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RESEARCH ARTICLE

Prototype Development of a Gamified Virtual Environment for Neuromonics Tinnitus Treatment

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ABSTRACT

The use of Virtual Reality (VR) in medical therapy has gained traction, as it offers an interactive, immersive, and controlled environment that is challenging to replicate in the real world. Tinnitus, a condition characterized by ringing in the ears, often requires a psychological therapeutic approach despite having a physical cause. Recently, a VR study was conducted in tinnitus therapy, but the simple virtual scenes lacked sufficient engagement to sustain patients' interest in the treatment. This also highlights the common challenge of patient treatment retention encountered in various therapeutic approaches. However, recent studies show that gamification elements, such as tablet computer games and achievement-based award mechanisms, can effectively enhance patient retention within therapy sessions. Inspired by this, this paper presents a thorough development of a prototype gamified VR application that incorporates acoustic stimulations for neuromonics tinnitus therapy. The application acquires the patient's specific tinnitus frequency and integrates it with other sounds to help lessen the user's perception of their unique tinnitus frequency during VR treatment. All functionalities of the application are detailed in the paper. Initial data on the usability and effectiveness of the application are not yet available. The alpha version of the application is available upon request.

1 INTRODUCTION

Tinnitus is a prevalent health condition characterized by a ringing sensation in the ears, which occurs in the absence of any external sound stimulus. This condition can manifest differently among individuals, with the specific tone of the ringing varying widely. It is estimated that between 10% to 15% of the global population suffers from some form of tinnitus. The origins of this condition can be diverse, ranging from ear or head injuries, age-related hearing loss, to chronic exposure to loud noise environments according to Moller et al. [11]. Currently, there is no known cure for tinnitus, although some extreme measures, such as cochlear implant surgery, may be considered. This procedure entails severing natural connections to the cochlea and installing a receiver behind the ear that captures external sounds, converting them into electrical impulses to stimulate the auditory nerves. While cochlear implants enable the brain to perceive these electrical signals as sound and allows the patient to hear, the resulting auditory experience differs significantly from natural sounds.

One innovative approach aimed at mitigating the distress associated with tinnitus is neuromonics tinnitus treatment. Neuromonics tinnitus treatment is a specialized approach designed to alleviate

the distress caused by tinnitus. This treatment involves the use of a customized sound therapy program that is carefully designed to match the auditory profile of the individual. It incorporates a blend of soothing sounds and music tuned to harmonize with the person's specific tinnitus frequency, with the goal of reducing the brain's sensitivity to tinnitus sounds. Over time, this therapeutic intervention can reduce the prominence and impact of tinnitus on the patient's daily life. Neuromonics treatment is typically delivered through a cochlear implant through the use of sound masking devices that obscure the tinnitus noise, as noted by the National Institutes of Health in 2010 [12]. Aside from physical devices, there are psychological interventions which typically involve counseling and require regular, often costly, in-person sessions. Recognizing the limitations of traditional methods, recent studies have investigated the potential of digital solutions, including smartphone and internet-based applications, to deliver tinnitus treatment more effectively. Researchers such as Beukes et al. [1], Demoen et al. [4], Kutyba et al. [9], Mehdi et al. [10], and Suh et al. [14] have highlighted these tools' ability to provide flexible treatment options that patients can utilize at their convenience. This adaptability not only enhances accessibility but also reduces the overall burden, making it a promising direction for future tinnitus management strategies.

Virtual Reality (VR) has gained traction in certain medical therapies due to its ability to transcend physical boundaries and be accessible in any environment. By combining visual and auditory stimuli within a three-dimensional immersive virtual environment, VR has demonstrated its effectiveness in treating conditions such as depression, Post-Traumatic Stress Disorder (PTSD), and psychological disorders in Bond et al. [2] and Snoswell et al. [13]. When given the option to choose between VR-based psychological therapy and traditional therapy methods, patients have shown a preference for VR-based approaches in Jin et al. [7]. Remarkably, despite the users' awareness that the VR environment is computer-generated and not physically real, their cognitive and emotional responses resemble those experienced in the physical world according to Kim et al. [8]. In a recent study by Draper et al. [5], a VR application was developed with three different scenes incorporating existing tinnitus sound therapy, and participants were just asked to complete questionnaires during the multisensory tinnitus treatment. It was observed that the scenes lacked sufficient engagement to sustain patients' interest in the treatment. This highlights the common challenge of patient treatment retention encountered in various therapeutic approaches. Fortunately, recent research work from Bocqué et al. [3] and Guala1 et al. [6] have shown that the inclusion of gamification elements, such as tablet computer games and achievement-based award mechanisms, can effectively enhance patient retention within therapy sessions. These findings underscore the potential of incorporating interactive and engaging elements to improve the overall treatment experience and promote better patient engagement and long-term outcomes.

Therefore, this paper first introduces a well-designed prototype development of a game-based VR environment designed for conducting neurologic tinnitus treatments. Within this VR-based treatment, the patient's unique tinnitus frequency is identified and played alongside other sounds, with the aim of training the user's brain to desensitize the perception of their specific tinnitus frequency gradually. By employing VR technology, neuromonics tinnitus therapy becomes accessible in any environment and at any time while also becoming more cost-effective for individuals seeking treatment. Additionally, integrating gamification elements with the treatment regimen can enhance patient engagement and long-term retention. Overall, this paper presents a clear description of the application design and development process. Initial user feedback on the usability and effectiveness of the application will be collected at local hearing rehabilitation centers.

This paper is organized into three sections. Section 2 describes the design and development of the virtual environment, providing an overview of the application's features and discussing future

enhancements in application. Section 3 presents the detailed plans for prospective tinnitus treatments and future user study of the application. Finally, Section 4 summarizes our work.

2 DESIGN AND DEVELOPMENT

In this work, the VR development utilized the newest version of Unreal Engine 5. Unreal Engine 5 development is managed using the built-in blueprint system. The blueprint system is a visual coding style where the user drags and drops different functions and objects and connects them with lines to obtain the desired output. See an example view in Figure 1.

Unreal Engine 5 was chosen due to the maturity of its development tools, VR-ready, and the extensive development community the engine has. Due to the nature of Unreal Engine VR development, many other VR devices can potentially run the project. The currently supported devices for this application are the Meta Quest 2 and Meta Quest 3. All other VR devices are considered unsupported.

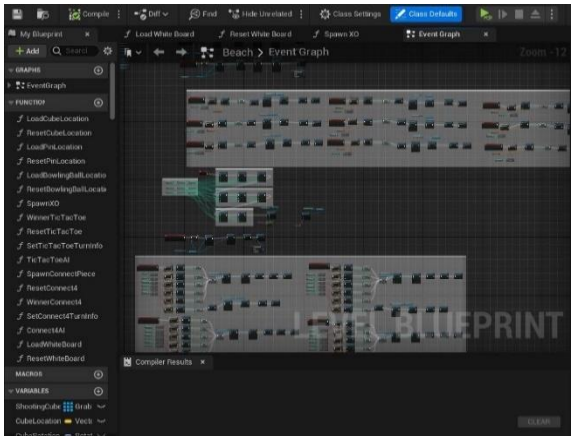

Figure 1: An Example View of a Blueprint System in Unreal Engine 5.

2.1 virtual treatment environment

One common way to initially try sound therapy is by selecting a relaxing, neutral sound—like ocean waves crashing, rain falling, white noise, or instrumental music—and playing it as background noise throughout the day. To facilitate this, the treatment environment was designed as an island adorned with palm trees. In order to make the island more engaging, an Asian-inspired pathway was constructed, leading from the beach to a central Asian-inspired town located on the island (see Figure 2). This town includes two experience rooms within a Zen Garden, each emanating different soothing sounds. Additionally, six gamified treatment sites accompanied by therapeutic sounds are available for users to explore. These games include Tic Tac Toe, Connect4, Bowling, Shooting Gallery, Maze Solving, and White Board Drawing in the virtual environment (further details in Section 2.4).

Figure 2: View of the Asian-inspired town located at the island's center with palm trees on it.

2.2 Functional Options within The Virtual Treatment

The virtual space's main menu was designed to appear quickly upon pressing the controller's menu button, as shown in Figure 3.

The option to Restart Level button permits the user to reset the current level at which they are located within the virtual environment. Upon clicking the button, the user's position will be returned to the original default location. Nonetheless, this button does not impact any settings related to Tinnitus Training or achievements progress. By selecting the Tinnitus Training button, users are directed to the user-controlled Tinnitus training module (detailed in Section 2.3). The Achievements button displays both locked and unlocked achievements among the gamified activities (detailed in Section 2.4). Lastly, the Exit button facilitates the closure and exit of the VR application. Moreover, given the specific time constraints involved in Tinnitus treatment, maintaining an accurate treatment time is of enormous importance. To address this, a continuous time counter was incorporated into the user's VR field of view and consistently positioned at the top-left corner.

Figure 3: main menu and a time counter.

In addition, considering the vast expanse of the island, utilizing traditional directional controller joystick inputs for walking can consume a substantial amount of time. A teleportation system was implemented to expedite movement within the virtual environment. A blue aura ring materializes on the screen when the user pushes forward on the right controller joystick, as seen in Figure 4. This ring serves as a visual indicator to inform the user about the destination they will be teleported to upon releasing the joystick.

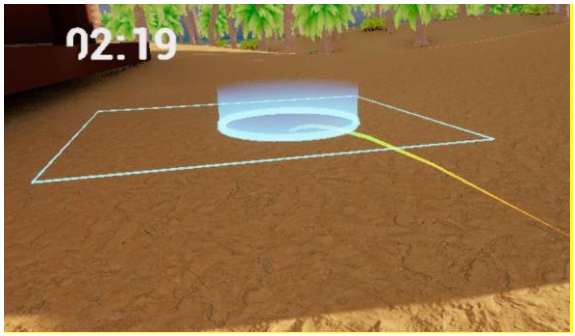

Figure 4: The blue aura ring informing the user about the designated teleportation location.

2.3 Tinnitus Training Module

Upon accessing the Tinnitus training module through the button on the main menu, various frequencies are presented, corresponding to the user's tinnitus frequency. See Figure 5.

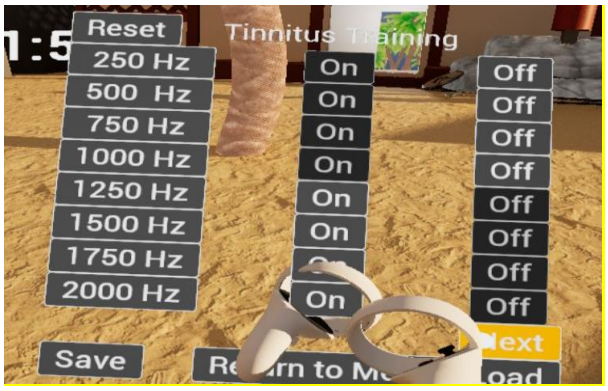

Figure 5: The main interface of the user-controlled tinnitus training module showcases some sound frequencies.

This interactive experience encompasses frequencies ranging from 250 Hz to 10,000 Hz, with increments of 250 Hz, empowering the user to select their desired frequency to train. All sound frequencies within this tinnitus treatment module are initially set to "Off" until the user's first tinnitus training session. The user is required to manually switch the desired frequencies to the "On" position, aligning with their individual tinnitus frequencies. Since some users may experience multiple tinnitus frequencies, the application permits the selection of multiple sound frequencies associated with their specific condition. When a selected sound frequency is activated, it will be played through the VR headphones. In the case of multiple selected sound frequencies, the application system will randomly play each chosen frequency in the background alongside the natural beach wave sounds. The intervals between the playback of each selected frequency will vary randomly between 10-15 seconds. The volume of the tinnitus-played sound frequency will be set to 60 percent of the ambient sound level.

Additional functional choices available in the Tinnitus training module include the Reset, Save, and Load buttons. The Reset option allows for the deactivation of all sound frequencies and removes all Tinnitus training settings. This would essentially reset the application back to the default base settings of the application where all frequencies settings are set to default of being set to the Off Setting. By selecting the Save option, a save file is generated to store the current setting of the user's tinnitus training sound frequencies. When the user returns to the training session, the application system will automatically load the most recent saved file created by the user. In the case that the user modifies their tinnitus training selection and realizes that their new choice of sound frequencies is less satisfactory than their previous selection, the Load button allows them to revert back to the latest saved file of sound frequencies within the application system.

2.4 Achievement-Based Award Mechanism In Gamified Virtual Treatment Environment

As stated earlier, ensuring patient treatment retention is a challenge when it comes to medical treatments of extended duration. To tackle this issue, an achievement system was developed and integrated into various game activities for training settings. This system aims to combat potential boredom over time by actively engaging users with the training games, ultimately enhancing their treatment retention. As seen in Figure 6, an achievement list is displayed in the virtual environment, which can be accessed through the main menu by clicking on the Achievements button.

Figure 6: The interface of the achievement list to various serious game activities.

The list showcases both accomplished and pending achievements for the user. Each achievement is accompanied by a title and description, providing users with guidance on the necessary actions to unlock each achievement. Additionally, a custom notification sound was designed to play when an achievement is achieved or unlocked. It is important to note that the achievement list can be customized based on discussions between the user and the doctor, tailoring it to the individual's treatment plan.

In this work, we designed two distinct experience rooms and a Zen Garden within the designed beach environment. In addition, we created six different serious game activities for users to engage with while therapeutic sounds play in the background. These games include Tic Tac Toe, Connect 4, Maze Solving, Bowling, Shooting Gallery, and White Board Drawing, as seen in Figures 9-14. These games can be reset within the VR play environment to facilitate repetitive training, allowing users to engage in repeated practice and exploration. Further explanations on the games and activities within the application are explained in the following sections.

2.4.1 Experience Rooms and Zen Garden

The two experience rooms (see Figure 7) feature immersive displays of varied lights and therapeutic sounds. These rooms do not offer interactive elements; they just promote relaxation and meditation. The Zen Garden (see Figure 8) is similar to the experience rooms and has therapeutic sounds but does not offer interactive elements.

Figure 7: Two different experience rooms that play therapeutic sounds only without interactive elements.

Figure 8: The Zen Garden that plays therapeutic sounds only without interactive elements.

2.4.2 Tic Tac Toe And Connect 4

The Tic Tac Toe, as seen in Figure 9, and Connect 4 in Figure 10, are located within the Asian Inspired town. These games utilize an AI-agent opponent to allow the user to play the game in a single-player mode in a typically two-player game. VR buttons would be on the wall of the game building, corresponding to the desired placement of the user's game piece for the Tic Tac Toe game activity. In the game Connect 4, the VR buttons are on the wall, and the corresponding column is for the placement of the user's game piece. When the VR button is pressed for Connect 4, the user's game piece would be placed in the lowest most available row in the selected row. When the column is full of game pieces, the VR button becomes unavailable and will no longer be interactable with the user.

The AI agent player would automatically select their piece location. Turn information would change based on who is turn it is, and Winner information would inform the user if there were a winner. When a winner is detected, all buttons will be disabled from adding new pieces until the reset button is pressed. When the reset button is pressed, all pieces on the board will be removed, and all the buttons will be enabled for play.

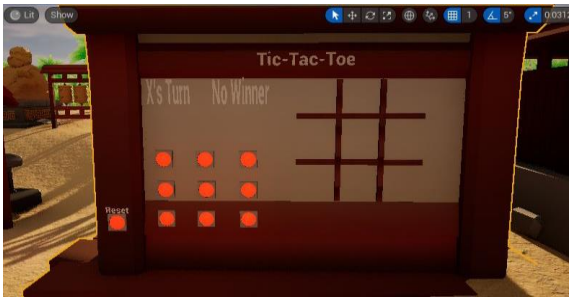

Figure 9: Tic Tac Toe.

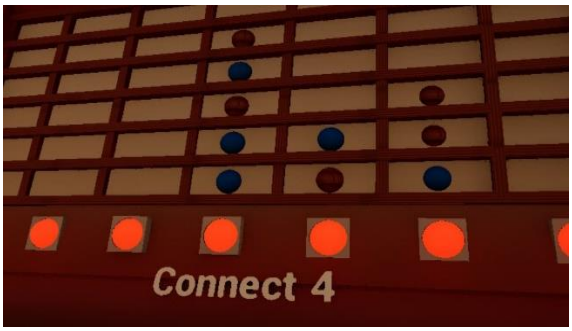

Figure 10: Connect 4.

2.4.3 Maze Solving

In the game Maze Solving (see Figure 11), users look at the maze and mentally solve it from the top left to the bottom right. Once completed, the user may go to the other maze on the wall or go up to the reset button. Each maze on the wall differs from the others, requiring a different solution. Once the reset button is pressed, the mazes on the wall will randomly create a new maze for the user to solve.

Figure 11: Maze Solving.

2.4.4 Bowling

In the Bowling activity, seen in Figure 12, the user would pick up the Bowling Ball by placing the VR remote over the Bowing Ball and pressing the Grip button on the remote. This would attach the Bowing Ball to the VR remote in the application environment. The user needs to hold onto the Grip button until the user wants to release the Bowling Ball. The bowling ball's speed and trajectory, when thrown at the bowling pins, are based on the speed and trajectory of the VR remote when holding the bowling ball before the release of the VR remote grip button.

Figure 12: Bowling.

When a pin is knocked down, the front score counter will go up for each pin knocked down. To reset pins and balls, the user can click the reset button. However, the reset button does not reset the score counter for this activity.

2.4.5 Shooting Gallery

The Shooting Gallery can be viewed in Figure 13. On the table, there are shooting guns. The shooting guns would shoot yellow ball projectiles. There are blocks on the rock and table, and the user's goal is to knock down the blocks off the rock or table. When the blocks are knocked off, the score counter will go up for each block that was knocked off.

Figure 13: Shooting Gallery.

The user would pick up the shooting gun by placing the VR remote over the shooting gun and pressing the Grip button on the VR Remote. This would attach the shooting gun to the VR remote in the application environment. The user needs to hold onto the Grip button when holding the shooting gun to be able to utilize the shooting gun shooting projectile action. To shoot the projectile, the user, while holding the grip button on the VR remote, would need to click on the Trigger on the VR remote. This would launch a projectile from the shooting gun; this action would be able to be repeated for an unlimited time as there is no limitation on ammunition in the shooting gun.

There are two options for resetting the blocks to their original location. The user can touch the VR button on the table or use the shooting gun to shoot a projectile to activate the reset button on the rock. The reset button does not reset the score counter for this activity.

2.4.6 White Board Drawing

In the White Board Drawing (see Figure 14), a white drawing marker is on the table near the whiteboard. The user can pick it up and draw it on the whiteboard. The user needs to click and hold the Grip button on the VR remote to pick up the drawing marker. The user then touches the marker with the whiteboard. The whiteboard will only be drawable when the user is holding the marker. The reset button would reset the whiteboard to its' original state of all white.

Figure 14: White Board Drawing.

2.5 Future Enhancement

Here are some recommendations to enhance the application. Firstly, expanding the range of available environments to include diverse settings, such as a medieval castle, library, Grand Canyon, could provide a richer experience. Each scene environment can offer unique activities to ensure variety and engagement for users. Secondly, consider improving the quality of sounds and expanding the selection of tinnitus sound frequencies available for therapy. This could involve reducing the intervals between frequencies (e.g., from 250Hz to 100Hz) or removing certain frequencies from the

high or low range, such as those above 8000Hz, based on user feedback and effectiveness. In addition, after the upcoming user study is completed, it may be beneficial to modify the application to address users' tinnitus levels more precisely. This could involve fine-tuning the sound levels of tinnitus sound frequencies and adjusting the random playback intervals to optimize the therapeutic effect. These proposed changes could significantly enhance the application's effectiveness and user satisfaction.

3 PROSPECTIVE TREATMENT PLAN AND USER STUDY

Future daily treatment sessions are designed to last between 30 to 60 minutes, with a minimum duration of 30 minutes and a recommended maximum of 60 minutes. Alternatively, if the user prefers, the daily treatment can be divided into two sessions that cumulatively add up to the recommended 30-60 minutes. For optimal results, it is recommended to follow a continuous treatment regimen once a day for 12 months. This recommendation is supported by Suh et al. [14] that reported high success rates following such a treatment period. To effectively monitor the progress of tinnitus throughout the treatment process, it is advisable to administer subjective tests, such as the Tinnitus Handicap Inventory (THI) or similar assessments, on a weekly basis. These tests will provide a subjective score reflecting the patient's perceived level of tinnitus, enabling the tracking of changes over time. Regular monitoring through these assessments can help in adjusting the treatment plan as needed, ensuring the best possible outcomes for patients.

The upcoming user study, which will span 12 months, will be structured into three distinct treatment groups, each following the previously outlined prospective treatment plans. The first group will act as the control group, comprising individuals who will not receive any form of tinnitus treatment. The second group will use our gamified VR application but without incorporating the tinnitus training sound frequencies in their treatment. The third group will employ both our gamified VR application and the tinnitus training sound frequencies as part of their treatment regimen. Throughout the duration of the user study, the Tinnitus Handicap Inventory (THI) or similar subjective tests will be administered to track each patient's perceived tinnitus improvement over time. These assessments will facilitate a comparative analysis of treatment outcomes across the different groups. Additionally, this study aims to evaluate the usability and effectiveness of our virtual neuromonics tinnitus treatment application. The clinical trial is planned in collaboration with a local Hearing Aid center in Orange County, Southern California, and is expected to tentatively begin in the Fall of 2024. The comprehensive analysis from this user study will be included in our future submission, which is expected to demonstrate the efficacy of our gamified VR application for neuromonics tinnitus therapy and provide valuable insights into future therapeutic approaches for tinnitus management.

4 CONCLUSION

This paper introduces a fully functional, gamified, interactive, and immersive virtual environment designed for neuromonics tinnitus treatment. Addressing the prevalent issue of patient retention in various therapeutic settings, our approach integrates gamification elements within the virtual tinnitus sound therapy environment. These elements are strategically included to significantly improve patient engagement and retention during therapy sessions. Additionally, the paper outlines potential enhancements to further develop the VR application's effectiveness and user experience.

While this paper does not yet include data on the usability and effectiveness of the application, preparations for a clinical trial are underway in partnership with a local Hearing Aid center. This trial is scheduled to start soon and will last for 12 months, dividing participants into three distinct treatment groups that adhere to the treatment plans outlined in the paper. The forthcoming user study aims to provide a thorough analysis both qualitatively and quantitatively, which will underpin our future submissions regarding the efficacy of our VR application in neuromonics tinnitus therapy.

We anticipate that the results of our study will not only foster the development of innovative therapeutic approaches that improve outcomes for tinnitus patients but also encourage professionals in the field of tinnitus management to adopt and validate the usability and effectiveness of our application. This effort seeks to contribute significantly to advancing treatment methodologies and enhancing patient care in the realm of tinnitus management.

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