyparis obtusa*), with pine emitting the highest concentration (Park et al., 2015). Therefore, in this experiment, pine oil was selected for its significant phytoncide content, while cypress, lavender, and chamomile oils were chosen for their respective therapeutic properties.

3. Research Results and Considerations

To investigate the effects of plant essential oils, the following sequential steps were undertaken:

Table 2. Homogeneity in the physiological stress indicators between the woody and herbaceous plant groups before treatment

	Item · Variable	Woody plants	Herbaceous plants	$t(p)/Z(p)$
Total Power (TP)	N	18	13	t = −0.124 (0.902) Mann-Whitney = 112.50 Z = −0.180 (0.857)
	Mean ± SD	7.35 ± 0.88	7.38 ± 0.56	
	Median (25%, 75%)	7.43 (6.57, 7.92)	7.29 (6.82, 7.83)	
High Frequency (HF)	N	18	13	t = 0.480 (0.636) Mann-Whitney = 104.00 Z = −0.520 (0.603)
	Mean ± SD	5.94 ± 0.91	5.78 ± 0.93	
	Median (25%, 75%)	5.85 (5.14, 6.86)	5.75 (4.94, 6.68)	
Low Frequency (LF)	N	18	13	t = −0.598 (0.554) Mann-Whitney = 93.50 Z = −0.941 (0.347)
	Mean ± SD	6.15 ± 1.04	6.35 ± 0.67	
	Median (25%, 75%)	6.25 (5.29, 6.70)	6.59 (5.85, 6.92)	
Total Balance (TB)	N	18	13	t = −1.599 (0.121) Mann-Whitney = 77.00 Z = −1.602 (0.109)
	Mean ± SD	50.75 ± 2.73	52.44 ± 3.10	
	Median (25%, 75%)	50.60 (48.60, 52.55)	52.00 (50.40, 55.99)	
Heart Rate Variability (HRV)	N	18	13	t = −1.098 (0.281) Mann-Whitney = 86.00 Z = −1.241 (0.214)
	Mean ± SD	11.55 ± 4.13	13.21 ± 4.20	
	Median (25%, 75%)	12.39 (9.16, 10.83)	13.16 (10.83, 15.42)	
Beats Per Minute (BPM)	N	18	13	t = −0.278 (0.783) Mann-Whitney = 111.50 Z = −0.220 (0.826)
	Mean ± SD	90.44 ± 30.89	93.54 ± 31.30	
	Median (25%, 75%)	87.00 (75.75, 99.50)	86.00 (73.50, 101.50)	
Theta waves	N	18	13	t = 0.874 (0.389) Mann-Whitney = 98.00 Z = −0.761 (0.447)
	Mean ± SD	7.63 ± 1.37	8.02 ± 1.10	
	Median (25%, 75%)	7.87 (6.56, 8.78)	7.82 (7.18, 9.12)	
Alpha waves	N	18	13	t = 0.606 (0.549) Mann-Whitney = 104.50 Z = −0.500 (0.617)
	Mean ± SD	6.30 ± 1.07	6.52 ± 0.95	
	Median (25%, 75%)	6.13 (5.38, 6.99)	6.42 (5.96, 6.83)	

*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$, determined using t and Z tests.

1) Measurements of autonomic nervous system activity, brainwaves (electroencephalogram (EEG)), and HRV were conducted before inhalation;
2) participants randomly selected and inhaled the aroma of one of the four essential oils (pine, cypress, lavender, or chamomile) for 1 min and then took a 5-min rest in a comfortable position, as shown in Fig. 1;
3) EEG and HRV measurements were taken again to assess the effects of inhaling the essential oils; and
4) finally the data obtained was analyzed using statistical tools.

Table 3. Differences in physiological stress indicators between the woody and herbaceous plant groups before and after treatment

Variable	Item	Woody plants	Herbaceous plants	$t(p)/Z(p)$
Total Power (TP)	*N*	18	13	t = -0.717 (0.479) Mann-Whitney = 95.00 Z = -0.881 (0.378)
	Mean ± SD	-1.11 ± 0.77	-0.91 ± 0.77	
	Median (25%, 75%)	-1.14 (-1.87, -0.49)	-0.74 (-1.79, -0.46)	
High Frequency (HF)	*N*	18	13	t = -0.617 (0.542) Mann-Whitney = 91.00 Z = -1.041 (0.298)
	Mean ± SD	-1.16 ± 1.02	-0.95 ± 0.74	
	Median (25%, 75%)	-1.28 (-1.93, -0.55)	-0.94 (-1.77, -0.52)	
Low Frequency (LF)	*N*	18	13	t = -1.229 (0.229) Mann-Whitney = 101.50 Z = -0.621 (0.535)
	Mean ± SD	-1.05 ± 1.07	-0.61 ± 0.87	
	Median (25%, 75%)	-0.62 (-2.03, -0.46)	-0.65 (-0.84, -0.38)	
Very Low Frequency (VLF)	*N*	18	13	t = -0.938 (0.356) Mann-Whitney = 97.00 Z = -0.801 (0.423)
	Mean ± SD	0.18 ± 3.35	1.39 ± 3.78	
	Median (25%, 75%)	0.60 (-2.00, 2.90)	0.71 (-1.15, 5.20)	
Heart Rate Variability (HRV)	*N*	18	13	t = -1.638 (0.112) Mann-Whitney = 74.00 Z = -1.721 (0.214)
	Mean ± SD	-1.91 ± 4.63	0.77 ± 4.31	
	Median (25%, 75%)	-1.19 (-4.78, 1.04)	0.74 (-1.12, 2.71)	
Beats Per Minute (BPM)	*N*	18	13	t = -0.374 (0.711) Mann-Whitney = 83.50 Z = -1.348 (0.178)
	Mean ± SD	-0.61 ± 35.95	3.46 ± 18.19	
	Median (25%, 75%)	3.00 (0.00, 5.25)	-1.00 (-2.50, 3.50)	
Theta waves	*N*	18	13	t = 0.186 (0.854) Mann-Whitney = 116.50 Z = -0.020 (0.984)
	Mean ± SD	0.65 ± 1.24	0.55 ± 1.76	
	Median (25%, 75%)	0.73 (-0.20, 3.50)	0.70 (-0.19, 1.34)	
Alpha waves	*N*	18	13	t = 0.706 (0.486) Mann-Whitney = 116.50 Z = -0.020 (0.984)
	Mean ± SD	0.53 ± 1.19	0.18 ± 1.58	
	Median (25%, 75%)	0.37 (-0.07, 0.77)	0.43 (-0.19, 0.86)	

$^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$, determined using t and Z tests.

The experiment aimed to investigate the effects of essential oils derived from woody and herbaceous plants on physiological stress. Participants were instructed to inhale 1–2 drops of the essential oil (derived from either woody or herbaceous plants) applied to a mask, and the impact on physiological stress was examined.

To verify the homogeneity in the relationship between woody and herbaceous plants, gender, and stress index, a cross-analysis was conducted. The results, as presented in Table 1, indicated no significant differences between woody and herbaceous plants, confirming the pre-existing homogeneity between the two plant types in terms of gender and stress index.

Table 4. Differences in the physiological stress indicators between the woody and herbaceous plant groups after treatmen

Variable	Item	Woody plants	Herbaceous plants	$t(p)/Z(p)$
Total Power (TP)	N	18	13	t = 0.676 (0.504) Mann-Whitney = 102.00 Z = -0.600 (0.548)
	Mean ± SD	8.46 ± 0.66	8.29 ± 0.70	
	Median (25%, 75%)	8.50 (7.87, 9.15)	8.21 (7.84, 8.91)	
High Frequency (HF)	N	18	13	t = 1.039 (0.308) Mann-Whitney = 97.50 Z = -0.781 (0.435)
	Mean ± SD	7.10 ± 0.1.02	6.73 ± 0.89	
	Median (25%, 75%)	6.85 (6.23, 7.83)	6.93 (5.88, 7.46)	
Low Frequency (LF)	N	18	13	t = 1.126 (0.269) Mann-Whitney = 105.00 Z = -0.480 (0.631)
	Mean ± SD	7.20 ± 0.60	6.96 ± 0.60	
	Median (25%, 75%)	7.19 (6.83, 7.50)	7.10 (6.46, 7.46)	
Total Balance (TB)	N	18	13	t = -0.411 (0.684) Mann-Whitney = 105.00 Z = -0.481 (0.631)
	Mean ± SD	50.58 ± 2.83	51.05 ± 3.64	
	Median (25%, 75%)	50.75 (47.95, 52.90)	51.40 (48.45, 54.05)	
Heart Rate Variability (HRV)	N	18	13	t = 1.271 (0.214) Mann-Whitney = 86.50 Z = -1.221 (0.222)
	Mean ± SD	13.46 ± 2.38	11.44 ± 1.94	
	Median (25%, 75%)	13.55 (11.40, 15.04)	12.14 (11.58, 13.52)	
Beats Per Minute (BPM)	N	18	13	t = 0.141 (0.889) Mann-Whitney = 113.50 Z = -0.140 (0.888)
	Mean ± SD	91.06 ± 19.56	90.08 ± 18.33	
	Median (25%, 75%)	85.50 (75.75, 100.25)	85.00 (76.50, 101.00)	
Theta waves	N	18	13	t = 0.643 (0.525) Mann-Whitney = 99.00 Z = -0.721 (0.471)
	Mean±SD	7.37 ± 1.13	7.08 ± 1.36	
	Median (25%, 75%)	7.13 (6.73, 8.48)	6.91 (5.99, 7.70)	
Alpha waves	N	18	13	t = -0.385 (0.703) Mann-Whitney = 110.00 Z = -0.280 (0.779)
	Mean ± SD	5.99 ± 0.78	6.12 ± 1.09	
	Median (25%, 75%)	5.85 (5.33, 6.51)	5.84 (5.56, 6.50)	

$^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$, determined using t and Z tests.

To assess the homogeneity of HRV, theta waves, and alpha waves between the woody and herbaceous plant groups, homogeneity tests were conducted. Due to the small sample sizes in each group, both parametric (independent t-test) and non-parametric (Mann-Whitney U test) tests were performed. The results (Table 2) indicated no statistically significant differences in any of the variables (HRV, theta waves, and alpha waves) between the woody and herbaceous plant groups. Therefore, it can be concluded that there was homogeneity between the woody and herbaceous plant groups in terms of HRV, theta waves, and alpha waves before the experiment.

Table 5. Differences in the physiological stress indicators before and after treatment in all participants

Variable	Item	Pre-treatment	Post-treatment	$t(p)/Z(p)$
Total Power	N	31	31	t = -7.483 (<0.001)*** Z = -0.059 (0.953)
	Mean ± SD	7.36 ± 0.75	8.39 ± 0.67	
	Paired differences	-1.03 ± 0.77		
	Median (25%, 75%)	7.42 (6.76, 7.80)	7.28 (6.90, 8.04)	
High Frequency (HF)	N	31	31	t = -6.610 (<0.001)*** Z = -0.627 (0.531)
	Mean ± SD	5.87 ± 0.91	6.94 ± 0.97	
	Paired differences	-1.07 ± 0.90		
	Median (25%, 75%)	5.75 (5.14, 6.70)	5.87 (5.18, 6.61)	
Low Frequency (LF)	N	31	31	t = -4.830 (<0.001)*** Z = -0.823 (0.410)
	Mean ± SD	6.23 ± 0.89	7.10 ± 0.61	
	Paired differences	-0.87 ± 1.00		
	Median (25%, 75%)	6.36 (5.50, 6.74)	6.17 (5.73, 6.44)	
Total Balance (TB)	N	31	31	t = 1.081 (0.288) Z = -0.980 (0.327)
	Mean ± SD	51.46 ± 2.97	50.78 ± 3.14	
	Paired differences	0.69 ± 3.52		
	Median (25%, 75%)	51.10 (49.70, 53.00)	51.20 (48.00, 52.90)	
Heart Rate Variability (HRV)	N	31	31	t = -0.948 (0.351) Z = -0.745 (0.456)
	Mean ± SD	12.24 ± 4.17	13.03 ± 2.23	
	Paired differences	-0.79 ± 4.63		
	Median (25%, 75%)	12.83 (9.66, 14.80)	11.85 (10.50, 13.83)	
Beats Per Minute (BPM)	N	31	31	t = 0.207 (0.837) Z = -1.680 (0.093)
	Mean ± SD	91.74 ± 30.12	90.65 ± 18.74	
	Paired differences	1.10 ± 29.47		
	Median (25%, 75%)	86.00 (76.00, 99.00)	85.00 (76.00, 100.00)	
Theta waves	N	31	31	t = 2.343 (0.026)* Z = -2.646 (0.008)**
	Mean ± SD	7.86 ± 1.21	7.25 ± 1.22	
	Paired differences	0.61 ± 1.45		
	Median (25%, 75%)	7.85 (7.09, 9.00)	7.09 (6.15, 8.00)	
Alpha waves	N	31	31	t = 1.575 (0.126) Z = -2.293 (0.022)*
	Mean ± SD	6.42 ± 0.99	6.04 ± 0.91	
	Paired differences	0.38 ± 1.35		
	Median (25%, 75%)	6.40 (5.87, 6.81)	5.84 (5.36, 6.41)	

*p < 0.05, **p < 0.01, and ***p < 0.001, determined using t and Z tests.

Table 6. Differences in physiological stress indicators before and after treatment based on oil type

		Pine (*n* = 10)		Cypress (*n* = 8)		Lavender (*n* = 7)		Chamomile (*n* = 6)	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
Total Power (TP)	Mean ± SD	7.08 ± 0.93	8.36 ± 0.77	7.68 ± 0.73	8.58 ± 0.52	7.57 ± 0.62	8.38 ± 0.88	7.16 ± 0.44	8.19 ± 0.49
	Paired differences	-1.29 ± 0.68		-0.90 ± 0.86		-0.81 ± 0.87		-1.03 ± 0.71	
	t (*p*)	-5.953 (<0.001)***		-2.930 (0.022)*		-2.480 (0.048)*		-3.565 (0.016)*	
	Z (*p*)	-2.803 (0.005)**		-2.100 (0.036)*		-1.859 (0.063)		-2.201 (0.028)*	
High Frequency (HF)	Mean ± SD	5.62 ± 0.97	7.02 ± 1.09	634 ± 0.70	7.20 ± 0.98	6.02 ± 0.90	6.75 ± 0.85	5.49 ± 0.95	6.72 ± 1.02
	Paired differences	-1.40 ± 0.70		-0.86 ± 1.130		-0.72 ± 0.89		-1.12 ± 0.43	
	t (*p*)	-6.293 (<0.001)***		-1.861 (0.105)		-2.138 (0.076)		-7.035 (0.001)**	
	Z (*p*)	-2.803 (0.005)**		-1.680 (0.093)		-1.859 (0.063)		-2.207 (-0.027)*	
Low Frequency (LF)	Mean ± SD	5.83 ± 1.08	7.10 ± 0.61	6.54 ± 0.90	7.33 ± 0.61	6.35 ± 0.71	7.03 ± 0.63	6.34 ± 0.68	6.86 ± 0.61
	Paired differences	-1.27 ± 0.85		-0.79 ± 1.30		-0.68 ± 0.36		-0.53 ± 0.85	
	t (*p*)	-4.692 (0.001)**		-1.716 (0.130)		-1.889 (0.108)		-1.524 (0.188)	
	Z (*p*)	-2.803 (0.005)**		-1.680 (0.093)		-1.352 (0.176)		-1.153 (0.249)	
Total Balance (TB)	Mean ± SD	50.82 ± 2.35	50.50 ± 2.67	50.67 ± 3.32	50.67 ± 3.20	51.36 ± 2.90	51.26 ± 3.52	53.69 ± 3.08	50.82 ± 4.09
	Paired differences	0.32 ± 3.33		0.01 ± 3.59		0.10 ± 4.00		2.88 ± 3.17	
	t (*p*)	0.305 (0.767)		.001 (0.999)		0.067 (0.949)		2.227 (0.076)	
	Z (*p*)	-0.306 (0.760)		-0.280 (0.779)		-0.169 (0.866)		-2.201 (0.028)*	
Heart Rate Variability (HRV)	Mean ± SD	11.14 ± 2.90	13.43 ± 2.87	12.05 ± 5.48	13.50 ± 1.78	14.98 ± 3.69	12.88 ± 2.63	11.14 ± 4.06	11.92 ± 0.33
	Paired differences	-2.28 ± 2.59		-1.45 ± 6.55		2.10 ± 4.34		-0.78 ± 4.08	
	t (*p*)	-2.776 (0.022)*		-0.627 (0.551)		1.283 (0.247)		-0.470 (0.658)	
	Z (*p*)	-2.293 (0.022)*		-0.140 (0.889)		1.183 (0.237)		-0.105 (0.917)	
Beats Per Minute (BPM)	Mean ± SD	98.20 ± 26.17	90.10 ± 17.18	80.75 ± 33.53	92.25 ± 23.37	93.00 ± 15.64	95.43 ± 14.29	94.17 ± 45.35	83.83 ± 21.78
	Paired differences	8.10 ± 23.27		-11.50 ± 46.89		-2.43 ± 9.83		10.33 ± 23.93	
	t (*p*)	1.101 (0.300)		-0.694 (0.510)		-0.654 (0.538)		-1.058 (0.339)	
	Z (*p*)	-1.739 (0.082)		-0.169 (0.866)		-0.341 (0.733)		-0.954 (0.340)	
Theta waves	Mean ± SD	7.54 ± 1.02	6.75 ± 0.83	8.62 ± 0.93	8.14 ± 1.01	7.66 ± 1.48	6.92 ± 1.55	7.60 ± 1.37	7.27 ± 1.19
	Paired differences	0.79 ± 0.86		0.49 ± 1.65		0.74 ± 2.38		0.33 ± 0.72	
	t (*p*)	2.898 (0.018)*		0.831 (0.433)		0.825 (0.441)		1.132 (0.309)	
	Z (*p*)	-2.293 (0.022)*		-0.700 (0.484)		-1.183 (0.237)		-1.153 (0.249)	
Alpha waves	Mean ± SD	6.11 ± 0.51	5.65 ± 0.34	7.03 ± 1.01	6.41 ± 0.98	6.42 ± 1.33	6.30 ± 1.38	6.15 ± 0.76	5.90 ± 0.67
	Paired differences	0.46 ± 0.49		0.61 ± 1.76		0.12 ± 2.17		0.25 ± 0.61	
	t (*p*)	2.934 (0.017)*		0.989 (0.356)		0.147 (0.888)		0.997 (0.364)	
	Z (*p*)	-2.395 (0.017)*		-0.420 (0.674)		-1.014 (0.310)		-0.943 (0.345)	

*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$, determined using *t* and *Z* tests.

Table 3 presents the results of the independent *t*-test and Mann-Whitney U test conducted to examine the pre-post differences between the woody and herbaceous plant groups in terms of physiological stress indicators, including HRV, theta waves, and alpha waves. Post-treatment measurements showed increases in HRV, total power (TP), high frequency (HF), and low frequency (LF); however, the differences were not statistically significant.

Table 4 presents the results of the independent *t*-test and Mann-Whitney U test conducted to examine the differences between the woody and herbaceous plant groups in terms of physiological stress indicators, including HRV, theta waves, and alpha waves, after inhaling the essential oil. Post-treatment measurements showed increases in HRV, TP, HF, LF, and theta waves when using essential oil derived from woody plants; however, the differences were not statistically significant.

Table 5 shows the results of the paired *t*-test and Wilcoxon test conducted to examine the differences in physiological stress indicators, including HRV, theta waves, and alpha waves, before and after treatment in all participants. The paired *t*-test revealed statistically significant differences in TP, HF, LF, and theta waves, while the Wilcoxon test showed statistically significant differences only in the theta and alpha waves.

Table 6 presents the results of the paired *t*-test and Wilcoxon test conducted to examine the differences in physiological stress indicators, including HRV, theta waves, and alpha waves, before and after treatment based on the oil type. For pine oil, both paired *t*-test and Wilcoxon test revealed statistically significant differences in TP, HF, LF, HRV, theta waves, and alpha waves. For cypress oil, both tests revealed statistically significant differences only in TP. Lavender oil did not exhibit statistically significant differences in any of the variables tested. Regarding chamomile oil, the paired *t*-test revealed statistically significant differences in TP and HF, while the Wilcoxon test showed significant differences in TP, HF, and autonomic nervous system balance.

4. Conclusion

This study investigated the relationship between inhaling plant-derived essential oils and physiological stress responses among university students exposed to stress. Lavender and chamomile essential oils, renowned for their stress-alleviating properties, alongside pine and cypress oils, associated with forest therapy effects, were employed to induce potential changes in stress levels. By measuring the stress stimuli-induced changes in HRV, θ waves, and α waves, the homogeneity of the relationship between woody and herbaceous plants in terms of gender and stress index was verified through a cross-analysis. The results confirmed the homogeneity between woody and herbaceous plants.

Unlike previous studies that simply verified changes in physiological responses following inhalation of plant essential oils, this study classified essential oils into woody and herbaceous types and aimed to verify whether effects comparable to forest therapy could be attained in urban settings. Paired *t*-tests revealed statistically significant differences in TP, HF, LF, and theta waves, while Wilcoxon tests showed significant differences only in theta and alpha waves. To determine which essential oil is most effective for alleviating physiological stress, pine, cypress, lavender, and chamomile oils were individually tested using paired *t*-tests and Wilcoxon tests. Pine oil showed significant differences in TP, HF, LF, HRV, theta waves, and alpha waves. Conversely, cypress oil showed significant differences only in TP. Lavender oil did not show significant differences in any of the studied variables. Furthermore, chamomile oil revealed significant differences in TP and HF in paired *t*-tests, as well as in TP, HF, and autonomic balance in Wilcoxon tests. These findings suggest that, among the tested essential oils, pine oil is most effective in providing forest therapy-like effects regardless of location constraints. Moreover, the results of the present study are consistent with those of previous studies by Lee(2014) and Lim(2020), further supporting the effectiveness of inhalation therapy.

As this study marks the initial endeavor to confirm physiological responses to stress, future studies should increase the duration and frequency of inhalation to bolster the reliability of physiological responses. Additionally, further research is warranted to compare the therapeutic effects obtained in natural forest environments with those obtained by inhaling essential oils in urban areas, without visiting forests, to verify the differences in physiological responses.

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