buildings

MDPI

Article

Psychological Effects of a Living Wall System on Office Occupants: A Comparative Study Based on Physiological Responses

Yiming Shao [1,*], Zhenghuan Zhou [1], Ding Ding [1], Yuanlong Cui [2,*] and Xianfeng Wu [3]

[1] School of Architecture, Nanjing Tech University, 30 Puzhu South Road, Nanjing 211816, China; 202161111027@njtech.edu.cn (Z.Z.); dingding@njtech.edu.cn (D.D.)
[2] School of Architecture and Urban Planning, Shandong Jianzhu University, 1000 Fengming Road, Jinan 250101, China
[3] School of Architecture and Urban Planning, Beijing University of Technology, No. 100 Pingle Yuan, Chaoyang District, Beijing 100124, China; xwu@bjut.edu.cn
* Correspondence: sym19851021@njtech.edu.cn (Y.S.); cuiyuanlong22@sdjzu.edu.cn (Y.C.)

Abstract: A Living wall system (LWS) is a biophilic design element that has been introduced into indoor environments in recent years. Previous studies have demonstrated that the LWS improves indoor visual comfort and air quality. However, studies on its psychological effects on occupants are still scarce. In this paper, the psychological effects were investigated by recording and analyzing the parameters of occupants' physiological responses including an electroencephalogram (EEG) and heart rate variability (HRV). A cross-over experiment was conducted among 43 participants under three different desk work environments based on various materials involving an LWS, a fake LWS, and a bare white wall. The results conclude that LWSs effectively reduce the accumulation speed of negative psychological states caused by desk work to about 1/3, compared with a regular office environment without an LWS. However, occupants tend to be less excited and focused after resting in the LWS environment. Therefore, it is recommended to place LWSs in the rest area rather than close to the desk area in an office building, considering the balance between mental health and work efficiency.

Keywords: living wall system; biophilic design; indoor environment; psychological effect; physiological response

check for updates

Citation: Shao, Y.; Zhou, Z.; Ding, D.; Cui, Y.; Wu, X. Psychological Effects of a Living Wall System on Office Occupants: A Comparative Study Based on Physiological Responses. *Buildings* **2024**, *14*, 1981. https://doi.org/10.3390/buildings14071981

Academic Editors: Nikos A. Salingaros and Hua Ge

Received: 14 March 2024
Revised: 17 June 2024
Accepted: 27 June 2024
Published: 1 July 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

With the development of industry and information technology in modern society, the primary living and working environment has been shifted from outdoor to indoor [1,2]. The reduction of outdoor activities and prolonged indoor work and life time may accumulate stress and fatigue, and increase the risk of depression [3–5]. Therefore, the effect of indoor environmental quality (IEQ) on occupants' physical and mental health has become an increasingly important subject of growing interest among scholars [6–9]. Some studies show that contact with the natural environment will improve attention [10], and relieve stress and depression [11], bringing great psychological health benefits. In recent years, biophilic design strategies have become increasingly popular as they introduce greenery into the indoor environment to create a natural sensory experience indoors. And among the emerging methods of indoor greening, the living wall system (LWS) has become a balanced good solution in various types of indoor environments because it improves the IEQ, while only occupying a small amount of area as it is vertically installed.

The LWS is a subcategory of vertical greening systems (VGSs). The VGS, which is a type of green infrastructure, is a planting system that consists of plants in various forms on a vertical surface with a maintenance system. As shown in Figure 1, VGSs are generally

divided into two categories depending on their location: green facade and LWS. A green facade is an outdoor building facade where plants are attached directly or indirectly using panels, geotextile mats, or modular trellis to survive. LWSs, usually used indoors, grow plants in modular planting carriers such as pots, trays, or vessels which are mounted on the surface of a wall [12,13].

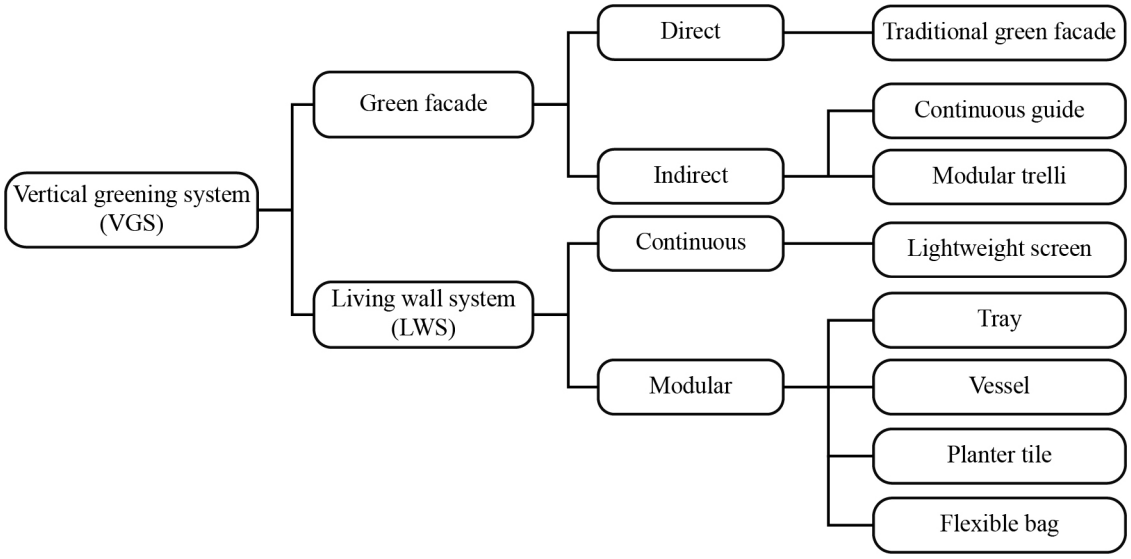


Figure 1. Categories of VGS.

Due to the modular installation, the aesthetic value of an LWS can be strengthened by its pixelated feature, i.e., the pattern of LWS can be customized and easily changed to suit the preferences of users [11,13]. In addition, LWSs have a purifying effect on indoor air quality, as they can effectively reduce the concentration of carbon dioxide (CO_2) [14] and particulate matters (PMs) [15].

Apart from the environmental values, LWSs can have beneficial effects on human physiology and psychology as a mimicry of the natural environment. The theoretical basis behind it includes biophilia theory, attention restoration theory (ART), and stress reduction theory (SRT). The biophilia theory suggests that humans are instinctively passionate about nature and subconsciously desire to be close to the natural environment. This theory starts from the perspective of species evolution and believes that in human evolution, survival activities, cognitive enhancement processes, etc., are all related to the natural environment. Therefore, the innate affinity to nature is deeply embedded in genes [16,17]. The ART theory suggests that the environment in which a person stays contains a vast amount of distracting information, and people need directed attention to maintain a high level of work efficiency. During this process, directed attention will gradually be consumed, leading to fatigue. However, the natural environment contributes to restoring directed attention and alleviating fatigue [18–20]. The SRT theory suggests that the stress comes from the psychological, physiological, and behavioral responses of individuals when facing threats to well-being. The natural environment can improve emotional and physiological states, thereby reducing psychological stress [21].

Some scholars have interpreted the biological mechanisms of human biophilia from the perspectives of human vision and neurology. They found that the experience of biophilia not only comes from the green plants in the environment, but also exists in the geometry and form of the space that can evoke people's natural feelings. Zeki [22] surveyed various neurological studies and concluded that the need of human beings for beauty is "not a luxury, but an essential ingredient in nourishing the emotional brain". Thus, the study of aesthetics is included in the study of biophilia. Michael Mehaffy [23] thought that symmetry is prevalent in nature and that the symmetry has developed as a form of biological signaling. This symmetry conveys the health and genetic quality of

the signaler [24]. The ability of humans to perceive symmetrical features enhances object recognition and contributes to the ability to "read" the structure of the environment and its possible effects on the health and well-being of the organism. Furthermore, the signaling is closely related to aesthetic preferences [25] and is a factor in environmental preferences and natural environmental benefits. Another perspective is provided in Richard Taylor's research, where he explores the effects of fractals on humans, exploring the relationship between fractals and biophilia [26]. Through experiments, he found that human vision is more easily attracted to things with fractal features and that eye movement tracks also have fractal features. Quantitative studies using EEG showed that mid-dimensional fractals lead to the largest changes in alpha and beta waves [27,28], and the change in their beta wave indicated that subjects' attention was being attracted to mid-dimensional fractals. Medium-dimensional fractals induce a large number of percepts [29] and they activate object perception and recognition areas in the visual cortex [30]. A series of subsequent studies have shown that fractal patterns help to relieve people's stress. Based on these findings, Taylor applied fractal patterns to design scenarios such as carpet weaving and solar panel arrangement. Yannick Joye [31] explores the expression of natural elements in architecture from a perspective of neuroscience. He thought that the human brain has evolved a natural information system (NIS) that specializes in processing conceptual and perceptual information about the natural world, and that the NIS is linked to areas of the brain involved in emotions. Humans are prone to positive emotions such as liking things that are favorable to survival, and conversely, negative emotions such as fear and disgust in the face of danger [32]. Positive emotions are seen as aesthetic responses, while negative emotions are seen as stress responses. In the aesthetic response, it was found that the natural environment is more attractive to people [16], and has the effect of reducing stress, improving concentration [20,21,33], and even promoting physical health [34].

The current research methods in the field of indoor biophilic environmental psychology mainly includes scale evaluation and physiological data measurement. Scale evaluation is a statistical analysis of respondents' subjective judgment on their emotional state through a questionnaire survey. Physiological data measurement more directly records and analyzes the changes in physiological data of the respondents, and assesses the environmental effect based on that data. Several studies have analyzed the effects of indoor greening on humans either by scale evaluation or monitoring their physiological responses, such as electroencephalogram (EEG) and heart rate variability (HRV), in response to natural elements. Ikei et al. [35] measured and analyzed the HRV of 85 participants in indoor spaces with and without foliage plants, and confirmed the relaxing effects of visual stimulation with plants. Jee Heon Rhee et al. [36] assessed the EEG and perceptual restorative scale (PRS) of 30 participants while viewing indoor scenes with varying degrees of naturalness, and found that nature landscapes contributed to the restoration of attention and relieved stress. Yun-Ah Oh et al. [37] explored the psychological and physiological responses of 23 elementary school students under different visual stimulus conditions based on EEG, the profile of mood state (POMS), and semantic differential. The results verified that after viewing live plants, students' attention improved. Participants showed more positive emotional states, such as feelings of comfort and naturalness. Jiang et al. [38] measured the blood pressure and EEG of 50 Chinese students viewing photos of natural landscapes and urban traffic. The students felt more natural, relaxed, and comfortable after viewing the landscape pictures, with lower anxiety scores, which verified the relaxation effects of different landscape pictures on people. Yeom et al. [39] used virtual reality (VR) technology to study the psychological and physiological effects of green walls of different sizes on 27 participants, applying HRV, EEG, EDA (electrodermal activity), and STAI (State-Trait Anxiety Inventory) tests to evaluate the stress level of the participants. The results verified the relaxation effect of indoor green walls. Additionally, it was found that a small-sized green wall performs better than a large-sized one.

In summary, the aforementioned studies explored the effect of indoor greening on human mental health by directly or indirectly measuring the physiological and psychological

responses of participants in a controlled or virtual indoor environment with and without greenery. These studies partially confirm that objects with natural attributes, whether they are outdoor landscapes, indoor plants, or even photos of nature, have a certain beneficial impact on human psychology. However, research on indoor greening and its effects on human mental health remains relatively limited. Previous studies did not extensively explore the specific impacts of LWSs on human psychological states. The existing studies were often conducted in virtual environments. Few studies have investigated the effects of LWSs on human physiological responses through field experiments. Moreover, some studies primarily focused on physiological changes during rest periods rather than comparing physiological changes in work status before and after rest. Overall, the research on the effects of indoor greening, particularly LWSs, on human mental health is still lacking comprehensive exploration and understanding.

Based on this, the study aims to address the following issues:

1. The psychological impact of LWSs on occupants in real-life desk work scenarios.
2. The difference in the effectiveness of genuine and fake LWSs.
3. The proper location of LWSs to maximize its beneficial impact on occupants' psychology.

In terms of theoretical implications, this study addresses a theoretical gap by extending our understanding of the impact of indoor LWSs on environmental psychology, particularly within work environments. It contributes to the literature by exploring how LWSs can influence psychological states and well-being in indoor settings.

From a practical perspective, this study provides insights into the strategic placement and arrangement of LWSs in office environments. It offers practical guidance on how LWSs can be effectively integrated into office spaces to enhance environmental quality, promote well-being, and potentially optimize productivity and satisfaction among occupants. By clarifying these practical implications, the study informs decision-making and design considerations for indoor greening initiatives in office settings.

2. Materials and Methods

In this study, the effect of indoor LWSs on the work status of subjects was explored by recording parameters of their physiological responses, including EEG and HRV. These parameters were analyzed using statistical methods to assess the psychological changes in subjects' work status before and after resting in LWS, fake LWS, and non-green wall conditions.

2.1. Experimental Conditions

In order to evaluate the effect of LWSs on human psychological state reflected by the physiological parameters, EEG and HRV were monitored for statistical analysis. A cross-over experiment was conducted wherein the participants were exposed to three different wall decoration materials while doing desk work or resting: (1) LWS, (2) fake LWS, (3) non-green wall. The experimental site is located at a small side hall in the building of Architecture Department, Nanjing Tech University (in Cfa zone in Köppen climate classification). The side hall is typically utilized as an informal learning and discussion space as shown in Figure 2. On the front wall of the side hall, there is an LWS of 14.04 m^2 (width = 5.2 m, height = 2.7 m). It is mainly covered by two species of plants, namely *Schefflera octophylla* (Lour.) Harms (52% of the total area) and *Chamaedorea elegans* Mart (48% of the total area).

The experiment started from 1 June, and was continually conducted until 4 June, daily from 9:00 am to 4:00 pm. During the experimental period, the weather outdoors was sunny and the temperature remained stable. The temperature and relative humidity of the indoor experimental area were monitored and recorded. The observation results show that there is only a small fluctuation in temperature and humidity, with an average temperature of 25.1 °C and an average relative humidity of 70.5%.



Figure 2. Experimental site. ((**A**) photo of the site; (**B**) section of the LWS.).

The arrangement of the experimental site is shown in Figure 3. In front of the LWS, movable baffles were used to divide the site into three equal volumes; each volume has an area of 6.48 m^2 (width = 1.8 m, depth = 3.6 m), and a height of 3.0 m. The front walls of the three divided spaces are of the same size, with a height of 2.7 m and a width of 1.8 m. The layout of the three spaces was the same, with one desk and two chairs. Each desk was set up with a pen, a question booklet, a pair of wearable devices, and a laptop. During the experiment, participants were asked to answer figural reasoning questions in the booklet and look at the opposite wall during break time. The wearable devices were connected to the laptop to record participants' physiological response parameters, i.e., EEG and HRV, throughout the entire process. The left chair was used by the participants, while the right chair was used by the researchers. Researchers were responsible for assisting participants in using wearable devices, as well as timing and issuing start and end commands. In order to reduce the disturbance to the participants, the researchers placed their chairs slightly back against the participants. Three different wall materials—LWS, a fake LWS made of plastic vines and leaves, and a white painted baffle—were deployed on the front wall. All three walls were illuminated with fill-in lights above them.

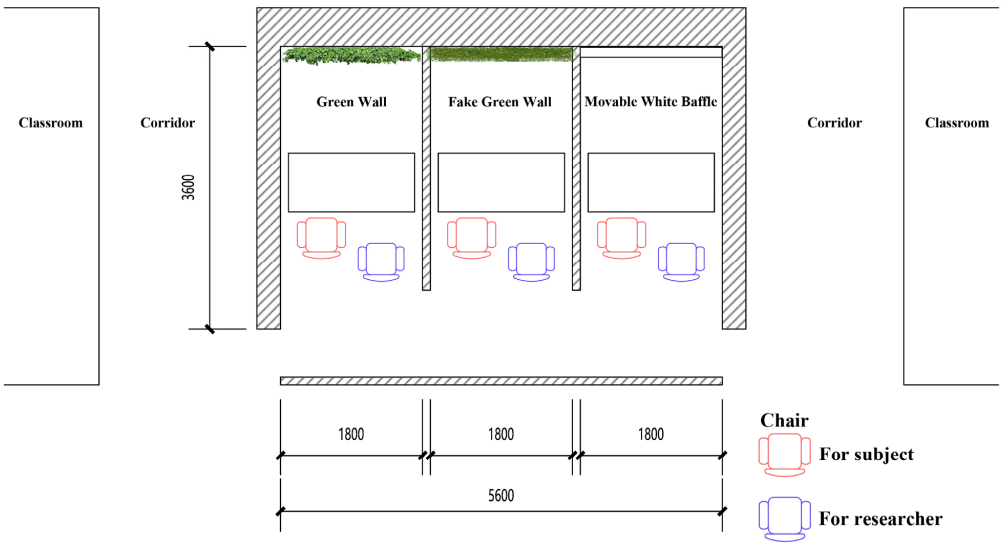


Figure 3. Layout of the experiment site.

2.2. Participants

A total of 43 students were recruited to participate in the experiment. The sample size was evaluated using G*Power 3.1.9.7 software by performing an a priori analysis with F tests (ANOVA: Fixed effects, omnibus, one-way). Setting the effect size to 0.3, α error probability to 0.05, and power (1-β error probability) to 0.8, the acceptable total sample size was calculated to be 111. Through a cross-over design, each student participated in 3 experiments, resulting in a total of 129 samples, which exceeds the required sample size.

The participants were 18–26 years old. They were undergraduate and postgraduate students, 23 males and 20 females, with an average height of 170.63 cm, weight of 63.99 kg, and BMI (Body Mass Index) of 21.78 kg/m^2, which is within the normal range (18.5–24 kg/m^2). All participants had no history of psychiatric illness and had not consumed any food or medication containing caffeine, alcohol, etc. before the experiment. Statistics of the participants are shown in Table 1. The study was approved by the Research Ethics Review Board of the Nanjing Tech University and was carried out in accordance with the Declaration of Helsinki.

Table 1. Information of the participants (mean ± standard deviation).

Gender	Number	Height (cm)	Weight (kg)	BMI (kg/m^2)
Male	23	177.74 ± 3.72	72.85 ± 11.57	23.02 ± 3.21
Female	20	162.45 ± 4.88	53.80 ± 6.30	20.37 ± 2.02

2.3. Instrument and Data Acquisition

Psychological response encompasses the emotional, cognitive, and behavioral reactions that individuals experience in response to internal or external stimuli. It is often challenging to assess psychological responses directly using quantifiable measures. Therefore, in this study, the psychological state of the participants is inferred or reflected through their physiological indicators. Physiological data, including HR (heart rate) and EEG, were measured and analyzed to quantitatively assess changes in participants' psychology under different environmental conditions. Table 2 summarizes the parameters and instrument details.

Table 2. Data acquisition.

Parameters	Devices	Measured Data	Recording Frequency
HR	Sichiray HRV ear-clip	Heart rate, HRV	Twice per second
EEG	Sichiray EEG headset	Alpha, Low beta, High beta, Theta, Delta, Gamma	Once per second

HR data include heart rate and HRV. Heart rate is the number of heart beats per minute. Generally, measurements are established using HRV, which reflects the temporal variation in heart rate, rather than raw HR data. Therefore, the excitement level would be assessed based on HRV. Both of these data were measured in this study using a Sichiray HRV ear-clip, as shown in Figure 4 (left), a device consisting of (1) an ear-clip with sensors, and (2) a USB connection device. The device can grade HRV into 10 levels from 1 to 10. Higher grades indicate that the heart rate is more unstable and the user is more emotionally excited or tense.

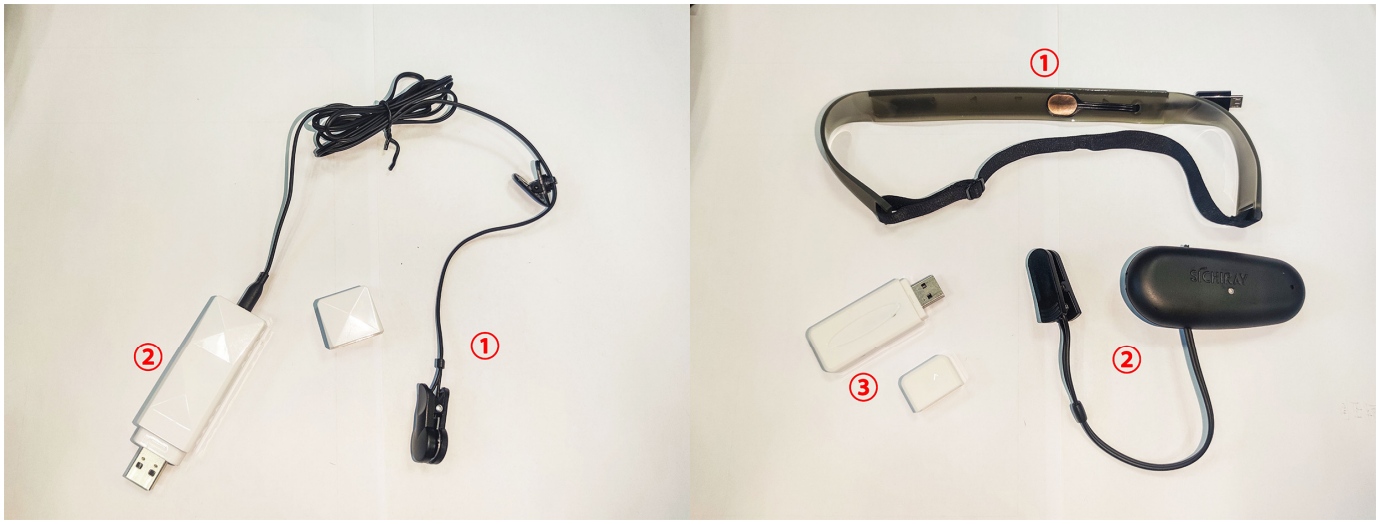


Figure 4. HRV ear-clip. ((**left**) ① Ear-clip with sensor; ② USB device); EEG headset ((**right**) ① headband with electrode; ② sensor and ear-clip with electrode; ③ Bluetooth device.)

EEG is a method of recording brain activity using electrophysiological indicators of the electrical activity that the brain produces in humans when they think or feel emotions. EEG devices use non-avoidance methods (e.g., attaching electrodes to the scalp of the participant) to amplify and record the amplitude of brain waves produced by brain cells in the cerebral cortex [40]. In the brain, neural activity generates a variety of electrical signals. By using an EEG device to detect and analyze electrical signals over time, psychological changes in the participant can be reflected. The EEG data in this study were detected by a Sichiray single-channel EEG device, as shown in Figure 4 (right), which has three basic components: (1) a headband with one electrode; (2) a sensor and an ear-clip with one electrode; and (3) a Bluetooth USB device. The device is lightweight and compact so it will not cause any discomfort to the user. The EEG device has two electrodes located on the positions Fp1 (Frontal pole) and A1 (Auricle) based on the International 10/20 system [41]. It records the energy values of alpha, beta, theta, delta, and gamma frequency bands. Figure 5 shows the EEG device operation interface.

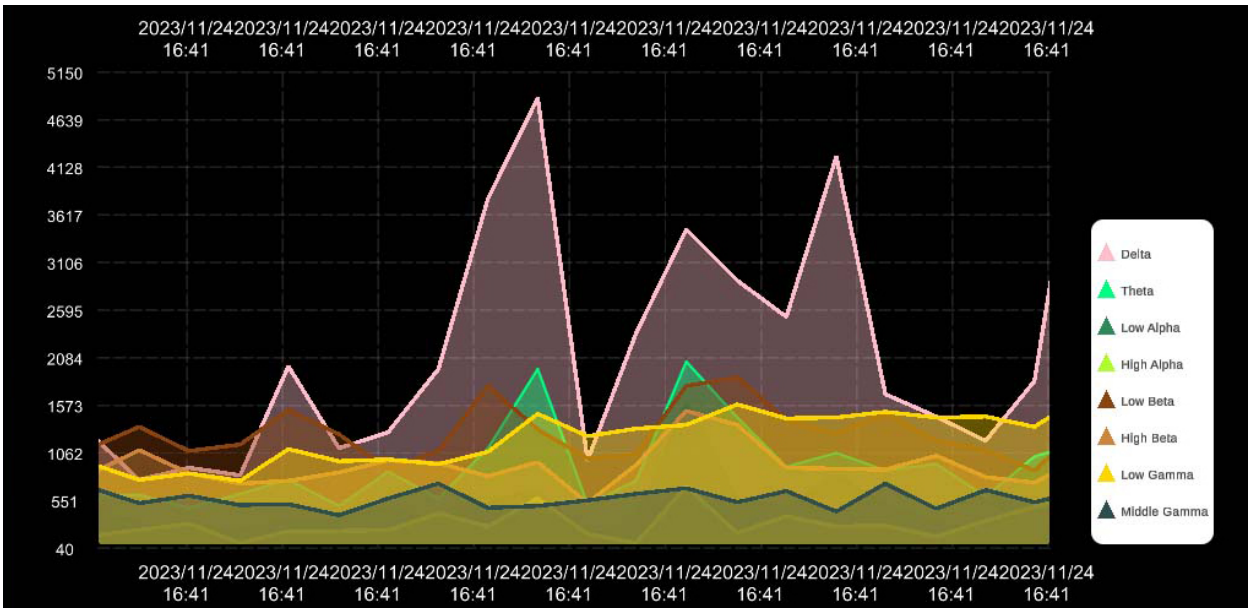


Figure 5. Sichiray EEG device operation interface.

Our study focused on analyzing the power changes in three frequency bands: alpha, beta, and theta. Alpha (8–13 Hz) mainly reflects the degree of relaxation. Its amplitude increases when the participant is stable and relaxed, and decreases when the participant is tense or concentrating on something. Beta (13–30 Hz) is usually produced when the participant is mentally active or anxious. The beta frequency band consists of low beta (13–20 Hz), which is generated during periods of concentration, study, and other mental activities, and high beta (20–30 Hz), which is generated when the participant is under stress or tension. Theta (4–8 Hz) primarily reflects levels of drowsiness and fatigue, but is also associated with confusion, distraction, and anxiety [37,39,42].

2.4. Hypothesis and Experiment Design

The biophilia theory and previous studies have provided preliminary evidence that biophilic design in indoor environments positively impacts human psychological states. Based on that, a hypothesis was made that after short breaks, the level of mental recovery varied among participants under different environmental conditions. To validate the above hypothesis, the EEG and HR data of the participants were recorded. And one-way ANOVA and Kruskal–Wallis tests were performed on the data to verify if there were statistically significant differences in EEG and HR for different environment groups.

Forty-three students were randomly invited to participate in the experiment. Before the experiment, they were asked to refrain from the consumption of food and medicine containing alcohol, caffeine, and other substances that affect their mental condition. Upon arriving at the experiment site, participants were asked to complete an informed consent form. This form addressed individual rights, privacy issues, as well as the research purpose and experimental procedures involved in the study.

During the experiment, participants used a question booklet containing 50 questions on figural reasoning described in the native language of participants as the experimental task. This task was arranged to simulate the daily desk work condition of the participants. The participants were required to complete the questions as much as possible during the experiment although the correctness of answers was not a criterion for evaluation. It was because different participants might have varying levels of knowledge and efficiency in answering the particular type of question. Answering the questions may cause mental tension and anxiety, which could be relieved partially or entirely after a short break. By monitoring and analyzing the physiological response of the participants when they were answering questions or resting, the effect of different environmental conditions on the participants' mental recovery could be compared.

The detailed experimental flow, which consists of two main phases, is shown in Figure 6, including: 1. Preparation phase and 2. Repeated experimental phase.

1. Preparation phase: After the participants arrived at the experimental site, they were asked to wait in a spare classroom where the procedure of the experiment was explained. They were also asked to fill in the information form (height, weight, etc.), and stabilize their mood to prepare for the experiment.
2. Repeated experimental phase: In each round of the experiment, 3 participants were asked to randomly enter one of the 3 experimental rooms. Participants were seated at a desk and adapted to the experimental environment for 3 min. Participants cleaned their face with the provided disinfectant wipes and waited for the experiment to start. The experimenter assisted the participant to put on the EEG and HRV devices and confirmed that the control software was working properly before starting the experiment. Participants experienced 3 periods: 3 min of work, 3 min of rest, and then 3 min of work. The EEG data and heart rate data of the participants were recorded throughout the entire experiment process. During the 3 min of work, participants were required to answer as many questions on the given booklet as possible. During the 3 min of resting time, participants had a break looking at the wall in front of them. At the end of the 9 min round, after removing the devices, participants returned to the classroom and rested for 10 min before they entered the next room for another round

of experiments. The 10 min rest was set to eliminate the residual effect caused by the last round of experiments. Participants were allowed to leave only after completing the experiment in each of the three rooms.

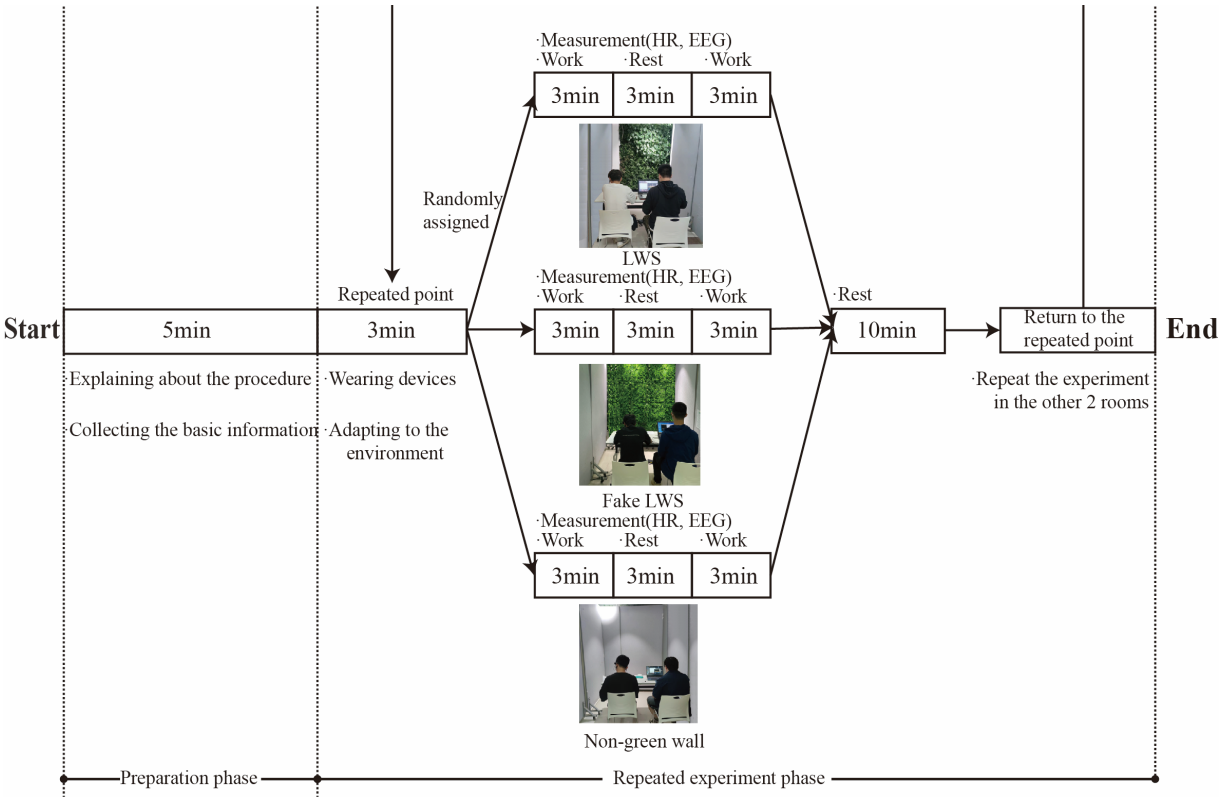


Figure 6. Experimental procedure.

2.5. Data Processing

Based on the above experimental process, EEG and HR data were collected. A small amount of abnormal and erroneous data was removed from the dataset. The data from the first and the third working period were paired for subsequent analyses.

To mitigate the effects of individual differences among participants, the EEG data were converted from absolute power values to relative power values. Alpha (P_α), low beta ($P_{L\beta}$), high beta ($P_{H\beta}$), and theta (P_θ) frequency bands were selected as the total frequency bands, and they were used to calculate the relative alpha power (*RA*), the relative low beta power (*RLB*), the relative high beta (*RHB*) power, and the relative theta power (*RT*) for the subsequent comparison [43]. The total power value, P, can be calculated with Equation (1):

$$P = P_\alpha + P_{L\beta} + P_{H\beta} + P_\theta \tag{1}$$

In Equations (1) to (7), P stands for total power value; P_α stands for alpha power; $P_{L\beta}$ stands for low beta power; $P_{H\beta}$ stands for high beta power; and P_θ stands for theta power. Additionally, the relative power value represents the ratio of the individual band power value to the total power value. *RA*, *RLB*, *RHB*, and *RT* can be calculated using Equations (2) to (5):

$$RA = \frac{P_\alpha}{P} \tag{2}$$

$$RLB = \frac{P_{L\beta}}{P} \tag{3}$$

$$RHB = \frac{P_{H\beta}}{P} \tag{4}$$

$$RT = \frac{P_\theta}{P} \tag{5}$$

In Equations (2) to (5), *RA* stands for relative alpha power; *RLB* stands for relative low beta power; *RHB* stands for relative high beta power; *RT* stands for relative theta power.

In addition, two neurophysiological indices were chosen for assessing the psychological status of participants, namely *BAR* (beta to alpha ratio) [44] and *TBR* (theta to beta Ratio), shown in Equations (6) to (7) [45,46]. *BAR* reflects the stress and cognitive load levels of the participants. *TBR* reflects the level of mind-wandering and is positively correlated with stress-induced declines in attentional control.

$$BAR = \frac{P_{L\beta} + P_{H\beta}}{P_\alpha} \tag{6}$$

$$TBR = \frac{P_\theta}{P_{L\beta} + P_{H\beta}} \tag{7}$$

Table 3 shows the descriptions of the assessment indicators and the relationship between the indicators and the psychological status of the participants. A positive relationship means the higher the indicator value, the higher the psychological status level.

Table 3. Overview of the physiological data [37,39,42,44–46].

Type	Physiological Indicators	Psychological Status	Correlation between Indicators and Status
EEG	*RA*	Relaxation level	Positive
	RLB	Attention level	Positive
	RHB	Anxiety level	Positive
	RT	Drowsiness level	Positive
	BAR	Stress level	Positive
	TBR	Attentional control level	Negative
HR	*HRV*	Tense level	Positive

The study aimed to analyze the changes in the psychological status of occupants at work after breaks in different environments. First, the differences in physiological data before and after the 3 min break were tested for the three experimental conditions using one-way ANOVA. Second, post hoc comparisons were performed on the data where statistical differences existed to analyze in detail the differences in the recovery effects among the groups. For data that did not follow a normal distribution or contain categorical variables, a Kruskal–Wallis test was used. Third, to evaluate the linear correlation between variable pairs, a Pearson correlation analysis was performed on the data for which there was statistical significance in the test results. The larger the absolute value of Pearson correlation coefficient, the stronger the correlation between the two parameters, as follows: (1) 0~0.30: negligible correlation; (2) 0.30~0.50: weak correlation; (3) 0.50~0.70: moderate correlation; (4) 0.70~0.90: strong correlation; and (5) greater than 0.90: very strong correlation [47].

3. Results

Table 4 shows the descriptive statistics of the EEG and HR data. There are differences in the mean of the indicators before and after the short break. The mean difference percentage ranges from −3.83% to 4.78%. A negative number indicates an increase in the mean value of the indicators, while a positive number stands for a decrease. In some of the indicators, the LWS effectively reduces the rate of accumulation of negative psychological states caused by desk work to about one-third, compared with the non-green wall condition. For example, the relative high beta power (*RHB*), which is an indicator of anxiety level, increases by 1.3%, 2.72%, and 3.83% in the LWS, fake LWS, and non-green wall conditions, respectively. Similarly, the beta to alpha ratio (*BAR*), which is an indicator of stress level, increases by 0.73%, 1.97%, and 2.17%. However, after resting in the LWS environment, participants became less excited and less focused. The RT (drowsiness level) decreases by 0.56% (LWS),

2.43% (fake LWS), and 2.96% (non-green wall), and the theta to beta ratio (*TBR*), an indicator of attentional control level, decreases by 0.13%, 3.15%, and 4.78%, respectively. In terms of relative alpha power (*RA*), indicating relaxation level, and relative low beta power (*RLB*), indicating attention level, no obvious patterns were observed. In order to clarify the statistical relationship, a one-way ANOVA test was performed among RA, RLB, RHB, RT, and TBR. As the beta to alpha ratio (*BAR*) data do not follow a normal distribution and the heart rate variability (*HRV*) data are categorical variables, they do not satisfy the conditions of the one-way ANOVA test. Therefore, a Kruskal–Wallis test was performed instead.

Table 4. Descriptive statistics of the physiological data.

	LWS			**Fake LWS**			**Non-Green Wall**		
Indicators	$\mathbf{M_B}$	$\mathbf{M_A}$	**ΔM%**	$\mathbf{M_B}$	$\mathbf{M_A}$	**ΔM%**	$\mathbf{M_B}$	$\mathbf{M_A}$	**ΔM%**
RA	0.15711	0.15621	0.57	0.15728	0.15537	1.21	0.15766	0.15620	0.92
RLB	0.34088	0.33994	0.28	0.34211	0.34325	−0.33	0.34263	0.34227	0.11
RHB	0.25100	0.25426	−1.30	0.25088	0.25771	−2.72	0.24439	0.25376	−3.83
RT	0.25101	0.24959	0.56	0.24973	0.24367	2.43	0.25532	0.24777	2.96
BAR	4.03174	4.06121	−0.73	4.03239	4.11176	−1.97	4.00530	4.09237	−2.17
TBR	0.45889	0.45830	0.13	0.45641	0.44202	3.15	0.47181	0.44927	4.78
HRV	3.85286	3.85711	−0.11	3.88124	3.73167	3.85	3.67709	3.78432	−2.92

Note: M_B, M_A stand for the mean before and after the rest, respectively. $\Delta M\% = \frac{M_B - M_A}{M_B} \times 100\%$.

Table 5 shows the results of the one-way ANOVA analysis. It can be found that the differences in RT, RHB, and TBR data among the three experimental conditions are statistically significant, while those in RA and RLB are not.

Table 5. One-way ANOVA of the physiological data.

Indicators	**Conditions**	**M ± SD**	**SE**	**95%CI**	**F**	***p*-Value**
$\Delta RA(RA_B\text{-}RA_A)$	LWS	0.00090 ± 0.048	0.00054	(−0.00017, 0.0020)		
	Fake LWS	0.0019 ± 0.046	0.00053	(0.00087, 0.0029)	0.86	0.422
	Non-green wall	0.0015 ± 0.049	0.00056	(0.00036, 0.0026)		
$\Delta RLB(RLB_B\text{-}RLB_A)$	LWS	0.00095 ± 0.075	0.00086	(−0.00073, 0.0026)		
	Fake LWS	−0.0011 ± 0.073	0.00083	(−0.0028, 0.00048)	1.63	0.197
	Non-green wall	0.00037 ± 0.074	0.00085	(−0.0013, 0.0020)		
$\Delta RT(RT_B\text{-}RT_A)$	LWS	0.0014 ± 0.12	0.0013	(−0.0012, 0.0040)		
	Fake LWS	0.0061 ± 0.11	0.0013	(0.0036, 0.0086)	6.13	0.002 *
	Non-green wall	0.0075 ± 0.11	0.0013	(0.0050, 0.010)		
$\Delta RHB(RHB_B\text{-}RHB_A)$	LWS	−0.0033 ± 0.071	0.00081	(−0.0048, −0.0017)		
	Fake LWS	−0.0068 ± 0.07	0.0008	(−0.0084, −0.0053)	14.53	0.000 *
	Non-green wall	−0.0094 ± 0.071	0.00082	(−0.011, −0.0078)		
$\Delta TBR(TBR_B\text{-}TBR_A)$	LWS	0.00059 ± 0.33	0.0038	(−0.0068, 0.0080)		
	Fake LWS	0.014 ± 0.32	0.0036	(0.0073, 0.022)	8.89	0.000 *
	Non-green wall	0.023 ± 0.33	0.0037	(0.015, 0.030)		

Note: M ± SD denotes mean ± standard deviation; SE denotes standard error; 95% CI denotes 95% confidence interval; * denotes statistical significance ($p < 0.05$); RA_B, RLB_B, RT_B, RHB_B, and TBR_B stand for RA, RLB, RT, RHB, and TBR, before rest, respectively. RA_A, RLB_A, RT_A, RHB_A, and TBR_A stand for RA, RLB, RT, RHB, and TBR, after rest, respectively.

The bar graph of the EEG from the three experimental conditions is shown in Figure 7. Positive differences in RT changes are observed in the LWS condition, the fake LWS condition, and the non-green wall condition. RT decreases after resting in all three conditions. The reduction in the LWS condition was much lower than the other two conditions. The highest reduction is observed in the non-green wall condition. There is no statistically significant difference between the fake LWS and non-green wall conditions. This reflects the fact that all participants were less sleepy and became more alert after the break. Participants in the non-green wall condition were substantially less sleepy, indicating that it has the

best arousal effect. The fake LWS condition was slightly less effective than the non-green wall condition, and the LWS condition had the lowest change in the level of drowsiness of the participants.

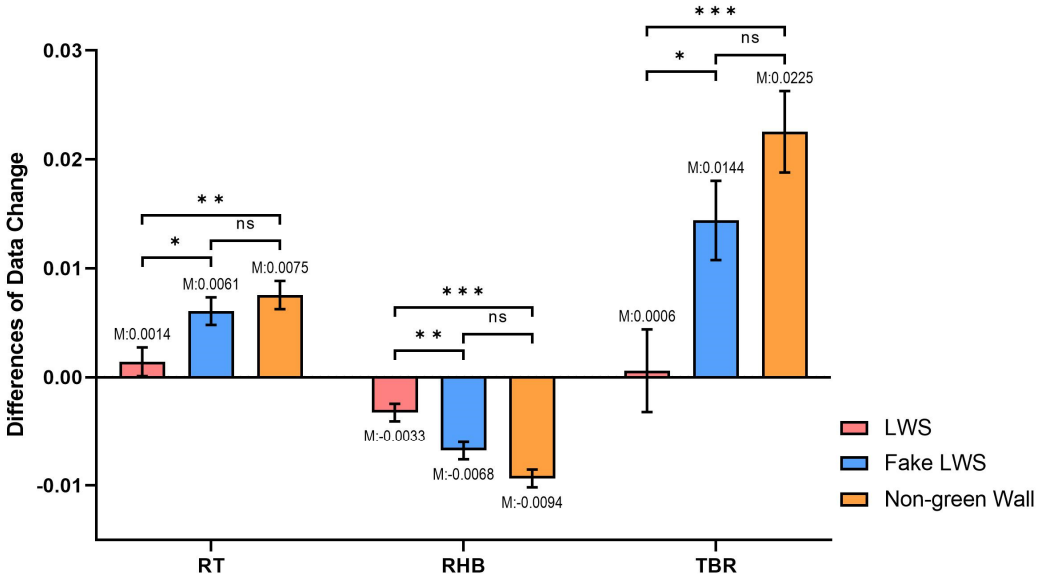


Figure 7. Differences of the *RT*, *RHB*, and *TBR* data change among three conditions (M: mean, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$, error bars represent the standard error of the mean, ns: no statistical significance).

Likewise, the differences in *RHB* change are negative in the LWS condition, the fake LWS condition, and the non-green wall condition. *RHB* increases after taking a break in all three conditions. The increase in the LWS condition is much lower than in the other two conditions. The highest increase is observed in the non-green wall condition. There is no statistically significant difference between the fake LWS and non-green wall conditions. This indicates that the anxiety level increased after rest, but the difference is the smallest in the LWS condition, which effectively slowed down the accumulation of anxiety.

Differences in *TBR* change are positive in the LWS condition, the fake LWS condition, and the non-green wall condition. The *TBR* decreases after taking a break in all three conditions. The decrease in the LWS condition is much lower than in the other two conditions, and the decrease is largest in the non-green wall condition. There is no significant difference between the fake LWS and non-green wall. As a result, the level of attentional control decreases in all cases, with the highest change in the non-green wall condition, implying that the non-green wall is effective in focusing the attention of the participants. The LWS condition has the smallest change.

The results of the Kruskal–Wallis test are shown in Table 6. It can be found that changes in *BAR* and *HRV* are statistically significant.

Table 6. Kruskal–Wallis test of the physiological data.

Indicators	Conditions	M ± SD	SE	95%CI	F	*p*-Value
ΔBAR (BAR_B-BAR_A)	LWS	−0.029 ± 1.88	0.021	(−0.071, 0.013)		
	Fake LWS	−0.079 ± 1.89	0.022	(−0.12, −0.037)	8.88	0.012 *
	Non-green wall	−0.087 ± 1.95	0.022	(−0.13, −0.043)		
ΔHRV (HRV_B-HRV_A)	LWS	−0.0043 ± 1.60	0.016	(−0.036, 0.027)		
	Fake LWS	0.15 ± 1.63	0.016	(0.12, 0.18)	97.47	0.000 *
	Non-green wall	−0.11 ± 1.65	0.017	(−0.14, −0.073)		

Note: M ± SD denotes mean ± standard deviation; SE denotes standard error; 95% CI denotes 95% confidence interval; * denotes statistical significance ($p < 0.05$); BAR_B and HRV_B stand for the BAR and HRV before the rest, respectively. BAR_B and HRV_B stand for BAR and HRV after the rest, respectively.

Figure 8 shows the changes in *BAR* and *HRV* in the three different experimental conditions. The differences in *BAR* are all negative in the LWS condition, the fake LWS condition, and the non-green wall condition. The *BAR* increases after taking a break in all three conditions. The difference between the LWS condition and the non-green wall condition is not statistically significant. The fake LWS and the non-green wall have similar results with a higher increase in *BAR*. This indicates that although the stress level of the participants still slightly increases after a short rest in all three conditions, the LWS condition is more effective in slowing down the accumulation of stress than the other two conditions.

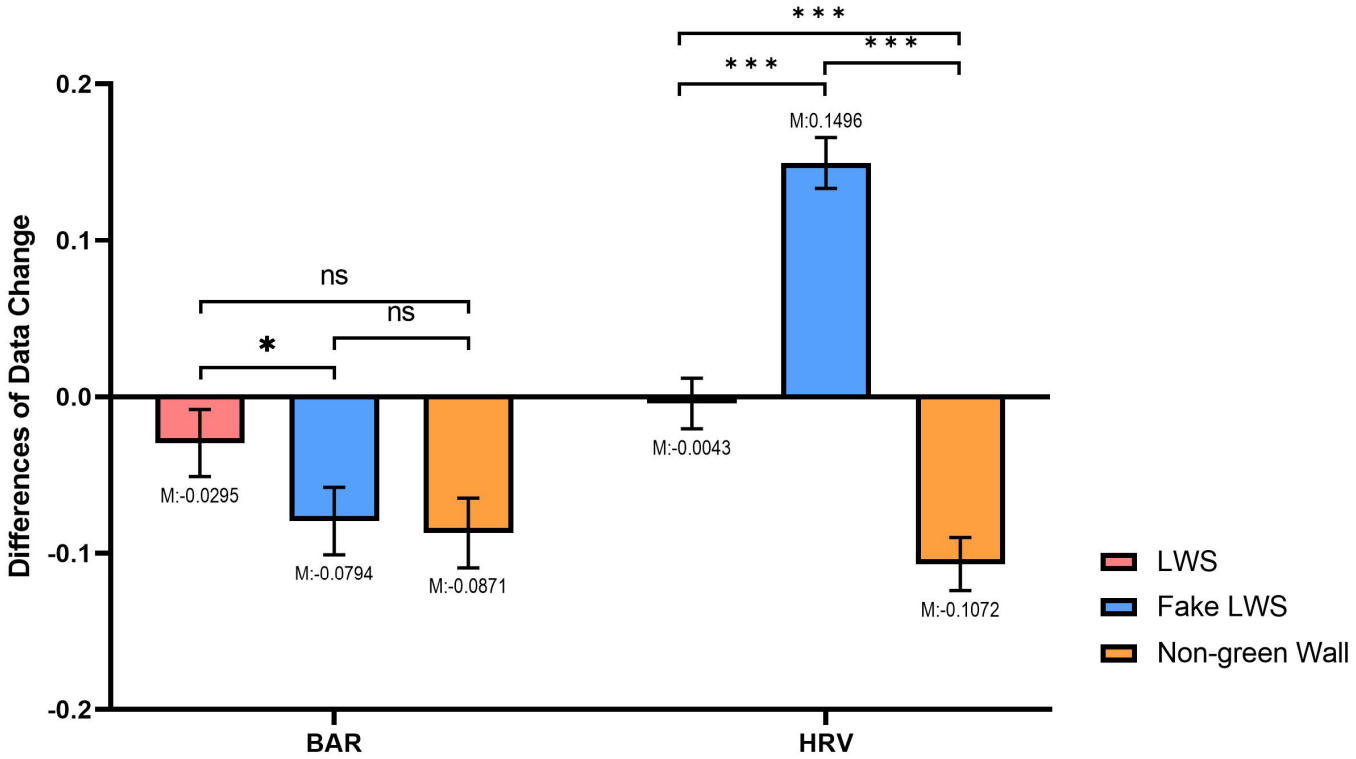


Figure 8. Differences of the *BAR* and *HRV* data change among three conditions (M: mean, *: $p < 0.05$, ***: $p < 0.001$, error bars represent the standard error of the mean, ns: no statistical significance).

Comparing the mean value of *HRV* before and after the rest, it can be found that the *HRV* increases after the rest in the fake LWS condition. Conversely, it decreases in the non-green wall condition. And it is stable in the LWS condition.

Table 7 demonstrates the results of the Pearson correlation analysis performed on the data which are statistically significant. In this case, the correlation coefficients reveal the following relationships among the physiological indicators:

1. There is a strong negative correlation between *RT* and *RHB*.
2. There is a very strong positive correlation between *RT* and *TBR*.
3. There is a moderate positive correlation between *RHB* and *BAR*.
4. There is a strong negative correlation between *RHB* and *TBR*.
5. There is a weak negative correlation between *BAR* and *TBR*.

Table 7. Pearson's correlation coefficients values of the physiological data.

	RT	*RHB*	*BAR*	*TBR*
RT	1	**−0.717**	−0.283	**0.963**
RHB		1	**0.505**	**−0.721**
BAR			1	−0.366
TBR				1

Note: Bold numbers indicate correlation coefficients greater than 0.5.

In summary, there is a negative correlation between the level of drowsiness and the level of anxiety, and a positive correlation with the level of attentional control. The level of anxiety is positively correlated with the level of stress, and negatively correlated with the level of attentional control; the level of stress is negatively correlated with the level of attentional control.

4. Discussion

Based on the results of the above statistical analysis, the changes in the participants' psychology in the three conditions was studied. The overall psychological status of the participants changed after resting in different conditions. The participants who rested in the LWS condition had the smallest change in their overall psychology, which was more stable, and the accumulation of stress and anxiety was effectively slowed down. Participants who rested in the non-green wall condition experienced the most significant changes, becoming more alert and focused. However, there was a significant increase in their anxiety and stress levels. Psychological changes of participants in the fake LWS condition were similar to those in the non-green wall condition, but the overall resting effect was slightly more effective than that of the non-green wall. In summary, resting in front of the LWS proved to be effective in slowing down the accumulation of negative mental states, and the resting effect was better than that of the fake LWS condition. Resting in front of the non-green wall reduces levels of attentional control and drowsiness, but is prone to accumulating more stress and anxiety.

Table 8 compares findings from this study and other literature. These studies share the common conclusion that indoor greenery has a restorative effect, improving the psychological state of occupants and reducing the accumulation of negative emotions. However, these studies differ somewhat in their methodology and conclusions. At the methodological level, experimental measurements were used in most of the studies ([36–38] and this study), whereas others [39,40] used VR or photographs instead of actual greenery as a testing tool. Jiang et al. [38], Yeom et al. [39], Ikei et al. [35], and Jee Heon Rhee et al. [36] compared the impact of the presence and absence of indoor greenery. In contrast, Yun-Ah Oh et al. [37] and this study also considered the different effects of genuine and fake greenery, concluding that genuine greenery had a stronger relaxing effect than fake greenery. In addition, while most studies focused on the psychological effects of viewing greenery during rest or the effects of viewing greenery on the work state afterward, this study compared psychological changes in the work state before and after rest, confirming the persistence of the psychological effects of greenery. Last but not the least, the HRV in studies was varied and influenced by various disturbing factors, making it less reliable as the main parameter for assessing the psychological effects of greenery. However, EEG reflects changes in psychological and emotional states relatively well.

Table 8. Findings from this and previous studies.

Studies	Measurement	Findings	Reference
Ikei et al.	HRV, HR, semantic differential	The HRV level of participants was higher when viewing green plants compared to the control group without plants.	[35]
Jee Heon Rhee et al.	EEG, PRS, backward digit span	The *TBR* of participants was significantly higher when viewing indoor unnatural scenes than when viewing indoor natural landscapes.	[36]
Yun-Ah Oh et al.	EEG, POMS, semantic differential	The theta wave of participants who viewed the genuine plant was lower, compared with those who viewed the fake plants. However, no significant difference was observed in the alpha wave.	[37]

Table 8. *Cont.*

Studies	Measurement	Findings	Reference
Jiang et al.	EEG, blood pressure, semantic differential, STAI	The brain waves of participants were significantly increased by short-term viewing of different landscape photographs.	[38]
Yeom et al.	EEG, *HRV*, EDA, STAI	Participants showed a decrease in *RA* and an increase in BAR after viewing the larger green wall. No significant change was observed in *HRV*.	[39]
Shao et al. (This study)	EEG, *HRV*	Participants had a decrease in *RT*, an increase in *RHB*, a decrease in *TBR*, and an increase in *BAR* when they returned to desk work after a short break viewing the LWS.	

4.1. Utility of LWSs

The effect of LWSs on participants in the office environment can be explained by the biophilia hypothesis. An LWS, as a product of biophilic design, enables participants to relax in the experimental space designed for this study, and relieves stress and fatigue. Previous studies also show that participants who have experienced biophilic behaviors have lower levels of stress [48]. Office staff do not have long breaks during working hours, and they can only temporarily detach from busy work through some instant behaviors such as looking into the distance for a short while. The experimental results show that even a brief viewing of the LWS can produce a restorative effect which helps to reduce the accumulation of stress and anxiety. This effect will persist when people return to their working state, thus maintaining sustained work efficiency at an appropriate level of stress.

According to the results of Pearson's correlation analysis in this study, there is a strong relationship between the levels of stress and anxiety and the levels of attentional control and drowsiness, implying that appropriate stress may help people maintain a more focused working status. Therefore, when designing office environments, it is suggested that an LWS be placed in rest areas rather than close to desk areas in office buildings, which can help alleviate work-related stress and create a more sustainable work environment. For example, a properly designed LWS located in the staff resting area may effectively reduce the pressure and anxiety accumulated during desk working time. When the staff finish their brief rest and return to their desks, they can be more focused and achieve higher work efficiency. Thus, an LWS can contribute to enhancing the indoor environment by incorporating small indoor green spaces and beautifying the surroundings. The use of flowering plants, where feasible, yields better results. Furthermore, LWSs can help improve indoor air quality to some extent by purifying the air and converting carbon dioxide into oxygen.

4.2. Utility of Fake LWSs

While participants in the non-green wall condition became more alert and focused, this change was accompanied by higher levels of stress and anxiety, possibly due to the depressing urban forest-like atmosphere of the non-green wall condition, which induced feelings of oppression and uneasiness. The resting effects in the fake LWS condition are similar to those in the non-green wall condition, and there were no significant differences in EEG changes. However, the change in *HRV* data in the fake LWS condition was positive and significantly higher than in the other conditions, implying that participants became calmer in that condition. Additionally, fake LWSs can still provide visual aesthetic value, and their construction is simple and inexpensive, requiring minimal maintenance or renewal, which significantly saves labor and costs. Therefore, a fake LWS is still a competitive method of indoor greening.

5. Conclusions

The purpose of this study is to investigate the changes in the work status of people before and after resting in different LWS conditions by measuring their physiological responses. To achieve this goal, three different experimental conditions were constructed, and the participants' psychology was analyzed based on their *HRV* and EEG.

The results revealed significant differences in five data points for the LWS condition compared to the other two conditions: *RT*, *RHB*, *TBR*, *BAR*, and *HRV*. Participants in the LWS condition experienced the fewest psychological changes and, overall, maintained a more stable work status. In contrast, participants in the other two conditions became more tense and focused, with a significant increase in stress levels. In essence, the LWS condition slows down the accumulation of stress and helps participants maintain a more stable work status, whereas other conditions may have the opposite effect.

Based on the findings from the experiment, the following conclusions were drawn:

1. Statistical analysis shows that LWSs can effectively reduce the accumulation rate of negative psychological states caused by desk work to about one-third compared to a regular office environment without an LWS. Additionally, viewing an LWS during breaks can effectively slow down the accumulation of stress and anxiety, thereby improving the work state.
2. The psychological benefits of fake LWSs are weaker than those of genuine LWSs. A fake LWS can also be aesthetically pleasing and is competitively priced with low construction and maintenance costs.
3. A side effect of LWSs is that after resting in the LWS condition, occupants experience less fluctuation in their overall mental state and become less aroused. In contrast, fake LWS and non-green wall conditions make occupants more focused but at the expense of increased stress and anxiety.
4. In office buildings, an LWS should be placed in the rest area, rather than the desk area, to relieve stress and anxiety of occupants, promote a more relaxing resting environment, and improve psychological well-being. Although an LWS in the desk area also creates a more ecological and natural indoor environment, it may distract people's attention, which can actually reduce their focus and affect work efficiency.

The results of this study complement existing research on indoor greenery and its effects on human mental health. They will also encourage designers to consider the positive impact of biophilic design on people and provide new strategies for the layout of indoor office environments. Placing LWSs in indoor office spaces can help occupants alleviate work-related stress and anxiety during breaks, enabling them to return to work more focused and achieve higher levels of productivity. This approach contributes to creating a sustainable work environment that enhances environmental quality and promotes overall well-being.

However, this study has some limitations that should be acknowledged:

1. The study was limited to a young population, which may restrict the generalizability of the findings. Future research should consider including a more diverse range of participants with different age groups and demographic characteristics to better understand the broader impact of LWSs on various populations.
2. The study did not account for how subjects viewed the LWS, such as the angle and distance of their viewpoint. The perception and experience of LWSs can vary based on these factors. Future studies should investigate the effects of different viewing angles and distances of indoor green walls on users' perceptions, preferences, and psychological responses.

Therefore, future research in this area should aim to address these limitations by expanding the participant demographics and incorporating considerations of viewing perspectives to provide a more comprehensive understanding of the effects and experiences associated with LWSs in indoor environments. This broader approach will contribute to

advancing our knowledge of the psychological and environmental impacts of greenery in indoor spaces.

Author Contributions: Conceptualization, Y.S.; methodology, Y.S. and Z.Z.; formal analysis, Y.S. and Z.Z.; data curation, Z.Z. and D.D.; writing—original draft preparation, Y.S. and Z.Z.; writing—review and editing, D.D., Y.C. and X.W.; project administration, Y.S. and Y.C.; funding acquisition, Y.S. and Y.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (Project number 51708283); the 'Taishan' Scholar Program of Shandong Province, China (Project Number: tsqn 202211183), the Outstanding Youth Science Foundation Project of Shandong Province (Overseas) (Project Number: 2023HWYQ-076).

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Nanjing Tech University (protocol code: 23010, approval date: 10 October 2023).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data can be made available upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviation

Abbreviation		Abbreviation	
A1	Auricle	PL_{β}	Low beta power
ANOVA	Analysis of variance	PM	Particulate matter
ART	Attention restoration theory	POMS	Profile of mood state
BAR	Beta alpha ratio	PRS	Perceptual restorative scale
BMI	Body mass index	P_{α}	Alpha power
CI	Confidence interval	P_{θ}	Theta power
CO_2	Carbon dioxide	*RA*	Relative alpha power
EDA	Electrodermal activity	*RHB*	Relative high beta power
EEG	Electroencephalogram	*RLB*	Relative low beta power
Fp1	Frontal pole	*RT*	Relative theta power
HR	Heart rate	SD	Standard deviation
HRV	Heart rate variability	SE	Standard error
IEQ	Indoor environmental quality	SRT	Stress reduction theory
LWS	Living wall system	STAI	State-trait anxiety inventory
M	Mean	*TBR*	Theta beta ratio
NIS	Natural information system	VGS	Vertical greening systems
P	Total power	VR	Virtual reality
PH_{β}	High beta power		

References

1. Chang, C.; Chen, P. Human Response to Window Views and Indoor Plants in the Workplace. *Hortscience* **2005**, *40*, 1354–1359. [CrossRef]
2. Deng, L.; Deng, Q. The basic roles of indoor plants in human health and comfort. *Environ. Sci. Pollut. Res.* **2018**, *25*, 36087–36101. [CrossRef] [PubMed]
3. Johnson, M.; Waliczek, T.M.; Etheredge, C.; Bradley, J.C. The Connection between Gardening and Outdoor Activity during the COVID-19 Pandemic and Perceptions of Hope, Hopelessness, and Levels of Stress, Anxiety, and Depression. *Horttechnology* **2023**, *33*, 168–175. [CrossRef]
4. Lee, K.; Suh, C.; Kim, J.; Park, J.O. The impact of long working hours on psychosocial stress response among white-collar workers. *Ind. Health* **2017**, *55*, 46–53. [CrossRef] [PubMed]
5. De Clercq, D.; Haq, I.U.; Azeem, M.U. Time-related work stress and counterproductive work behavior. *Pers. Rev.* **2019**, *48*, 1756–1781. [CrossRef]
6. Watts, N.; Adger, W.N.; Agnolucci, P.; Blackstock, J.; Byass, P.; Cai, W.; Chaytor, S.; Colbourn, T.; Collins, M.; Cooper, A.; et al. Health and climate change: Policy responses to protect public health. *Lancet* **2015**, *386*, 1861–1914. [CrossRef] [PubMed]

7. Reichert, M.; Braun, U.; Lautenbach, S.; Zipf, A.; Ebner-Priemer, U.; Tost, H.; Meyer-Lindenberg, A. Studying the impact of built environments on human mental health in everyday life: Methodological developments, state-of-the-art and technological frontiers. *Curr. Opin. Psychol.* **2020**, *32*, 158–164. [CrossRef] [PubMed]
8. Gullone, E. The Biophilia Hypothesis and Life in the 21st Century: Increasing Mental Health or Increasing Pathology? *J. Happiness Stud.* **2000**, *1*, 293–322. [CrossRef]
9. Flies, E.J.; Mavoa, S.; Zosky, G.R.; Mantzioris, E.; Williams, C.; Eri, R.; Brook, B.W.; Buettel, J.C. Urban-associated diseases: Candidate diseases, environmental risk factors, and a path forward. *Environ. Int.* **2019**, *133*, 105187. [CrossRef]
10. Kimura, T.; Yamada, T.; Hirokawa, Y.; Shinohara, K. Brief and Indirect Exposure to Natural Environment Restores the Directed Attention for the Task. *Front. Psychol.* **2021**, *12*, 619347. [CrossRef]
11. Raman, T.L.; Abdul Aziz, N.A.; Yaakob, S.S.N. The Effects of Different Natural Environment Influences on Health and Psychological Well-Being of People: A Case Study in Selangor. *Sustainability* **2021**, *13*, 8597. [CrossRef]
12. Susca, T.; Zanghirella, F.; Colasuonno, L.; Del Fatto, V. Effect of green wall installation on urban heat island and building energy use: A climate-informed systematic literature review. *Renew. Sustain. Energy Rev.* **2022**, *159*, 112100. [CrossRef]
13. Gunawardena, K.; Steemers, K. Living walls in indoor environments. *Build. Environ.* **2019**, *148*, 478–487. [CrossRef]
14. Shao, Y.; Li, J.; Zhou, Z.; Hu, Z.; Zhang, F.; Cui, Y.; Chen, H. The effects of vertical farming on indoor carbon dioxide concentration and fresh air energy consumption in office buildings. *Build. Environ.* **2021**, *195*, 107766. [CrossRef]
15. Shao, Y.; Li, J.; Zhou, Z.; Zhang, F.; Cui, Y. The Impact of Indoor Living Wall System on Air Quality: A Comparative Monitoring Test in Building Corridors. *Sustainability* **2021**, *13*, 7884. [CrossRef]
16. Ulrich, R.S. Biophilia, biophobia, and natural landscapes. In *The Biophilia Hypothesis*; Island Press: Washington, DC, USA, 1993; pp. 73–137.
17. Kahn, P.H. Developmental Psychology and the Biophilia Hypothesis: Children's Affiliation with Nature. *Dev. Rev.* **1997**, *17*, 1–61. [CrossRef]
18. Herzog, T.R.; Black, A.M.; Fountaine, K.A.; Knotts, D.J. Reflection and Attentional Recovery as Distinctive Benefits of Restorative Environments. *J. Environ. Psychol.* **1997**, *17*, 165–170. [CrossRef]
19. Kaplan, S. The restorative benefits of nature: Toward an integrative framework. *J. Environ. Psychol.* **1995**, *15*, 169–182. [CrossRef]
20. Hartig, T.; Evans, G.W.; Jamner, L.D.; Davis, D.S.; Gärling, T. Tracking restoration in natural and urban field settings. *J. Environ. Psychol.* **2003**, *23*, 109–123. [CrossRef]
21. Ulrich, R.S.; Simons, R.F.; Losito, B.D.; Fiorito, E.; Miles, M.A.; Zelson, M. Stress recovery during exposure to natural and urban environments. *J. Environ. Psychol.* **1991**, *11*, 201–230. [CrossRef]
22. Zeki, S. Beauty in Architecture: Not a Luxury—Only a Necessity. *Archit. Des.* **2019**, *89*, 14–19. [CrossRef]
23. Mehaffy, M.W. The Impacts of symmetry in architecture and urbanism: Toward a new research agenda. *Buildings* **2020**, *10*, 249. [CrossRef]
24. Watson, P.J.; Thornhill, R. Fluctuating asymmetry and sexual selection. *Trends Ecol. Evol.* **1994**, *9*, 21–25. [CrossRef] [PubMed]
25. Enquist, M.; Arak, A. Symmetry, beauty and evolution. *Nature* **1994**, *372*, 169–172. [CrossRef] [PubMed]
26. Taylor, R.P. The potential of biophilic fractal designs to promote health and performance: A review of experiments and applications. *Sustainability* **2021**, *13*, 823. [CrossRef]
27. Hägerhäll, C.M.; Laike, T.O.R.; Küller, M.; Marcheschi, E.; Boydston, C.; Taylor, R.P. Human physiological benefits of viewing nature: EEG responses to exact and statistical fractal patterns. *Nonlinear Dyn. Psychol. Life Sci.* **2015**, *19*, 1–12.
28. Hagerhall, C.M.; Laike, T.O.R.; Taylor, R.P.; K U Ller, M.; K U Ller, R.; Martin, T.P. Investigations of human EEG response to viewing fractal patterns. *Perception* **2008**, *37*, 1488–1494. [CrossRef] [PubMed]
29. Bies, A.; Kikumoto, A.; Boydston, C.; Greeenfield, A.; Chauvin, K.; Taylor, R.; Sereno, M. Percepts from noise patterns: The role of fractal dimension in object pareidolia. *J. Vis.* **2016**, *16*, 790. [CrossRef]
30. Bies, A.J.; Wekselblatt, J.; Boydston, C.R.; Taylor, R.P.; Sereno, M.E. The effects of visual scene complexity on human visual cortex. In Proceedings of the 2015 Neuroscience Meeting Planner, Chicago, IL, USA, 17–21 October 2015.
31. Joye, Y. An interdisciplinary argument for natural morphologies in architectural design. *Environ. Plan. B Plan. Des.* **2006**, *33*, 239–252. [CrossRef]
32. Mineka, S.; Öhman, A. Phobias and preparedness: The selective, automatic, and encapsulated nature of fear. *Biol. Psychiatry* **2002**, *52*, 927–937. [CrossRef]
33. Ulrich, R.S. Natural versus urban scenes: Some psychophysiological effects. *Environ. Behav.* **1981**, *13*, 523–556. [CrossRef]
34. Frumkin, H. Beyond toxicity: Human health and the natural environment. *Am. J. Prev. Med.* **2001**, *20*, 234–240. [CrossRef] [PubMed]
35. Ikei, H.; Song, C.; Igarashi, M.; Namekawa, T.; Miyazaki, Y. Physiological and psychological relaxing effects of visual stimulation with foliage plants in high school students. *Adv. Hortic. Sci.* **2014**, *28*, 111–116.
36. Rhee, J.H.; Schermer, B.; Han, G.; Park, S.Y.; Lee, K.H. Effects of nature on restorative and cognitive benefits in indoor environment. *Sci. Rep.* **2023**, *13*, 13199. [CrossRef] [PubMed]
37. Oh, Y.; Kim, S.; Park, S. Real Foliage Plants as Visual Stimuli to Improve Concentration and Attention in Elementary Students. *Int. J. Environ. Res. Public Health* **2019**, *16*, 796. [CrossRef]
38. Jiang, M.; Hassan, A.; Chen, Q.; Liu, Y. Effects of different landscape visual stimuli on psychophysiological responses in Chinese students. *Indoor Built Environ.* **2020**, *29*, 1006–1016. [CrossRef]

39. Yeom, S.; Kim, H.; Hong, T. Psychological and physiological effects of a green wall on occupants: A cross-over study in virtual reality. *Build. Environ.* **2021**, *204*, 108134. [CrossRef]
40. Schoffelen, J.; Poort, J.; Oostenveld, R.; Fries, P. Selective Movement Preparation Is Subserved by Selective Increases in Corticomuscular Gamma-Band Coherence. *J. Neurosci.* **2011**, *31*, 6750–6758. [CrossRef] [PubMed]
41. Jasper, H.H. The Ten Twenty Electrode System: International Federation of Societies for Electroencephalography and Clinical Neurophysiology. *Am. J. EEG Technol.* **1961**, *1*, 13–19.
42. Jiang, S.; Deng, L.; Luo, H.; Li, X.; Guo, B.; Jiang, M.; Jia, Y.; Ma, J.; Sun, L.; Huang, Z. Effect of Fragrant Primula Flowers on Physiology and Psychology in Female College Students: An Empirical Study. *Front. Psychol.* **2021**, *12*, 607876. [CrossRef]
43. Huberty, S.; Carter Leno, V.; van Noordt, S.J.R.; Bedford, R.; Pickles, A.; Desjardins, J.A.; Webb, S.J.; Elsabbagh, M. Association between spectral electroencephalography power and autism risk and diagnosis in early development. *Autism Res.* **2021**, *14*, 1390–1403. [CrossRef] [PubMed]
44. Giannakakis, G.; Grigoriadis, D.; Giannakaki, K.; Simantiraki, O.; Roniotis, A.; Tsiknakis, M. Review on Psychological Stress Detection Using Biosignals. *IEEE Trans. Affect. Comput.* **2022**, *13*, 440–460. [CrossRef]
45. van Son, D.; De Blasio, F.M.; Fogarty, J.S.; Angelidis, A.; Barry, R.J.; Putman, P. Frontal EEG theta/beta ratio during mind wandering episodes. *Biol. Psychol.* **2019**, *140*, 19–27. [CrossRef] [PubMed]
46. Poole, K.L.; Hassan, R.; Schmidt, L.A. Temperamental Shyness, Frontal EEG Theta/Beta Ratio, and Social Anxiety in Children. *Child Dev.* **2021**, *92*, 2006–2019. [CrossRef]
47. Mukaka, M. Statistics Corner: A guide to appropriate use of Correlation coefficient in medical research. *Malawi Med. J. J. Med. Assoc. Malawi* **2012**, *24*, 69–71.
48. Kellert, S.; McVay, S.; Katcher, A.; McCarthy, C. *The Biophilia Hypothesis*; Bibliovault OAI Repository, The University of Chicago Press: Chicago, IL, USA, 1994.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.