Article

Empirical Study on the Impact of Different Types of Forest Environments in Wuyishan National Park on Public Physiological and Psychological Health

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Abstract: Amidst the challenges of global environmental change and urbanization, the salutary effects of natural environments on public health are increasingly being recognized. This study investigates the specific effects of varied forest environments in China's Wuyishan National Park on physiological and psychological health. Eight distinct forest environments were carefully selected, and a repeated-measures ANOVA approach was used to evaluate 41 participants over three days. Physiological assessments included Heart Rate Variability, Skin Conductance Level, and surface Electromyography, complemented by psychological evaluations using the Profile of Mood States. The key findings include the following: (1) Notable variations in physiological indicators were observed among different forest types. In valley tea gardens and broadleaf forest streamside, significant changes in heart rate indicators highlighted the influence of these settings on autonomic nervous activities. Skin Conductance Level and surface Electromyography also indicated varying emotional arousal and pleasure across the forests. The mixed broadleaf and coniferous forest valley, along with the rock-bedded streamscape, elicited emotions of low arousal but high pleasure, inducing feelings of calmness and pleasure. The valley's tea gardens were associated with low arousal and pleasure, suggesting tranquility without positive emotional induction, while the broadleaf ridge forest induced high arousal and pleasure, reflecting an exciting and joyful environment. (2) The study found that different forest environments had a notable impact on participants' mood states, indicating reductions in tension, anger, fatigue, and depression, along with an increase in vigor levels. In summary, forest environments offer unique psychological and physiological health benefits compared to urban settings. These findings underscore the importance of integrating forest environments into urban development and public health frameworks, and the need to further explore their impact on the health of diverse populations.

Keywords: forest bathing; physiological health effects; psychological well-being; environmental psychology; landscape design optimization

1. Introduction

The global environment is undergoing significant transformations, particularly due to climate change and rapid urbanization, which have a substantial impact on both natural ecosystems and human health. Studies have indicated a close connection between these factors—climate change, urbanization, environmental pollution—and various health challenges, including cardiovascular diseases, respiratory issues, and psychological health concerns [1,2]. In response to these challenges, researchers are delving into the impact of the environment on health, with a special focus on the positive role of natural settings in public health. In this context, forest bathing, also known as forest therapy, has garnered

significant attention. This approach involves visiting forests and participating in specific activities designed to promote health within a forest environment [3]. Its core practices include walking, experiencing the forest through all five senses, meditation, Qi-Gong, and aromatherapy, aiming to harness the power of nature to enhance individuals' comfort, immunity, and well-being [4]. Moreover, forest bathing emphasizes the healing effects of the forest environment and fosters a deeper appreciation and positive experiences of natural landscapes. Investigations into this therapeutic approach highlight the critical role of natural environments in promoting health and lay the groundwork for comprehensive health promotion strategies. This study aims to evaluate the effects of different forest environments within Wuyishan National Park on public physiological and psychological well-being. Its objective is to deepen our empirical understanding of the positive contribution of natural environments to health enhancement and to establish a scientific foundation for future health promotion initiatives and therapeutic interventions.

1.1. Forest Environments and Psychophysiological Well-Being

Since the 1980s, Japan has led in developing and popularizing the concept of 'Shinrin-yoku', a traditional natural therapy. This approach, emphasizing the engagement of all five senses, aims for complete immersion in forest environments, often accompanied by structured, therapeutic activities in nature. Since 2004, there's been a notable increase in cross-disciplinary research between forest environments and public health, particularly in Asian and European countries. Japan has been at the forefront, establishing institutions dedicated to forest medicine and significantly advancing the theoretical aspects of this field [5].

Globally, forest bathing has emerged as an innovative, nature-based therapy, especially during health challenges like the COVID-19 pandemic. Empirical studies underscore its wide-ranging therapeutic impacts, from improving mental health and cardiovascular and immune system function to enhancing sleep quality and resilience [6–10]. These activities enhance mood state, affect, and overall happiness and are effective in reducing symptoms of anxiety, stress, and depression. These benefits, attributed to rich sensory experiences in natural settings, extend to well-being, reducing anxiety, stress, and depression [5].

Physiologically, forest bathing has been shown to lower blood pressure, enhance heart rate variability [11,12], reduce salivary cortisol levels, and decrease systolic blood pressure [13,14], with benefits lasting up to five days post-experience [15]. The underlying mechanisms are thought to include a reduction in stress hormone levels, a decrease in sympathetic nervous system activity, enhancement of parasympathetic nervous system functioning, and suppression of the adrenaline-angiotensin system [16–18]. Furthermore, it boosts immune efficacy, including anti-cancer protein production in NK cells [19–21], with sustained effects in women for at least seven days [22]. It is also believed to enhance immunity by improving the functionality of immune cells and reducing inflammatory markers [23], possibly influenced by inhaling phytoncides from forests.

Studies have suggested that forest therapy can positively affect metabolic status and emotional regulation by raising serum levels of serotonin, adiponectin (a hormone secreted by adipose tissue), and dehydroepiandrosterone sulfate (DHEA-S) [24,25]. Regarding sleep quality, participants in forest bathing programs have reported significant improvements in sleep duration and a heightened sense of refreshment upon awakening [25,26], possibly attributable to the reduced noise levels and the natural light-dark cycles inherent in forest environments. Preliminary research also points to the potential benefits of forest bathing in addressing non-communicable diseases such as impaired lung function [27], hypertension [28], chronic fatigue syndrome [29], coronary heart disease [30], depression [31], myocardial infarction [32], and chronic widespread pain [20]. During the COVID-19 pandemic, forest bathing has been notably effective in psychological health interventions, aiding in the alleviation of stress, fatigue, and depression associated with home isolation, while enhancing positive emotions and mindfulness [33]. Its implementation among healthcare professionals has also resulted in significant improvements in emotional stress and

sleep quality [26]. Additionally, the utilization of virtual forest videos has demonstrated potential in providing temporary relief from anxiety during lockdown periods [34].

1.2. Special Impacts of Different Forest Environments on Health

Forest therapy has gained significant attention due to its positive effects on physiological and psychological health, leading to an increasing body of research investigating the impact of diverse forest environments on public health. An et al. explored the impact of forest stand density on human physiological and psychological responses. Their research indicated that varying densities of forest stands influence brain activity and mood states, thereby impacting mental health and the quality of leisure experiences [35]. Sonntag-Öström et al. found that environments near lakeside forests were perceived as more calming and harmonious than those in rugged, rocky terrains, with the latter scoring lower in relaxation and comfort metrics [29]. Zhu et al. revealed significant differences among various types of forests, like bamboo forests, subtropical evergreen broadleaf forests, and Liquidambar forests, in aspects such as air negative ion concentration, oxygen, and human comfort level. Particularly, mixed coniferous and broadleaf forests showed the best overall health indices, while subtropical evergreen broadleaf forests exhibited the highest relative concentration of "phytoncides", beneficial for human health [36]. Liu et al. conducted two studies to assess the restorative perceptions of forest environments on university students' health, considering both physiological and psychological aspects. Their findings highlight how different forest types uniquely contribute to reducing blood pressure and heart rate, while also enhancing vitality and mental well-being. In particular, mixed forests demonstrated superior restorative properties in these aspects [37]. Zhang et al. also indicated that different forest environments exert varying degrees of positive impact on individuals' physical and mental health. [38]. Collectively, these studies demonstrate that different forest environments have unique effects on health. By scientifically selecting and applying different forest environments, their therapeutic potential can be maximized, thereby enhancing both the individual benefits of forest bathing and the broader social utility of forest resources.

1.3. Current Research

Current research recognizes the positive health impacts of forest therapy, yet deeper insights into how different forest types influence health remain unexplored. This gap includes understanding the specific roles of tree species, forest structures, and unique environmental characteristics on psychological and physiological responses. Our study in Wuyishan National Park aims to deepen this knowledge by examining the varied forest environments and their effects on human health. The study will focus on the following key inquiries:

(1) What are the differential impacts of various forest environments in Wuyishan National Park on the physiological indicators of participants?
(2) How do these distinct forest environments influence the mood states of participants?
(3) In comparison to urban environments, what are the unique benefits that forest settings provide in augmenting human psychological and physiological health?

The aim of this research is to provide more robust empirical evidence to enhance our understanding of the relationship between natural environments and human health, thereby establishing a strong scientific foundation for the development of forest therapy and the formulation of effective health promotion strategies.

2. Materials and Methods

2.1. Study Area

Wuyishan National Park, situated at the border between Fujian and Jiangxi provinces in China (E 117°24′13″~117°59′19″, N 27°31′20″~27°55′49″), is the only scenic area in China honored with both 'World Biosphere Reserve' and 'World Heritage—Mixed Property' designations. This reflects its global significance in natural conservation and historical and

cultural values. The study area, at an average altitude of 1200 m, experiences a typical subtropical monsoon climate with an annual temperature range from 8.5 °C to 18 °C and an average yearly precipitation of approximately 1800 mm. The primary focus of this study was the core viewing area in the eastern part of the park, as shown in Figure 1. The main forest canopy comprises predominantly evergreen species from the Fagaceae family, along with species from Theaceae, Lauraceae, and Hamamelidaceae. The coniferous flora includes species such as *Pinus massoniana*, *Pinus taiwanensis*, *Cunninghamia lanceolata*, and *Taxus chinensis var. mairei*. In summary, the diverse ecosystems and unique geographic characteristics of Wuyishan National Park create an ideal environment for this research.
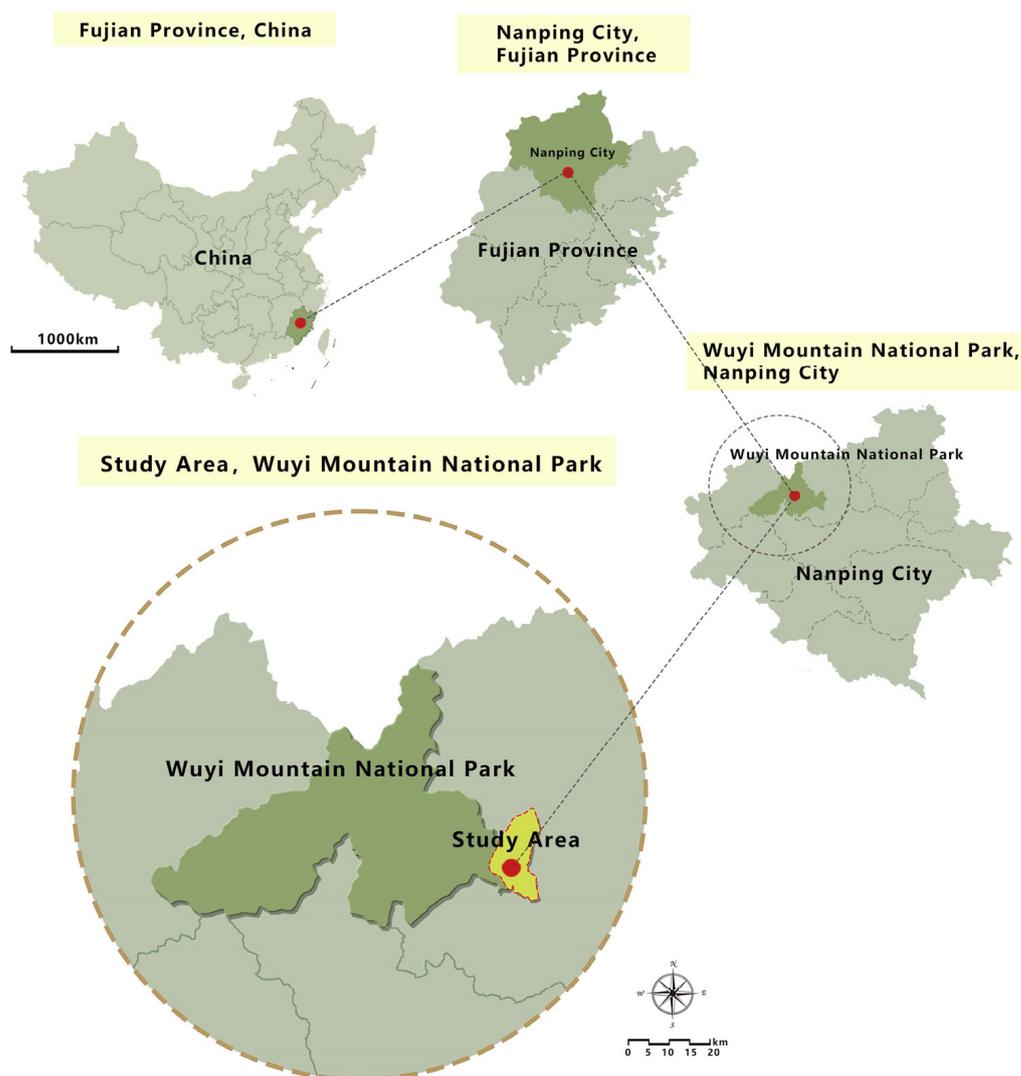
Figure 1. Location of the Wuyishan National Park.

2.2. Study Sites

To ensure comprehensive representation of all landscape types within the study area, we initially employed Data Processing System (DPS) software (http://www.dpsw.cn/index.html, accessed on 8 February 2024) for Fisher's ordered cluster analysis on landscapes surrounding forest trails. These segments, oriented from north to south and west to east (Figure 2). Primary observational variables of the forest landscape, including topography, vegetation types, and land use patterns, were extracted from field interviews and survey data. These variables, expertly coded, formed a spatial matrix to guide the optimal zoning plan, resulting in the division of the area into eight distinct segments. These segments, oriented from north to south and west to east, include grassland slopes, broadleaf forest valley, mixed

broadleaf and coniferous forest valley, broadleaf ridge forest, mixed broadleaf and coniferous forest slopes, tea gardens of the valley, broadleaf forest streamside, and rock-bedded streamscape (Figure 3). The selection criteria for these segments encompassed representativeness, accessibility and convenience for visitors, landscape and vegetation diversity, and the viability of experimental designs. In each of these eight segments, one experimental plot (S1–S8) was established, as detailed in Figures 2 and 3. Following methodologies from prior studies [11,18,28], a control group (CG) was established in urban streets, detailed in Figure 4.
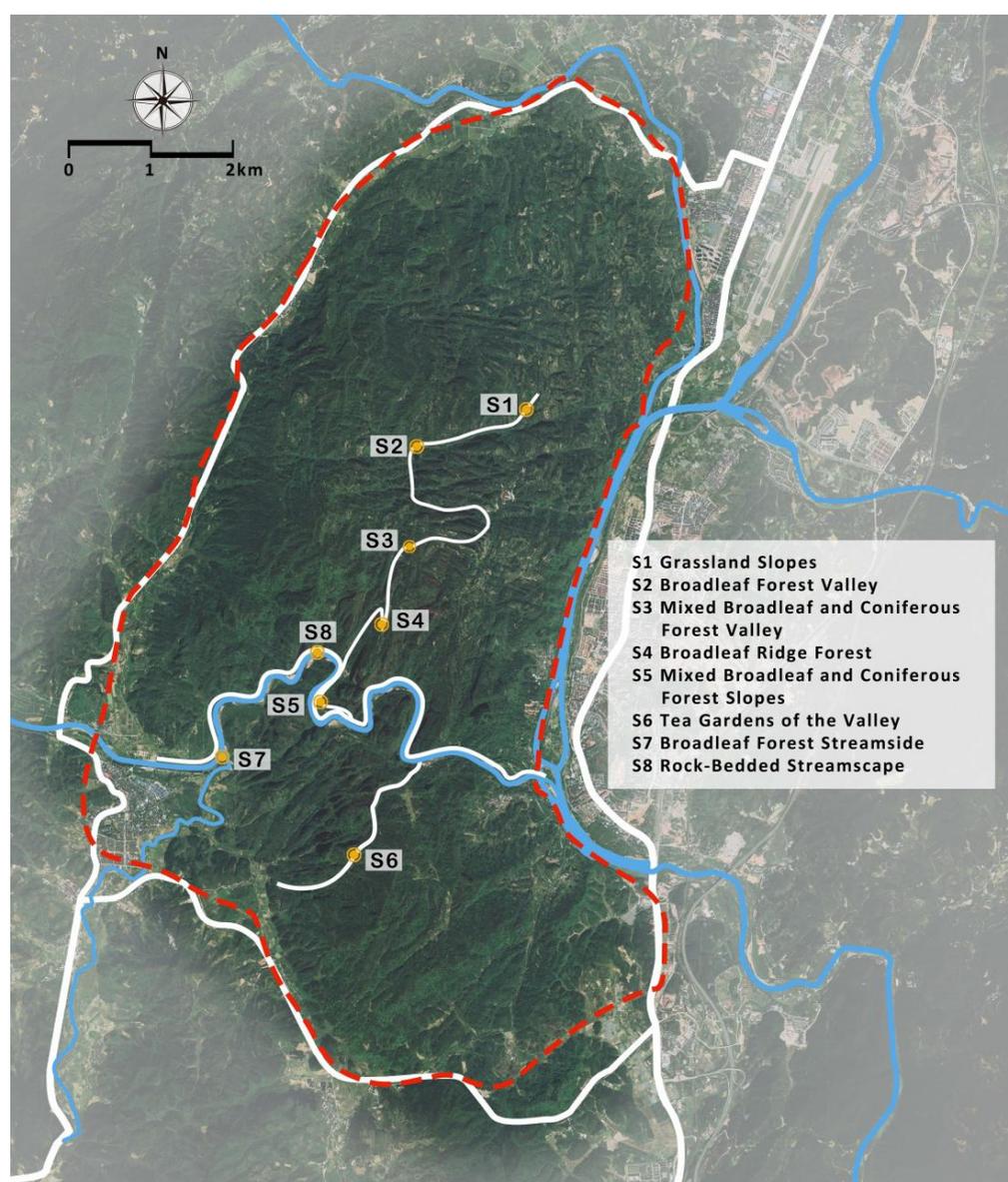
Figure 2. Location of the experimental plots (S1–S8), with the boundary of the Wuyi Mountain National Park tour area indicated by a red dashed line.

In this investigation, the KEC900+II Air Negative Ion Monitor (Shenzhen Wanyi Technology Co., Ltd., Shenzhen, China) was employed for quantifying air negative ion concentrations. Wind velocity was measured using the PM6252B (Shenzhen Triple Gold Technology Development Co., Ltd., Shenzhen, China) Digital Anemometer. Temperature and humidity parameters were recorded with the TES 1360A Hygro-Thermometer (TES Electrical Electronic Corp., Taipei, China), and sound pressure levels were assessed using the TES-1350A Sound Level Meter (TES Electrical Electronic Corp., Taipei, China). The

collection of this physical and meteorological data were synchronized with the participant experiments. Monitoring occurred daily between 8:00 a.m. and 4:30 p.m., with data recorded at 30 min intervals. At each experimental site, three distinct monitoring points were established, with the data for each site's physical and meteorological conditions calculated as the mean of three consecutive stable recordings. This methodology was designed to mitigate the influence of atmospheric conditions and other extraneous variables on the experimental outcomes. Measurements were consistently taken at a height of 1.5 m from the ground. Table 1 presents a detailed enumeration of the physical and meteorological parameters pertinent to this research study.
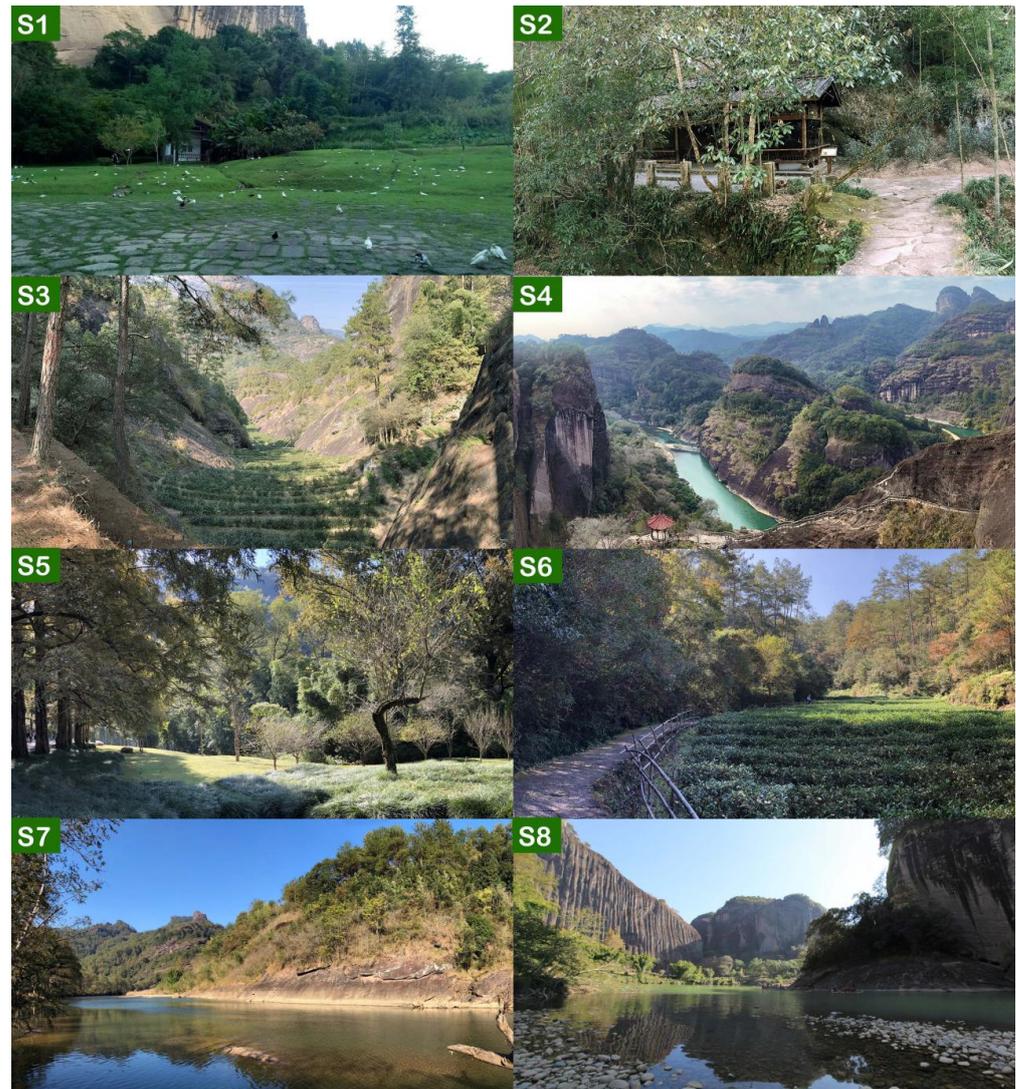
Figure 3. Experimental plots of the Wuyishan National Park. (**S1**) Grassland slopes; (**S2**) Broadleaf forest valley; (**S3**) Mixed broadleaf and coniferous forest valley; (**S4**) Broadleaf ridge forest; (**S5**) Mixed broadleaf and coniferous forest slopes; (**S6**) Tea gardens of the valley; (**S7**) Broadleaf forest streamside; (**S8**) Rock-bedded streamscape.

Figure 4. (CG) Urban environment (control group).

Table 1. Physical and meteorological parameters during the forest therapy experiment.

Exp. Design	ETs	Test Sites	SPL (dB)	Temp (°C)	Hum (%)	WSp (m/s)	NIs (per/cm³)	Ill (LUX)
CG	Urban environment	-	68.29 ± 5.60	27.60 ± 4.63	37.26 ± 4.24	0.22 ± 0.13	464.23 ± 80.74	-
EG	Grassland slopes	S1	40.03 ± 5.01	22.91 ± 5.77	37.92 ± 2.11	0.53 ± 0.31	3250.32 ± 1294.48	7904.32 ± 3742.08
	Broadleaf forest valley	S2	38.01 ± 3.99	25.60 ± 6.12	38.48 ± 6.94	0.45 ± 0.26	4615.68 ± 1631.46	5907.42 ± 2860.59
	Mixed broadleaf and coniferous forest valley	S3	33.73 ± 1.79	19.97 ± 5.49	40.68 ± 1.94	1.39 ± 0.35	2192.27 ± 663.14	5711.36 ± 2305.11
	Broadleaf ridge forest	S4	48.34 ± 4.65	25.96 ± 5.59	32.00 ± 4.50	0.43 ± 0.11	1911.82 ± 533.64	12,950.45 ± 3293.77
	Mixed broadleaf and coniferous forest slopes	S5	38.23 ± 4.40	25.24 ± 5.27	40.60 ± 7.32	0.09 ± 0.09	2558.64 ± 969.83	7721.14 ± 2042.44
	Tea gardens of the valley	S6	34.42 ± 2.11	16.56 ± 5.49	47.91 ± 3.85	0.23 ± 0.11	1458.86 ± 285.75	4501.36 ± 1555.05
	Broadleaf forest streamside	S7	38.34 ± 4.78	26.15 ± 3.44	39.98 ± 4.58	0.18 ± 0.11	2147.50 ± 828.58	8109.39 ± 2960.48
	Rock-bedded streamscape	S8	37.16 ± 3.15	23.31 ± 5.28	41.48 ± 5.69	0.59 ± 0.19	2913.18 ± 1263.86	9668.64 ± 3068.39

Note: Exp. design: experimental design; CG: control group; EG: experimental group; ETs: environmental types; SPL: sound pressure level; Temp: temperature; Hum: humidity; WSp: wind speed; NIs: negative ions; Ill: illuminance.

2.3. Participants

In this research, G*Power v 3.1.9.2 software, as recommended by the Digital Research and Education Institute at the University of California, Los Angeles, was employed to determine the necessary sample size. For sample evaluation, the effect size (f) was set at 0.25, the alpha error probability at 0.05, and the statistical power at 0.95, ensuring the significance of the research outcomes. This led to an estimated minimum sample size of 22 individuals. To enhance study reliability, volunteers were solicited based on specific inclusion criteria: (1) individuals in good physical health without a history of neurological, cardiovascular, or metabolic disorders; (2) abstention from medication for at least one week prior to the experiment; (3) avoidance of alcohol and coffee consumption and strenuous physical activities on the day before the experiment; (4) no prior involvement in similar experimental studies; (5) no professional background in forestry or landscape design; (6) informed consent provided, adhering to the Declaration of Helsinki guidelines. Initially, 47 volunteers were recruited, but 6 were excluded due to withdrawal or abnormal data occurrences. The final participant pool comprised 41 individuals, aged between 21 and 55 years (mean age 32.17 ± 8.08 years), with a gender ratio of 51% males (mean age 31.95 ± 7.86 years) and 49% females (mean age 32.4 ± 8.30 years). Measurements of the physiological and psychological indices, which are detailed in the methods Section 2.5, are foundational to the interpretation of these demographic data. Detailed demographic

data are presented in Table 2. This balanced representation contributes to the robustness and generalizability of the findings, ensuring comprehensive understanding across diverse population segments.

Table 2. Demographic information of study participants.

Parameter	Value (Mean $\pm$ SD)		
	All	**Male**	**Female**
Total sample number	41	21	20
Age (years)	32.17 $\pm$ 8.08	31.95 $\pm$ 7.86	32.4 $\pm$ 8.30
Height (m)	1.68 $\pm$ 0.09	1.76 $\pm$ 0.03	1.60 $\pm$ 0.04
Weight (kg)	59.27 $\pm$ 8.28	65.71 $\pm$ 4.85	52.5 $\pm$ 5.12
BMI	20.84 $\pm$ 1.98	21.14 $\pm$ 1.73	20.51 $\pm$ 2.17

Note: BMI: body mass index; SD: standard deviation.

2.4. Study Design

This study utilized a repeated-measures ANOVA design, with the independent variable being the various types of forest environments. The dependent variables included key physiological and psychological indices, which are detailed in the methods section. To mitigate the influence of external factors, the study carefully monitored and controlled variables like weather conditions, ambient temperature, and noise levels throughout the experimental process, maintaining uniformity in the experimental settings. Efforts to reduce the effects of random incidents included measures such as setting mobile phones to silent mode and insulating the experimental zones from pedestrian disruptions and other unplanned stimuli. This study adopted a carefully designed experimental layout to ensure the accuracy and reliability of data collection. Specifically, we utilized a Latin square design strategy, executed via four designated walking paths. These paths included all experimental sites, and each was meticulously planned to ensure that every participant could experience all sites, albeit in a different order. This design permitted the random allocation of participants to the four walking paths in varied sequences, thus ensuring a balanced distribution across different sequence groups within the experiment.

2.5. Measurements

2.5.1. Physiological Indices

This study was conducted using the ErgoLAB Human–computer Environment Synchronization Platform, which employs Photoplethysmography (PPG) technology for advanced ear-clip heart rate monitoring. This method is essential for the accurate assessment of Heart Rate Variability (HRV). Furthermore, the Skin Conductance Level (SCL) was precisely evaluated by measuring the electrical conductivity across specific points on the fingers, an approach integral to Electrodermal Activity (EDA) assessment, reflects the skin's ability to conduct electricity, which varies with its moisture level. This moisture level is influenced by sweat gland activity, which is controlled by the sympathetic nervous system, making EDA a valuable indicator of physiological and emotional arousal. Additionally, the study utilized Surface Electromyography (sEMG) to precisely monitor and analyze the activities of specific facial muscles, namely the corrugator supercilii and zygomaticus major.

HRV as an essential indicator, capturing the variability in the intervals between heartbeats as recorded in electrocardiogram R-R intervals. This parameter serves as an indirect marker of the cardiac autonomic nervous system's equilibrium and the interplay between the sympathetic and parasympathetic nervous systems. Key temporal features of HRV examined include SDNN (Standard Deviation of Normal-to-Normal intervals, representing an overarching measure of autonomic nervous system functionality), RMSSD (Root Mean Square of the Successive Differences between R-R intervals), and PNN50 (the proportion of adjacent R-R intervals exceeding a 50 ms variation, indicative of parasympathetic nervous

activity). Additionally, the study analyzed frequency domain characteristics, with the LF/HF ratio shedding light on the overall balance of autonomic regulation.

In assessing SCL, a direct measure of EDA, the study focused on the absolute electrical conductivity measured between two distinct skin points. This measure is a direct reflection of fluctuations in sympathetic nervous activity and emotional arousal levels, notable for its independence from parasympathetic nervous system influence [39]. Building on previous research findings, the study acknowledges that sympathetic nervous activity can show significant increases within a two-minute timeframe [40]. The SCL metric has been extensively adopted in the emotional evaluation of environmental experiences [41,42]. For consistency and comparability in the analysis, SCL data were normalized according to the formula:

$$X_0 = X_{emotion} - X_{calm}, \tag{1}$$

where X_0 denotes the standardized SCL reading, $X_{emotion}$ represents the SCL measurement post-emotional experience, and X_{calm} signifies the baseline value in a tranquil state.

The research also incorporated Facial Electromyography, focusing on the detection of electrical signals associated with the neural regulation of facial muscle activities, encompassing both contraction and relaxation [43]. This technique sensitively captures mood states, with the corrugator supercilii muscle's contraction typically signaling tension or an alert state, and the zygomaticus major muscle's contraction suggesting relaxation or joy.

2.5.2. Psychological Indices

In this investigation, the Profile Of Mood States (POMS) scale, devised by McNair et al. in 1971, was employed to ascertain the influence of forest settings on the mood states of the participants. Extensively utilized in related fields of research [44,45], this scale encompasses 30 items designed to appraise six facets of mood states: Anger (A), Confusion (C), Depression (D), Fatigue (F), Tension (T), and Vigor (V). The instrument has demonstrated substantial reliability and validity, evidenced by a Cronbach's alpha coefficient in the range of 0.62 to 0.82 [46]. It employs a 5-point Likert scale for scoring, extending from 0 (barely) to 4 (extremely). The computation of the Total Mood Disturbance (TMD) score is formulated as

$$TMD = (T + F + A + C + D) - V, \tag{2}$$

This holistic assessment across multiple dimensions accurately mirrors the participants' overall mood condition.

2.6. Experimental Procedure

The experimental procedure of this study was executed over a period extending from September to November. Each experiment lasted for three days and two nights, ensuring a uniform schedule for the psychological and physiological measurements, which were consistently conducted daily between 8:30 a.m. and 4:30 p.m. To maintain a focused and manageable experimental environment, the number of participants in each experimental group was carefully capped at a maximum of six individuals.

In the preparatory phase, the experimenter comprehensively elucidated the study's objectives, methodologies, and the application of the instruments to the participants. Following the acquisition of informed consent and the signing of consent forms, participants' basic demographics and self-assessed health status were recorded. The first day commenced with the following sequence: ① Participants were transported to the urban experimental zone, where they were outfitted with physiological signal sensors by the experimenter. ② A 5 min period of relaxation was followed by a 3 min session for the baseline collection of EDA. ③ The participants then engaged in a 15 min period of standing observation, immersing themselves in the environment of the specified area. ④ Post-experience, the equipment was detached, and participants proceeded to fill out a POMS. Post-lunch, they were transported to the forest experimental site. ⑤ Another EDA baseline measurement

was conducted following a 5 min calming period (3 min in duration). ⑥ The aforementioned steps ③ and ④ were repeated until the activities for the day concluded at 16:30. On the second and third days, the participants directly proceeded to the forest experimental site, repeating steps ③ and ④ post-baseline EDA collection at each location until the end of the day's schedule. Figure 5 visually depicts this experimental procedure.
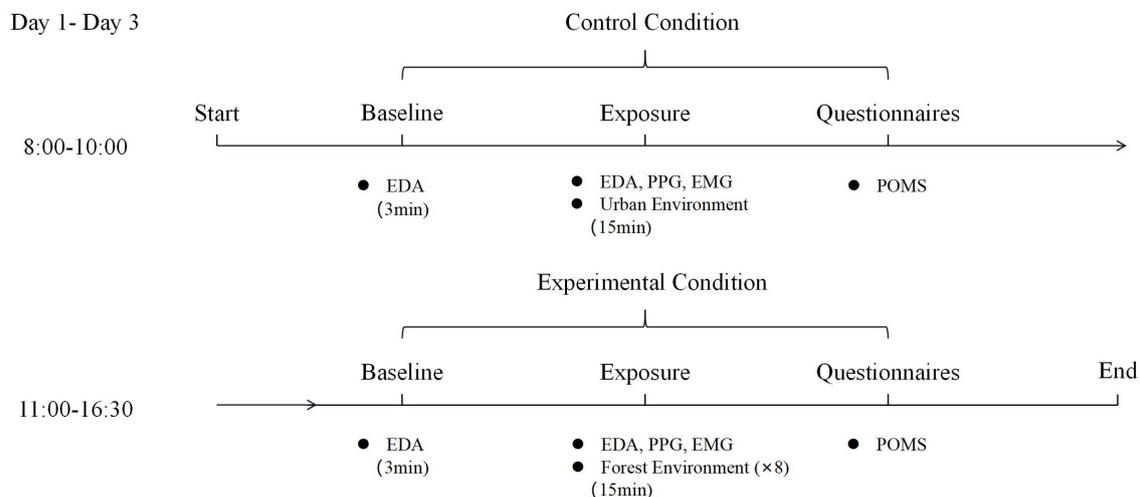
Figure 5. Experimental procedure.

2.7. Data Analysis

Data entry and analysis were carried out using SPSS 23 (IBM, Armonk, NY, USA). For the comparative assessment of the measurement outcomes between urban and forest participant groups, we applied a repeated measures ANOVA. Adjustments utilizing the Greenhouse–Geisser or Huynh–Feldt corrections were employed as required [47]. In cases where interaction effects were evident, we proceeded with a detailed analysis of simple effects. Statistical significance was established at a *p*-value threshold of less than 0.05.

3. Results

3.1. Effects of Different Forest Environments on HRV

A unifactorial repeated-measures analysis of variance (ANOVA) revealed significant differences in HRV indices across different types of forest environments, as detailed in Table 3. Specifically, the SDNN index demonstrated a pronounced main effect across diverse forest landscapes ($F_{(8, 344)} = 4.439$, $p < 0.001$). Post hoc Bonferroni tests highlighted that the HRV indices in the S6 and S7 groups were significantly elevated compared to those in the urban group ($p < 0.01$), while no other group comparisons showed statistical significance, as depicted in Figure 6. In the case of the RMSSD index, similar significant main effects were discerned in varied forest settings ($F_{(5.649, 225.947)} = 3.935$, $p < 0.001$). Further analysis using Bonferroni post hoc tests revealed that both S6 and S8 groups exhibited notably higher RMSSD values compared to the urban group ($p < 0.05$), and the S7 group displayed a significant increase over the urban group ($p < 0.01$), as elucidated in Figure 7. Concerning the pNN50 index, there was a significant main effect across the different forest types ($F_{(8, 344)} = 2.416$, $p < 0.05$). The Bonferroni post hoc analysis indicated a significant elevation in the S7 group relative to the urban group ($p < 0.05$), as illustrated in Figure 8. Regarding the LF/HF ratio, significant main effects were observed across the varied forest environments ($F_{(8, 320)} = 2.579$, $p < 0.01$). Subsequent Bonferroni post hoc tests revealed a significant decrease in the S6 group compared to the urban group ($p < 0.01$), and a notable reduction in the S7 group relative to the urban group ($p < 0.05$), as indicated in Figure 9. Overall, these findings highlight the considerable influence of forest environments on HRV. Specifically, the S6 and S7 sites demonstrated significant variations in multiple

indices, emphasizing the regulatory effects of the valley's tea gardens and the streamside of broadleaf forests on autonomic nervous system activity.

Table 3. One-way repeated-measures ANOVA results of HRV across urban and different forest environments.

HRV	Source	SS	df	MS	F	p
SDNN	Environment	11,627.539	8	1453.442	4.439	0.000 **
	Error (Environment)	112,622.315	344	327.390		
RMSSD	Environment	1898.853	5.649	336.159	3.935	0.001 **
	Error (Environment)	19,301.915	225.947	85.427		
pNN50	Environment	93.106	8	11.638	2.416	0.015 *
	Error (Environment)	1657.017	344	4.817		
LF/HF	Environment	2.957	8	0.370	2.579	0.010 **
	Error (Environment)	45.866	320	0.143		

Note: SS: Type III Sum of Squares; MS: Mean Square; *: $p < 0.05$; **: $p < 0.01$.
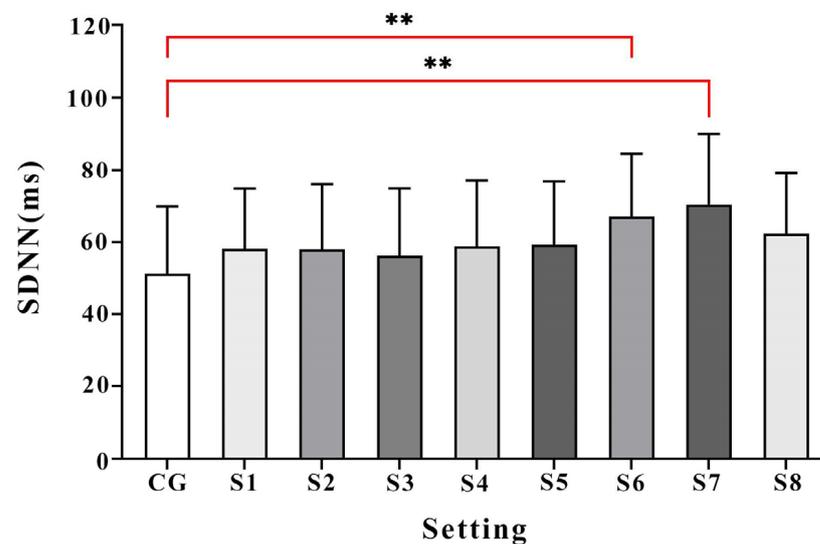
Figure 6. Post hoc analysis of SDNN across urban and different forest environments; **: $p < 0.01$.
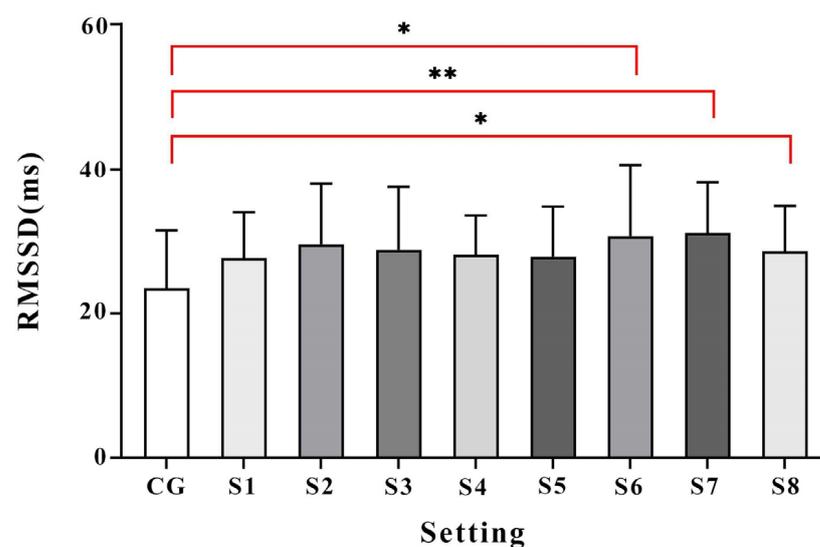
Figure 7. Post hoc analysis of RMSSD across urban and different forest environments, *: $p < 0.05$; **: $p < 0.01$.
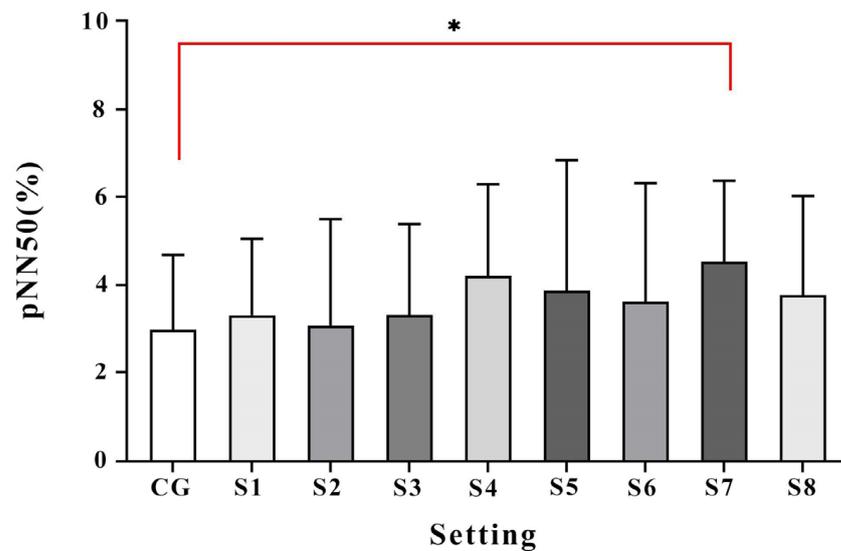
Figure 8. Post hoc analysis of pNN50 across urban and different forest environments, *: $p < 0.05$.
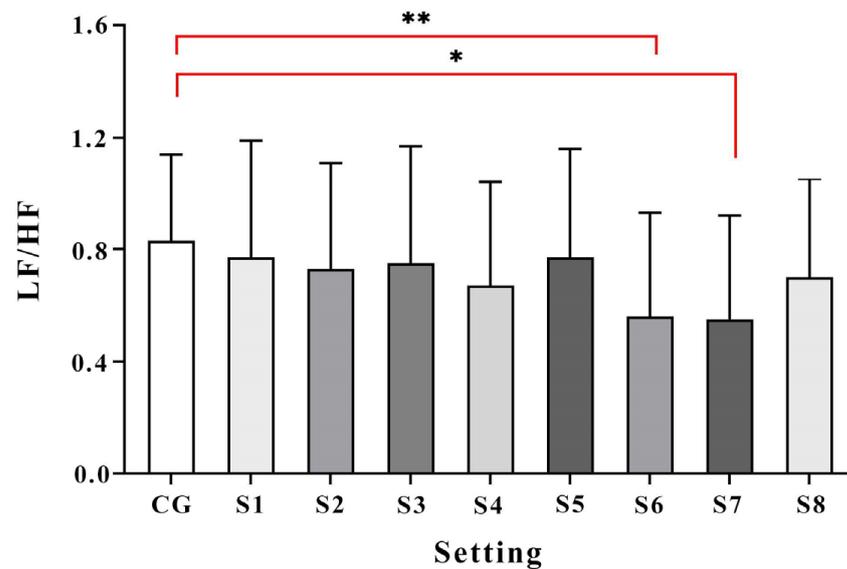
Figure 9. Post hoc analysis of LF/HF across urban and different forest environments, *: $p < 0.05$; **: $p < 0.01$.

3.2. Effects of Different Forest Environments on SCL and sEMG

Table 4 presents the descriptive analysis of SCL and sEMG in urban and various forest environments. Observational results indicate differential impacts of different forest environments on SCL and sEMG, underscoring heterogeneous patterns of physiological activation and mood states. In pursuit of validating the significance of these observed disparities, a unifactorial repeated-measures analysis was conducted, with the findings detailed in Table 5. The analysis revealed a significant effect of different forest environments on SCL ($F (5.447, 217.883) = 4.357$, $p < 0.001$). Specifically, the S4 group was significantly higher than S3 ($p < 0.05$), S6 ($p < 0.05$), S7 ($p < 0.01$), and urban group ($p < 0.05$); the S8 group was significantly lower than S4 ($p < 0.01$) and urban group ($p < 0.05$), while comparisons among other groups did not show statistical significance ($p > 0.05$). Different types of forest environments had a significant effect on sEMG ($F (5.181, 207.235) = 4.169$, $p < 0.001$). Specifically, the S4 group was significantly higher than the S2 ($p < 0.05$), S5 ($p < 0.05$), S6 ($p < 0.05$), and urban group ($p < 0.01$), with no statistical differences observed in other group

comparisons ($p > 0.05$). Overall, these findings provide empirical support for the regulatory effects of forest bathing on mood states.

Table 4. Descriptive analysis of SCL and sEMG ($n = 41$).

Exp. Design	Test Sites	SCL (µS)	sEMG (µV)
		Mean ± SD	Mean ± SD
CG	-	1.56 ± 0.99	4.52 ± 0.80
EG	S1	1.37 ± 0.89	4.99 ± 0.56
	S2	1.17 ± 0.84	4.68 ± 0.76
	S3	1.04 ± 0.74	4.92 ± 0.62
	S4	1.80 ± 1.14	5.26 ± 0.63
	S5	1.20 ± 0.98	4.65 ± 0.81
	S6	0.92 ± 0.95	4.50 ± 1.16
	S7	0.88 ± 0.69	4.83 ± 0.84
	S8	0.97 ± 0.60	5.11 ± 1.02

Note: Exp. design: experimental design; CG: control group; EG: experimental group; SCL: skin conductance level; sEMG: electromyography.

Table 5. One-way repeated-measures ANOVA results of SCL and sEMG across urban and different forest environments.

Parameter	Source	SS	df	MS	*F*	*p*
SCL	Environment	24.056	5.447	4.416	4.357	0.001 **
	Error (Environment)	220.872	217.883	1.014		
sEMG	Environment	22.811	5.181	4.403	4.169	0.001 **
	Error (Environment)	218.846	207.235	1.056		

Note: SS: Type III sum of squares; MS: Mean square; **: $p < 0.01$.

Figure 10 presents a two-dimensional quadrant diagram, illustrating the two emotional dimensions described in Russell's circumplex model of affect [48]. We employed SCL and sEMG indices as objective measures to systematically map the emotional arousal and pleasure experienced by individuals in diverse forest settings. In this diagram, the horizontal axis is labeled 'Pleasure', and the vertical axis is labeled 'Arousal', consistent with the two fundamental emotional dimensions defined within the model. To determine the axes' placement at sEMG = 4.83 and SCL = 1.20, we based our analysis on the average values derived from our sample data. These thresholds were specifically chosen to reflect the 'neutral' state in participants' emotional responses to different forest environments. Specifically, participants' responses to the mixed coniferous–broadleaf forest valley (S3) and the rock-bedded streamscape (S8) indicate a state of low arousal yet high pleasure, suggesting these environments elicit sensations of serenity and satisfaction. Observations in the valley's tea gardens (S6) reveal low levels of both arousal and pleasure, implying that, despite their tranquil appearance, these settings may not effectively engender positive emotional responses. The broadleaf ridge forest (S4) correlates with high arousal and pleasure, indicating these landscapes are particularly efficacious in stimulating excitement and engendering pleasurable emotions among participants.
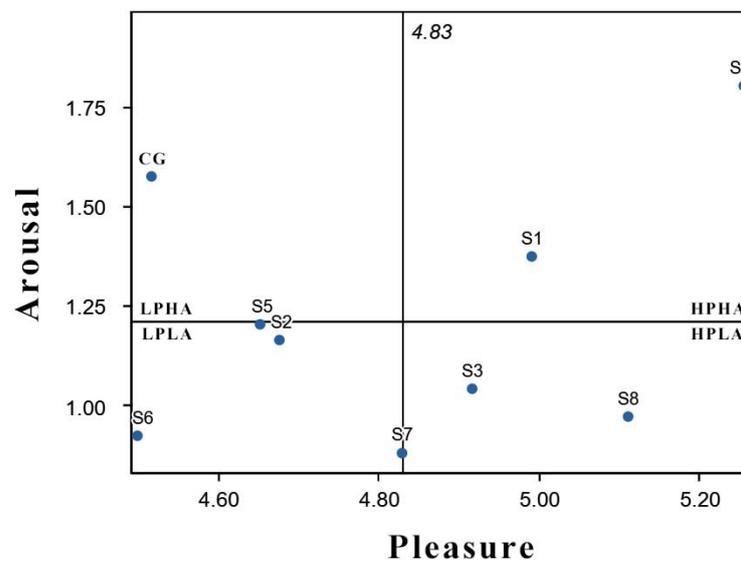
Figure 10. Mapping of subject's arousal (SCL) and pleasure (sEMG) onto a two-dimensional quadrant diagram in different forest environments. CG: Control group; "LPHA" means low pleasure, high arousal; "LPLA" means low pleasure, low arousal; "HPHA" means high pleasure, high arousal; "HPLA" means high pleasure, low arousal.

3.3. Effects of Different Forest Environments on POMS

Table 6 presents a descriptive analysis of the POMS scores under urban settings and various forest environments. The observational results demonstrate that there are variations in the POMS scores across different forest environments, indicative of changes in individuals' mood states.

Table 6. Descriptive analysis of POMS (n = 41).

Exp Design	Test Sites	Tension (T) Mean ± SD	Anger (A) Mean ± SD	Fatigue (F) Mean ± SD	Confusion (C + D) Mean ± SD	Vigor (V) Mean ± SD	TMD Mean ± SD
CG	-	1.98 ± 0.79	1.81 ± 2.17	4.79 ± 1.39	5.63 ± 4.17	5.44 ± 3.70	8.77 ± 6.95
EG	S1	0.98 ± 0.93	0.84 ± 1.18	2.65 ± 2.51	3.42 ± 2.57	8.26 ± 4.73	−0.37 ± 5.64
	S2	1.47 ± 1.17	0.58 ± 1.08	2.30 ± 1.97	3.56 ± 2.36	7.81 ± 4.59	0.09 ± 6.24
	S3	1.02 ± 1.02	0.86 ± 0.88	1.58 ± 0.87	1.98 ± 1.96	8.47 ± 4.30	−3.02 ± 5.34
	S4	1.77 ± 1.54	0.81 ± 0.97	2.42 ± 1.63	2.72 ± 2.14	11.09 ± 3.16	−3.37 ± 4.84
	S5	0.88 ± 0.97	1.26 ± 1.16	1.95 ± 0.96	3.51 ± 2.40	8.63 ± 4.56	−1.02 ± 6.04
	S6	1.21 ± 1.11	0.63 ± 0.78	1.86 ± 1.15	2.05 ± 2.16	8.19 ± 4.29	−2.44 ± 5.64
	S7	0.93 ± 1.07	0.49 ± 0.76	1.37 ± 1.77	2.00 ± 2.22	8.19 ± 4.59	−3.40 ± 5.41
	S8	0.72 ± 1.00	0.67 ± 1.07	1.88 ± 2.23	1.53 ± 1.93	9.12 ± 2.90	−4.30 ± 4.59

Note: Exp design: experimental design; CG: control group; EG: experimental group.

To ascertain the significance of different forest environments on the POMS scores, a one-way repeated measures analysis was conducted, the results of which are presented in Table 7. The analysis revealed a significant impact of different types of forest environments on TMD scores, ($F_{(8, 336)}$ = 25.076, $p < 0.001$). The post hoc Bonferroni test revealed that in the perception of Tension (T), the S4 group was significantly higher than the S8 group ($p < 0.01$), and the urban group was significantly higher than the S1, S3, S5, S7, and S8 groups ($p < 0.001$). In Anger Perception (A), the urban group was significantly higher than the S7 group ($p < 0.05$). In Fatigue Perception (F), the urban group was significantly higher than the forest groups ($p < 0.001$). In Confusion and Depression Perception (C + D), the S2 group was significantly higher than the S8 group ($p < 0.01$), the S5 group was significantly higher than the S8 group ($p < 0.01$), and the urban group was significantly higher than the S3, S4, S6, S7, and S8 groups ($p < 0.001$). In Vigor Perception (V), the S1 group was

significantly higher than the S2, S3, S6, and urban groups ($p < 0.05$), and the S3, S4, S5, and S8 groups were significantly higher than the urban group ($p < 0.05$). Regarding TMD, the S1 group was significantly higher than the S8 group ($p < 0.05$), the S2 group was significantly higher than the S8 group ($p < 0.05$), and the urban group was significantly higher than the forest groups ($p < 0.001$). Overall, these findings underscore the impact of various types of forest environments on individuals' mood states. Forest bathing, to a certain extent, helps in reducing feelings of tension, anger, fatigue, confusion, and depression, while enhancing vitality. This provides empirical support for the regulatory role of forest bathing in regulating mood states.

Table 7. One-way repeated-measures ANOVA results of POMS across urban and different forest environments.

Mood State (POMS)	Source	SS	df	MS	F	p
Tension (T)	Environment	63.488	5.609	11.319	7.223	0.000 **
	Error (Environment)	369.178	235.587	1.567		
Anger (A)	Environment	58.837	4.250	13.845	5.348	0.000 **
	Error (Environment)	462.052	178.492	2.589		
Fatigue (F)	Environment	352.749	4.644	75.966	15.685	0.000 **
	Error (Environment)	944.584	195.029	4.843		
Confusion (C + D)	Environment	550.160	4.773	115.259	11.458	0.000 **
	Error (Environment)	2016.729	200.477	10.060		
Vigor (V)	Environment	731.385	8	91.423	5.454	0.000 **
	Error (Environment)	5632.615	336	16.764		
TMD	Environment	6208.765	8	776.096	25.076	0.000 **
	Error (Environment)	10,399.013	336	30.949		

Note: SS: type III sum of squares; MS: mean square; **: $p < 0.01$.

4. Discussion

4.1. Physiological Effects

4.1.1. HRV

This research emphasizes the significant and beneficial effects of diverse forest environments on Heart Rate Variability, in agreement with multiple existing studies. For example, a 0.5 h forest bathing experiment revealed a decline in the SDNN and RMSSD indices among the forest group participants, consistent with our findings [49]. The study by Zhang et al. also confirmed that forest environments amplify parasympathetic nervous activity [38]. Additionally, a study involving 72 female participants found that walking in forest environments resulted in significant changes in HRV indices, underscoring the positive role of forest environments in modulating the activity of the autonomic nervous system [50]. However, our research also uncovers findings that diverge from those reported in the existing literature. Previous studies have shown that walking in forest environments, as opposed to urban settings, significantly increases lnHF and decreases ln (LF/HF), suggesting that walking in forests augments parasympathetic nervous activity and reduces sympathetic nervous activity. In contrast, mere observation of forest environments did not yield significant changes in the low-frequency to high-frequency ratio (LF/HF) [12]. Our study delves deeper into this phenomenon and discovers that in specific forest environments, such as valley tea gardens and broadleaf forest streamside, there is a notable reduction in the LF/HF ratio of participants. This finding indicates that visual stimuli in different forest environments might exert varying influences on the regulation of the autonomic nervous system. Such discrepancies could be attributed to specific characteristics of forest environments, including vegetation type, topography, and climatic conditions. These insights offer new perspectives for further research into the specific health benefits of forest environments, particularly in the design of forest therapy programs and the evaluation of their impact on cardiovascular health.

These effects may involve the following mechanisms: Firstly, forests provide natural visual stimuli, which are instrumental in diminishing physiological stress and stimulating the parasympathetic nervous system, thereby contributing to improved HRV. Secondly, the elevated concentration of negative ions in forest air is postulated to attenuate sympathetic nervous system excitability, while bolstering parasympathetic regulation. This can amplify the effects on HRV metrics, including RMSSD and pNN50. Additionally, Engaging in activities such as walking and meditating in forest settings can stimulate cardiovascular functions and enhance HRV. Through a comparative analysis of the distinct impacts exerted by various types of forest landscapes, this study sheds light on optimizing environments for forest therapy. Future research should focus on investigating the modulation mechanisms exerted by forest environments on HRV, particularly by monitoring shifts in autonomic neurotransmitters.

4.1.2. SCL and sEMG

This study examines the differential effects of various forest environments on mood states and arousal levels among individuals. Huang et al. found that tranquil and comfortable lawn landscapes, when simulated in Virtual Reality, effectively reduce skin conductance levels [51]. Medvedev's research indicates that soundscape perceptions characterized by high pleasure and familiarity correlate with lower skin conductance [52]. Further, Jiang et al. identified that the most effective stress recovery, indicated by the lowest skin conductance, occurs with tree canopy coverage between 24–34% [53]. These findings collectively suggest that positive emotions and satisfaction are typically associated with lower arousal levels. Our research additionally shows that, compared to urban environments, skin conductance significantly decreases in broadleaf forest streamside and rock-bedded streamscape settings (by 43.6% and 37.8%, respectively), underscoring their role in fostering a state of calm and relaxation. Conversely, ridge broadleaf forest environments led to heightened emotional arousal among participants, likely due to the intense excitement and thrill of mountaintop views. It is crucial to acknowledge that emotional reactions to both positive (e.g., the thrill and enjoyment from mountaintop views) and negative (e.g., apprehension or frustration from navigating challenging terrains) experiences contribute to arousal level changes. These reactions serve as psychological and emotional feedback to environmental and social stimuli, affecting arousal states. Thus, arousal states emerge not directly from stimuli themselves, but from a complex interaction of emotional responses, emphasizing the need to incorporate an emotional pleasure index for a comprehensive understanding of these dynamics.

Furthermore, our findings suggest that the sEMG levels in participants within ridge broadleaf forests are significantly higher than in other forest environments, indicating these forests evoke an exciting and vibrant emotional quality. This suggests that forest therapy environments might be particularly beneficial for individuals seeking to enhance positive emotions, including those with depression as well as children and adolescents looking for engaging experiences. However, such environments might not be the best fit for individuals experiencing symptoms of agitation or insomnia. Similar characteristics were observed in sloped lawn landscapes, where the presence of white doves might contribute to these characteristics. On the contrary, mixed conifer and broadleaf forests, as well as rocky streamside landscapes, are characterized by a more serene and peaceful emotional quality. These environments are effective for rapidly inducing a calm mental and physical state, ideal for practices like mindfulness meditation or Zen therapy, thus aiding significantly in alleviating symptoms in patients with anxiety disorders. We observed that, compared to other types of forest environments, tea garden landscapes exhibit lower levels of arousal and pleasure. This finding suggests that while the tranquil beauty of tea gardens holds certain appeal for individuals seeking peace and quietude, this singular emotional experience may not suffice to evoke a broader spectrum of positive emotional responses. Consequently, we recommend design interventions such as the incorporation of interactive elements within the tea garden or the diversification of visual and olfactory landscapes to enhance people's

emotional pleasure and arousal levels. Through such means, it is possible to enrich visitors' experiences, circumvent potential monotony and dullness, and potentially elicit a wider array of positive emotional reactions, thereby augmenting the allure of tea gardens as therapeutic spaces.

Overall, this study explores the impact of different forest environments on individuals' skin conductance levels and electromyogram (sEMG) levels, revealing the intricate relationship between natural environment characteristics and emotional responses. Our findings emphasize that specific forest settings can significantly modulate individuals' mood states and arousal levels, demonstrating the varied effects of forest therapy environments in promoting calmness and relaxation or stimulating excitement and vitality.

4.2. Psychological Effects

Numerous studies have demonstrated that forest bathing contributes to reducing negative emotions such as anger, confusion, tension, and fatigue, and enhances individual vitality scores [32,54–56]. This study corroborates these previous findings and highlights the significant impact of different types of forest environments on the mood states of participants. Specifically, it was found that in sloping grasslands, valley coniferous-broadleaf mixed forests, sloping coniferous-broadleaf mixed forests, broadleaf forest streamside, and rock-bedded streamscape, tension in participants was significantly reduced compared to urban environments. Additionally, valley coniferous-broadleaf mixed forests, ridge broadleaf forests, valley tea gardens, broadleaf forest streamsides, and rock-bedded streamscapes significantly alleviated feelings of confusion and depression. An increase in the sense of vigor was particularly noticeable in these forest settings. Remarkably, rock-bedded streamscapes were associated with the lowest levels of tension, confusion, depression, and overall mood disturbance, underscoring the substantial efficacy of these forest environments in alleviating negative mood states. This aligns with the findings of Sonntag-Öström et al. findings, highlighting more pronounced positive emotions in forested versus urban areas, especially forest landscapes proximate to streams, which engender deeper relaxation and tranquility [29]. Our results also support the role of waterscapes in enhancing attention and relieving stress [57,58]. Moreover, the close association between vitality and restorativeness suggests that these forest environments represent a higher level of positive life states. This supports Stilgoe's perspective on the essentiality of regular natural engagement for psychological equilibrium, vitality enhancement, and fatigue alleviation [59]. In summary, this study not only confirms the positive role of forest bathing in improving mental health but also reveals the variability in psychological effects across different forest environments, providing crucial references for further optimizing forest therapy.

5. Limitations and Future Studies

This study, while providing valuable insights into the health benefits associated with exposure to forest environments, nevertheless presents several limitations: (1) The sample size used in our research was relatively small and lacked demographic diversity. This limitation challenges the generalizability of our findings. Future investigations should endeavor to incorporate a more extensive and diverse sample pool, ensuring representation across various demographic dimensions such as age, gender, and cultural backgrounds. Employing stratified random sampling methods could aid in encompassing a wider array of socioeconomic statuses, educational levels, and occupational types, thereby offering a nuanced understanding of the differential health impacts of forest environments across distinct population groups. (2) Our study's geographical confinement to Wuyishan National Park, while providing a unique ecological backdrop, may not accurately reflect the health impacts of diverse forest environments prevalent across other climatic zones. Future research should consider a broader range of environmental settings, such as subtropical montane coniferous forests, tropical rainforests, temperate deciduous broadleaf forests, temperate mixed forests, temperate coniferous forests, and urban green spaces, thereby providing data support and empirical evidence for specific regional environmental healing

benefits and health planning initiatives. (3) Methodologically, our study was limited by the data collection tools used, which may not have captured a comprehensive range of physiological and psychological effects. In terms of psychological assessment, a more comprehensive description of the impact of exposure to natural environments on mental health could be provided, rather than merely using the POMS scale to assess short-term mood states. Moreover, the cross-sectional nature of our research design curtails the inference of long-term health benefits attributable to forest exposure. Future studies might benefit from longitudinal frameworks employing cutting-edge biometric monitoring technologies, offering deeper insights into the enduring impacts of nature on human health.

Probing into the effects of forest green spaces on psychological and physiological health presents an opportunity to derive actionable insights for public health policy formulation. Future research agendas could delve into the integration of digital and physical green spaces to explore how virtual reality simulations alongside real green spaces can synergistically enhance mental health. Investigations into the use of smart technologies in forest spaces are also promising, aiming to assess their effectiveness in promoting physical activity, social engagement, and overall well-being. Furthermore, studies on the economic implications of forest greenery through the lens of ecosystem services could provide valuable insights into their value in reducing public health costs. These studies promise to furnish planners with evidence-based strategies for integrating natural elements, particularly forest environments, into broader landscape and public health planning.

6. Conclusions

This study, through empirical analysis, uncovers the significant influence of forest environments on human physiological and mood states, as measured by Heart Rate Variability, Skin Conductance Level, Facial Electromyography, and mood states (assessed via the Profile of Mood States. It highlights the pivotal role of natural settings in modulating the human autonomic nervous system and mood states. The research findings reveal that HRV indicators within valley tea gardens and broadleaf forest streamsides have a positive and significant impact. This underscores the potential of these specific environments to enhance autonomic nervous system function, promote cardiac health, and bolster stress adaptability. The analysis of SCL and sEMG outcomes further reveals subtle differences in emotional arousal and pleasure across forest settings. This suggests that valleys with mixed broadleaf and coniferous forests, as well as streamscapes with rocky beds, can foster states characterized by low arousal yet high pleasure. In contrast, broadleaf ridge forests trigger states of high arousal and high pleasure. These discoveries emphasize the significant role of environmental characteristics in regulating emotions and enhancing psychological well-being. Results from the POMS assessment suggest that individuals participating in forest bathing universally reported reductions in tension, anger, fatigue, confusion, and depression, alongside a notable increase in vigor. This not only affirms the positive effects of forest environments on improving short-term emotional states but also supports their utility in alleviating modern life stress. The insights from this study not only deepen our understanding of the relationship between natural environments and human health but also have significant practical implications for the development of nature-based health promotion strategies, the formulation of targeted nature therapy programs, and the integration of natural environments into everyday life and public health policies.

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