THE EFFECTS OF FOREST TRAIL'S VIRTUAL WINTER LANDSCAPE ON THE ANXIETY STATUS OF YOUNG ADULTS

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Abstract. Forest environments are widely recognized for their restorative effects, yet research on the benefits of winter forest trails—particularly from a multidimensional perceptual perspective—remains limited. This study conducted a visual-tactile interaction experiment using three virtual snowy forest trail videos (no snow: NS; post-snowfall landscape: A; during snowfall: S) and two tactile stimuli conditions (touching snow: T; not touching snow: DT). Ninety anxious young adults (mean age 22.2 ± 3.28 years) were tested across five virtual settings (NS, A-DT, A-T, S-DT, S-T), with psychological changes measured via the Profile of Mood States (POMS) and State-Anxiety Inventory (S-AI), and physiological changes tracked using electroencephalography (EEG) brainwaves. Results revealed four key findings: (1) Post-snowfall winter trails significantly reduced anxiety, as evidenced by lower total mood disturbance (TMD) and state anxiety (S-AI scores), alongside increased EEG indicators of relaxation and alertness; (2) Both touching snow and experiencing falling snowflakes enhanced brain alertness; (3) The tranquility of snow exerted a particularly strong restorative effect on anxious youths experiencing tension; (4) Snow-touching mediated the recovery of EEG brainwave indicators. These nuanced findings provide insights for designing targeted, seasonally adaptive forest therapy interventions for mental health, emphasizing the importance of carefully integrating sensory modalities in nature-based health practices.
Keywords: *restorative benefits, virtual reality, tactile perception, young adults, snow-covered landscapes*

Introduction

In recent years, fast-paced lifestyles and shrinking green spaces have significantly reduced residents' access to nature (Jiang, 2020; Xie et al., 2021) , which has had a serious impact on the physical and mental health of the population (Iamtrakul et al., 2024). The accelerated pace of life and increased stress among students have contributed to higher rates of depression and anxiety among young adults (Sikström et al., 2023). Mental health surveys conducted by the World Health Organization in 21 countries revealed that 20.3 percent of university students experience mental health issues (Wang et al., 2024). The physical and mental health of contemporary youth is crucial for the development and progress of the country. Therefore, addressing students' mental health is an urgent research priority (Sheldon et al., 2021).

Numerous studies have confirmed the rehabilitative, preventive, and health benefits of walking in forests (Oh et al., 2017; Zhang et al., 2020). For instance, engaging in such activities can restore both physical and mental health while alleviating symptoms of anxiety and fatigue (Ochiai et al., 2015; Pröbstl-Haider, 2015; Song et al., 2017; Bielinis et al., 2018b; Li et al., 2020). Additionally, it may contribute to reductions in blood pressure, heart rate, and cortisol concentrations, among other health indicators (Park et al., 2009; Horiuchi et al., 2014; Song et al., 2018). Consequently, urban forest trails have

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garnered significant attention from scholars both domestically and internationally as fundamental restorative environments (Chang et al., 2008; Li et al., 2008; Sung et al., 2012; Shi et al., 2024). Mattila et al. (2020) demonstrated that exposure to forest trails for just 15 minutes positively impacts the restoration of physical and mental health. However, cold temperatures, snow, and limited daylight during winter severely restrict outdoor activities for young adults (Wagner et al., 2019). This lack of outdoor engagement can lead to increased anxiety, fear, and depression among youth, potentially resulting in serious psychological issues (Wang, 2020). Furthermore, it may exacerbate various cardiometabolic risk factors during the winter months (Fröhlich et al., 1997; Spencer et al., 1998; Fares, 2013; Marti-Soler et al., 2014). To address this concern, researchers have increasingly shifted their focus toward investigating the benefits of landscape restoration in cold environments (Bielinis et al., 2018b; Bao et al., 2023;). Nevertheless, many existing studies have employed methods that applied pressure on individuals without emotional abnormalities, followed by recovery tests aimed at understanding the benefits of recovery (Bao et al., 2023; Zeng et al., 2023). There is a notable lack of in-depth studies focusing specifically on youth experiencing anxiety. Moreover, current research concerning winter is predominantly limited to the dimension of visual perception (Bielinis et al., 2019), with few studies exploring interactions across multiple perceptual dimensions.

In addition to the visual appeal of winter forest landscapes, many individuals choose to engage with the snow directly. Although humans derive more than 80 percent of their information from the visual system (Yang et al., 2020). Ligier's theory of perception posits that visual perception is non-invasive. In contrast, haptics—a unique sensory channel capable of transferring information bidirectionally (Chen, 2019) can effectively compensate for this limitation. Horticultural therapy emphasizes that 'only touch can be real'. During horticultural therapy activities, individuals experience the temperature, hardness, and texture of various objects, which stimulate the intuitive regions of the cerebral cortex, leading to feelings of comfort and enjoyment (Townsend, 2006; Guo et al., 2024). The basic tactile senses encompass pain, cold, warmth, pressure, itch, and five additional senses (Wang et al., 2022). Most investigations into the relationship between tactile elements and landscapes have been categorized based on active and passive touch (Xie et al., 2022). The act of humanly touching snow and ice in this study provides a warming experience that engages the fundamental senses of touch and focuses on the human active touch factor. The human body's multisensory associative response is significantly greater than the information processed by any single sense (Liang et al., 2024). However, there is a paucity of research on the restorative benefits of visual-tactile interactive perception. For instance, does the act of touching snow detract from the positive restorative benefits associated with winter forest trails? Such questions have yet to be scientifically validated.

Electroencephalography (EEG) technology can identify and visualise human emotions in real time (Liu et al., 2010), reflecting changes in the electrical signals of the cerebral cortex as it recognises information about the environment (Ma et al., 2023), and reflecting changes in the physiological and psychological states of human beings (Han and Chun, 2021). Among them, α-wave and β-wave have been widely used in the assessment of psychological state. α-wave represents the human body entering into a state of relaxation, with a subjective feeling of comfort and relaxation (Feng and Shen, 2023), β-wave reflects a higher degree of alertness, arousal, and concentration (Bonnet and Arand, 2001; Bao et al., 2024). The value of α/β represents the ratio of relaxation to alertness, which is

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the state of relaxation and alertness. And the value of α/β represents the situation of relaxation and alertness, with a lower ratio representing a higher degree of alertness. Outdoor experiments can cause irrelevant factors to interfere with the subjects and bias the brainwave signals. Moreover, relevant studies have shown that virtual experience can still provide the same restorative properties as real-life experience (Vassiljev and Bell, 2023). Therefore, this study chose to explore the most intuitive and rational restorative benefits of human physical and mental health through the visual and tactile interactive perception of a simulated winter white landscape by means of virtual technology.

In this study, we investigate the restorative benefits of various snow states, as well as human visual and tactile sensations, on human emotions in winter urban forest park trail landscapes through virtual reality. The goal of this research is to enhance our understanding of these interactions:

Q1·1. Does the winter snow landscape of the urban forest trail significantly improve the psychological and physiological indicators of anxious young people?

Q2·2. Assuming the first question is valid, do different states of snow significantly influence recovery effects in young anxious adults? Is touch related to recoverability? What are the pathways of influence?

Q3·3. Does the experience of having touched snow affect the recovery path?

Materials and methods

Experimental site

As shown in *Figure 1*, this experiment was conducted in Jilin Agricultural University in Changchun City, Jilin Province, China, where two mutually undisturbed rooms were chosen to be designated as the lounge and the laboratory, respectively. To simulate the actual outdoor winter temperature, during the intervals between the two test subjects, the windows were opened for ventilation to allow cold outdoor air to enter the room. The RSD-KY-50R industrial refrigeration and air conditioning device by ROYALSTAR was used, along with an indoor thermometer to monitor the temperature, keeping the temperature in the laboratory at -10°C. To ensure the physical safety of the test subjects and to simulate the actual routine outdoor clothing patterns of tourists in the cold winter and to unify the subjects' perceived temperature, cotton clothes were uniformly prepared for the experiment. The subjects were required to alternate wearing public cotton clothes during the test period. The room featured a 1.28 m × 1.08 m projection screen, while all other surfaces visible to the subjects were kept white. Additionally, the room was maintained in a quiet, clean, and odorless condition to minimize interference from non-experimental factors. During this experiment, none of the participants left the room or experienced any physical discomfort.

Experimental objects

When recruiting volunteers, we will properly inform the participants of the purpose of the experiment, the information required for the experiment and the scientific research significance. For the psychological and physiological data of the participants, we will use anonymous recording methods. We strictly abide by the ethical principles outlined in the Helsinki Declaration to protect the privacy of the participants. This is to reduce the participants' uncertainty expectations and minimize the potential biases that the participants may worry about.

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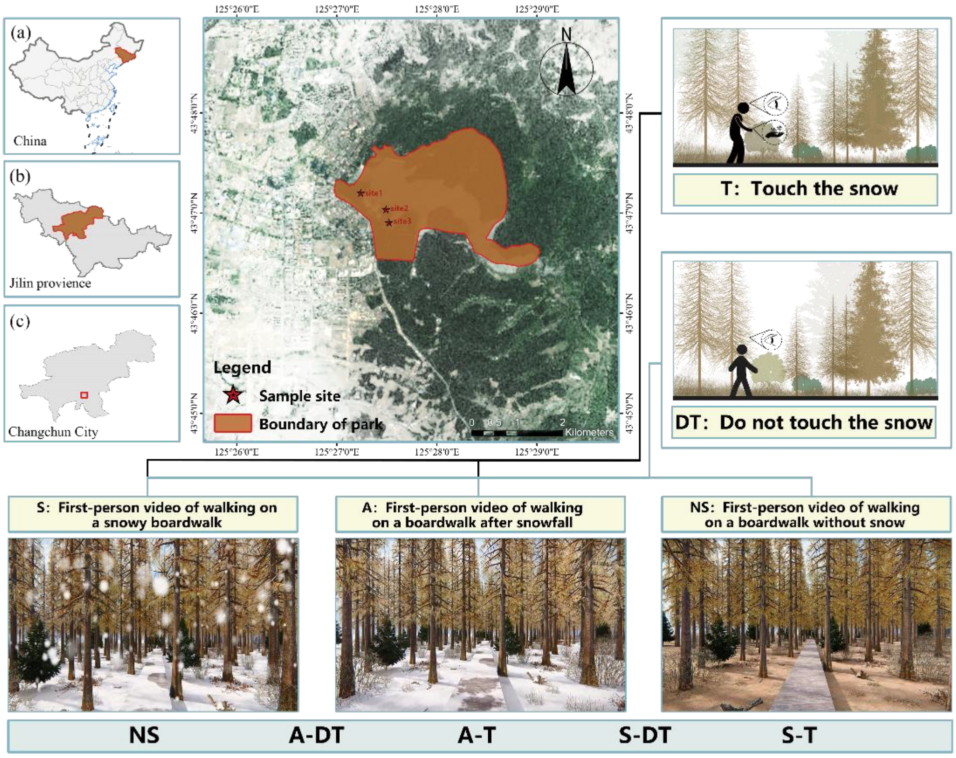

Figure 1. *Detailed location maps and grouping variable maps of the study plots (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group). Source: Plotted by the authors using ArcMap 10.8.1 (https://www.esri.com/) and Adobe Photoshop 2021 (https://www.adobe.com/products/photoshop.html)*

In this study, the G*power software was used to determine the minimum sample size required for a specific effect size, the alpha level (usually 0.05, representing the significance level), and the statistical power (usually 0.80 or higher). Based on this, the G*power software calculated that the minimum sample size for each group was 12 people. In this study, the sample size for each group was selected as 18 people, which is greater than the minimum sample size value and is scientifically meaningful. In this study, the S-AI sub-scale from the STAI (State-Trait Anxiety Inventory - Revised STAI - From Y 1980; Chinese translation; applicable to adults with junior high school education or above) was used to screen the anxiety subjects. The subjects were screened based on their scores on the S-AI State Anxiety Inventory, which utilizes a 4-point Likert-type scale (ranging from 1 to 4 points). A cut-off value of 53 was established for males and 55 for females (Spielberger, 2010). Consequently, select volunteers whose male score is above 53 and whose female score is above 55 (including/excluding criteria), and who are right-handed by habit, have not taken any medication in the past month, and have maintained 7-9 hours of sleep in the past three days as the subsequent subjects of this experiment. The subjects are required to avoid caffeine intake the day before the experiment.

Recruit 200 volunteers who are willing to participate in the experiment. Among them, 105 individuals have S-AI scores that meet the anxiety threshold. Considering the gender ratio, age range, and the required number of subjects for the experiment, 90 subjects are finally selected as the participants of this experiment and their psychological and

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physiological data are analyzed. The ethical principles outlined in the Declaration of Helsinki were rigorously adhered to throughout this study, and the study protocol received approval from the Ethics Committee of Jilin Agricultural University (the approval number is documented in the Academic Committee records). The number of participants at each stage is shown in *Figure 2*.

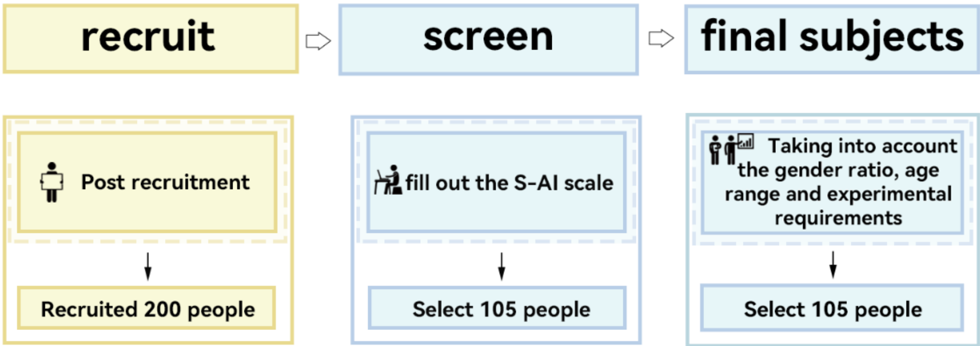

Figure 2. *A flowchart showing the number of participants throughout the recruitment stage, group allocation, and data analysis process*

Groups and variables

In this study, 90 subjects were randomly (22.2 ± 3.28 years old) divided into five groups(Under the premise of ensuring a 1:1 male-to-female ratio in each experimental group, the "Random Bang" computer software was used to randomly assign group membership through a lottery system), and the five experimental groups were the 'no white snow group' (control group NS: refers to a control group that has a landscape environment with neither snow cover nor snow that is falling in mid-winter and where subjects do not touch snow or ice, as shown in the NS diagram in *Figure 1*), 'No snow touching after snow fall group' (Experimental group A-DT: refers to the experimental group in which the ground surface and trees have a snow-covered landscape environment after snowfall and subjects do not touch the snow or ice.), 'Snow touching after snow fall group' (experimental group A-T: refers to the landscape environment where the ground surface and trees are snow-covered and the subjects touch snow and ice in mid-winter), 'snowfall without touching snow group' (experimental group S-DT: refers to the experimental group in the winter landscape environment where snow is falling and subjects do not touch snow and ice), 'snowfall touching snow group' (experimental group S-T: refers to the experimental group in the winter landscape environment where snow is falling and subjects touch snow and ice), with 18 participants in each group. *Figure 1* illustrates the grouping. The staff collected tactile materials from the natural snow outdoors and put them into white rectangular containers for the experiment. The visual material is a video of a forest path with the original sounds of the site, which was produced using virtual technology. The original video was recorded live at Changchun Jingyuetan National Forest Park using a GoPro 360° panoramic camera. To account for seasonal changes in forest plants, aesthetic considerations, and visitor browsing patterns, this study selected the mixed forest trail landscape of Changbai larch and red bark Yunshan within the park. The height, width, and folding angle of the original wooden trestle video, as well as the density and height of the mixed forest and the sky-to-ground ratio, were scaled down to accurately represent the real scene. A virtual video was established in computer

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image processing software, simulating a first-person viewpoint of walking at a uniform speed of 1 m/s. In addition, the TASCAM Portacapture X6 recorder was used to record environmental sounds from the landscape space to recreate the true environment of the scene. To avoid differences in recovery benefits caused by variations in sound, in this study, during the experiment, the computer equipment played the original audio of the site in a consistent manner.

Visual and tactile experiment

Experimental flow

We selected the period from December 1, 2023, to December 7, 2023, as the experimental days, conducting sessions daily from 9:00 AM to 4:00 PM. Prior to the experiment, subjects were brought to the designated experimental location, where they wore EEG equipment and were informed about the experimental procedures and precautions. The participants were required to undergo a uniform stress test, which included: solving three difficult university-level math problems within a limited time (3 minutes) or performing a rapid translation from Chinese to English within a limited time (2 minutes) (note: the provided practice session was shorter than the normal required time for solving problems). After the test, the volunteers provided a quick rating. The score contributions of each participant in the group were also disclosed to ensure an increase in the participants' stress levels. Subsequent paired sample t-tests were conducted on the physiological and psychological data of the participants after and before the stress application, and the results showed a significant difference between the post-stress data and the pre-stress data, proving that the TSST stress test was effective. After completing the stress test, subjects were asked to fill out the Profile of Mood States (POMS) scale and monitor their brainwave power spectral density (PSD) as pre-test values for psychological and physiological indicators. A simplified flow of the experiment is demonstrated as shown in *Figure 3*.

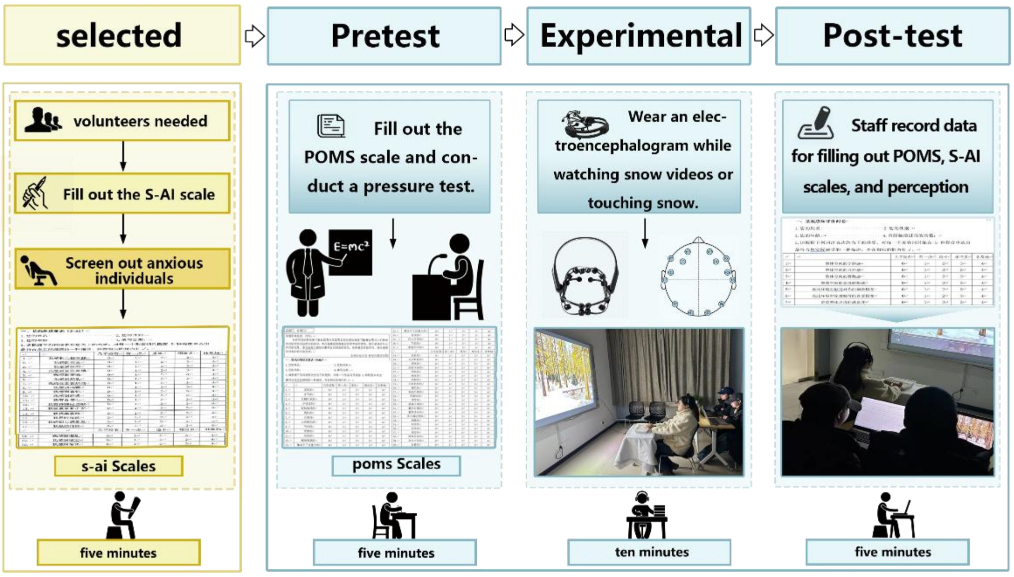

Figure 3. *The simplified flow of the experiment is shown in Fig. (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group)*

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At the beginning of the experiment, the NS control group, along with the A-DT and S-DT experimental groups, viewed a 5-minute snow video. Meanwhile, the A-T and S-T experimental groups were guided by volunteers to touch the snow in the containers while watching the snow video. To mitigate the potential confusion caused by the frequency of touch operations during the recovery process, the timing of the touch snow is aligned with the turning points of the trajectory in each video.

At the conclusion of the experiment, subjects were asked to complete the posttest Profile of Mood States (POMS) scale, the State Anxiety Inventory (S-AI) scale, and the landscape perception evaluation questionnaire. In addition, the Emotiv PRO software (Emotiv PRO 4.3.7.557, https://www.emotiv.com/products/emotivpro) was used to record the real-time power spectral density (PSD) test data of the subjects' brain waves, and the groups were clearly named to distinguish the data. Subsequently, the EEG equipment of the subjects was removed. The staff updated the materials for each subject to ensure hygiene. Finally, the subjects left the testing location.

Experimental methods

Electroencephalography (EEG) has emerged as a crucial tool for elucidating the factors underlying mood changes (Jiang et al., 2024). It offers valuable insights into neurological and affective computations due to its non-invasive nature and low cost (Alarcão and Fonseca, 2019). In this study, we selected EEG α-(8-13Hz) and β-(13-30Hz) wave power spectral densities (PSD) and calculated values of α/β as physiological metrics. In this study, the EMOTIV EPOC X (a portable electroencephalogram (EEG) device with electrodes developed by the American neurotechnology company EmotivSystem, located in San Francisco, California, USA) with saline channels was selected to non-invasively collect the scalp EEG data of the subjects, with a sampling rate up to 256Hz. This device employs non-invasive EEG technology and has 14 sensors set on the head-worn device. The positions of the device and electrodes are shown in *Figure 4*. Following the international 10/20 system, the 14 electrodes integrated with the device are AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4. This device can sense the electrical signals of each user's brain neurons, analyze and interpret them using advanced software, and then convert them into information that the computer can understand.

The POMS Brief Mood Scale (POMS) and S-AI State Anxiety Inventory (S-AI) were selected as the measurement tools for the psychological indicators in this study. The Profile of Mood State (POMS) is an emotional state assessment scale developed by American psychologist McNair et al. in 1971. During its application, POMS was simplified and developed by Grove JR et al. into a simplified version of POMS. In 1994, it was introduced to China and revised to establish the Chinese normative standards. The reliability of the Chinese simplified POMS ranges from 0.62 to 0.82, demonstrating high reliability and validity. The POMS scale consists of 40 mindfulness ratings, and the 40 indicators were classified into seven categories of emotional factors, including: tension (T), anger (A), fatigue (F), depression (D), panic (P), energy (E), and self-esteem (S). The S-AI scale is a sub-scale of the STAI (State-Trait Anxiety Inventory - Revised STAI - From Y 1980; Chinese translation; applicable to adults with junior high school education or above). S-AI (State Anxiety Scale) is usually a transient unpleasant emotional experience, such as tension, fear, worry, and neuroticism. The test-retest reliability of S-AI is 0.88, indicating a relatively high level of validity and reliability. The subjects in this study were classified into physiological indicators and psychological indicators. The main assessment indicators were electroencephalogram (EEG), as compared to psychological

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indicators, EEG provides more timely and accurate information. Secondary indicators include: changes in POMS indicators and changes in S-AI indicators. Total Mood Disorder (TMD) was calculated by assigning scores to the seven mood factors [TMD = T+A+F+D+P-(E+S) +100], with higher TMD scores indicating poorer overall mood. The S-AI State Anxiety Inventory quantitatively assesses the severity of participants' anxiety (Pang et al., 2019). and serves as the foundation for identifying subjects for this study. Higher scores on this scale indicate greater levels of anxiety. In this experiment, males with scores exceeding 53 and females with scores exceeding 55 are classified as anxious (Spielberger, 2010). Furthermore, the landscape perception evaluation questionnaire was developed based on the theoretical framework presented in The Theory of Landscape Planning and Design (China Agricultural Publishing House, 3rd edition). This questionnaire was constructed from both visual and tactile dimensions. The referenced book is a key educational resource for national planning and landscape architecture theory and practice courses in China, offering a comprehensive and systematic explanation of landscape planning and design, thereby providing a crucial theoretical foundation for landscape planning.

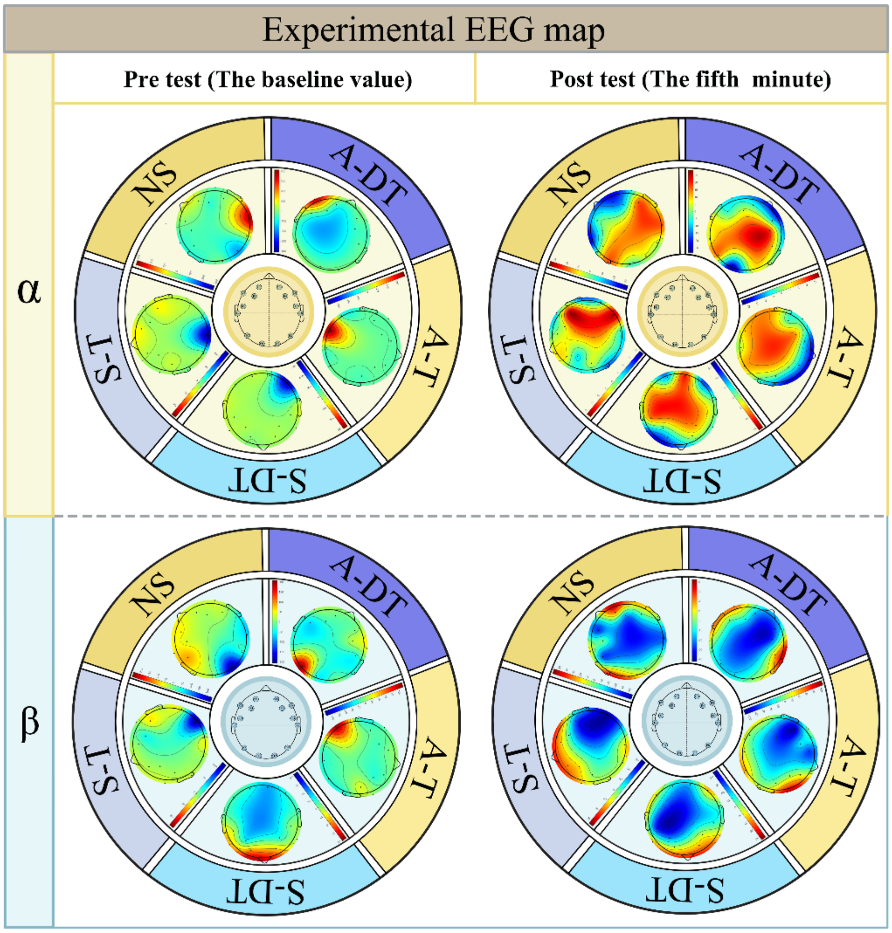

Figure 4. *Topographic maps of α- and β-wave power spectral density (PSD) before and after the experiment across the five experimental groups. (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group)*

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The questionnaire consisted of basic information. Frequency of ever touching snow (the subjects' experience of ever touching snow before this experiment, see *Table 1*). "Sense of tranquil" (the degree of tranquillity brought by the overall environment to the subjects: it can reflect the subjects' inner sense of tranquillity after the recovery experiment). "Sense of natural" (how natural and ecological the overall environment is to the subject: this reflects the subject's inner sense of the natural and ecological level of the overall environment after the restoration experiment). "Sense of hazy" (the subject feels the misty feeling of the picture visually: it can reflect the misty feeling that the overall picture brings to the subject). "Artistic conception associations" (the associations that the subject feels in the context: the extent to which the subject feels the associations that he/she has made throughout the experiment after the experiment is resumed). "The level of excitement of touching the snow" (the degree of excitement felt by the subject when touching the cold snow). "How much you love to touch the snow" (how much the participant enjoys touching snow). "Overall environmental satisfaction" (the level of overall satisfaction with the overall picture environment and the feeling of touching snow). The questionnaire was a five-point scale with a rating level of 5 for each question, and the subjects were asked to fill in this questionnaire after watching the video, as shown in *Table 1*.

Table 1. *Landscape perception questionnaire form*

<table>
<tr><td>1. Your Name:</td><td colspan="3">2. Your Gender:</td><td colspan="3">3. Your Age:</td></tr>
<tr><td colspan="6">4. How often you have touched snow: (1 never touched snow, 2 touched snow but only a few times, 3 touched snow and often)</td></tr>
<tr><th>Item</th><th colspan="5">Grading scale</th></tr>
<tr><td>Tranquil</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Natural</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Hazy</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Artistic conception associations</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>The level of excitement of touching the snow</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>How much you love to touch the snow</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Overall environmental satisfaction</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
</table>

Note: Please rate the space according to the degree of favouritism. Only select the description that best matches your actual feelings out of the 5 levels and mark the appropriate box!

Statistical analysis methods

In this study, we used the Emotiv PRO software to export the original brain electrical PSD (in EDF format file) and selected the baseline (60s) and 5th minute (60s) EEG values of the subjects' EEGs as the pre- and post-test data values. values were selected as the pre- and post-test data values. Data preprocessing of the EEG PSD was performed using MATLAB R2021b software (R2021b https://www.mathworks.cn/products/matlab.html), which firstly performed electrode position localisation to remove useless electrode data. Then the sampling rate was reduced, the re-reference was set to the average reference, and the filtering was set to high-pass filtering (0.5 Hz) and notch filtering (48-52 Hz) to filter out the low-frequency interference and industrial frequency interference. Next, the data were browsed for artefact rejection, keeping the default options to run the ICA. Next, the properties of each independent component were observed, and the independent components associated with artefacts were again removed to correct errors due to eye

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movements and EMG. After completing the preprocessing to ensure the quality of the brainwave signals, the power spectrum analysis technique is used to analyze the changes in brainwaves before and after the experiment.

This study utilized SPSS 26.0 software for data analysis. A normality test was conducted beforehand, and the results indicated that the data indicators followed an approximately normal distribution. The histograms, normal P-P plots, and normal Q-Q plots obtained from the data analysis conformed to the characteristics of a normal distribution. (IBM SPSS Statistics 26 https://www.ibm.com/cn-zh/spss), and the data were plotted using origin 2022 software (2022 https://www.originlab.com/) for data plotting. (Note: All data analyses in this study were conducted in a blinded manner.) *Figure 4* shows the changes in brain topography before and after the participation of some of the experimenters in this study.

Results

Descriptive statistics and analysis

Descriptive statistical analysis of psychological recovery

According to *Figure 5*, the negative mood scores (tension, anger, fatigue, depression, panic) and the total mood disorder (TMD) indicators from the POMS scale for the five experimental groups exhibited a significant downward trend ($P < 0.01$). Conversely, the positive mood indicators (energy, ego) for each group demonstrated a significant upward trend. In the experimental groups A-DT, the negative mood indicators in the post-test decreased significantly ($P < 0.001$), while the positive mood indicators in the post-test increased significantly. These findings suggest that the snow-covered white landscape environment in winter is conducive to the psychological recovery of the subjects, with the recovery benefits of this environment being particularly pronounced. The mean values and their standard deviations as well as the exact p-values before and after each group's measurement are presented in *Table 2*.

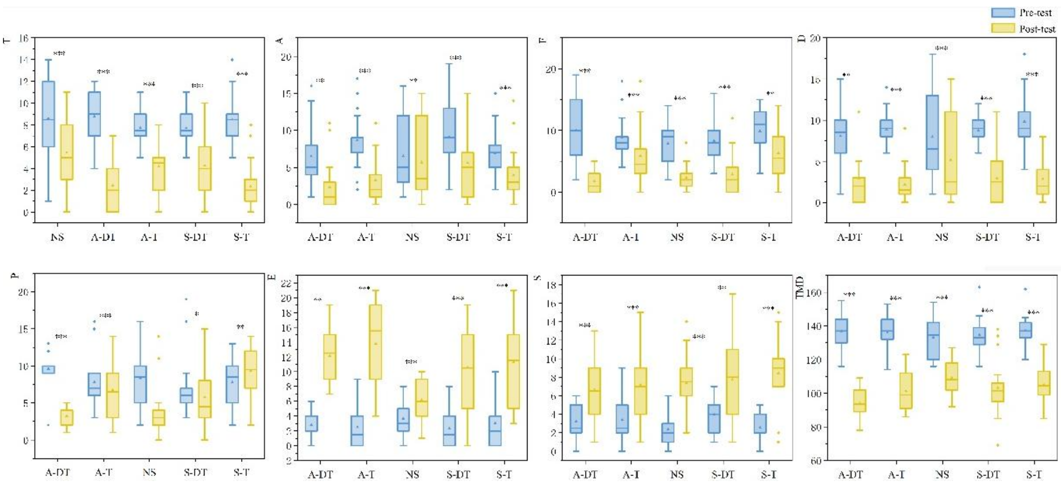

Figure 5. *Box plots of pre- and post-experimental changes in POMS scale scores for each mood factor, (N=18 per group). (*** p < 0.001. ** p < 0.01. * p < 0.05) (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group)*

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Table 2. *Means ± Standard Deviation (SD) for each group with exact p-values*

Item	Groups	Mean ± Mean Difference Pre-test	Post-test	p-value
Tension	NS	8.611±0.845	5.444±0.768	0.000
	A-DT	8.778±0.608	2.444±0.579	0.000
	A-T	7.722±0.394	4.167±0.513	0.000
	S-DT	7.722±0.394	4.278±0.737	0.000
	S-T	8.500±2.333	2.333±0.536	0.000
Anger	NS	6.500±1.153	5.667±1.226	0.009
	A-DT	6.500±0.988	2.333±0.784	0.000
	A-T	8.667±0.897	3.278±0.709	0.000
	S-DT	9.111±1.016	5.611±1.138	0.002
	S-T	6.889±0.762	3.944±0.869	0.000
Fatigue	NS	7.889±0.788	2.333±0.471	0.000
	A-DT	10.000±1.311	1.778±0.392	0.000
	A-T	8.833±0.797	5.889±1.051	0.000
	S-DT	8.333±0.775	2.833±0.746	0.000
	S-T	9.889±0.847	6.333±0.997	0.002
Depression	NS	7.944±1.184	5.167±1.144	0.001
	A-DT	8.056±0.951	2.944±0.927	0.000
	A-T	8.889±0.498	2.167±0.525	0.000
	S-DT	8.778±0.440	2.944±0.674	0.000
	S-T	9.833±0.751	2.833±0.493	0.000
Energy	NS	3.667±0.560	6.167±0.678	0.007
	A-DT	2.833±0.422	12.167±0.919	0.000
	A-T	2.500±0.673	13.778±1.282	0.000
	S-DT	2.333±0.594	10.556±1.314	0.000
	S-T	3.056±0.806	11.278±1.397	0.000
Panic	NS	8.333±0.950	4.111±0.921	0.000
	A-DT	9.611±0.561	3.222±0.339	0.000
	A-T	7.833±0.905	6.722±0.959	0.020
	S-DT	7.111±0.956	5.778±0.941	0.062
	S-T	7.778±0.769	9.333±0.812	0.004
Self-Esteem	NS	2.389±0.354	7.389±0.705	0.000
	A-DT	3.222±0.475	6.611±0.755	0.000
	A-T	3.389±0.549	7.167±0.875	0.001
	S-DT	3.944±0.439	7.722±1.041	0.000
	S-T	2.556±0.345	8.444±0.940	0.000
TMD	NS	133.222±2.742	109.167±2.427	0.000
	A-DT	136.889±2.597	93.944±2.032	0.000
	A-T	136.056±2.585	101.278±2.642	0.000
	S-DT	134.778±2.599	103.167±4.020	0.000
	S-T	137.278±2.209	105.056±2.614	0.000

As shown in *Figure 6*, the total posttest scores of the S-AI State Anxiety Inventory for the five experimental groups were all lower than the pretest scores. Notably, the posttest values of the A-DT group exhibited a highly significant decreasing trend compared to the pretest scores ($P < 0.001$). It suggests that white snow-covered landscapes in winter have a mitigating effect on human anxiety states, with highly significant restorative benefits in landscapes where the snow stops without touching the snow, and weaker restorative ability of landscape environments touching the snow to restore subjects' anxiety states. The mean values and their standard deviations (or standard errors) before and after each group's measurement, as well as the sig values, are shown in *Table 3*.

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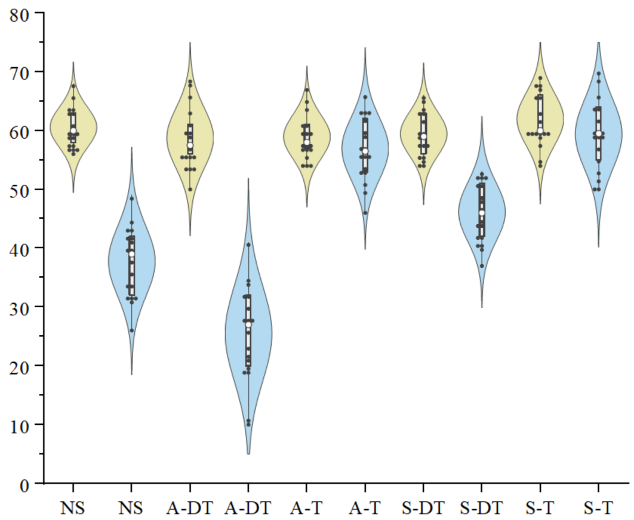

Figure 6. *Histogram of pre- and post-experimental changes in S-AI scale scores (N=18 per group). (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group.) (*** p < 0.001. ** p < 0.01. * p < 0.05)*

Table 3. *Means ± Standard Deviation (SD) for each group with sig*

Item	Groups	Mean±Mean Difference		Sig
		Pre-test	Post-test	
S-AI	NS	60.556±0.805	37.778±37.778	0.000
	A-DT	58.722±1.209	25.500±1.922	0.000
	A-T	58.944±0.876	56.944±1.248	0.011
	S-DT	59.444±0.879	46.167±1.183	0.000
	S-T	61.944±1.056	59.389±59.389	0.069

Descriptive statistical analysis of physiological recovery

The five-minute changes of α-wave, β-wave and α/β-wave PSD of the subjects in different conditions are shown in *Figure 7*, and the paired-sample t-test shows that after the experiment, only the A-DT group and the NS group showed an increasing trend of α-wave and α/β-wave and a decreasing trend of β-wave in comparison with the NS group.

The rest of the groups showed the opposite negative recovery trend. This suggests that a general forest landscape environment without snow elements can lead to neurological relaxation of the brain and is a confirmation of previous studies by scholars (Mattila et al., 2020; Shi et al., 2024). Similarly, for the present study, it illustrates that landscape environments without touching snow after snowfall can have positive restorative benefits on human brain by increasing the sense of relaxation and decreasing the sense of tension, which can have positive restorative benefits on human mood and brain relaxation. The mean values and their standard deviations before and after each group's measurement, as well as the sig values, are shown in *Table 4*.

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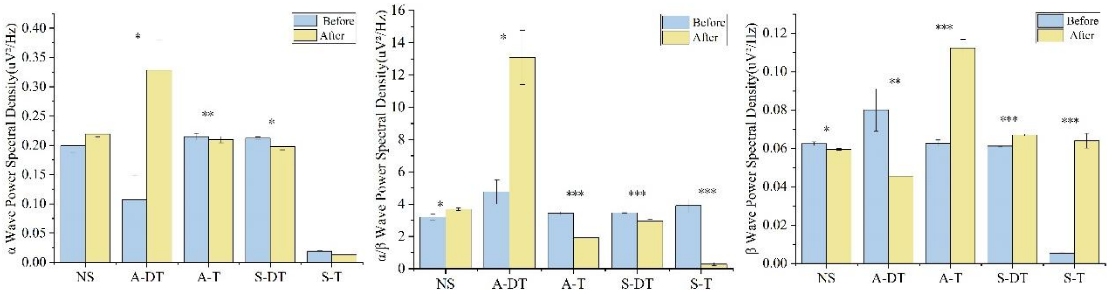

(a) (b) (c)

Figure 7. *Histograms of pre- and post-experimental changes in each brain wave of the EEG in the five experimental groups. (a) Change in Alpha Wave Power Spectral Density (PSD); (b) Changes in Beta wave Power Spectral Density (PSD); (c) Change in Alpha/ Beta wave Power Spectral Density (PSD); (N=18 per group). (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group.) (*** p < 0.001. ** p < 0.01. * p < 0.05)*

Table 4. *Means ± Standard Deviation (SD) for each group with sig*

Item	Groups	Mean±Mean Difference		Sig
		Pre-test	Post-test	
α	NS	0.199±0.011	0.219±0.005	0.074
	A-DT	0.312±0.041	0.533±0.052	0.019
	A-T	0.215±0.006	0.210±0.006	0.001
	S-DT	0.212±0.002	0.198±0.006	0.013
	S-T	0.019±0.002	0.013±0.004	0.105
β	NS	0.062±0.001	0.059±0.000	0.013
	A-DT	0.080±0.011	0.045±0.003	0.005
	A-T	0.063±0.002	0.112±0.004	0.000
	S-DT	0.061±0.001	0.067±0.001	0.000
	S-T	0.005±0.001	0.064±0.004	0.000
α/β	NS	3.198±3.689	0.182±0.081	0.013
	A-DT	4.760±13.090	0.745±1.686	0.000
	A-T	3.441±1.923	0.077±0.093	0.000
	S-DT	3.469±2.961	0.037±0.091	0.000
	S-T	3.908±0.280	0.373±0.099	0.000

Descriptive statistics of landscape perception evaluation scores

The reliability of the collected questionnaire data on landscape perception preferences was tested. The Cronbach's alpha value was 0.712, indicating that the questionnaire data had a high level of reliability. The KMO (Kaiser-Meyer-Olkin) test was conducted on the questionnaire data, and the KMO value was 0.772, suggesting that the validity of this questionnaire data was high.

As shown in *Figure 8*, the scores for 'sense of tranquility' (3.9444±0.23523) and 'sense of nature' (3.8889±0.33224) in the A-DT and S-DT groups were the highest among the six groups, indicating that the winter environment, devoid of direct snow stimulation, elicited the strongest feelings of tranquility and connection to nature in the subjects. The S-T group recorded the highest score for 'hazy feeling' (4.2222±0.17482), followed closely by the S-DT group (4.1111±0.31195), suggesting that the presence of falling

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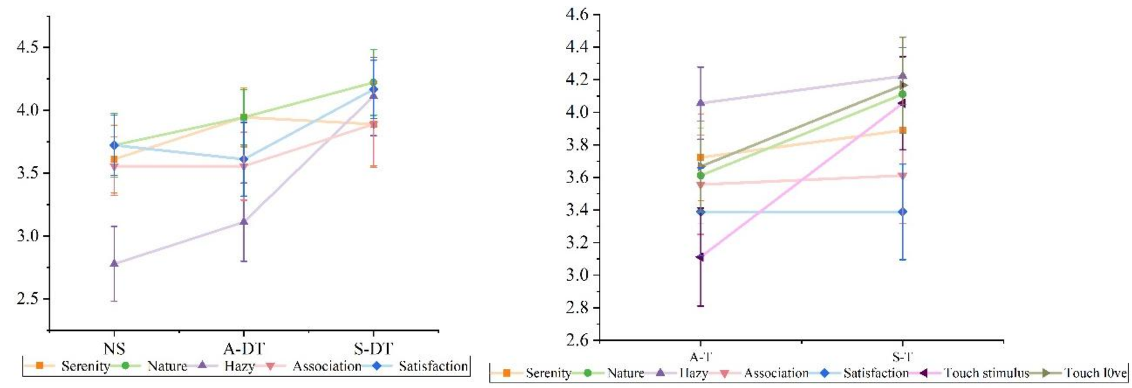
snowflakes obscured visibility, resulting in a hazy perception. Additionally, the S-DT group achieved the highest score for 'sense of contextual association' (3.8889±0.34432), with the S-T group following at (3.6111±0.29304), indicating that falling snowflakes in a snowy environment foster a stronger sense of contextual association among the subjects.



(a) (b)

Figure 8. *Descriptive chart of the scores of each indicator of the landscape perception evaluation questionnaire for the five experimental groups. (a) Descriptive statistics for the three groups not touching snow; (b) Descriptive statistics results for two groups touching snow (N=18 for each group). (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group)*

Recovery results of visual and tactile perception dimensions

Comparison of recovery results of psychological indicators

Table 5 presents the results of a one-way ANOVA analysis, indicating significant differences in the subjects' recovery scores across various factors, including tension, anger, fatigue, depression, energy, panic, and TMD mood factors on the POMS scale. Notably, there was no significant difference observed in the self-emotional recovery scores. Subsequent post hoc multiple comparisons revealed that subjects in the A-DT group exhibited superior recovery in terms of tension, fatigue, panic, and the total value of TMD emotional strife compared to the other four groups.

Table 6 presents the results of a one-way analysis of variance (ANOVA), demonstrating significant differences in the recovery values of subjects measured by the S-AI scale. Subsequent post hoc tests for multiple comparisons revealed that subjects in the A-DT group exhibited the most effective recovery from anxiety. This indicates that, among the five groups studied, the A-DT group achieved the highest level of anxiety recovery.

Comparison of recovery results of physiological indicators

Table 7 presents the results of a one-way ANOVA analyzing the variance in recovered values of α, β-wave power spectral density (PSD), and α/β ratios in the brain waves of the subjects. Subsequent multiple comparisons using the time test indicated that the subjects in the A-DT group exhibited the most significant recovery in α, β-wave PSD, and α/β values. This was followed by the NS group, which showed improvements in α-wave PSD, β-wave PSD, and α/β ratios. These findings suggest that, among the five groups studied,

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the A-DT group experienced superior EEG recovery benefits compared to the other four groups.

Table 5. *One-way ANOVA table for recovery of POMS scale mood factor*

Item	Groups	Mean	Standard Deviation	ANOVA F	ANOVA Sig	After-the-fact Comparison
Tension	NS	-3.167	1.295	7.159	0.000**	NS＞S-T＞A-DT
	A-DT	-6.333	2.787			
	A-T	-3.556	2.175			
	S-DT	-3.444	2.526			
	S-T	-6.167	3.258			
Anger	NS	-.8333	1.201	5.889	0.000**	NS＞S-T＞A-DT＞A-T
	A-DT	-4.167	2.936			
	A-T	-5.389	3.550			
	S-DT	-3.500	4.033			
	S-T	-2.944	2.100			
Fatigue	NS	-5.556	2.995	4.989	0.001**	A-T＞S-T＞A-DT
	A-DT	-8.222	4.870			
	A-T	-2.944	2.754			
	S-DT	-5.500	4.579			
	S-T	-3.556	4.003			
Depression	NS	-2.778	3.001	6.830	0.000**	NS＞S-DT＞ A-T＞ S-T
	A-DT	-5.111	2.541			
	A-T	-6.722	2.164			
	S-DT	-5.833	2.936			
	S-T	-7.000	2.970			
Energy	NS	2.500	3.434	7.153	0.000**	A-T ＞A-DT＞S-DT= S-T
	A-DT	9.333	3.881			
	A-T	11.278	5.839			
	S-DT	8.222	6.691			
	S-T	8.222	5.386			
Panic	NS	-4.222	2.074	33.192	0.000**	S-T＞A-T S-DT＞ NS＞ A-DT
	A-DT	-6.389	2.404			
	A-T	-1.111	1.844			
	S-DT	-1.333	2.828			
	S-T	1.556	2.007			
Self-Esteem	NS	5.000	2.590	1.713	0.157	
	A-DT	3.333	1.782			
	A-T	3.778	3.949			
	S-DT	3.778	3.719			
	S-T	5.833	4.162			
TMD	NS	-24.056	8.7480	5.431	0.001**	NS＞A-T＞A-DT
	A-DT	-42.944	11.227			
	A-T	-34.778	11.471			
	S-DT	-31.611	16.501			
	S-T	-32.222	12.568			

Notes: (*** p < 0.001. ** p < 0.01. * p < 0.05) (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group.) ("A > B" indicates that group A showed a greater improvement (i.e., better recovery) than group B)

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Table 6. *One-way ANOVA table for S-AI scale anxiety recovery*

Item	Groups	Mean	Standard Deviation	ANOVA		After-the-fact Comparison
				F	Sig	
S-AI	NS	-28.889	7.475	131.845	0.000**	A-T＞S-T＞S-DT＞NS＞A-DT
	A-DT	-33.222	6.348			
	A-T	-2.000	2.990			
	S-DT	-13.278	2.866			
	S-T	-2.556	5.586			

Notes: (*** p < 0.001. ** p < 0.01. * p < 0.05) (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group)

Table 7. *One-way ANOVA table for each brainwave recovery*

Item	Groups	Mean	Standard Deviation	ANOVA		After-the-fact Comparison
				F	Sig	
α	NS	0.02011	0.04486	6.715	0.000***	A-DT＞NS＞S-DT＞A-T＞S-T
	A-DT	0.22096	0.36280			
	A-T	-0.00496	0.00506			
	S-DT	0.00602	0.00142			
	S-T	-0.01448	0.02202			
β	NS	-0.00303	0.00462	57.476	0.000***	S-DT＞A-T＞S-T＞NS＞A-DT
	A-DT	-0.03461	0.04611			
	A-T	0.04961	0.01820			
	S-DT	0.06294	0.00314			
	S-T	0.00561	0.00170			
α/β	NS	0.49135	0.74757	9.479	0.000***	A-DT＞NS＞S-T＞A-T＞S-DT
	A-DT	13.06929	19.31967			
	A-T	-1.51764	0.43784			
	S-DT	-1.76662	0.22238			
	S-T	-0.50819	0.36602			

Notes: (*** p < 0.001. ** p < 0.01. * p < 0.05) (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group.) ("A > B" indicates that group A showed a greater improvement (i.e., better recovery) than group B)

Correlation analysis of snow perception evaluation and human psychophysiological recovery

Correlation analysis of psychological indicators

The Spearman correlation analysis of landscape perception evaluation and POMS scale scores revealed that there were significant correlations among the various factors. As illustrated in *Figure 9*, changes in tranquillity and tension across the five experimental groups exhibited a negative correlation, suggesting that the recovery benefits from tension were greater when subjects experienced higher levels of tranquillity in the snow-covered environment. Conversely, changes in haziness and depression within the S-DT and S-T groups showed a positive correlation, indicating that the recovery benefits from depression were diminished when subjects perceived increased haziness in the snowy setting. Furthermore, the degree of snow stimulation in the A-T and S-T groups was positively correlated with the recovery benefits from panic, implying that panic recovery was less effective when subjects experienced higher levels of snow stimulation. This

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positive correlation further suggests that the recovery from panic is compromised under conditions of heightened snow stimulation in a snowy environment.

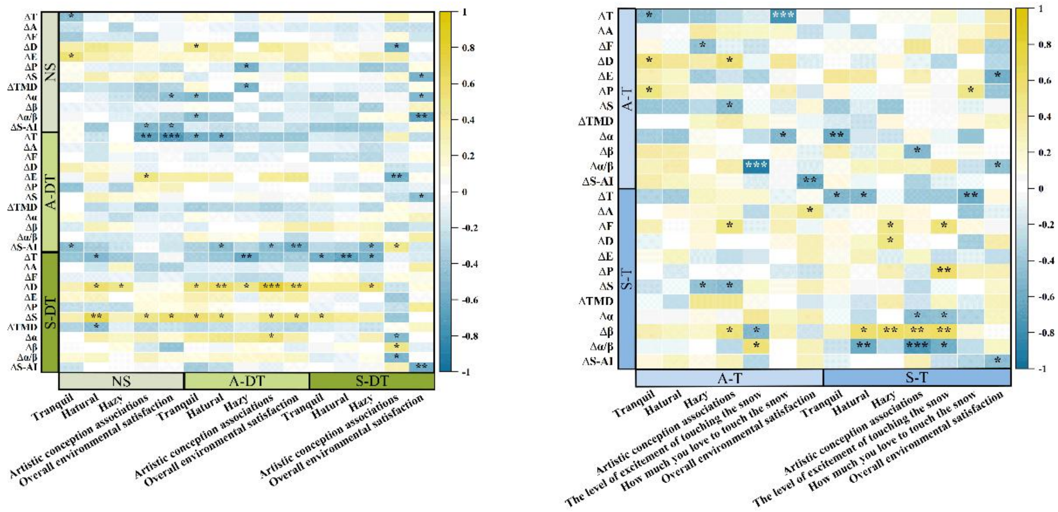

Figure 9. *Heatmap of correlation analysis between landscape perception evaluation indicators and Psychophysiological recovery indicators (N=18 per group). (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group.) (*** $p < 0.001$. ** $p < 0.01$. * $p < 0.05$). Note: In the correlation analysis of this study, the values of the psychological and physiological indicators used are the changes before and after the experiment*

The Spearman correlation analysis between landscape perception evaluation and the S-AI scale score revealed an important finding. As illustrated in *Figure 9*, overall environmental satisfaction exhibited a negative correlation with the degree of change in total anxiety across the five experimental groups. This suggests that subjects experienced a more effective recovery from anxiety when their overall satisfaction with the landscape was heightened in the snow-covered environment.

Correlation analysis of physiological indicators

The evaluation of landscape perception and the analysis of the Spearman correlation between brain waves revealed significant findings. As illustrated in *Figure 9*, the degree of snow stimulation experienced by the A-T and S-T groups was found to be negatively correlated with the power spectral density (PSD) of α-waves and changes in α/β-wave activity, while showing a positive correlation with the PSD of β-waves. This suggests that subjects experience lower levels of brain relaxation and heightened concentration and tension when exposed to higher levels of stimulation from touching snow and ice. Furthermore, a negative correlation was observed between the sense of contextual association and changes in α-wave PSD and α/β-wave activity, alongside a positive correlation with changes in β-wave PSD within the S-T and S-DT groups. These findings indicate that subjects exhibit reduced brain relaxation and increased concentration and tension when experiencing a strong sense of contextual association in the falling snow environment.

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Relationship between touch experience and human recovery

As shown in *Table 8*, in the A-T and S-T groups, the 'frequency of ever touching snow' in the landscape perception evaluation was negatively correlated with the 'degree of stimulation of touching snow' in the landscape perception questionnaire. Conversely, the 'frequency of ever touching snow' was positively correlated with the '$\Delta\alpha/\beta$' in the landscape perception questionnaire for both the A-T and S-T groups. Notably, 'frequency of ever touching snow' exhibited a negative correlation with '$\Delta\alpha/\beta$' in the landscape perception questionnaire, while simultaneously demonstrating a positive correlation with '$\Delta\alpha/\beta$' in the A-T and S-T groups. For instance, a subject who had never touched snow before experienced a heightened sensation of snow and ice stimulation during this experiment. However, when this individual touched snow while viewing a video of winter snow-covered landscapes, their EEG recovery benefit was diminished.

Table 8. *Correlation analysis table for snow touch stimulation score*

Item	A-T The thrill of touching snow	A-TΔα/β	Item	S-T The thrill of touching snow	S-TΔα/β
A-T The experience of having touched the snow	-0.953***	0.565*	**S-T The experience of having touched the snow**	-0.544*	0.545*

Notes: (*** p < 0.001. ** p < 0.01. * p < 0.05). (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group.) (*** p < 0.001. ** p < 0.01. * p < 0.05)

The mediating role of touch experiences

As shown in *Table 9*, a mediation effect model was established with the degree of the subjects' perception of the snow's stimulus as the independent variable (X); the subjects' past experiences of touching the snow as the mediating variable (M); and the $\Delta\alpha/\beta$ data after the subjects conducted the recovery experiment as the dependent variable (Y).

Table 9. *Table analysing intermediation effects*

item	C Total Effect	a×b Intermediary Effect Value	a×b (Boot SE)	a×b (95% BootCI)	c' Direct Effect	Inspection Conclusion	Effect Proportion
A-T The thrill of touching snow≥Δα/β	-1.418	-0.954***	0.624	-2.178 - 0.269	-0.463	Partial intermediation	67%
S-T The thrill of touching snow≥Δα/β	-0.367	-0.268***	0.183	-0.627- 0.090	-0.098	Partial intermediation	73%

Notes: (*** p < 0.001. ** p < 0.01. * p < 0.05). (NS: No white Snow group; A-DT: After snow falling and Don't Touch snow group; A-T: After snow falling and Touch snow group; S-DT: during Snow falling and Don't Touch snow group; S-T: during Snow falling and Touch snow group.) (*** p < 0.001. ** p < 0.01. * p < 0.05)

The model indicates that in the A-T group and the S-T group, "previous snow contact experience" has a significant partial mediating effect on the $\Delta\alpha/\beta$ pathway of the snow contact stimulus, with the mediating effect values being -0.954 and -0.268 respectively.

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This suggests that the changes in the subjects' brain waves are influenced not only by the degree of snow and ice stimulation they experience but also by their prior encounters with snow during the snow touching experiments.

Discussion

Winter forest trail snow landscapes can relieve anxiety

The creation of attractive urban green landscapes is essential for enhancing perceived recovery, as individuals in winter forest environments can experience emotional recovery benefits (Bielinis et al., 2018b, 2019; Bao et al., 2023). The comparison between the A-DT group and the NS group in this study shows that white snow-covered landscape environments in winter can produce better physiological and psychological recovery benefits for anxious youth compared to snow-free landscape environments. This finding effectively addresses research question 1 (RQ1). Furthermore, the present study posits that individuals walking along a forest trail after snowfall may experience even greater recovery benefits. This could be attributed to the fact that snow is a highly favored element of the winter atmosphere (Hidalgo, 2021), with people often associating it with winter outdoor sports. Consequently, winter forest bathing therapy appears to have a positive impact on individuals' mood (Bielinis et al., 2018a). Additionally, the absence of leaves in mixed forests during winter significantly enhances light penetration, while the white snow covering the ground creates a smooth, bright backdrop that reflects light intensely (Terao and Hoaki, 2010). This bright light has been shown to alleviate low mood (Toscani et al., 2020), thereby contributing to restorative benefits for the participants.

Touching snow and falling snowflakes inhibits brain relaxation in anxious people

EEG signals, which measure the transient effects of neural activity with millisecond temporal accuracy, can be utilized to directly assess a person's transient recovery benefits (Yu and Chen, 2023; Yu et al., 2023). In contrast, psychological recovery depends on the mobilization of positive emotions and has long-term benefits (Mayer et al., 2009), leading to a recovery lag. Consistent with the findings of the present study, landscape and snow stimuli during snowfall were associated with an increasing trend in psychological recovery benefit values among subjects, whereas physiological recovery benefit values exhibited a decreasing trend. The diminished physiological recovery benefits observed in subjects during snowfall may be attributed to the phenomenon that, even when individuals deliberately focus on a specific stimulus, their attention can be involuntarily diverted by irrelevant events (Alho et al., 2015). This distraction may activate the parietal and frontal regions of the cerebral cortex, thereby impairing concentration (Salo et al., 2017). Consequently, while watching a video of falling snow, the snowflakes may divert the subjects' attention and heighten their arousal, resulting in reduced recovery. This distraction could also explain the heightened 'sense of contextual association' and 'sense of haze' experienced by the subjects. Therefore, while tourists seeking the hazy beauty and contextual associations offered by falling snowflakes might choose to travel during snowfall, it is our belief that this environment does not provide substantial healing benefits for anxiety. The observed poor recovery benefits when subjects touched the snow may stem from the immediate contact with a cold object, which induces local vasoconstriction. This response triggers the release of neuropeptide Y (NPY) due to low-temperature stimulation, exciting the sympathetic nerves and consequently elevating

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blood pressure and heart rate (Coovadia et al., 2024). Such physiological responses may exacerbate the load on the heart, leading individuals to feel alert, nervous, and tense.

In summary, when designing plant arrangements along forest trails, designers must consider that 'falling snowflakes' and 'touching snow' can elicit non-positive physiological responses in individuals. For instance, in a specific area of the trail, it may be beneficial to plant tall evergreen trees to provide wider foliage during the winter months in Northeast China, thereby minimizing the exposure of dry branches and reducing the impact of falling snowflakes on tourists' relaxation and mental well-being. Additionally, strategically placed billboards and slogans can utilize warm language to inform visitors that interacting with cold snow and ice may offer varying recovery benefits on both physical and psychological levels. Ultimately, the decision to engage with the snow and ice rests with the visitor, based on their individual condition.

The serenity of snowy forest trails is more restorative to tension

The sense of tranquility elicited by forest spaces is closely linked to the density of forest greenery (Shi, 2017). When the degree of spatial closure exceeds 1/2, evaluations of soundscape pleasure increase correspondingly (Liu et al., 2023). More spatial closure in forest trails fosters a strong sense of privacy and isolation, thereby enhancing the overall spatial serenity. Consequently, even during winter when leaves have fallen, the inherent secrecy and isolation of the forest continue to promote relaxation and enjoyment of the soundscape among subjects. In this study, correlation analysis between the 'sense of tranquility' experienced on the forest landscape trail and the recovery index of the subjects reveals that, across all five experimental groups, the tranquility associated with snow significantly alleviates tension. Notably, the A-DT group, which demonstrates the most substantial recovery benefits, also exhibits the most pronounced reduction in tension. Thus, the tranquility provided by snow is particularly restorative in terms of tension. This finding addresses Research Question 2 (RQ2) comprehensively.

The effect of previous snow touching experience on recovery in anxious people

The experiment involving the tactile experience of snow suggests that the brain's poor mental recovery is linked to 'the degree of stimulation felt when touching snow.' This stimulation is closely associated with the individual's experience of touching snow. Consequently, the limited recovery benefits derived from touching snow may stem from the fact that individuals who have never encountered snow experience a sense of novelty and possess a low tolerance for cold. When such individuals touch snow, they may feel nervous, leading to heightened states of alertness, excitement, or mental concentration. This state can result in a significant decrease in α-wave power spectral density (PSD) and a notable increase in β-wave PSD (Wen et al., 2024), thereby contributing to the diminished recovery benefits. Thus, the experience of touching snow inversely influences the level of stimulation perceived by the subjects, while also facilitating their physical and mental recovery. Ultimately, for visitors who have never interacted with snow and ice, engaging with these elements while recreating the landscape can provide a novel and exhilarating experience. This discussion addresses Research Question 3 (RQ3).

Research limitations and outlook

This study has several limitations: the findings are confined to contemporary anxious young adults, and no comprehensive investigation has been conducted across the entire

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age spectrum of the anxious population. Additionally, the current research is based on virtual experimentation conducted indoors, neglecting the potential impact of various objective factors present in outdoor settings. The conclusions of this study are particularly persuasive due to our focus on a specific age group of youth experiencing anxiety. Additionally, the virtual experimental approach employed in this study minimized the influence of uncontrollable external factors, resulting in more precise data. However, in order to enhance the practical applicability of our research results, we plan to conduct future studies involving different age groups, narrowing the age classification range, refining the gender distribution of the subjects and the duration of their anxiety states, in order to obtain more precise conclusions; at the same time, we also consider conducting long-term follow-up research trials to explore the changes in the physical and mental health of the subjects over a long period. In the subsequent research, we will continue to improve the experimental conditions, such as the EEG equipment and temperature control equipment we use, to provide more forward-looking and comprehensive conclusions. Moreover, our goal is to explore the outdoor environment to achieve broader and more comprehensive scientific and theoretical significance. Future research should include outdoor field studies covering a wider range of age groups and a more diverse population. This research can serve as the theoretical basis for generating new guidelines for the design of urban forest park trails. Given the dual nature of white healing, it is crucial for tourists to recognize the recovery benefits of snow and travel accordingly during outdoor winter activities. Furthermore, forest trails should incorporate suitable recreational facilities that enable visitors to interact with the snow. If these conclusions are widely implemented in the future, visitors will be better positioned to fully utilize natural landscape resources for therapeutic purposes.

Conclusions

This study explores the relationship between landscape and tactile elements and restoration benefits, using winter urban forest trails as the centre of the study. Our study reached the following conclusions: Firstly, in winter environments in forest trails, the restoration benefits of Environment without touching the snow after snowfall are more significant than those of snow-free landscapes after it falls, and both can produce positive physiological and psychological indicators of restoration benefits. Second, falling snowflakes and touching snow and ice inhibit neural relaxation in the brain. The above two findings fully illustrate the two-sided nature of the healing effects of winter whiteness. Once again, subjects 'perception of snow was an important subjective factor in subjects' recovery benefits, and we found that the sense of tranquillity brought by snowy forest trails promoted subjects' tension recovery even more. Finally, subjects' previous experience of touching snow plays a non-negligible mediating role in the human physiological recovery process. This study enabled subjects to experience a winter landscape environment through virtual video, thus providing this more convenient virtual avenue for emotional recovery for anxious youth who are unable to physically visit outdoor winter environments. Providing a restorative environment that warms the body and mind during the cold winter months is necessary for urban forest trails to have a profound impact on the health and well-being of anxious people. At the same time, in the current social context, there is a growing concern and emphasis on the physical and mental health of young students. Therefore, research on restorative winter forest trails landscapes should be a focus for policy makers.

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At the same time, it is hoped that the strategic theory derived from this research can provide inspiration for landscape planners. When designing park landscapes and routes, they should not merely consider the convenience of transportation or the zoning of the planning; whether it is the planning of the routes or the placement of slogan-type billboards, they should all be based on the people-oriented principle, so that tourists can be exposed to as many excellent restoration benefits as possible, and make the park a comprehensive health care venue that can provide true health benefits for tourists, rather than just a single venue that provides visual beauty.

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Author contributions statement. Ning, W., Cai Y., Wang, Y. Y. and Sun M. carried out the overall design of this project, Wang, Y. Y., Sun, M., Wang, Q. H., Zhang, X. and Chen, H. N. were involved in the specific work of the experiment, Wang, Y.Y. and Sun, M. carried out the writing of the text of this study as well as the data analysis and processing, and Ning, W. and Cai, Y. guided and revised the text of the study. All authors have reviewed and commented on the manuscript.

Data availability statement. In this study, it is not appropriate to disclose the private data of the participants due to the ethical issue of protecting the privacy of the trial participants. Please contact Ning, W. about the experimental data and code.

Competing interests. The authors declare no competing interests.

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