The Effects of Virtual Reality Environments on Physiological Stress: A Platform Comparison Between Room-Scale Displays and Desktop Computers

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Table of Contents

Abstract

Studies have proven the effectiveness of mindfulness and forest-immersion therapy as an option for stress reduction. However, what happens when an individual is seeking stress relief but the outdoors is unavailable due to unpredictable weather or even a lack of accessibility? The purpose of this research project is to observe the effects of guided scenic meditation in a virtual reality environment on physiological stress. Additionally, it performs a platform comparison by deploying the same meditative experience and testing its effectiveness using a room-scale immersive environment and a desktop computer, as desktops ($400 - $1000) are far more affordable and widely available compared to room-scale immersive environments ($1 million+). Using each platform, twenty participants were asked to engage with a meditative application that simulates the sights, sounds, and smells of a forest environment. Based on the objective data collected, the participants experienced a decrease in both heart rate and blood pressure, demonstrating the effectiveness of the simulation in reducing physiological stress. However, the room-scale immersive environment proved to be more successful in reducing the heart rate than the desktop computer. Furthermore, according to the participants, their subjectively perceived stress levels decreased, resulting in a far more relaxed state than before. The results showcase that a virtual simulation of a real environment actively contributes to stress reduction and can be used in cases when the outdoors is unavailable. The platform comparison demonstrates that the product of the research — a guided scenic meditation application that simulates a forest — is accessible and does not require a million-dollar room-scale display in order to be effective in reducing stress.

Introduction

As summarized by Hong et al., forest therapy — a conscious and contemplative practice that promotes wellness through self-immersion in a forest environment — is an effective option for stress reduction [4]. The study reported that walking in forest environments as opposed to urban environments significantly increases the activity of the parasympathetic nervous system and significantly decreases the activity of the sympathetic nervous system. Similarly, Jung et al. discovered that simply viewing forest landscapes increases “comfortable”, “natural”, and “soothed” feelings while decreasing the mean heart rate [5]. Although visual stimuli are undoubtedly effective, it should be noted that they are not the only sensory contributors to stress reduction; it can also be the result of auditory and olfactory stimuli. Alvarsson et al. reported that, after being under stress, listening to natural sounds, such as chirping birds, as opposed to loud noises, such as honking cars, also improves the sympathetic nervous system [1]. Additionally, as observed by Lee et al., inhaling scents such as wood while working or studying increases the level of bodily arousal and improves psychological stability [7].

Presenting an alternative to the outdoors, the purpose of this research project is to simulate the sights, sounds, and smells of a forest environment in virtual reality in order to observe and assess its effectiveness in reducing stress objectively and subjectively. To do so, a guided scenic meditation application simulating a forest environment was developed in the cross-platform game engine Unity. In addition to observing the effectiveness of the application in virtual reality, the project performs a platform comparison between room-scale displays and desktop computers to ensure that the product of the research is accessible, as a desktop computer, which costs between $400 to $1000, is far more affordable and widely available than a million-dollar room-scale display. The first objective is similar to the work of Kamińska et al. except that, rather than using a head-mounted display like the HTC Vive to induce stress reduction through a walk in the woods, the research project tests the effectiveness of a room-scale display in simulating a forest environment and reducing physiological stress [6].

Fig. 1. The CAVE2 Hybrid Reality Environment as photographed by Lance Long.

The room-scale display in question is the CAVE2 Hybrid Reality Environment located at the University of Illinois Chicago's Electronic Visualization Laboratory. This project utilizes the CAVE2's Fully Immersive mode that dedicates the entire display to one simulation which, in this case, is the guided scenic meditation application of a three-dimensional forest model created using Unity [3]. As demonstrated by the work of Hong et al. whose results showcase that watching a VR video of a forest environment decreases the stress index, stabilizes the physiological state, and positively impacts the psychological state of its viewers, an indoor simulation of a forest environment, as opposed to a real outdoor forest environment, can also contribute to the reduction of physiological stress [4]. Therefore, in cases when the outdoors are unavailable due to unpredictable weather or even a lack of accessibility, an indoor simulation that uses the sights, sounds, and smells of a forest environment can serve as an alternative option. This project proposes a guided scenic meditation application that utilizes all three components for a stress-reducing experience. The use of a virtual reality environment intends to increase the immersion of the user and, as hypothesized, decrease their levels of stress.

Methods

Application Development

In order to test the effectiveness of a forest simulation on physiological stress, the first task was to create an application for use in a virtual reality environment, specifically the CAVE2. The forest model of the initial application, developed in Unity, was completed to fulfill the requirements of the course CS 398 titled "Undergraduate Research/Design" at the University of Illinois Chicago. At the time, there was no prior experience working with the game engine, so modeling the forest proved to be a steep learning curve. Briefly put, the process involved sculpting a terrain, painting a trail, scaling models, and importing assets, the result of which was a lush and vibrant stretch of land decorated with tall conifer trees, swaying grass blades, colorful flowers, and large stones.

Fig. 2. The forest model developed in Unity.

The assets used to create the forest environment were all derived from the Unity Asset Store. The conifer tree models, which are distributed throughout the 1000 x 1000 meter terrain, come from “Conifers [BOTD]” by Forst. The various textures painted atop the terrain are the creation of A Dog’s Life Software titled “Outdoor Ground Textures”. To achieve the swaying grass blades and colorful flowers, the work of ALP called “Grass Flowers Pack Free” was used. To further populate the environment, the stones of SHUI861WY’s “Rock Package” were scattered about. Lastly, to simulate a sunny day, a skybox was acquired from Avionx’s “Skybox Series Free”.

Because “research has shown that viewing natural scenes can lower heart rate and restore focus, both of which are important for combatting physical and mental health disorders,” enhancing the visuals of the forest model was a priority [10]. With the visuals completed, the next task was to script the application as a guided scenic meditation using the programming language C#. With the knowledge that the application would eventually be used by future participants in a series of user studies, a simple user interface was created in the form of a start menu. It informs the user how to begin the guided scenic meditation depending on their designated platform. If using the CAVE2, the user must press the L1 button on the platform’s main interaction method called the “wand” controller. If using the desktop, the user must press the left mouse button on a standard mouse.

Fig. 3. The start menu that appears when the application is first launched.

Regarding functionality, the shots of the guided scenic meditation were achieved by primarily scripting the in-game camera which assists in navigating the view of the user. Its position, rotation, and speed were altered depending on the context provided by the two accompanying voice-overs. As credited in Figure 3, the voice-over for the first part of the guided scenic meditation — which lasts for three minutes of the ten minute runtime — originates from “Guided Imagery Meditation: Forest CHOC” and has been provided by the accredited hospital Children’s Health of Orange County [2]. The voice over for the second part — which lasts for the other seven minutes of the ten minute runtime — originates from “Guided Imagery - Walk Through Forest” as provided by the meditation channel Mindfully [8].

Because research studies have found that “listening to clips of multiple bird species singing in an urban area had a stronger positive effect on people’s perception of the space [around them]”, it is made clear that visuals are not the only sensory contributors to stress reduction [10]. Therefore, to enhance the forest simulation, a looping audio clip of chirping birds titled “Sunny Day” from SoundBible was added. In addition, because “smells might have a much more profound effect on reducing stress compared with sights and sounds”, a coniferous scent diffuser was placed in front of all participants to simulate the smell of a forest [10].

With the forest model and guided scenic meditation application in a completed state, the next course of action was to deploy the project to the CAVE2. In order to do so, the project needed to be configured and built for the room-scale display. This was achieved using the CAVE2/Unity simulator developed by Dr. Arthur Nishimoto as well as his guide that is aptly-titled *Guide for running Unity in CAVE2* [9]. When initially developed, the project was created using the Unity version 2018.4.14f1. To ensure that it was compatible with the CAVE2 and its Unity simulator, the project was upgraded to 2019.2.11f1, the latest Unity version that is supported.

Fig. 4. The guided scenic meditation application deployed to the CAVE2, pictured on the left, and the desktop, pictured on the right.

IRB Approval and User Studies

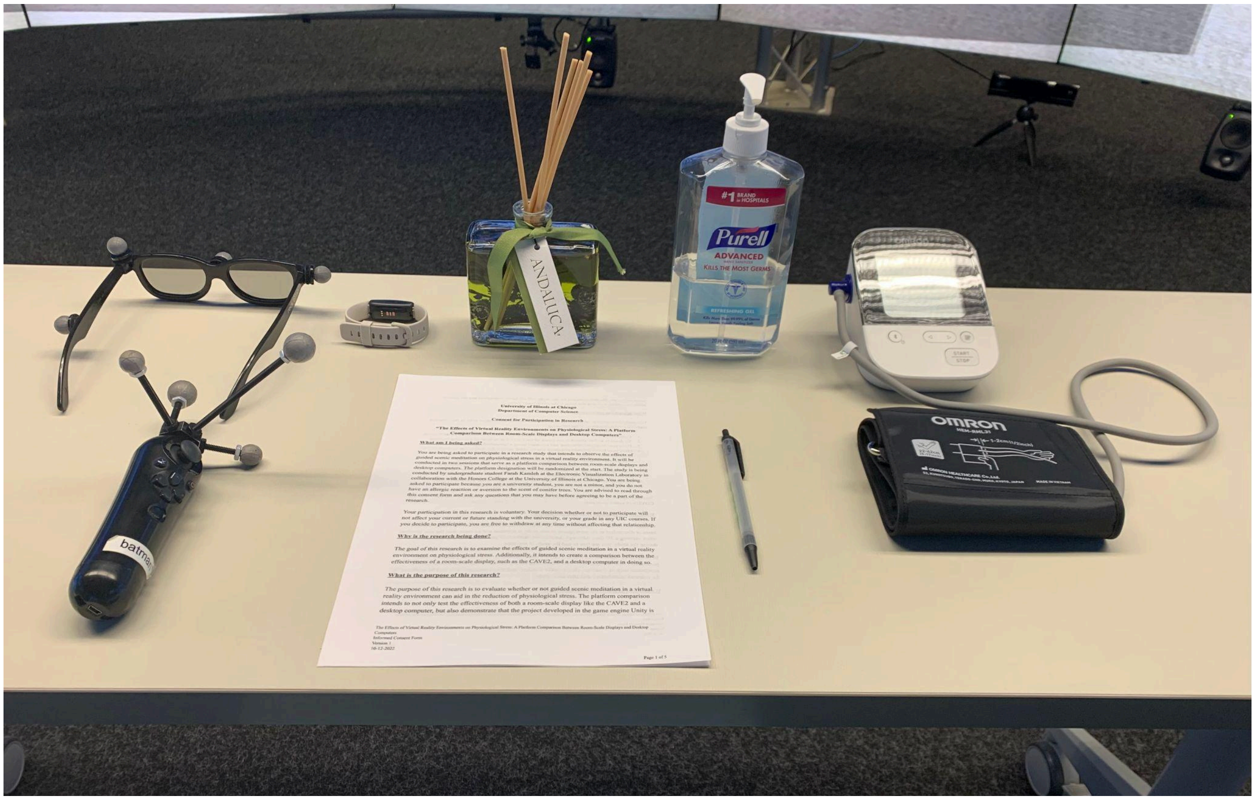

Fig. 5. The placement of all the materials needed for the user studies with CAVE2 designation.

After successfully testing the finalized application on both platforms, the next step was to prepare for user studies with human subjects. Due to their involvement, it was vital that the study first be approved by the Institutional Review Board (IRB). After the completion of the CITI Training courses “IPS For Researchers” and “Group 2. HSP, Social / Behavioral Research Investigators and Key Personnel” as well as the submission of a protocol, recruitment form, informed consent form, and additional documents, the study was successfully approved by the IRB on January 5th of 2023 (STUDY2022-1377).

The study consisted of two hour-long sessions hosted a week apart from one another that asked twenty participants — all of whom were university students that were 18 years or older — to engage with the same Unity-built, meditative application using two different platforms for comparison: the CAVE2 and a desktop computer. At the start, the platform designation was randomized. Before and after each session, the participants were asked to complete a subjectively perceived stress evaluation survey using Likert scales. In a similar fashion, the heart rate and blood pressure of the participants was recorded before and after each session using a lab-owned, general use Fitbit bracelet and a standard OMRON HEM-FL31 blood pressure monitor respectively.

Prior to their arrival, the participants were to ensure that, by the time of their scheduled user study, it had been at least 30 minutes since exercising, eating, smoking, drinking, or bathing in order to receive better readings. Similarly, to successfully place the cuff of the blood pressure monitor on their upper left arms, they were requested to wear clothes that can expose that part of their arms using short or folded sleeves. Finally, at the end, the participants were given the opportunity to provide suggestions for the study and application. The same procedures were performed for both sessions.

Platform Comparison

While the procedures described above remained consistent across platforms, there are notable differences between the experiences, especially in regards to the visual, auditory, and interactive components. As pictured in the top left corner of Figure 5, when assigned CAVE2-designation, participants were requested to wear 3D glasses with tracked retro-reflective markers. As a result, the displayed visuals on the 88 passive stereo screens shifted relative to the position of the participants' heads. Additionally, to optimize the frame rate, the hypnotic, swaying motion of the grass observed in the desktop version was omitted from that of the CAVE2. Lastly, as shown in Figure 7, the desktop version had a single screen as opposed to the CAVE2's 88.

Regarding the auditory component, although the CAVE2 has a 20.2 channel sound system, the meditative experience used Unity's built-in 7.1 output. The desktop computer, however, required the use of spatialized, wired Beats Solo^3 On-Ear headphones. Present in the bottom left corner of Figure 5 is the input method of the CAVE2 — a tracked and modified PlayStation Move controller referred to as the "wand" — which allowed the user to begin, quit, and restart the guided scenic meditation throughout the study with the press of a button. More familiar to the participants on the other hand is the input method of the desktop computer which was a standard, wired mouse. While the visual, auditory, and interactive components between platforms have their differences, it should be noted that the olfactory component remained the same; both platforms made use of the same coniferous scent diffuser.

For the environment in which both versions of the study took place, the CAVE2 and desktop designations were performed in the same laboratory room and, therefore, retained the same bright illumination, ambient fan noise, and student conversations. For the CAVE2 version, the participants were seated in a chair that was 12 feet away from the surrounding screens. For the desktop version, on the other hand, they were placed about 2.5 feet away from the single screen. Each screen of the CAVE2 has a resolution of 37 Megapixels in 3D. For comparison, the desktop's monitor has a resolution of about 8 Megapixels. In terms of screen sizes, a single screen of the CAVE2 is 40.5 inches in width and 23 inches in height while the desktop monitor is 24 inches in width and 14 inches in height.

Fig. 6. The guided scenic meditation application running in the CAVE2 with its accompanying user study set-up.

Fig. 7. The guided scenic meditation application running on a desktop computer with its accompanying user study set-up.

Results

Participant Demographics

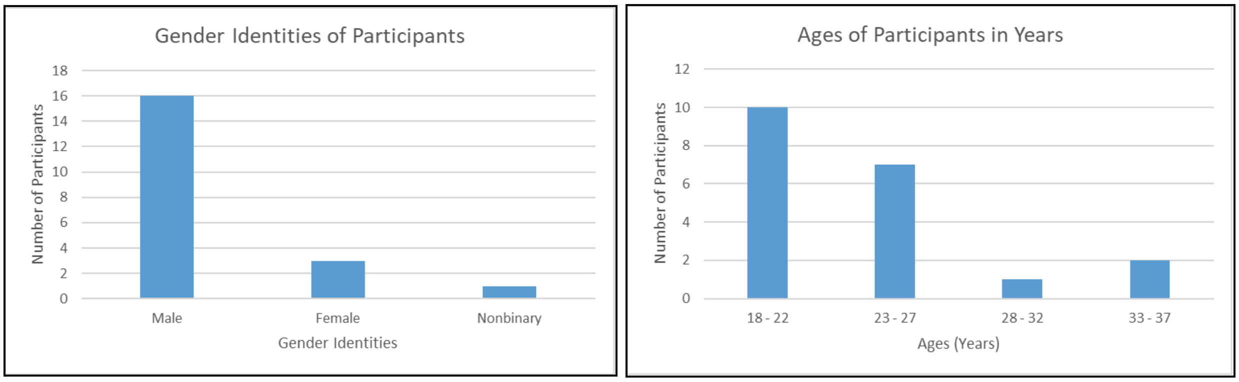

Fig. 8. The gender identities and ages of the participants on the left and right respectively.

The forty hour-long user study sessions were conducted within two consecutive semesters at the Electronic Visualization Laboratory located at the University of Illinois Chicago with a total of twenty participants. In 2023, the first half were conducted over three weeks during the month of March while the second half were conducted over six weeks from the end of October to the start of December. Among the participants, sixteen identified as male, three identified as female, and one identified as nonbinary. The ages of the participants ranged from 18 years old to 36 years old, half of which fell within the range of 18 to 22 years old as shown in Figure 8.

Objective Data

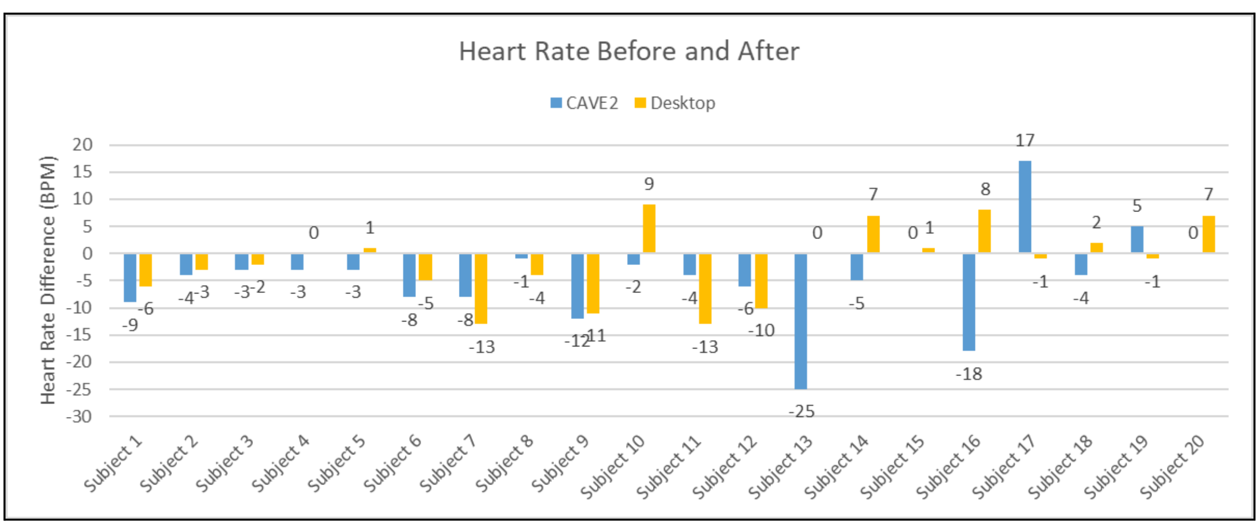

Fig. 9. The heart rate differences of participants before and after application engagement using both the CAVE2 and desktop.

Before and after engaging with the guided scenic meditation application using both platforms, the heart rates of the participants were collected and recorded. As shown in Figure 9, sixteen of the twenty participants experienced a decrease in heart rate when using the CAVE2 as their platform (80%) while only eleven did when using the desktop version of the application (55%). When observing the difference in heart rate decrease between platforms per participant, the CAVE2 resulted in a greater decrease in fourteen cases (70%), outperforming the other.

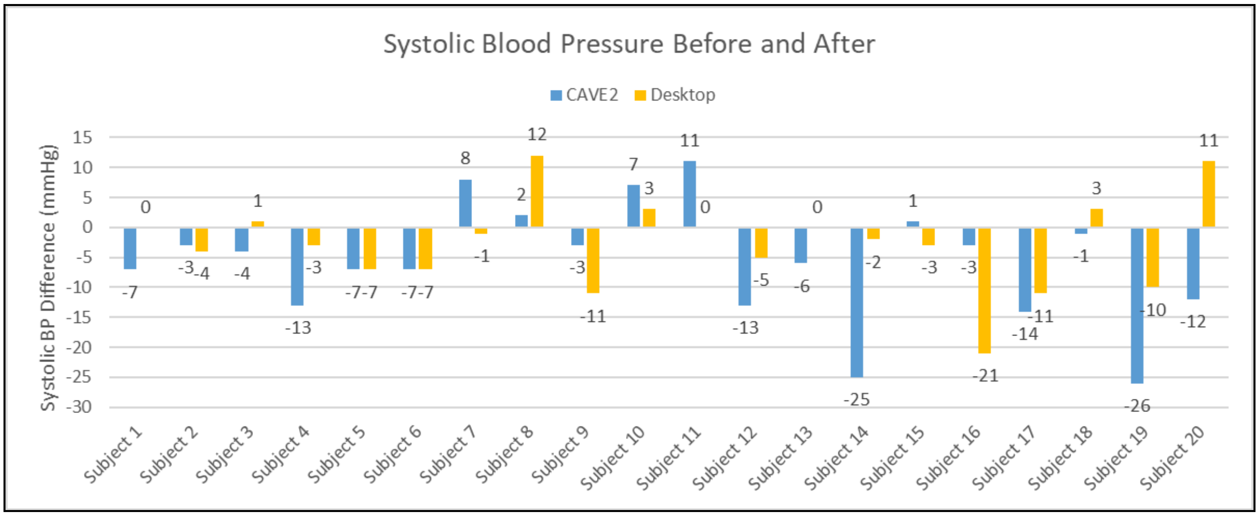

Fig. 10. The systolic blood pressure differences of participants before and after application engagement using both the CAVE2 and desktop.

Like the heart rate, the blood pressures of the participants were collected and recorded before and after their engagement with the guided scenic meditation application using both platforms. For systolic blood pressure, which is the measurement of pressure in the arteries during heartbeats, the CAVE2 version of the application resulted in a decrease with fifteen of the twenty participants (75%). With the desktop version, on the other hand, only twelve experienced a decrease (60%). When evaluating the difference in decrease for each platform per participant, the CAVE2 resulted in a greater decrease in only eleven cases (55%), making the platforms almost equal in this regard.

When it comes to diastolic blood pressure, which is the measurement of pressure in the arteries between heartbeats, the CAVE2 version resulted in a decrease in thirteen cases (65%) while the desktop version did in fourteen (70%). In terms of how significant the difference was before and after per participant, the CAVE2 resulted in a greater decrease only half of the time (50%). Therefore, with diastolic blood pressure, the platforms are equal in effectiveness.

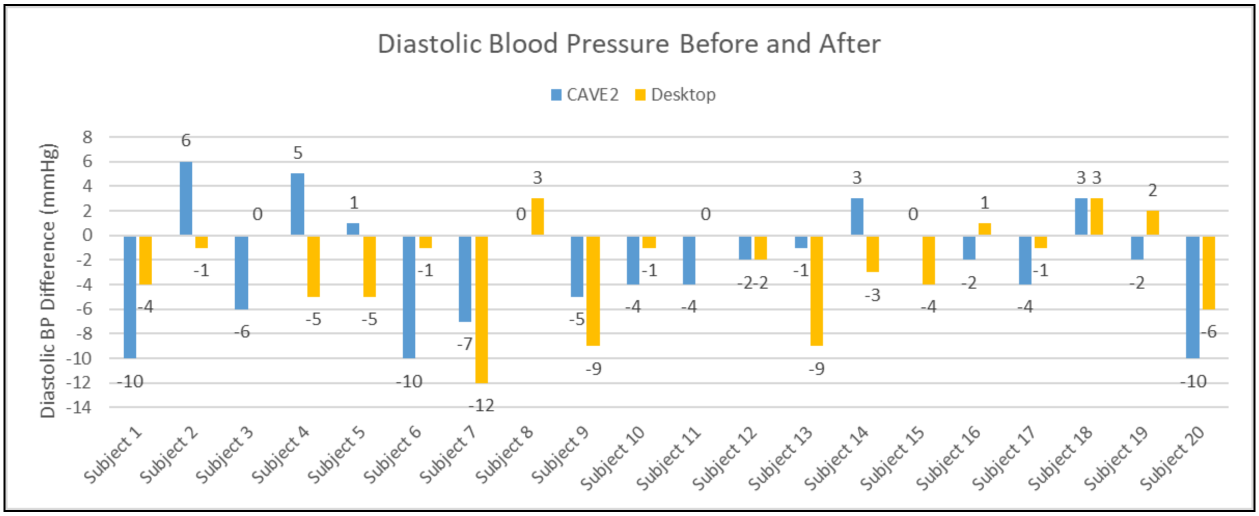

Fig. 11. The diastolic blood pressure differences of the participants before and after application engagement using both the CAVE2 and desktop.

Subjective Data

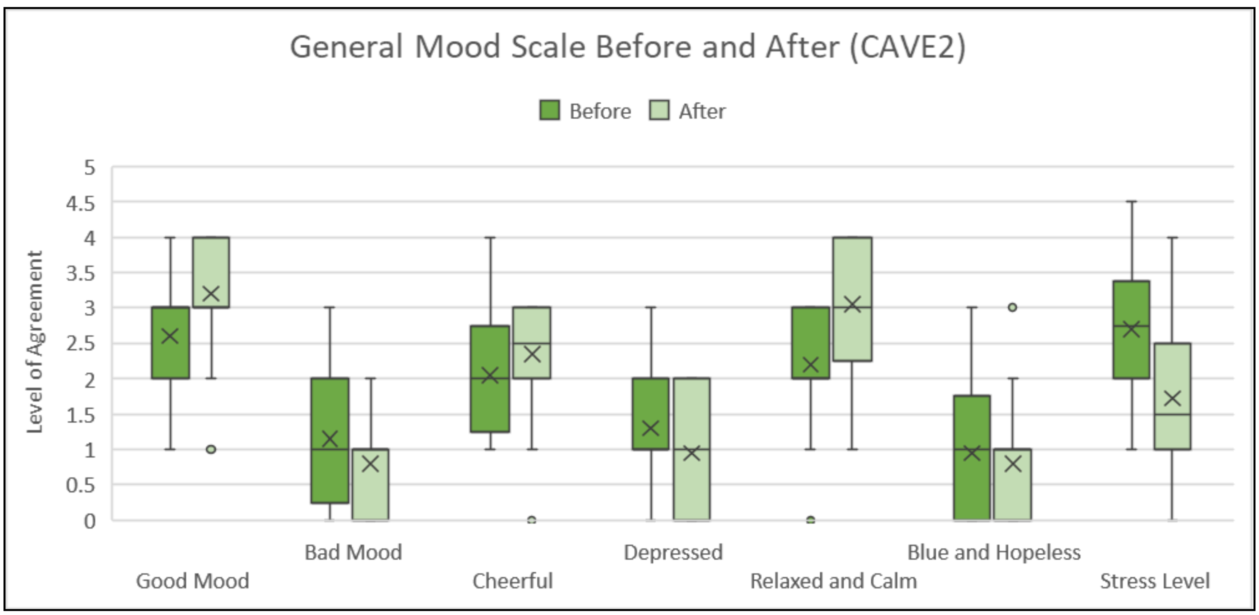

Fig. 12. A box and whisker plot showcasing the subjectively perceived moods and stress levels of the participants before and after application engagement using the CAVE2.

Before and after engaging with the guided scenic meditation application, the participants were asked to fill out a survey about their subjectively perceived moods and stress levels. Using Likert scales, they were made to select their levels of agreement or disagreement with statements such as “I feel relaxed and calm” and “I feel blue and hopeless”. According to the box and whisker plots of Figures 12 and 13, almost all participants experienced an improvement in their mood and stress levels after engagement regardless of platform. A similar trend is observed with the CAVE2 and the desktop.

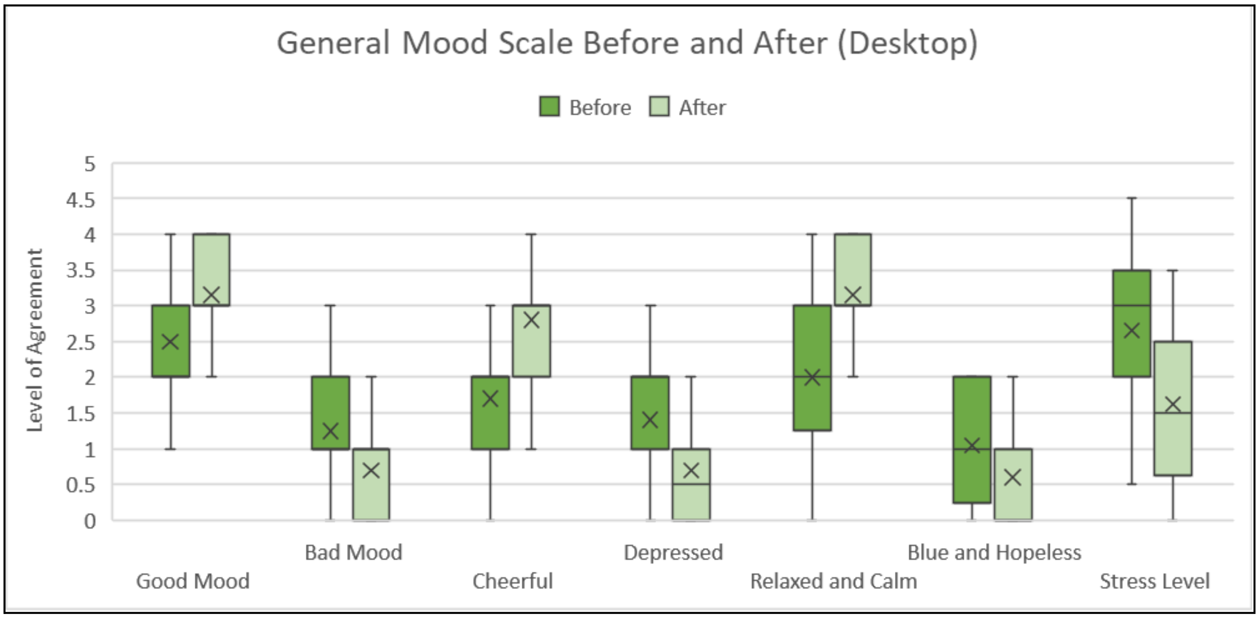

Fig. 13. A box and whisker plot showcasing the subjectively perceived moods and stress levels of the participants before and after application engagement using the desktop.

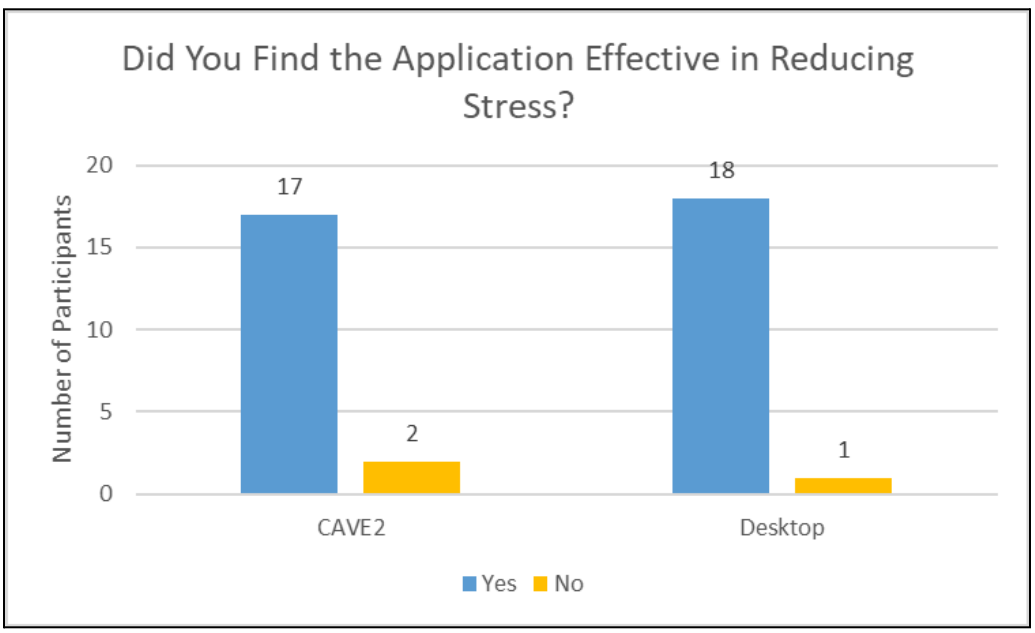

Fig. 14. A subjective evaluation of the application's effectiveness in reducing stress for the CAVE2 and the desktop on the left and right respectively.

At the end of each session, the participants were given the opportunity to fill out an evaluation of the application and provide suggestions for improvement for each platform. One of the questions asked, “Did you find the application effective in reducing stress?”. As shown in Figure 14, for both the CAVE2 and the desktop, the majority of participants voted yes, confirming that, subjectively, the guided scenic meditation and forest simulation successfully reduced their stress as intended. For the two participants who voted no for the CAVE2, a preference for the desktop version was verbalized. They felt that the use of headphones and the close proximity to the single screen was far more immersive than the surrounding sounds and screens of the CAVE2. For the single individual who voted no for the effectiveness of the desktop, they felt as though they were simply watching a YouTube video rather than feeling present within the environment.

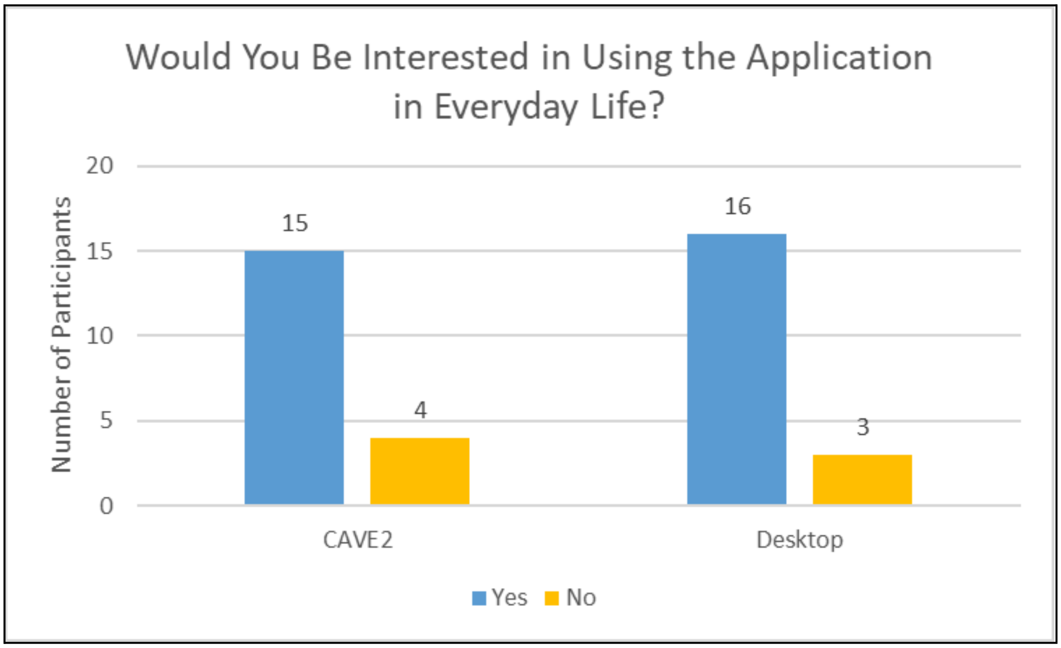

Fig. 15. A bar chart showcasing whether participants would be interested in using the application in everyday life for the CAVE2 and the desktop on the left and right respectively.

With the intention of assessing whether the product of the research would be used by people, another question asked, “Would you be interested in using the application in everyday life?”. Fifteen of the nineteen participants who voted would be interested in using the CAVE2 version of the application in everyday life and sixteen would be interested in using the desktop version of the application in everyday life. One of the participants who voted no for both platforms expressed an interest in having the environment be a location that is nostalgic to them rather than a forest. In other words, they would have preferred a more personalized experience. Although not a significant enough difference, a slight preference towards the desktop version of the application may be due to the frequently reported comment that it is a more feasible setup than the CAVE2 version, as desktops are more accessible in terms of cost and availability. On a similar note, a participant who voted no for the usage of the CAVE2 version in everyday life expressed that they would rather use a head-mounted display than a room-scale display for the same reason. Lastly, one of the participants who voted no for the desktop application stated that they would not use the application unless the olfactory component were preserved.

Conclusion

Based on the results, it can be concluded that the guided scenic meditation application simulating a forest environment is effective in reducing stress, especially subjectively. It is capable of reducing the heart rates and blood pressures of its users regardless of platform, as the CAVE2 and desktop exhibited similar trends. However, it should be noted that a reduction in heart rate was far more successful than a reduction in blood pressure, especially with the CAVE2. In addition, the application is capable of improving moods and stress levels according to the subjective data collected from the participants. Because the desktop can also reduce stress, it can be concluded that the product of the research is accessible and affordable. This also showcases that, while effective in virtual reality, it is not a requirement to achieve the aforementioned results. However, based on participant feedback, the desktop is less immersive due to potential external distractions. If more subjects were included in the research study, the results would be far more conclusive. Therefore, a future endeavor would be to perform additional user studies with more participants in order to confidently report results and make conclusions.

Future Work

Limitations

Throughout the paper, the criterion by which success is determined for objective stress reduction is any decrease observed in the heart rates and blood pressures of the participants after engaging with the application on their designated platform. Consequently, in the case that the decreases observed are small enough that they fall within the margin of error, the claim of a success may be misleading. To potentially alleviate this limitation, the methodology should incorporate the collection of objective measures like heart rate during the guided scenic meditation to observe how they vary over time, especially in comparison to the other platform.

As briefly mentioned in the conclusion, one of the limitations of this research is the collection of objective and subjective data from only twenty participants. The recruitment of additional participants will lead to more conclusive results. Similarly, another limitation is the lack of a control variable related to the reduction in physical activity. The two conditions in which all subjects have been exposed to are the same meditative application deployed to a desktop computer and a room-scale display. In both settings, participants sat in a chair for the entire duration of the study. It is unclear whether the decrease in heart rate and blood pressure is the result of exposure to the guided scenic meditation or the reduction of physical activity.

Therefore, in a future version of the study, a control condition could be having the participants remain seated for the duration of the study without any exposure to the application.

To investigate, the graduate researcher partook in a mock control condition in which they performed the procedure on themself, recording their heart rate and blood pressure before and after exposure to no application and no sensory stimuli while remaining seated for the same 10-minute length of the guided scenic meditation. Their heart rate remained 77 beats per minute before and after, but their systolic blood pressure changed from 111 mmHg to 102 mmHg with a 9 mmHg decrease and their diastolic blood pressure shifted from 81 mmHg to 75 mmHg with a 6 mmHg decrease. These objective results could potentially demonstrate that, while heart rate is unaffected, both systolic and diastolic blood pressure decrease as a result of no physical activity, but it should be repeated that only one individual — the graduate investigator — participated in this mock control condition. Therefore, more data is required to make concrete conclusions.

Another potential limitation is the difference in platform setting. For participants who have never seen the CAVE2 before nor stepped foot within it, the surrounding 88 passive stereo screens and 14-camera optical tracking system may be overwhelming, possibly affecting their heart rate and blood pressure. To mitigate this, the proper setup for the desktop platform should have been within the CAVE2 space as well. However, as shown in Figure 7, the user studies that used the desktop computer took place outside of the space. This choice was also arguably detrimental to the desktop results, as many participants expressed that, despite the use of headphones, they were distracted by events that took place within the laboratory beyond the single desktop screen such as student conversations.

Lastly, not taken into consideration in the reporting of objective data is the effect of external factors on the participants' heart rates and blood pressures. For example, in Figure 10, Subject 8's systolic blood pressure increased by 12 mmHg after engaging with the desktop version of the application. Prior to engagement, when placing the headphones onto their head, the participant accidentally snapped the band in half, resulting in broken equipment. Therefore, having expressed guilt, the increase in systolic blood pressure may have been the result of the accident rather than the application. Similarly, Subject 1, who experienced a decrease in both heart rate and blood pressure in both conditions barring the same systolic blood pressure for desktop, communicated that they naturally have a low heart rate. Although only the difference for all objective data is reported, 30 minutes of repeated difficulty in detecting measurements occurred with the blood pressure monitor for this participant. It was hypothesized that this was the result of the combination of Subject 1's low heart rate and participation in fasting for the month of Ramadan, as fasting reduces the resting heart rate. Therefore, Subject 1 was rescheduled after Iftar, the fast-breaking evening meal. Finally, when asked about the olfactory component of the simulation, Subject 6 self-reported that, to their knowledge, they have had a complete inability to detect odors since birth.

Participant Suggestions

According to the participants in the evaluation section of the survey, the application's use of visual, auditory, and olfactory stimuli successfully simulated a forest environment. However, there is more that can be done to increase immersion and create the illusion of a real forest for relaxation. The following are the observations and suggestions of the participants in regards to the use of sensory stimuli and the future of the application.

A common request among the participants was the addition of touch to the sensory stimuli being used. While engaging with the application, the user can interact with physical objects that simulate textures found in forests such as tree bark and pine cones. Some participants even suggested the placement of fake grass underneath the user's feet and a glass of water to dip their hands in. On a similar note, it was suggested that a different chair be used rather than the one present in Figures 6 and 7, as it was often described as uncomfortable. Therefore, for the second round of user studies, the chair was replaced. Lastly, a few participants requested that the temperature of the room be adjusted to match the virtual environment. For example, during the scene in which sunlight peeks through and between the trees, the room should be made warmer.

Among the sensory stimuli being used, expansions were especially suggested for the application's use of sounds and smells. Additional sound effects that the participants believed would strengthen the simulation are rustling leaves, crunching footsteps, and blowing winds. It was also requested that the visuals match the voice-over more closely. To cater to this request, birds were added to the environment's skies and trees for the second round of studies using the "Living Birds" asset by Dinopunch, but this update surprisingly resulted in the opposite of the intended effect. Some participants found that the bird models, specifically the few that were static, broke their immersion. When it came to the voice-overs of the guided scenic meditation, a few participants requested the ability to toggle them on or off, as they found them to be distracting rather than assisting. However, others found that they provided direction and increased their focus, claiming them to be the most helpful of the sensory stimuli. Finally, when it comes to smells, only a single scent, that of conifer trees, is present. One participant suggested the use of flowers for greater presence.

In order to increase immersion and engagement, user interaction with the application was heavily requested. Other than being able to freely move throughout the environment, the participants encouraged the inclusion of engaging activities such as locating objects and building their surroundings. Some even encouraged activities to be performed outside of the application with the voice-over serving as a guide or instructor. Such activities include stacking rocks, separating grass blades, and pushing away branches. However, a few participants believed that the addition of interaction would disrupt the goal of relaxation, especially in cases where the interactive tasks could result in errors.

Finally, in order to expand the application, participants suggested the inclusion of additional environments. Rather than only being able to engage with a forest, the user would be able to choose which environmental simulation to be immersed in. Such environments include beaches, deserts, and jungles. Lastly, it was requested that the application be available on more platforms than a room-scale display and desktop computer. It is predicted by the participants that a head-mounted display would be best for immersion, as it would dispel all external distractions as well as those that are platform-specific such as synchronization delays between the panels of the CAVE2. Additional platforms suggested include televisions, mobile phones, and tablets, all of which are more widely available and affordable than a room-scale display.

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