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Twelve-Day Space Station Isolation Simulation: The Effect of Virtual Nature Therapy on Depression in an Isolated, Enclosed Environment

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This study investigates the therapeutic effects of virtual reality (VR)-based nature therapy on mild depression in a simulated space station isolation environment. The confined and enclosed environment of a space station deprives individuals of contact with the natural environment, potentially exacerbating depressive symptoms. We designed an experiment combining traditional depression treatments with VR-based virtual nature therapy to explore a novel therapeutic approach. Thirty participants (15 males and 15 females) were randomly assigned to 2 groups: One receiving traditional treatment plus VR-based nature therapy, and the other receiving only traditional treatment. Depression symptoms were assessed at the baseline and after 12 days. The experimental group underwent 12 days of VR-based nature therapy, resulting in reduced depressive symptoms as measured by the Hospital Anxiety and Depression Scale and the Positive and Negative Affect Schedule. However, there were no marked changes in the Quick Inventory of Depressive Symptomatology—Self-Report scale scores. Compared to the experimental group, the control group exhibited smaller improvements in depressive symptoms. These findings affirm the efficacy and applicability of VR-based nature therapy, offering insights for future research into habitat environments for deep-space exploration.

Introduction

Long-term human habitation beyond Earth—whether on orbital space stations, future lunar bases, or crewed deep-space missions—places astronauts in environments characterized by strict isolation, limited physical space, and social deprivation [1]. Since the advent of human spaceflight, the assessment and optimization of astronauts' psychological and emotional well-being have been a primary focus of research at astronaut training centers worldwide [2]. Identifying the most effective training methods for enhancing human performance in space is a critical issue for spaceflight missions. In recent years, many nations have redirected their human spaceflight programs toward crewed deep-space exploration, lunar research stations, or Mars missions [1–3]. In these environments, astronauts are isolated, face isolation from their familiar social networks, and are unable to directly interact with natural landscapes—a condition referred to as "nature disengagement" [4]. In addition to spatial constraints, mission demands such as extended work shifts, continuous monitoring of complex life support systems, and rapid problem-solving under high-pressure conditions amplify stress and elevate the risk of emotional dysregulation [5]. Sensory monotony limits interpersonal interaction, and separation from Earth's biosphere may precipitate emotional fluctuations, irritability, and reduced crew cohesion. These are effects that must be anticipated for future long-term lunar research stations and Mars missions [6]. Consequently, psychological challenges will present new significant hurdles for astronauts in terms of maintaining normal psychological states and emotional performance during extended space missions.

Empirical studies of space-analog environments consistently reveal a cascade of physiological and psychological responses to prolonged confinement and isolation. Physiologically, disruptions in circadian rhythms are among the earliest and most pervasive effects [5–7]: Under constant artificial lighting and in the absence of natural day–night cues aboard space stations, astronauts exhibit altered melatonin secretion patterns, leading to fragmented sleep and chronic fatigue [7]. Concurrently, stress-related elevations in cortisol and catecholamines emerge within weeks of isolation, impairing immune function and wound healing, and increasing susceptibility to infections [8]. Alarmingly, data from missions exceeding 6 months indicate that 10% to 15% of crew members suffer moderate to severe depressive symptoms, and microgravity-induced pharmacokinetic alterations—up to a 30% change in selective serotonin reuptake inhibitor (SSRI) metabolism, severely compromising standard antidepressant protocols [9], prompting urgent efforts in some countries to identify new alternative or adjunctive therapies. Bone densitometry scans and muscle atrophy assessments further indicate that the absence of gravitational loading, combined with the sedentary routines often imposed by confined habitats, accelerates musculoskeletal deconditioning—a somatic stressor that exacerbates psychological malaise and distress [10,11]. Psychologically, confinement in closed, extreme environments triggers a spectrum of mood and cognitive disturbances. Early Antarctic overwintering teams reported "winter-over syndrome", characterized by irritability, social withdrawal, and depressive episodes after months of isolation—a pattern later observed in space-station analogs such as Mars-500 and NASA Extreme Environment Mission Operations (NEEMO) [12–15]. Neurocognitive testing in these settings has demonstrated declines in sustained attention and executive function, which correlates with self-reported increases in anxiety and apathy [4]. Moreover, sensory monotony—arising from unvarying, metal-dominated interiors and the lack of dynamic environmental stimuli—intensifies rumination and heightens emotional lability, with participants reporting cabin fever and reduced motivation [16]. Building on these findings, Saniotis et al. [17] propose an integrated evolutionary medicine and bioastronautics framework to pinpoint mismatches between ancestral environments and space habitats and to develop evolutionarily informed therapeutic countermeasures aimed at mitigating adverse mental health effects in long-duration missions. While this framework underscores the importance of addressing "ancestral environment mismatches", its translation into practice is constrained by the limited payload capacity of space missions and the absence of authentic natural stimuli. In this context, virtual reality (VR)-mediated nature therapy represents a distinctive innovation, offering a means of simulating restorative environmental cues without the mass, volume, or biological maintenance requirements associated with physical nature-based interventions. Meanwhile, Buckey [9] reviews established Russian psychological support procedures—such as continuous Earth-crew communication, regular cargo resupply, and the use of emerging VR tools—and assesses their adaptation for countering isolation and communication delays in future interplanetary expeditions. These physiological and psychological sequelae underscore the need for integrated countermeasures that support both homeostatic regulation and mental resilience in confined space habitats.

Similar patterns of affective disturbance appear in terrestrial settings of prolonged isolation and confinement, such as polar research stations, submarines, and remote outposts, where studies report a higher prevalence of mild to moderate depressive symptoms, including anhedonia, sleep disruption, and cognitive slowing, compared to matched community controls [18–20]. Standard treatment for moderate depression typically involves pharmacotherapy with SSRIs or serotonin–norepinephrine reuptake inhibitors, which reduce core symptoms over 6 to 12 weeks [21]. Adjunctive psychological therapies, most notably cognitive-behavioral therapy (CBT), aim to restructure maladaptive thought patterns and enhance coping strategies; meta-analyses suggest CBT yields effect sizes comparable to medication for mild to moderate depression, with superior relapse prevention [22]. However, both pharmacological and psychotherapeutic approaches demand trained personnel, reliable supply chains, and controlled storage—resources potentially limited during deep-space missions. Moreover, altered pharmacokinetics under microgravity and radiation exposure raise concerns about dosing accuracy and side-effect profiles [23]. Saniotis et al. [17] further explore how prolonged exposure to microgravity, radiation, and resource constraints in extraterrestrial habitats could exert selection pressures that drive human microevolutionary adaptations—insights that underscore the need to incorporate evolutionary-informed countermeasures into long-duration mission planning.

Nature-based interventions have emerged as complementary strategies for mood enhancement and stress reduction, capitalizing on the restorative qualities of natural environments. Ulrich's psychoevolutionary theory posits that viewing natural scenes rapidly reduces physiological arousal—lowering blood pressure, heart rate, and muscle tension—by engaging evolutionarily ingrained preferences for biophilic stimuli [24]. Kaplan and Kaplan's attention-restoration theory suggests that natural settings evoke involuntary ("soft") fascination, replenishing directed-attention capacities and alleviating cognitive fatigue [25]. In contexts where real nature is inaccessible, VR platforms can be used to simulate immersive forests, rivers, and shorelines. Randomized trials on Earth demonstrate that even brief (5 to 10 min) VR nature exposures significantly reduce self-reported stress and negative affect [26], improve heart-rate variability markers of parasympathetic activation [27], and modestly decrease depressive symptomatology symptoms over multiweek interventions [28]. These findings suggest that VR-mediated natural environments represent scalable and resource-efficient countermeasures to psychological strain in isolated settings, and their translation into habitat design could plausibly involve the development of dedicated VR therapy suites within lunar or orbital bases. Such suites would be technically feasible through the use of lightweight head-mounted displays or compact projection systems with modest power demands, and their integration with existing life-support and environmental-control infrastructures (e.g., ventilation, lighting, acoustic regulation) would support safe and sustainable operation in closed extraterrestrial environments [29].

Although VR nature therapies have demonstrated restorative benefits in terrestrial contexts, their translation to space-relevant settings requires important distinctions. Ground-based studies typically involve short-term laboratory exposures or clinical applications aimed at reducing stress and improving mood in populations with access to natural light, open social networks, and flexible activity schedules. In contrast, spaceflight and its analogs are characterized by closed, confined, and extreme (CCE) conditions, where individuals are subjected to constant artificial lighting, restricted interpersonal interaction, and sustained cognitive and operational demands. These mission-specific stressors fundamentally alter both the psychological needs of astronauts and the mechanisms through which VR interventions exert their effects. The present study therefore extends VR nature therapy beyond conventional terrestrial applications, positioning it as a targeted countermeasure within the unique psychosocial and environmental constraints of space habitation [30–32]. To address this gap, this study implemented a 12-day space-station isolation simulation in which participants receiving either standard depression interventions alone or in conjunction with daily VR-based nature therapy were compared. Using changes in the Hospital Anxiety and Depression Scale (HADS), the Positive and Negative Affect Schedule (PANAS), and the Quick Inventory of Depressive Symptomatology—Self-Report (QIDS-SR 16), we evaluated the adjunctive efficacy of virtual nature exposure in mitigating mild depressive symptoms under prolonged confinement and natural deprivation.

Materials and Methods

Study design

This study employed a randomized controlled trial design to compare depressive symptoms and negative emotion levels between an experimental group receiving virtual nature therapy alongside traditional treatment for mild depression and a control group receiving only traditional treatment. Unlike prior ground-based VR nature therapy research, this trial uniquely integrates core simulated space stressors—constant artificial lighting, enforced social confinement, and operational task loads—to more accurately emulate the "nature disengagement" conditions of space habitats. Mild depression was chosen as the target because it is prevalent in space-analog crews and represents an early, environment-driven affective disturbance that VR-based attentional and arousal restoration can most effectively address before deeper ruminative symptoms manifest. Symptoms were measured before and after the intervention to assess the effects of VR-based nature therapy on the participants. This study was approved by the ethics review committee of Xiangtan Central Hospital.

Participants

The researchers recruited participants who met the research criteria, using methods such as posting recruitment advertisements at the university and utilizing the campus network. After the end of the application phase, initial phone screenings were conducted to invite applicants who understood and agreed to adhere to the research requirements and schedule, and who were willing to participate in the entire study, to a designated location for a pretest (the participants' emotional stability was confirmed before the pretest). The participants were administered the QIDS-SR 16 scale [33,34], and based on the scores obtained, participants with scores ranging from 6 to 12 (indicating mild depressive symptoms) were considered eligible for the study. Additionally, verification was carried out to confirm that participants did not have any severe mental disorders and were free from contraindications for using VR devices, such as severe motion sickness or epilepsy. In the 24 h preceding the experiment and during the experimental period, all participants were required to abstain from consuming caffeine, alcohol, prescription drugs not specified for the experiment's treatment, and smoking as per the experiment's guidelines.

In this study, a total of 36 eligible patients were recruited (18 participants in each group) and randomly assigned to either the experimental group or the control group. Over the course of the study, 6 participants were excluded or withdrew due to personal reasons, leaving 15 participants in each group. The age range was between 18 and 25 years. To ensure precision and rigor of the research, these participants were all university students, with 95% pursuing undergraduate degrees and the remaining 5% pursuing postgraduate degrees. During the experiment, all 30 participants studied on the same campus. Their dormitory living spaces were of the same size, and meals were provided by the university canteen at fixed times to ensure dietary consistency. The participants were evenly distributed by gender, with 15 males and 15 females. Overall, the participants had a high level of education. The demographic characteristics of the participants are shown in Table 1.

Simulated cabin environment setting

The experiment was conducted in a simulated space station isolation chamber constructed by us. The isolation chamber is 3 m long, 3 m wide, and 2.5 m high. Each simulated chamber is equipped with a single bed, a small desk, a chair, and a small bookshelf. A floor plan is shown in Fig. 1. The walls, floors, and ceilings of the environment are painted white. The desk, cabinets, and chairs are white and gray, with bright blue used on handles such as wardrobe handles to simulate the anodized blue hand and foot restraints of a space station. Each simulated cabin has a separate bathroom for participants to wash and use the toilet. The bathrooms are white, and neither the bathrooms nor the rooms have windows. The main lighting in the rooms is provided by ceiling-mounted lights with an illuminance of 150 lux, a color temperature of 3,500 K, and a color rendering index of RA85. The temperature in the simulated cabins is maintained at 25 °C, and the humidity and temperature are consistent across all cabins. The floor plan and partial renderings of the simulation cabin are shown in Fig. 1.

Settings for virtual nature therapy scenes

For this study, we collected virtual nature imagery. Initially, field locations were chosen for scanning, encompassing 4 types of natural landscapes: forests, beaches, mountains, and lakes. The selection of these 4 landscapes was based on research from nature therapy and environmental psychology, as these environments are believed to have a positive impact on human mental well-being. For instance, earlier studies have found that "forest bathing" (short periods of relaxation in forests) can lower stress levels, improve mood, and enhance cognitive function [35]. Similarly, beaches and bodies of water are thought to induce a state of relaxation known as "blue space", which can

Table 1. Characteristics of participant population

Parameter	Total ($N = 30$)	Experimental group ($n = 15$)	Control group ($n = 15$)
Gender			
Male	15	7	8
Female	15	8	7
Age (years)			
18–20	15	7	8
21–23	10	5	5
24–25	5	3	2
Mean age ± standard deviation	22.5±1.5	22.6±1.4	22.4±1.7
Educational level			
Undergraduate	26	13	13
Postgraduate	4	2	2
Career			
University student	30	15	15

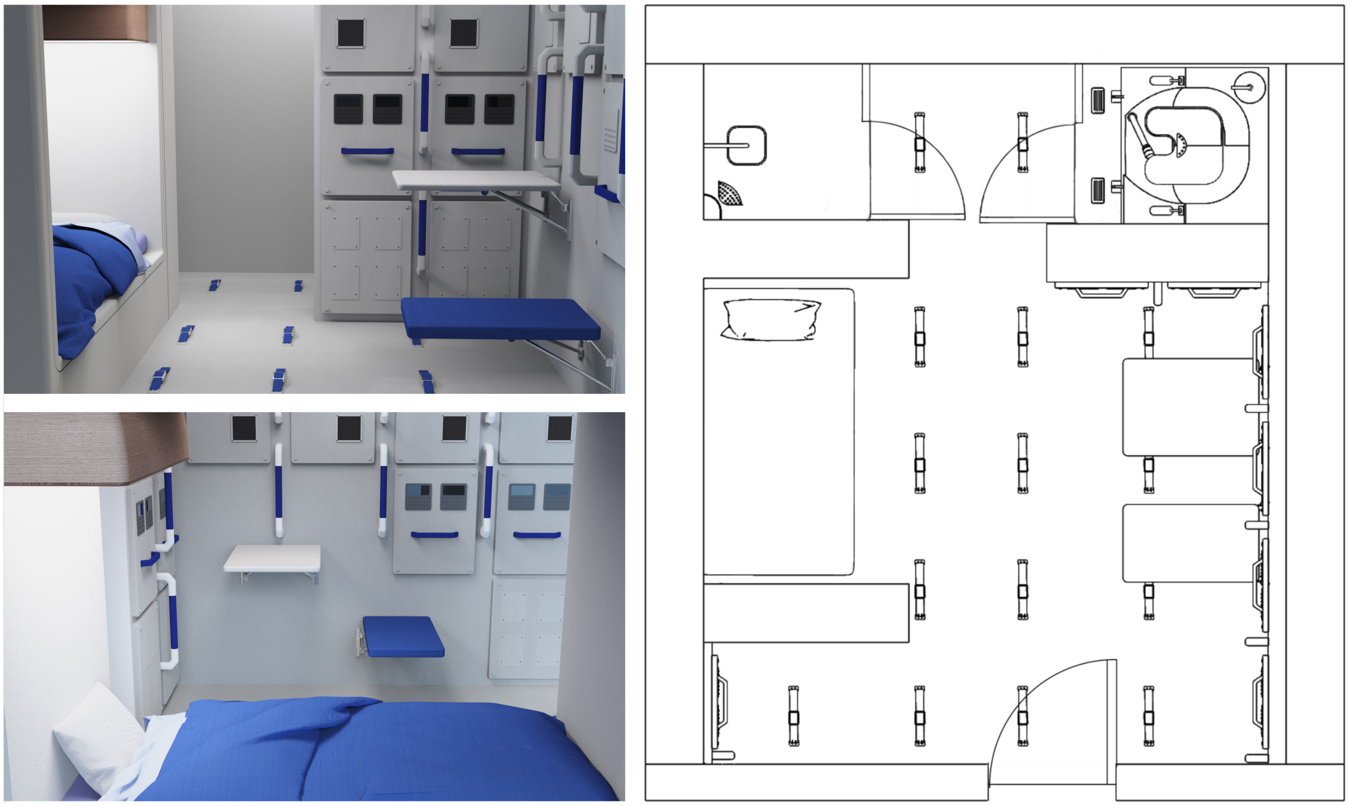

Fig. 1. Floor plan and partial renderings of the simulation cabin.

aid in stress reduction and boost psychological well-being [36,37]. Likewise, mountains and lakes are also considered to possess psychological rejuvenation qualities, helping individuals recover from mental stress and enhance emotions and psychological well-being [38]. Additionally, the 4 landscape categories were prevalidated in a pilot study using the Perceived Restorativeness Scale, with forests, beaches, mountains, and lakes all ranking in the top quartile for restorative potential. This selection is consistent with attention restoration theory (ART), which posits that natural environments high in "being away", "fascination", and "extent" are particularly effective in supporting psychological restoration [39]. Empirical studies further support these categories as highly restorative: exposure to forests and mountains has been linked to reduced physiological stress and improved mood [40], while aquatic environments such as lakes and beaches are consistently associated with heightened relaxation and perceived restorative quality [41]. The 40-min duration and every-other-day frequency were informed by prior experimental protocols in environmental psychology, where 30 to 45 min of nature exposure is generally considered sufficient to elicit measurable cognitive and affective benefits [42,43]. Furthermore, the choice of 40-min sessions every other day was based on prior terrestrial findings that exposures of 30 to 45 min optimize restorative outcomes without inducing fatigue or attentional decline [43]. Daily VR sessions, while theoretically enhancing short-term effects, risk habituation and are less feasible for long-duration missions due to crew time and resource constraints. Accordingly, an every-other-day schedule was selected to balance efficacy, sustainability, and operational feasibility in space-analog conditions.

The specific locations for these 4 natural landscapes were chosen based on geographical location, accessibility, and representativeness. The particular forests, beaches, mountains, and lakes were selected from various geographical environments in China to ensure broad representativeness. The forest scene was captured in an original forest area in eastern China; the beach scene was filmed on a coastal stretch along the East China Sea; and the mountain and lake scenes were shot in a well-known mountain range and a lake area, respectively, in northern China. These scenes feature a green-based color palette and are considered typical, beneficial natural environments for mental well-being [44].

After filming, the 4 natural scenes were edited into a 40-min, highly immersive compilation; the 40-min session length and every-other-day frequency follow ART guidelines, indicating that 20- to 60-min exposures maximize cognitive and emotional recovery without habituation and mirror operational work–rest cycles recommended for space mission protocols. This method has been employed in previous research and has been validated for its accuracy in representing real-life settings [26,45,46].

Equipment and materials

The experiment was conducted in a standard VR laboratory. We used the VIVE Pro 2 Full Kit VR equipment, including the HTC VIVE Pro 2 VR Headset and VIVE Controller 2.0. The head-mounted display offers a resolution of 2,160 × 1,200 pixels per eye and a refresh rate of 90 Hz. The field of view was 100° horizontally and 100° vertically.

For measuring depression and anxiety, we employed the HADS, a scale consisting of 14 items. Among these, 7 items assess depression while the remaining 7 items assess anxiety. In this study, we utilized the depression subscale of the HADS, known as HADS-D. This subscale comprises 7 items, each with 4 response options. The total score range is from 0 to 21, with higher scores indicating more severe symptoms. Based on the total score, the scores are categorized into the following levels: 0 to 7: normal range; 8 to 10: mild abnormality; 11 to 14: moderate abnormality; and 15 to 21: severe abnormality [47]. The internal consistency of the scale was $\alpha = 0.91$.

The PANAS is widely used to assess psychological disorders such as depression, anxiety, and related symptoms [48–50]. The scale comprises 20 items, with 10 assessing positive affect and another 10 assessing negative affect. Participants rate each item based on their emotional state on a 5-point scale, ranging from 1 (very rarely or not at all) to 5 (very frequently or almost always). Scores for each subscale range from 10 to 50, with higher positive affect (PA) scores reflecting greater positive mood and higher negative affect (NA) scores indicating more intense distress; PA scores more than one standard deviation below normative adult means ($\approx 30 \pm 8$) and NA scores more than one standard deviation above normative adult means ($\approx 15 \pm 6$) are associated with clinically significant affective dysregulation [51,52]. The scale's internal consistency was $\alpha = 0.95$ for positive affect and $\alpha = 0.92$ for negative affect.

The QIDS-SR 16 is designed to assess depression in treatment and research settings. It has been extensively employed in previous studies to measure depression symptoms [33,34]. The scale consists of 16 items covering 9 domains of depressive symptoms. Each item is scored from 0 to 3 points, leading to a total score ranging from 0 to 27 points. Higher scores indicate more severe depression symptoms. The total score classifies the severity of depression symptoms: no depression (0 to 5 points), mild depression (6 to 10 points), moderate depression (11 to 15 points), moderately severe depression (16 to 20 points), and severe depression (21 to 27 points). The scale's internal consistency was $\alpha = 0.95$.

Data collection time points

Data were collected at 2 main time points to assess the effects of virtual nature therapy on patients with depression in a 12-day isolated and enclosed environment. The experimental period was 12 days. The data collection period was from 2024 November 20 to 2024 December 12. The first data collection was conducted on 2024 November 20 to obtain baseline data prior to the experiment. The second data collection was conducted on 2024 December 12, the last day of the experiment [53].

Pre-experiment (baseline): On the day before the experiment began, the participants underwent preliminary surveys and assessments using the HADS-D, PANAS, and QIDS-SR 16 scales. These data served as baseline measurements for the comparison with the results of the experiment.

Post-experiment (day 12): On day 12, the participants underwent reassessment. Data were collected using the same scales (HADS-D, PANAS, and QIDS-SR 16) and compared with the baseline measurements.

Control group and experimental group

Participants in the control group received conventional treatment for depression to enable comparison with the experimental group. The conventional treatment methods for the control group participants included the following:

CBT: Psychologists assisted the participants in recognizing and altering negative thought patterns to enhance psychological resilience. In the control group, the participants received CBT based on their individual needs, aimed at identifying and changing negative thought and behavior patterns. Sessions were conducted once a week, with each session lasting 40 min [51].

In the control group, CBT was delivered by licensed clinical psychologists (Master's level or higher, with ≥5 years' experience) following a standardized treatment manual. Each of the 8 weekly, 40-min sessions was structured into a 5-min homework review; 20 min of cognitive restructuring exercises; 10 min of behavioral activation planning; and a 5-min assignment of home practice, allocating roughly 60% of time to cognitive restructuring and 40% to behavioral activation. Therapist adherence was monitored via session checklists and weekly supervision to ensure fidelity across participants [51].

The experimental group received VR nature therapy alongside standard depression treatment. The intervention process was structured as follows:

The participants visited a standard VR laboratory setup within the experimental area every other day during the 12-day experimental period to experience virtual nature therapy. The interventions were conducted from 4:00 to 5:00 PM, with each session lasting 40 min. The VR lab is close to the isolation cabin, ensuring that the isolation status is not affected. After the intervention, the participants returned directly to the isolation cabin. The choice of every-other-day frequency aimed to ensure sufficient exposure time for the participants to experience the virtual natural environment while also avoiding potential fatigue or adverse reactions from too frequent interventions [53]. The participants wore VR equipment and held VR controllers to enter predesigned virtual natural environments. During each intervention, the participants were guided through relaxation techniques such as deep breathing. Throughout the 12-day experimental period, the participants experienced the forest, beach, mountain, and lake virtual environments in randomized order, with each environment lasting for 10 min. Each environment was viewed a total of 15 times over the course of the experiment. This sequence and frequency were selected to ensure that the participants had ample exposure to each natural environment while minimizing the potential for fatigue or adverse reactions. Fig. 2 shows a scene of the experiment where a participant looked at the VR scene.

During the intervention period, the researchers closely monitored the participants' experience to ensure the safety and effectiveness of the intervention. Additionally, the participants could provide feedback to the researchers at any time during the intervention process. If any discomfort or other issues arose, the researchers promptly halted the intervention or offered appropriate support.

Statistical analysis

We used the statistical software SPSS 25.0 to analyze the data. One-way analysis of variance (ANOVA) was used to compare the baseline scores of HADS-D, PANAS-PA, PANAS-NA, and QIDS-SR 16 between the control group and the experimental groups and to assess the psychological states of the groups at the baseline. Paired t tests were used to assess psychological changes within the experimental group before and after the experiment, to determine significant differences in their psychological states, and to evaluate the impact of virtual nature therapy. One-way ANOVA was used to evaluate the psychological changes in both groups, to determine significant differences in psychological states, and to assess the efficacy of virtual nature therapy in alleviating symptoms in participants with depression. The normality test found that the Shapiro–Wilk test results showed that all variables had $P < 0.20$.

Results

Table 2 presents the baseline results for both the experimental and the control group. It was observed that there were no significant differences in the data between the control group and the experimental group for HADS-D, PANAS-PA, PANAS-NA, and QIDS-SR 16 ($P > 0.1$). This indicates that the overall average baseline depression scores did not show significant differences between the experimental group and the control group.

Table 3 presents the analysis results for the experimental group at the baseline and post-intervention. By utilizing paired *t* tests to investigate variations in the experimental data, it can be observed from Table 2 that, in comparison to the baseline, the experimental group exhibited significant differences in HADS-D, PANAS-PA, and PANAS-NA scores after the 12-day experiment ($P < 0.05$). However, the difference in QIDS-SR 16 did not reach statistical significance ($P = 0.084 > 0.05$, Cohen's $d = 3.416$). This suggests that virtual nature therapy has a certain degree of alleviating effect on depressive symptoms in individuals with mild depression exposed to a 12-day simulated, isolated, and enclosed space station environment. Nevertheless, the results of QIDS-SR 16 did not show significant differences, implying that the impact of nature therapy on depression treatment is not yet significant. As has been shown in previous studies, paired *t* tests are also effective for analyzing the efficacy of depression treatment [51,52]. A post hoc power analysis indicated that, given the observed effect size, the current sample size ($n = 15$ per group) achieved only limited statistical power (<0.60) to detect changes in QIDS-SR 16.

Table 4 presents the analysis results for the control group that received only CBT at baseline and post-experimental stages. Paired comparisons before and after the 12-day isolation intervention showed that, compared with baseline, there were no significant differences in HADS-D, QIDS-SR 16, and PANAS-NA scores in the control group after the 12-day intervention ($P > 0.05$). PANAS-PA showed only a weak effect ($P = 0.053 < 0.01$, Cohen's $d = 0.637$). Overall, in this experimental setting, traditional CBT alone failed to alleviate depressive symptoms, indicating its limited efficacy when used alone.

Table 5 displays the results of the experimental group and the control group after the 12-day experiment. Both groups exhibited significant differences in the HADS-D, PANAS-PA,

Fig. 2. Participants looked at the experimental scene via VR.

Table 2. Comparison of baseline depression scores between experimental and control groups

Name	Group (mean ± standard deviation)		F	P
	Experimental group ($n = 15$)	Control group ($n = 15$)		
Baseline HADS-D	12.44 ± 1.29	12.51 ± 0.646	0.610	0.445
Baseline PANAS-PA	19.45 ± 1.33	19.73 ± 0.594	0.007	0.973
Baseline PANAS-NA	26.41 ± 1.55	27.13 ± 0.575	0.041	0.836
Baseline QIDS-SR 16	11.25 ± 1.57	14.07 ± 0.492	0.032	0.887

Table 3. Comparison of depressive scores in the experimental group at the baseline and after 12 days of the experiment

Name	Paired (mean ± standard deviation)		Difference (pairing 1 – pairing 2)	t	P	Cohen's d
	Pairing 1	Pairing 2				
Baseline HADS-D paired with Experiment 12 days HADS-D	12.44 ± 1.29	10.61 ± 2.43	2.34	8.201	0.041*	2.065
Baseline PANAS-PA paired with Experiment 12 days PANAS-PA	19.45 ± 1.33	22.62 ± 3.12	−2.55	−7.382	0.007**	0.637
Baseline PANAS-NA paired with Experiment 12 days PANAS-NA	26.41 ± 1.55	23.81 ± 3.27	2.91	8.316	0.016*	0.221
Baseline QIDS-SR 16 paired with Experiment 12 days QIDS-SR 16	11.25 ± 1.57	11.09 ± 1.45	3.27	7.127	0.084	3.416

Table 4. Comparison of depressive scores in the control group at the baseline and after 12 days of the experiment

Name	Paired (mean ± standard deviation)		Difference (pairing 1 – pairing 2)	t	P	Cohen's d
	Pairing 1	Pairing 2				
Baseline HADS-D paired with Experiment 12 days HADS-D	12.51 ± 0.65	12.09 ± 0.52	−1.087	−7.997	0.092	2.065
Baseline PANAS-PA paired with Experiment 12 days PANAS-PA	19.73 ± 0.60	18.12 ± 0.53	0.613	2.467	0.053	0.637
Baseline PANAS-NA paired with Experiment 12 days PANAS-NA	27.13 ± 0.56	26.94 ± 0.51	−0.173	−0.856	0.064	0.221
Baseline QIDS-SR 16 paired with Experiment 12 days QIDS-SR 16	14.07 ± 0.49	13.84 ± 0.44	−0.667	−13.229	0.082	3.416

Table 5. Comparison of post-experimental depression scores between experimental and control groups. *P < 0.05.

Name	Group (mean ± standard deviation)		F	P
	Experimental group (n = 15)	Control group (n = 15)		
Post-experimental HADS-D	10.61 ± 2.43	13.59 ± 0.52	156.412	0.021*
Post-experimental PANAS-PA	22.62 ± 3.12	19.12 ± 0.53	131.526	0.036*
Post-experimental PANAS-NA	23.81 ± 3.27	27.32 ± 0.51	102.019	0.029*
Post-experimental QIDS-SR 16	11.09 ± 1.45	14.74 ± 0.44	246.105	0.076

and PANAS-NA scores after the 12-day experiment ($P < 0.05$). However, the difference in QIDS-SR 16 was not statistically significant ($P = 0.76 > 0.05$). The experimental group demonstrated significantly higher levels of positive emotions than the control group ($P = 0.036 < 0.05$) and significantly lower levels of negative emotions ($P = 0.029 < 0.05$). Moreover, the average score for HADS-D was significantly higher in the experimental group than in the control group ($P = 0.021 < 0.05$). This suggests that, after the 12-day experiment, the participants in the experimental group who received the additional intervention of virtual nature therapy showed some improvement in their depression symptoms compared to the control group, which only received traditional depression treatment methods. However, the results from QIDS-SR 16 indicate that there was no significant difference between the experimental group and the control group after the 12-day experiment, suggesting that the effectiveness of virtual nature therapy in improving depression symptoms remains limited.

Discussion

This study investigated the effect of VR-based nature therapy on depressive symptoms in participants with mild depression within a simulated space station environment. After 12 days of VR nature therapy, the experimental group showed significant improvements in their HADS and PANAS scores. However, there was no significant change in their QIDS-SR 16 scores, indicating that VR nature therapy alleviates depressive symptoms, particularly by reducing negative emotions. Compared to the experimental group, the control group showed smaller improvements in negative emotions. The experimental group receiving virtual nature therapy significantly outperformed the control group in terms of improvement in negative emotions. Analysis of the experimental group showed that virtual nature therapy improved the symptoms of participants with mild to moderate depression. This may also indicate that HADS and PANAS primarily assess limbic-driven emotional and affective processes, whereas the QIDS-SR 16 targets prefrontal-mediated cognitive-motivational symptoms such as anhedonia and rumination [54,55]. Neuroimaging studies indicate that VR nature exposure dampens amygdala reactivity and strengthens emotion–regulation networks, yielding rapid improvements in mood and attention, while engaging prefrontal circuits to a lesser extent and limiting effects on motivation and executive function [56].These differential neural effects may be a potential explanation for the pronounced gains on HADS and PANAS versus the null QIDS-SR 16 findings. These findings demonstrate that VR-based nature therapy can alleviate mild depressive symptoms—particularly by reducing negative affect and enhancing positive mood—in humans confined in space-station analogs. In orbital habitats and other extreme isolation settings, "nature disengagement" and sensory monotony exacerbate emotional dysregulation, irritability, and cognitive fatigue (such as "cabin fever") [57,58]—effects documented in Antarctic overwintering teams and analog missions like Mars-500 and NEEMO [53,59]. The absence of natural stimuli aboard spacecraft is associated with altered circadian rhythms, elevated cortisol levels, and sleep fragmentation, contributing to mood disturbances [60,61].

By embedding a 12-day VR intervention into a space station isolation cabin simulation, this study aimed to improve depressive conditions triggered by psychological and physiological stress during deep-space missions [62,63]. The results of this study further confirm that regular immersion in virtual forest, beach, mountain, and lake scenes (selected for their empirically validated restorative properties) can partially offset the natural deprivation effect, significantly reducing HADS-D and PANAS-NA scores and significantly improving PANAS-PA scores. Previous studies in similar simulated environments have shown that prolonged exposure to a closed environment lacking bioaffinity cues accelerates the deterioration of both physical (e.g., muscle atrophy and bone loss) and psychological (e.g., anxiety and apathy) symptoms [64]. This validates previous findings that psychological sequelae in extreme environments, including depression, irritability, social withdrawal, and cognitive slowing, are consistent with the "overwintering syndrome" first documented at Antarctic research stations and validated in space station simulations such as NEEMO and Mars-500, where sensory monotony and closed environments triggered negative emotional fluctuations, reduced attention, and impaired executive function. Nevertheless, traditional intervention measures, such as medication, cognitive behavioral support, and structured schedules, though crucial, require complex payload resources and are complicated by altered pharmacokinetics in microgravity environments [65,66]. In contrast, the 12-day VR immersion program proposed in this study offers a highly controllable and easily deployable adjunctive approach: Daily 40-min exposures to scenes such as forests, beaches, mountains, and lakes, which have the potential to restore autonomic nervous system balance and attention capacity, alleviate negative emotions and enhance positive emotions [66,67]. These results suggest that future deep-space habitats should incorporate dedicated VR therapy suites directly into crew living quarters to provide regular nature exposure. Mission psychological protocols for lunar bases or Mars voyages can then schedule structured VR nature sessions alongside remote CBT, light therapy, and exercise regimens to bolster emotional resilience. By embedding real-time mood monitoring and adaptive content delivery within the habitat's architecture, interventions can be personalized and timed to mission phases, ensuring optimal support for crew well-being.

The QIDS-SR 16 scores showed no significant changes within or between groups ($P = 0.084$ and $P = 0.076$, respectively), which is consistent with Ulrich's psychoevolutionary theory and Kaplan and Kaplan's ART [68,69]. These theories suggest that exposure to (even simulated) natural environments primarily leads to a rapid reduction in physiological arousal levels and restoration of attention focus—effects reflected in the significant improvements in our HADS-D and PANAS scores—rather than directly improving the deeper, ruminative, and motivational deficits captured by the QIDS-SR 16. This finding is consistent with previous research, which suggests that while VR-based nature therapy demonstrates clear practical utility in alleviating emotional symptoms, such approaches should be considered adjunctive interventions rather than stand-alone interventions [66,70]. This may also indicate that VR nature therapy primarily engages limbic-driven affective circuits while exerting minimal influence on prefrontal-mediated cognitive–motivational domains. Browning et al. [71] reported significant reductions in self-reported stress and negative affect following VR forest exposure, yet found no improvements in working memory performance. Similarly, Annerstedt et al. [72] demonstrated enhanced relaxation and mood but no change in executive task accuracy after immersive virtual nature sessions. In interpreting these findings, it is important to consider cohort-specific factors. The younger participants (18 to 25 years) in our sample may be particularly receptive to VR-based interventions, given their developmental history of growing up with image-dominant technologies such as social media, which may enhance their engagement with immersive environments and amplify affective benefits. At the same time, frequent exposure to novel technologies and social media use has been linked to alterations in dopaminergic regulation, potentially shaping how this group's reward and affective circuits respond to VR. However, reliance on this younger cohort also introduces limitations, as the frontal cortex—responsible for executive functions such as planning, impulse control, and decision-making—continues developing into the mid-20s, whereas limbic structures mature earlier, leading to greater affective reactivity but reduced regulatory capacity compared to older age groups. Consequently, the effects of VR nature therapy in this age group may primarily reflect short-term limbic modulation rather than sustained prefrontal-driven cognitive changes. Therefore, to comprehensively address the spectrum of depressive symptoms that may arise during long-duration deep-space missions, particularly those related to motivation, self-efficacy, and anhedonia, virtual nature-based healing programs should be integrated with pharmacological treatments (considering pharmacokinetic changes in microgravity environments) and structured psychological therapy support (such as remote CBT) to target the cognitive-motivational domain and ensure the sustained well-being of deep-space exploration mission crew members [64,73]. However, the current VR nature therapy is solely visual; multisensory approaches—such as holographic displays combined with natural sounds and olfactory cues—could engage limbic and parasympathetic systems more effectively, as recommended by Saniotis et al. [56]. Including nonhuman animals (e.g., birds and fish) in virtual scenes may further stimulate parasympathetic responses and enhance biophilic affinity. Moreover, integrating presession mindfulness or relaxation training can amplify VR's restorative effects, as evidenced in analog and spaceflight contexts [74,75]. Embedding such enriched VR interventions within existing psychological support frameworks (e.g., remote CBT and light therapy) and tailoring them to mission duration and individual preferences will optimize countermeasure efficacy throughout long-duration missions. Furthermore, VR nature therapy can be differentially applied across mission profiles, serving as short restorative sessions for acute stress relief in short-term missions and as longer, immersive protocols for mitigating monotony and cumulative stress in long-duration missions. Personalized landscape selection, informed by pre-mission assessments and adapted through biometric feedback, enhances its precision and efficacy. When embedded within existing routines such as exercise and circadian light protocols, and supplemented with dynamic content variation, VR therapy offers a sustainable and integrative countermeasure for maintaining psychological resilience during spaceflight.

This study selected a virtual environment dominated by green tones in a VR nature therapy protocol, based on extensive prior research evidence indicating that green tones in natural environments improve mental health, alleviate stress, and improve physical health and activity motivation [38]. In previous ground-based studies, longer exposure to green spaces was associated with lower heart rate and blood pressure, reduced cortisol secretion, and improved mood [54]; however, these effects were influenced by factors such as exposure duration, personal preferences, and socioeconomic background [67,76]. By providing a virtual forest and grassland rich in greenery within a 12-day simulated space station isolation and confinement VR program, these bioaffinity virtual stimuli were reintroduced in a fully controlled, windowless isolation chamber. This approach aligns with field experiments conducted at the Antarctic Concordia Station and the underwater NEEMO habitat, both of which tested limited natural stimulus interventions [65,66]. Furthermore, by simulating various restorative landscapes on demand, the study found that virtual green exposure can replicate key restorative processes, rapidly reducing physiological arousal levels and restoring attention, even in a microgravity environment lacking real vegetation [55,64]. However, cultural variability in restorative responses to natural environments suggests that the psychological benefits of green spaces may not be universal. For instance, astronauts from diverse cultural backgrounds, particularly those unfamiliar with green-toned landscapes, might experience differing restorative effects. Research on "blue spaces", such as that by Gascon et al. [77], has shown that aquatic environments can offer restorative benefits that differ by cultural exposure and familiarity. This highlights the importance of considering cultural context in future studies on virtual nature therapy. Non-Chinese astronauts, for example, might respond differently to Chinese landscapes, potentially influencing the therapeutic outcomes of VR interventions in international crewed space missions. Such cross-cultural studies should be a critical future direction, particularly as space missions expand to include astronauts from diverse nations. This could provide a potentially scalable intervention for addressing emotional and cognitive decline observed in space station crew members and participants in simulated experiments.

This study has several limitations. The 12-day simulated space station experiment optimized certain changes in mild depression in the participants in a confined, cramped cabin environment and found that virtual natural landscapes experienced via VR could alleviate mild depression caused by short-term confinement and isolation. However, this 12-day simulated space station task simulation had limitations in terms of measuring depressive symptom states, particularly in obtaining statistically significant results for the QIDS-SR 16 scores. Moreover, the sample size of this study was relatively small and may not fully represent all participants with mild depression. This may also have potentially influenced the QIDS-SR 16 not finding a significant effect. Post hoc analysis indicated <60% power with the current sample (n = 15 per group), whereas N = 50 per group may exceed 80%. Future research may consider expanding the sample size and extending the experimental period, as well as exploring dose–response effects, individual preference matching (e.g., comparing forest and aquatic environments), and the integration of biofeedback or adaptive content to optimize treatment outcomes. Such studies will be crucial for refining habitat architecture and behavioral health protocols, providing a reference for humanity's next steps in exploration beyond Earth. Recruiting only 18- to 25-year-olds restricts applicability to the older, more experienced astronaut population. Younger participants are accustomed to image-based technologies and still have ongoing frontal cortex maturation, and they may respond more favorably to VR nature therapy than older age groups, introducing cohort-specific dopaminergic and cognitive-lability biases. Additionally, the simulated cabin stressors did not replicate the high workload and unique psychosocial pressures experienced by astronauts; they may affect both baseline affective state and responsiveness to VR interventions. Therefore, future studies should include pilots undergoing space training or reserve astronauts to better evaluate the efficacy and dose–response characteristics of VR natural therapy in real mission scenarios. In addition, the 11 scene materials are sourced from the Chinese environment. Future research may consider incorporating landscapes from different biogeographical and cultural backgrounds to determine whether VR nature therapy has the same efficacy in multinational astronaut teams. The simulated settings only replicated a physically isolated environment and did not incorporate critical space-specific stress factors—such as microgravity, radiation exposure, and mission risk factors—which may result in overly simplified conditions that limit direct extrapolation to real space environments. Future studies should further develop space-like environments that simulate microgravity and radiation to validate and expand the current findings.

Conclusion

This study highlights the preliminary efficacy of VR-based nature therapy as an adjunctive treatment for mild depressive symptoms in short-term, confined isolation environments, such as space mission analogs. The results show significant improvements in mood, particularly through reduced negative emotions and enhanced positive affect; however, no significant changes were observed in cognitive-motivational symptoms, as measured by the QIDS-SR 16. This suggests that VR therapy, while promising, cannot provide comprehensive depression relief on its own. As such, VR nature exposure should be considered a complementary intervention rather than a replacement for standard pharmacological and psychotherapeutic treatments. Given its scalability and resource efficiency, this approach may offer valuable support for addressing acute "nature disengagement" in isolated environments. Further studies, particularly with astronaut cohorts, are needed to optimize session dosing, multisensory content, and integration into broader psychological support strategies for long-term space missions.

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Data Availability

The data used to support the findings of this study are available from the corresponding author upon reasonable request.

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