Exploring VR Shinrin-Yoku Stress Relief: A Comparative Study of Virtual and Multi-Sensory Extended Reality Environments

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ABSTRACT

'*Shinrin-Yoku*', a practice originating in Japan, describes a person spending time and relaxing in a forest environment, with research showing it has relaxing properties that can help relieve stress and anxiety. Not everyone has easy access to natural environments, so research has shown that using Virtual Reality (VR) can provide an immersive medium to simulate this experience. This paper explores the extension of such research by utilizing an Extended Reality (XR) implementation with real objects matching the virtual environment. We utilize several real-world physical props, like a tree stump, plants, and a scent diffuser, to achieve the XR immersive multimodal experience. We compare a VR and an XR version of the environment while measuring participants' stress levels through three questionnaires, namely ZIPERS, PANAS, and PRS, together with a heart rate monitor. We found that both versions made participants less stressed, but participants had a slight preference for the XR version and explored that environment much more. We show our experience provides comparable restorativeness to users to state-of-the-art applications by utilizing a much more stylized environment.

Keywords

Virtual reality (VR), shinrin-yoku, stress relief, extended reality (XR), multi-sensory

INTRODUCTION

Global Trends in Work-Related Stress and Economic Implications

As people's everyday lives become faster and busier, the effects on their physical and mental health are becoming more obvious. People have less time and fewer possibilities for relaxation, travel, and experiencing nature. A longitudinal study of 52,763 Danish employees (2012–2020) used multi-state modeling to examine work-related stress, linking a significant public health concern to reduced labor market participation and increased disease burden(Pedersen et al. 2024). They followed survey participants over two years, with an estimation of 110,559 person-years accumulated, 26–37% of participants reported at least

one indicator of work-related stress. The estimated economic cost was €305.2 million for men and €868.5 million for women(Pedersen et al. 2024). This is a global problem, where in the United States, stress-related costs are estimated at $190 billion in annual healthcare costs and costing an estimated $300 billion in industry losses due to absenteeism, diminished productivity, and accidents, while in Europe in 2002, they reached €20 billion per year(Hassard et al. 2014) in industry losses.

Figure 1: The virtual environment of our '*shinrin-yoku*' experience.

Forest Bathing -- Historical Context and Scientific Use

'*Shinrin-Yoku*', translated to forest bathing, was introduced in 1982 by the Japanese Ministry of Agriculture, Forestry and Fisheries. Forest bathing was originally a method designed to attract people to visit the Japanese forests(Timko Olson et al. 2020). Since then, the term has turned into a practice of slowly and mindfully walking in a forest environment while using all five senses. This has prompted research into physiological and psychological outcomes of experiencing nature(Tsunetsugu et al. 2010). Studies were done to assess forest bathing's effects on the autonomic nervous system, including brain wave activity, supporting its role in enhancing well-being and reducing healthcare strain(Tsunetsugu et al. 2010; Timko Olson et al. 2020; Wen Y 2019; Li 2022).

Even with these benefits of nature exposure known, not all individuals can experience nature this way, especially due to distance or health constraints (Bagger et al. 2024). However, the increasing affordability and availability of head-mounted displays (HMDs) offer virtual reality (VR) as an alternative, providing immersive forest environments for individuals unable to access nature directly.

Virtual Reality -- Innovations in Nature Therapy

With VR technology becoming increasingly accessible in homes and workplaces, researchers are investigating its potential for simulating forest bathing for individuals with limited access to nature(Newman et al. 2022; de Kort et al. 2006; Verzwyvelt et al. 2021). Given that people spend 86.9% of their lives indoors(Klepeis 2001), VR-based nature simulations offer a promising avenue for stress relief and mental restoration. Emerging research highlights the health applications of VR, showing evidence that immersive nature experiences can effectively reduce stress and promote psychological well-being(Voigt-Antons et al. 2021; Bagger et al. 2024). Studies highlight the potential of virtual environments (VEs) to replicate

the restorative and emotional benefits of natural settings (Newman et al. 2022; Liang et al. 2024; Nukarinen 2020). Newman et al.(Newman et al. 2022) demonstrated that immersive VR realism significantly enhances affective responses, making it a viable alternative for individuals lacking access to nature. Liang et al.(Liang et al. 2024) showed that advanced 3D VEs viewed via HMDs provide restorative effects comparable to real-world nature, with implications for urban green space design. Nukarinen et al.(Nukarinen 2020) acknowledged the superiority of real nature but confirmed that 3D virtual forests are more emotionally restorative than simpler representations, such as 360-degree videos. While higher realism in VEs is associated with greater restorative effects, studies reveal that individuals prefer iconic, less realistic environments over real forests and parks (Masters et al. 2022; Masters et al. 2024). We build upon these findings by adopting (Masters et al. 2022) evaluation methods, which require first stressing the participants and later relaxing them through the experience. We design our own stylized VR environment (Figure 1). Through it, we can test our first Hypothesis that a more stylized environment, together with virtual animals, can produce similar effects of restorativeness to more highly detailed, photorealistic, but more hardware demanding environments that previous researchers have used. Our second Hypothesis is that using extended reality (XR) elements to engage additional senses, such as touch and smell, and to more closely mimic the original practice would improve the forest bathing experience. Most VR experiences currently rely on vision, audio, and sometimes haptic feedback, with studies indicating these three senses as the most crucial for individuals (Enoch et al. 2019; Hutmacher 2019). Our two main hypotheses are:

1. **Hypothesis 1**: A more stylized shinrin-yoku virtual environment containing animals and interactive objects can produce similar restorativeness to more photorealistic ones used in the state-of-the-art.
2. **Hypothesis 2**: Using XR elements and providing a multimodal experience will improve the virtual forest bathing experience.

We test the difference between the users' experience using three widely-used questionnaires, additional open-answer questions, a measurement of users' heart rate, and a comparison of their movement patterns in the experiences. We show that we achieve similar restorativeness results with our stylized but more interactive environment to the state-of-the-art, even when factoring in differences in testing environments. We do not find a statistically significant difference between the VR and XR experiences, but further analysis of the open questions and quantitative data shows a pattern of preference and a calming effect for the XR experience. We thus prove our first hypothesis, but cannot definitely answer the second one, showing that more research is needed.

BACKGROUND RESEARCH

Research on Shinrin-yoku in VR Settings

A large body of work points at the restorative nature of shinrin-yoku experiences (Hansen et al. 2017; Li 2022), especially helping with lowering stress and "technostress" from everyday life. Being able to translate these restorative properties to a digital environment

and bring them to more people has pushed more research on the topic. Using immersive cave environments (Takayama et al. 2022) and videos (Markwell and Gladwin 2020) has shown promising results, but requires capturing a lot of high-fidelity real footage and the use of hard-to-replicate environments. This is mitigated by the rise of VR forest bathing experiences, which have shown similar restorativeness to real forests (Reese and Stahlberg 2022) for both younger people and older people alike (Bagger et al. 2024). Of special interest are the digital Shinrin-yoku experiences built in Unreal Engine 4 ((Masters et al. 2022) and (Masters et al. 2024)), which use photorealistic assets. For the testing procedure, a series of questionnaires, which include Zuckerman Inventory of Personal Reaction Scale (ZIPERS)(Lee and Park 2018), Positive and Negative Aspect Schedule (PANAS)(Watson et al. 1988), and Perceived Restorative Scale (PRS)(Hartig 1997), are used to evaluate the users' stress level at the beginning. After that, a Markus and Peter Arithmetic stressor test (MPA)(Peters et al. 1998) is administered to everyone, and their baseline "stressed" levels are measured. Finally, users are exposed to the VR experience for 10 minutes, and again answer the same questions. In the first study, the main limitations were cited as the need to render large quantities of complex virtual assets in VR, latency, limited movement, and limited viewpoints. In the second study, users requested a way to move inside the VE, animals, and a water source, and complained about bad optimization. This led us to the current paper, where we wanted to see whether a less demanding, more optimized stylized environment, together with the required animals and more interactive elements, would provide similar or better restorative effects. Together with the addition of multimodal XR, which would leverage the importance of senses like smell and touch (Reese and Stahlberg 2022).

Access to Nature Through VR

For many people who have low mobility or low affinity to nature (Leung et al. 2022) and are from places that do not have easy access to nature (Li et al. 2021), utilizing immersive experiences through VR can be a way to connect with natural environments. It has been shown to boost physical well-being and mental health. Especially for bedridden people, VR therapy and simulated nature walks have been shown to improve health (White et al. 2018). Many of these experiences utilize visuals and sounds of nature, but do not utilize more multi-sensory experiences (Li et al. 2021; Finkler et al. 2025).

Human Senses Subjectively Ranked

Ranking the human senses in virtual environments (VEs) is challenging due to subjectivity, but two studies offer empirical insights. Hutmacher (Hutmacher 2019) asked 91 participants which sense they feared losing most: 67 chose vision, 13 hearing, 10 tactile/haptic, and one gustatory. Enoch et al. (Enoch et al. 2019) had 250 participants rank senses from most (8) to least (1) important; 220 ranked vision highest, followed by hearing, balance, touch, taste, smell, pain, and temperature. Hutmacher (Hutmacher 2019) also analyzed PsycINFO records from 2008 to 2019, finding 1540 papers on visual, 296 on auditory, 101 on olfactory, 46 on tactile/haptic, and five on gustatory modalities. This brings us to the choice of additional simulated senses in the XR environment, where we will focus on vision, hearing, tactile, and olfactory sensations, as these are seen as the most important.

Conclusion from Background Research

We see that the need for reconnecting with nature and experiencing it through the means of a more immersive medium is becoming an important research topic. But most research focuses on the visual and auditory parts of the experience, leaving aside many possible benefits from a truly multimodal XR experience. We also see that many of the VR experiences rely on a very low amount of mobility and a limited number of interactions, which directly contradicts the idea of immersion and presence in a virtual environment. We will address these open questions, together with exploring the introduction of different graphical fidelity and more interactivity.

METHODOLOGY

To build the virtual forest environment, we use the Unity engine and Meta Quest 2, and noise-canceling headphones. The application was built using the XR Interaction Toolkit, and interactions were done using the hand-tracking Unity library. To simulate a forest setting, dynamic animals were incorporated, such as butterflies, frogs, birds, and fish, which can be seen in Figure 2. In addition to the virtual elements, the VR experience was complemented with physical objects that users could touch and interact with in the real world, to enhance multisensory immersion. **The project files and codes are omitted for anonymization purposes**.

Figure 2: The dynamic animals present in the Virtual forest. From left to right - Butterfly, frog, bird, and fish.

Environment

The setting situates the user in the center of a forest, within a clearing located in an area that provides a clear view over a nearby creek. The surroundings consist of a dense forest and bushes, which reinforce the sense of immersion within the natural environment. The clearing contains a tree, a patch of flowers, and a radio. The time of day is set at noon, with the sky being blue with a few clouds to suggest a naturally filtered light quality. High-key lighting is employed, allowing light to scatter down through the trees, with intensified lighting focused on the flower patch and the tree. Snapshots of our VE can be seen in Figure 3.

Implementation of Dynamic Elements

Users can interact with the environment by engaging with the bushes and trees. Hand-tracking creates visual and auditory effects, such as rustling leaves when bushes or trees are touched, and can be used to turn on a radio, which can be found in the environment. Additionally, users can interact with birds in the tree.

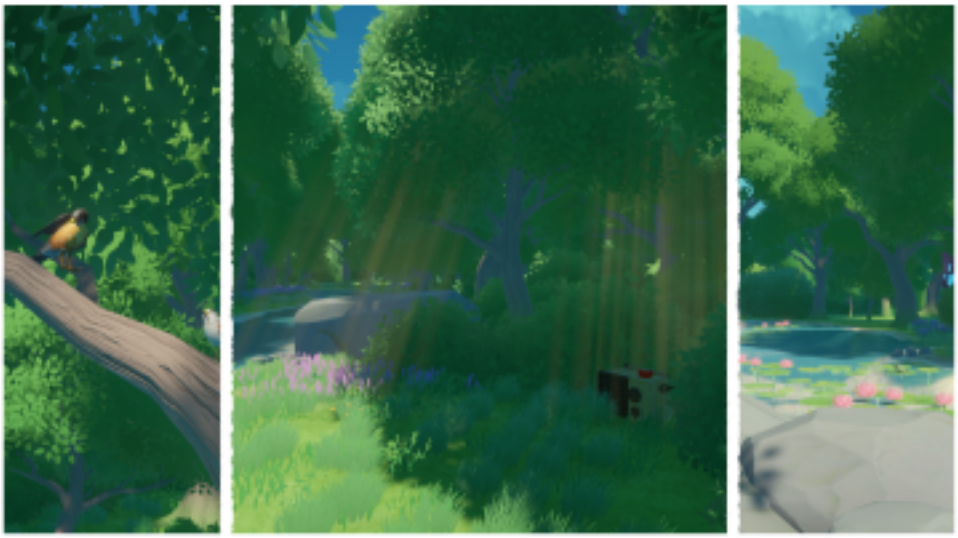


Figure 3: Snapshots of the environment depicting birds located on tree branches, the walkable area, and a view towards an opening of the creek.

Vegetation

The interaction with bushes in the environment is designed to provide both auditory and visual feedback as the user moves their hands through the foliage. To create a realistic and interactive virtual environment, colliders are used to define the physical boundaries and interactive properties of objects within the scene. Mesh colliders allow the colliders to conform precisely to the shape of the 3D models, ensuring that objects within the scene interact realistically with the terrain and vegetation.

Radio

The radio interaction in the environment allows users to toggle the radio on or off, triggering both visual and auditory feedback through animation and music.

Birds

The interaction with the birds depends on the user's position in the environment. When the user gets close to the tree in the walkable area, the birds react by flying away. They fly around the environment, targeting predetermined areas. There are two different kinds of targets, being ground and perch, each affecting the birds' behavior by making them display different kinds of bird animations. The birds aim for the targets and can avoid collisions, making them seem more realistic. They cycle through several predefined states like sing, fly, hop around, peck, preen, etc.

Non Interactable Elements

Butterflies are implemented in the environment using a particle system with predefined random motion in a volume around the interaction area. The frogs in the pond cycle through an animation, subtly blowing up their chins, and fish swim through the stream in the lake, managed. All of these are dynamic and cycle through random states to make them more natural. Fish move through the water using motion vectors set up using Unity's built-in A* navigation.

Implementation of Physical Objects

The XR environment also has objects that have physical equivalents in the real world and can be interacted with by users, providing them with a multisensory experience. First, the tree object, which was custom-built for the experience. The object consists of a real tree log screwed onto a metal pipe, spot-welded to a custom-built metal plate, which can be rotated and adjusted. The XR environment was calibrated so that the real tree log's position and height were matched by the virtual tree lit up by sunlight and easily visible to users. Real potted flowers were added to the real environment and also calibrated with the virtual ones, so users can touch them in the XR environment. A fan was set in one part of the real laboratory and started when users got close to a specific part of the virtual environment. And finally, an aroma diffuser with forest smells was positioned on one side of the room and was set to disperse every 30 seconds. The physical objects can be seen in Figure 4.

Figure 4: The Physical objects implemented to enhance the experience. From left to right - Flowers, diffuser + oil scent, log, and fan.

EVALUATION

Evaluation Setup

To show if there are any differences between a purely VR and a more immersive XR version of a digital Shinrin-Yoku, we will compare users' experience between the two versions. It is an important distinction, as adding physical elements makes such an experience more multimodal but also introduces a more complicated setup. For evaluation, 12 participants went through the testing setup - 6 in each condition (XR & VR), balanced with 4 male and 2 female participants, all of them between 23 and 34 years old. All participants have had experience with VR, and come from Denmark. All participants had previous experience with virtual reality. A between-subjects test was conducted on the participants, as repeated stressing of the participants was not advised. Participants were randomized into the two conditions, XR and VR, taking into consideration gender, VR experience, and age. Each participant was instructed on how the testing scenario would go about and gave their acceptance to participate, knowing that there would be parts of the scenario that might mentally stress and tire them. They then signed a consent form that also detailed the data collection methods. Finally, they were equipped with a Polar H10 heart rate monitor. We would also like to indirectly compare the results from our two versions to another Shinrin-Yoku VR experience that has directly inspired the development of the research application. The application in question (Masters et al. 2022) is represented by a Canyon and Forest environments representing different levels of fidelity and nature biomes. Both environments rely on pure visual VR experiences with limited interactions.

The baseline stress levels were recorded using PANAS(Watson et al. 1988), ZIPERS(Lee and Park 2018), and PRS(Hartig 1997) questionnaires. Participants then underwent the MPA-test(Peters et al. 1998), followed by one again the same questionnaires once again, to establish their ”stressed” baseline. Participants were afterwards put into a 10-minute forest bathing experience - either VR or XR. Afterward, participants completed the questionnaires again to measure stress relief. Participants provided additional feedback on the experience in a semi-structured interview afterwards. The evaluation setup can be seen in Figure 5.

Figure 5: Illustrates the test area during an XR test, where a participant is seen sitting on the ground, with the extended elements seen in the image; tree (1), fan (2), diffuser (3), and a pot of flowers (4).

Data Collection

The data collected from the participants includes the following information:

- PANAS(Watson et al. 1988): Assesses affect changes, specifically positive and negative emotional affect, before and after the MPA-test(Peters et al. 1998) and forest bathing experience after one of the two conditions, either VR or XR.
- ZIPERS(Lee and Park 2018): Evaluates emotional and physiological responses, focusing on relaxation, sensory engagement, and stress reduction.
- PRS(Hartig 1997): Measures perceptions of restorative qualities in the environments, such as feelings of being away, fascination, and coherence. By removing the ‘coherence’ subscale, the results show users’ “General Restorativeness,” according to Masters et al. (2022)(Masters et al. 2022).

- Polar H10 Heart rate monitor: Provides objective physiological data by recording the participant's heart rate (BPM) throughout the evaluation. It complements the subjective questionnaire responses by identifying stress and relaxation patterns in participants.

The MPA-stressor test was designed to assess participants' physiological and psychological stress responses through challenging tasks(Peters et al. 1998). These tasks simulate high-pressure situations to induce stress, which was measured using the subjective questionnaires (PANAS(Watson et al. 1988) and ZIPERS(Lee and Park 2018)) and the objective physiological data gathered from the Polar H10 heart rate monitor.

- Stressor tasks: Participants engaged in time-sensitive mathematical problem-solving and performance tasks to evoke stress.
- Stress assessment: Stress levels were evaluated by comparing Pre- and Post-Environment emotional states and physiological data in the form of heart rate.

RESULTS

Questionnaire Results Statistical Analysis

Stressor Test

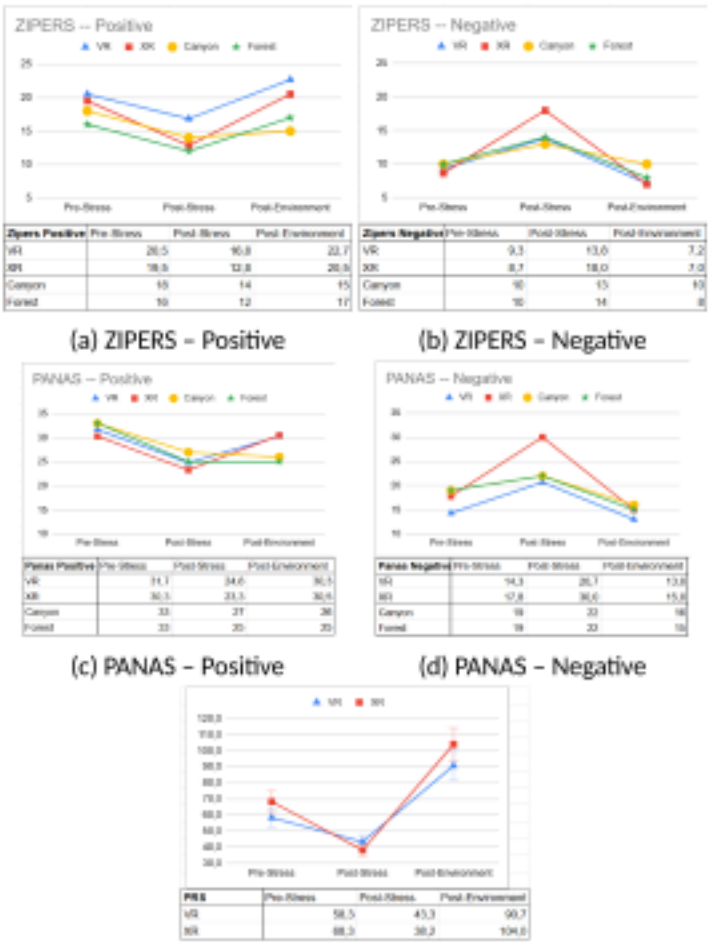
Assumptions for normality using the Shapiro-Wilk test, assessed homogeneity, and checked for outliers. The data was normally distributed and showed no significant variance, and no outliers were found. We conducted t-tests for ZIPERS, PANAS, and PRS results between the baseline and the stressor. For ZIPERS positive, there was a statistically significant decrease ($t = 3.5245$, $p = 0.0019$), whereas ZIPERS negative exhibited a statistically significant increase ($t = -4.2063$, $p = 0.0004$). PANAS positive found a statistically significant decrease ($t = 2.8510$, $p = 0.0093$) and PANAS negative a significant increase ($t = -3.0456$, $p = 0.0059$). PRS also showed a significant decrease ($t = 3.3550$, $p = 0.0029$). Furthermore, to see if the experience in both VR and XR successfully succeeded in relaxing the participant, an independent t-test was conducted between stressor and experience for ZIPERS, PANAS, and PRS.

Post-Stress to Post-VR

For the VR experience, ZIPERS positive showcased a statistically significant increase ($t = -2.7182$, $p = 0.0216$), which ZIPERS negative significantly decreased ($t = 3.6214$, $p = 0.0047$). PANAS positive was found to be not statistically significant ($t = -1.5743$, $p = 0.1465$). PANAS negative showed a statistically significant decrease ($t = 3.0680$, $p = 0.0119$). The general restorativeness of PRS also significantly increased ($t = -4.2698$, $p = 0.0016$).

Post-Stress to Post-XR

The XR experience, ZIPERS postive significantly increased ($t = -4.4679$, $p = 0.0012$), while ZIPERS negative significantly decreased ($t = 4.6209$, $p = 0.0010$). PANAS positive showed not to be statistically significant ($t = -1.6095$, $p = 0.1386$). PANAS negative significantly decreased ($t = 3.2476$, $p = 0.0088$). PRS found significant increase in the general restorativeness ($t = -5.6308$, $p = 0.0002$).



(a) ZIPERS – Positive (b) ZIPERS – Negative

(c) PANAS – Positive (d) PANAS – Negative

(e) PRS – General

Figure 6: Illustrating the mean scores of both groups of (Masters et al. 2022) and our groups across different questionnaires, presented in four different plots. The figures include positive and negative aspects of ZIPERS and PANAS, with a separate figure highlighting the mean scores of PRS.

Questionnaire Results - Deeper Look

Both VR and XR environments exhibited a restorative effect on both negative and positive emotions, Post-Environment, aligning with the patterns observed in the Canyon and Forest evaluations(Masters et al. 2022). Below, we compare our results to the results from Masters et. al, but it needs to be mentioned that we compare them without having redone their setup, so differences in users, physical environment, hardware, and software setup could be seen as confounding variables.

Pre-Stress conditions

ZIPERS: Both VR and XR participants began with a stronger positive baseline and slightly lower negative scores compared to the Canyon and Forest environments (see *Subfigures* 6a & 6b). **PANAS**: Pre-Stress scores showed that the Canyon and Forest had more similar

levels in both negative and positive emotions compared to VR and XR participants, while they had lower negative scores (see *Subfigures* 6c & 6d).

Post-Stress effects

ZIPERS: The stress test negatively impacted all groups, but the XR group was particularly affected in both ZIPERS dimensions. However, the VR group demonstrated greater gains in positive emotions, while XR excelled in reducing negative emotions, Post-Environment. **PANAS**: Stress hurt both positive and negative emotions across all groups. Notably, PANAS data revealed: Recovery in negative emotions across VR and XR groups, Post-Stress and no recovery in positive emotions for the Canyon and Forest.

Post-Environment recovery

ZIPERS: Both VR and XR groups showed effective recovery in emotional states, bringing scores back to baseline levels. In contrast, the Canyon and Forest groups showed no recovery in positive emotions. **PANAS**: The XR group experienced the most significant decline in emotional scores Post-Stress, while the Canyon showed the smallest reduction in positive scores (dropping by just 6 points). In the Post-Environment, VR and XR showed restorative effects, surpassing baseline levels.

Perceived Restorativeness Scale

Pre-Stress PRS scores: Participants in the XR group had a PRS score of 68.3 while the VR group had a PRS score of 58.3 in the Pre-Stress (see *Subfigure* 6e). XR participants perceived their environment as slightly more restorative initially. **Post-Stress PRS scores:** XR participants dropped by 44% (from 68.3 to 38.2), while VR participants dropped by 26% (from 58.3 to 43.3). The XR group experienced a more significant decline in the perception of restorativeness Post-Stress.

Post-Environment PRS recovery: XR participants' PRS score surged from 38.2 to 104, surpassing their Pre-Stress score and indicating XR's strong restorative effect. The VR group also showed recovery, but XR participants perceived the environment as more restorative overall.

Thematic Coding

A semi-structured interview was conducted after the XR experience to determine how the participants felt about the inclusion of physical elements. *Table* 1 shows themes of the common codes across all the participants' answers, with some example quotes that support the codes and thus themes.

Most of the participants perceived an enhanced experience with physical elements, recognizing that the smell, although noticeable, faded rather quickly. From the semi-structured interview, not all participants found the four real-life elements in the experience.

Heart Rate Results

The resulting data from using the Polar H10 heartbeat tracker shows a trend for a difference between the two groups, VR and XR, as depicted in Figure 7. The mean heartbeat difference

Table 1: Lists common codes and themes across the participants' answers in the XR experience, with example quotes supporting the representative code/theme.

Theme	Codes	Example Quotes
Interaction with Physical Elements	Tree, flower, wind, tactile experience	"The tree was very cool because you could touch it," "The wind felt much more real."
Immersion and Realism	Enhanced reality, immersion	"Really cool with the tree trunk," "It felt like it was something real to interact with."
Sensory Experience	Smell fading, wind perception, sound	"The smell settled very quickly," "The breeze was also very nice."
Challenges with Alignment	Alignment issues, realism problems	"It did not line up with the tree," "The second time it did not match up perfectly."
Suggestions for Improvement	Add elements, improve alignment	"I would have liked water," "It was a little scary when it did not line up with the tree."

was higher in the XR group (***M*** *= -5.5*) than the VR group (***M*** *= -1.33*), with a lower value meaning a further relaxed state, which is preferred. An independent t-test was used to see if there was a significant difference, but before the test, assumption checks on normality, homogeneity, and outliers were performed and satisfied. The independent t-test yielded ***t*** *= -1.8707*, and ***p*** *= 0.0909*, suggesting no significant difference, for the heartbeat difference, between VR and XR groups. The effect size, calculated as *Cohen's d = 1.08*, indicates a large effect ($|d| > 0.8$) despite the absence of a statistically significant difference, meaning that if more participants were tested, a more promising trend could have been observed between the two groups.

Position Logging

Positions of test participants were logged during testing. Using the data, scatter plots were created to show where users were within the environment and their most frequent positions for the two test groups.

The VR experience data reveals one somewhat prominent spot to the right of the tree and two prominent areas in the middle of the walkable area and by the radio, where test participants spent most of their time. The XR experience data reveal that the participants spent most of their time at: The radio, the creek, and a larger spread across the environment and around the XR physical objects. This demonstrates that users were more encouraged to explore and move, which can lead to better relaxation (Reese and Stahlberg 2022). The plots for both versions can be seen in Figure 8.

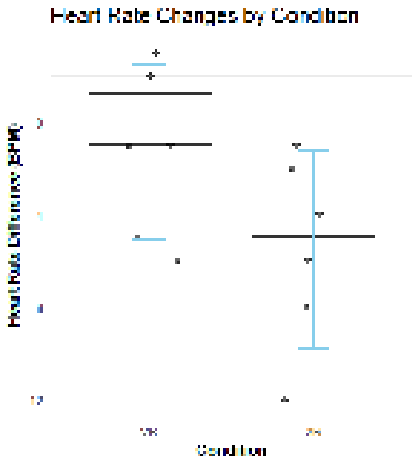


Figure 7: Heart Rate changes by condition. The boxplot shows the distribution of heart rate differences (in BPM) for the two groups: VR and XR. Lower values are a desired effect, as they indicate a more relaxed state after going through the forest-bathing experience.

DISCUSSION

Questionnaire results - t-test

Results from base data to Post-Stress data show that participants were successfully stressed by the MPA test, which can be seen in both the positive and negative values of ZIPERS and PANAS. Additionally, PRS decreased Post-Stress, indicating a successful stress test.

Looking at Post-Stress to Post-VR, the data exhibits both ZIPERS values to have a restorative effect on stress and emotional response, PANAS' negative aspect contributed to this, although the positive aspect had no significant difference, it showed an increase. With the backing of the other questionnaires, the scores from PRS also significantly increased, thus proving that participants conditioned with the VR experience were successfully able to relax in the VR condition, even improving results further than the baseline. For the Post-stress to Post-XR, ZIPERS data showed improved restorative effect on stress and emotional response, PANAS negative also followed this direction. Unfortunately, the PANAS positive showed no statistical significance, even though it reveals improvement. The PRS increase proves a significant general positive restorativeness. This implies that participants were relaxed after being exposed to the XR environment, even improving results further than the baseline. Generally, the VR and XR experiences showed improvements from both baseline and Post-Stress conditions, though performing a t-test of the two groups showed no significance in any category between them, and it is not possible to state that one is better than the other. This specifies that our Hypothesis 2 could not be verified concretely.

Comparison to Masters et al's (2022) study

Comparing our results with (Masters et al. 2022) reveals multiple tendencies suggesting our VR and XR perform comparatively to their Canyon and Forest conditions. Even though our PANAS positive did not show any significant differences when performing a t-test on Post-Stress/Post-VR and Post-Stress/Post-XR, the results still show an increase, where Canyon

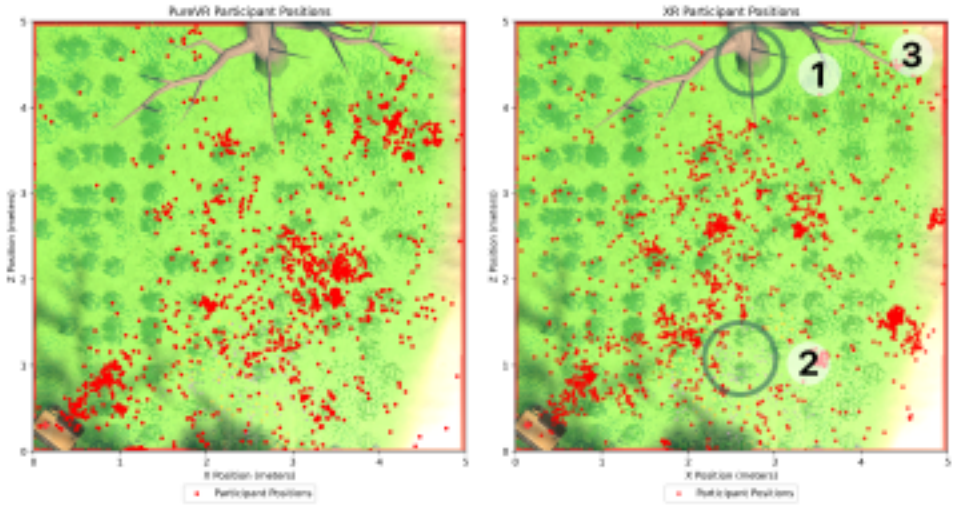


Figure 8: Illustrates the positions of the test participants during the VR experience (left) and the XR experience (right) with the tree (1), flower (2), fan and diffuser (3) marked with a circle. The fan and diffuser's path of air flow is diagonally towards the radio. The position is logged every two seconds. The X and Y axes represent the area where the testing occurred.

and Forest decreased. This indicates that (Masters et al. 2022) fell short in creating a restorative environment based on the positive aspect of PANAS, where we successfully see a restorative effect among participants in both VR and XR.

This is further supported by ZIPERS positive showing improved results, while Canyon stagnated and only Forest appeared to improve participants' psychological measures. This suggests that (Masters et al. 2022) environments faced issues in helping participants restore positive emotional aspects, where ours succeed in both, and unexpectedly observe PRS values doubling from Post-Stress to Post-Environment, further supporting the success of the stylised VR and XR environments. Again, these results might be due to differences in users and environmental conditions. Even with that can see a trend demonstrating that a less photorealistic, stylized environment that provides more interactions, together with more lively animal and background elements, can achieve the same or even greater level of restorativeness. With this, we believe that our Hypothesis 1 shows a positive trend towards verification and a good starting position for future work.

FUTURE WORK AND LIMITATIONS

Lack of participants: Due to the lack of participants in each group of our between-subjects test, with six participants per group, our data is affected by noise and bias. To address this, a power analysis with an 80% confidence level was conducted, resulting in an estimate that approximately 64 participants per group are needed to reliably validate statistical significance.

Spatial drift: '*Positional*' or "*spatial drift*", common in VR headsets with inside-out tracking, misaligns visual and tactile feedback, potentially confusing or startling participants. This issue is worsened in featureless spaces. Adding a ground grid, as suggested by Mulvany

et al.(Mulvany et al. 2020), could minimise drift without complicating the setup. While outside-in tracking systems like the XR-3 offer greater accuracy than the Quest 2(Alanko 2023), their higher cost limits accessibility. Since the project focuses on consumer-friendly solutions, the Quest 2 remains appropriate despite its limitations.

Improvements of XR: The XR elements—a tree, flower pot, fan, and diffuser—physically represented VE objects, allowing interactions like touching bark or feeling a breeze. However, spatial drift and collisions, particularly with the flower pot, occasionally disrupted immersion. The scent experience, limited to the oil diffuser behind the fan, lacked variety and intensity; participants noticed it only briefly. Future setups should improve XR element visibility, familiarize users with their placement, and incorporate more diverse, localized scents. Thematic coding also revealed a desire to touch water, suggesting that additional physical elements could enhance the experience.

CONCLUSION

This paper demonstrates the effectiveness of a VR and XR forest bathing experience on users' perceived restorativeness. Using self-reported psychological measures, we compared positive and negative emotional states across Pre-Stress, Post-Stress, and Post-Environment phases, examining differences between VR and XR conditions. We developed a dynamic VR forest environment featuring interactive elements, aiming to replicate the stress-relieving benefits of shinrin-yoku. Both VR and XR positively impacted emotional restorativeness, with no significant difference in effectiveness. However, open-ended responses, heart rate data, and movement patterns indicated a user preference for XR due to its extended interaction capabilities. We propose further research into a more comprehensive XR experience, addressing limitations such as spatial drift and improving XR elements. These enhancements could lead to a more immersive and restorative digital shinrin-yoku experience

Thematic coding: Responses from participants of the XR experience painted a picture that the enjoyment of it would overall be greater than that of VR. Though the data does not reflect this, which could mean that the elements, while enjoyed, do not change the experience further. This can potentially be tied back to the importance of the senses, which advocated for vision and sound as being the most important (see *Section*), these being the main elements of VR.

Heart rate: The physiological data provided by the pulse tracker pointed to the XR environment being a more calming experience. While the resulting significance did not meet the required threshold, the physiological data may still have a meaningful practical difference between VR and XR, indicating the latter to be more calming and relaxing. It is important to note that some participants may have done more physical exertion before starting the test or may have medical conditions resulting in a varying heart rate, which was not accounted for. Even with that, an effect size larger than the threshold suggests the potential of further investigation, particularly with a larger sample size.

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