Insomnia VR: A serious game pilot study exploring the effects of virtual reality on insomnia in individuals with spinal cord injury undergoing inpatient rehabilitation

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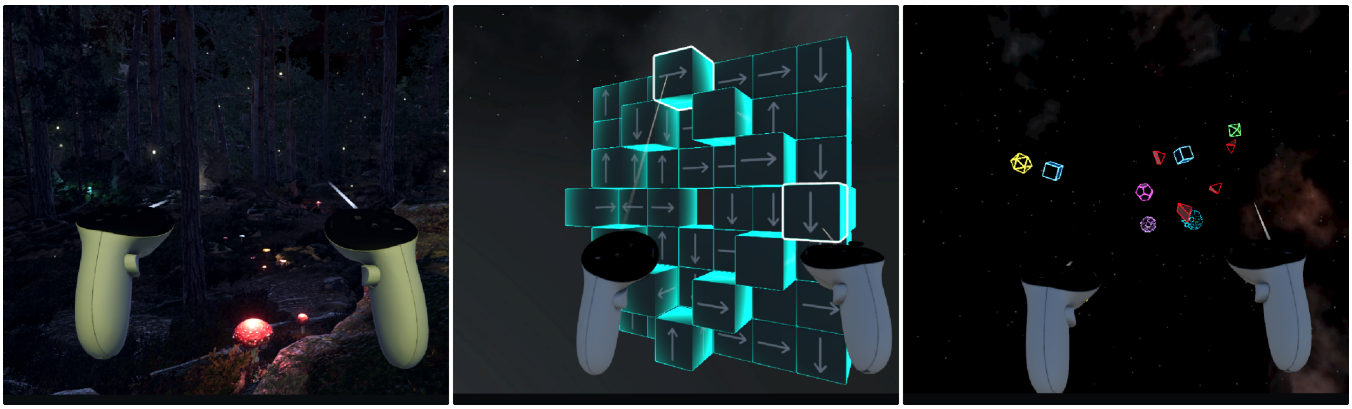


Figure 1: Representative images of the games developed. (Left) Game 1, The Mushroom Forest; (Center) Game 2, Tap Away; (Right) Game 3, Shape Fusion

Abstract

Sleep disturbances are frequent amongst hospitalised patients and even though they are viewed as secondary problems, sleep is an essential biological process that can directly affect patients' recovery. These disorders are managed through pharmacological treatments, which may present limited effectiveness and undesirable side effects in the long-term perspective. As a result, there is a growing interest in complementary non-pharmacological interventions with less invasive treatments. This paper evaluates the feasibility, acceptability, and preliminary effects of a virtual reality (VR) application to improve well-being and sleep-related outcomes in people undergoing inpatient rehabilitation. Our application serves as a prototype and contains three serious games. The application was developed for a commercially available VR headset (Meta Quest 3) and initially evaluated in 20 healthy participants to assess user experience. Subsequently, it was tested in seven individuals with varying baseline levels of insomnia during a two-week period of inpatient rehabilitation following spinal cord injury (SCI). All participants showed reductions in Athens Insomnia Scale (AIS) scores after the intervention, with baseline ratings ranging from moderate to severe insomnia improving to lower severity categories. Participants also reported improvements in sleep latency, nocturnal awakenings, and daytime alertness. User experience evaluations indicated high levels of enjoyment, as well as a strong willingness to continue using and recommend the intervention. These findings suggest that VR-based serious games are a feasible and well-accepted complementary tool for sleep support in hospitalized patients.

CCS Concepts

• **Computing methodologies** → **Computer graphics**; • **Applied computing** → **Health informatics**.



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1 Introduction

Hospitalised patients can often face significant challenges related to sleep disorders which can worsen their recovery process and make their whole stay an arduous and almost traumatic experience. While pharmacological treatments are the standard of care, there is a growing demand for non-invasive, complementary interventions that can improve the quality of life of these patients without additional side effects. The motivation for this study arises from the need to address sleep deprivation as a prevalent conditions seen in individuals undergoing inpatient rehabilitation, which can often be overshadowed by the patient's primary pathology due to the clinical focus on physical recovery. But more often than not, these two fields are directly connected, since it is almost impossible to have a good performance in rehabilitation sessions without a good night's rest and a calm mind. Although VR has proven effective as distraction therapy in various clinical settings, this demographic is too concrete and the current commercial application, though promising, often fails to meet the special demands to use a VR experience in this way due to lack of adaptability. Most available VR applications are designed for gamers, who use complex controller inputs and fast-paced motion, which can produce nausea, stress and sensory overload. That is why this project heavily relied on solving these accessibility and design problems by developing a custom VR environment that could adapt to patients' needs while providing a safe place to relax and immerse in the experience.

The primary goal of this research is to design, develop, and evaluate a relaxing, interactive VR serious game application as a

non-pharmacological, non-invasive tool to improve sleep quality and overall well-being in hospitalised rehabilitation patients with spinal cord injury (SCI) experiencing sleep deprivation. This objective is motivated by the need for alternative, non-pharmacological and non-invasive tools so they can complement conventional treatments as well as improve patient comfort during long rehabilitation programs. This paper presents a complete VR application designed to test our primary hypothesis, alongside a two-phase evaluation. First, a preliminary usability assessment was conducted with a general public cohort. Building on those insights, a subsequent preliminary evaluation was performed to assess the application's efficacy in patients experiencing the aforementioned conditions. The system was tested exclusively within a controlled, supervised clinical environment. To ensure safety and protocol adherence, the participant cohort was restricted to adult individuals undergoing an inpatient rehabilitation process who had suffered a spinal cord injury with intact upper extremities and no cognitive deficiencies, but who exhibited symptoms of onset insomnia.

2 Related Work

Nowadays, with the growing popularity of VR and the low cost equipment, many medical applications have been developed in the last decade across multiple fields. Virtual reality has the capacity to isolate patients from external stimuli, providing immersive environments that can distract patients from pain or create relaxing experiences to treat several disorders. Therefore, virtual reality offers a treatment of many pathologies without relying exclusively on pharmacological interventions. In recent years, virtual reality has been also used as a complementary tool for reducing stress, anxiety and sleep-related disorders such as insomnia, particularly in clinical rehabilitation.

2.1 Virtual Reality for Therapeutic and Clinical Applications

One of the most common VR applications in the medical field is pain management [Viderman et al. 2023], where adult and/or paediatric patients are exposed to painful medical procedures. It has been proven that surrounding patients with a VR environment can effectively divert their attention away from nociceptive stimuli, which reduces perceived pain and anxiety during commonly known interventions such as burn wound care [Norouzkhani et al. 2022], needle procedures [Czech et al. 2021] and other minor treatments.

García-de-la-Banda-García et al. [García-de-la Banda-García et al. 2025] conducted a review of randomised controlled trials evaluating VR interventions for adults with chronic non-specific low back pain. Fourteen studies reported that VR-based treatments were associated with significant reductions in pain intensity, disability and kinesiophobia, with some studies also showing sustained effects at long-term follow-up. Additionally, several trials observed favourable changes in neuromuscular activation patterns, suggesting that VR may influence both motor control and pain-related physiological mechanisms.

Another interesting application of VR is in physical rehabilitation and neurorehabilitation. Nowadays, there are VR-based programs that help to improve motor function [Chen et al. 2022], balance and coordination in patients recovering from a stroke [Landim et al. 2024], a spinal cord injury [Franzo' et al. 2025] or another orthopaedic surgery. The combination of multisensory feedback and real-time monitoring, plus the gamification aspect of the rehabilitation process, greatly enhances patients' motivation and adherence to therapy protocols [Wang et al. 2023]. Nam et al. [Nam et al. 2024] described the design of a VR-based rehabilitation application for patients with various types of shoulder surgery. The system used a standalone VR headset to guide patients through postoperative, range-of-motion and strengthening exercises tailored to the type of surgical procedure and recovery phase. The authors also noted the potential advantages of VR for home rehabilitation, including improved visualisation of correct movement, increased motivation through immersion and the automation of unsupervised exercise programs. However, the article also mentioned a few important limitations, like the usability challenges for older patients plus safety concerns related to occlusion of the real environment, while also highlighting the importance of future validation studies.

2.2 Virtual Reality for Insomnia Treatment

Through immersion in virtual environments and participation in cognitive activities, virtual reality has shown therapeutic potential for a range of mental health conditions, including anxiety, depressive symptoms, and insomnia [Jerath and Beveridge 2021; Liu and Li 2025].

Zhou et al. divided participants with insomnia symptoms into two groups and, during two weeks, one group only took psychotropic medications, while the other group received the same pharmacological treatment combined with exposure to 14 virtual different environments combining relaxation therapy, musicotherapy, mindfulness meditation and hypnotherapy [Zhou et al. 2024]. Their results showed significant differences for the remission rates of anxiety and insomnia between the two groups. However, the study does not provide a detailed description of the content of the virtual environments or the activities carried out by the participants. In a similar way, Orakpo et al. details a successful intervention using virtual reality neurofeedback for a patient suffering from chronic pain and secondary insomnia [Orakpo et al. 2022]. Neurofeedback stimulates brain plasticity and engages cortical and subcortical neuronal circuits to help patients regain better central nervous system functionality. Before starting the VR treatment, the patient was dependent on several controlled medications (such as hydrocodone and diazepam) and he was feared of becoming dependent on them, but he successfully managed to discontinue the medication by the middle of the treatment. After 20 sessions of virtual reality neurofeedback therapy, pain and insomnia were reduced and 1-year follow-up confirmed that the patient's analgesia was sustained and he remained medication-free. The VR experience consists of various games and videos that served as an immersive distraction for the patient; however, the authors did not provide a detailed description of the games. Wan et al. used 360 videos designed to draw the patient's attention away from the external world and help them to relax [Wan et al. 2024].

Virtual reality mindfulness and meditation have also been used as a treatment for insomnia reducing or eliminating the need of pharmacological treatment. Four commercially VR mindfulness applications were evaluated by 19 patients with insomnia symptons in

[Hitching et al. 2025] to check its feasibility as a potential treatment for chronic insomnia. After the evaluation, patients and clinicians were enthusiastic about VR mindfulness describing it as "easy to use" and "more engaging" than other approaches and 89.5% of patients became confident on using VR mindfulness to be effective for insomnia treatment. The applications selected included guided meditation in a similar way to the work presented by de Zambotti et al. in which adolescents with and without insomnia symptoms were treated with mind-body practices including meditation [de Zambotti et al. 2022]. The primary objective of these interventions is to reduce bedtime arousal in adolescents with insomnia. The practices include bedtime meditation, guided imagery, pre-asleep yoga exercises, progressive muscle relaxation or autogenic training. The adolescents were divided into two groups and participated in two evening sessions: the control session in which participants did a quiet activity, and the intervention session in which participants engaged a 20 minutes of nature-based VR-guided meditation and paced breathing before bedtime. Brain and heart activity were measured and the results sowed a reduction of the hyperarousal while performing the VR experience. The VR experience consisted it a virtual forest during an orange sunset including the forest's sound with very simple interaction consisting in grabbing, moving and releasing spheres to activate different effects on the VR environment. In a similar way, Deng et al. also used forest therapy and VR therapy to treat submarine personnel obtaining comparable results [Deng et al. 2026].

Following a similar mindfulness-oriented approach. Huang et al. designed a hybrid model that combines EEG with virtual reality to induce sleep in participants [Huang et al. 2022]. The system detects and classifies sleep cycles with EEG signals and sends them to a server which decides the relaxing content to be displayed on the HMD using AI.

The use of mindfulness and meditation virtual reality applications may constitute a promising non-pharmacological approach for the management of insomnia. By promoting relaxation and facilitating the adoption of healthy sleep habits, these interventions have the potential to alleviate insomnia symptoms without relying exclusively on medication.

In this paper, we present a virtual reality application consisting of three different serious games intended to reduce arousal, promote relaxation, and facilitate sleep onset. They diverge from traditional game design values, which typically prioritize challenges, adrenaline, and a series of rewards, and adopt a more "slow tech" approach, where the well-being of a person is prioritized, promoting physiological relaxation and reducing pre-sleep cognitive arousal. Unlike previous VR applications for insomnia treatment, which mainly rely on relaxing static images or passive 360° video experiences, our application incorporates meaningful yet low-demand interactions with virtual objects. These interactions are designed to maintain a calm and relaxing experience while helping to reduce insomnia symptoms, promote relaxation, and facilitate sleep onset.

3 Design and Development of the Application

3.1 Design principles

To achieve the aforementioned goals, we have designed three serious games. All the games share 5 core principles:

- Relaxation promotion: Each game was particularly made to evoke a state of physical and mental relaxation by transitioning from a heightened state of alertness to a calming state. This can be done through slow-paced interactions, gentle visual motion, and calm environmental elements.
- Reduction of cognitive hyperarousal: These games have simple, low-effort interactions that engage the user's attention without requiring sustained concentration or causing mental fatigue, considering the goal to reduce intrusive or repetitive thoughts.
- Preparation for sleep through auditory stimulus: Relaxing auditory elements were selected to support the transition towards a state of calmness. These stimuli, paired with soft lighting and calming colors, create a pre-sleep atmosphere that avoids stimulating effects that can alter nighttime conditions.
- Minimization of adverse stimuli: Elements that cause discomfort or anxiety were avoided, like sudden sounds, rapid camera movements, and flashing visual effects.
- The "No failure" approach: There is no timer or 'game over' state, removing any sense of pressure or performance evaluation. This ensures that users cannot fail and are not exposed to any potentially stressful elements. However, there is an information panel acting as a complementary function inside these games that tracks certain actions during each game, but it doesn't influence their interaction or experience.

Since the central objective is the stress reduction, we intentionally designed the games with a minimized level of interactivity. Therefore, cognitive load is reduced, and fatigue is prevented. Thus, the virtual experiences utilize low-frequency, repetitive interactions—such as collecting, tapping, or merging items—ensuring the tasks remain manageable and adaptable without compromising user engagement with the surrounding environment. Within each game, a sense of agency and progression is maintained; however, this progression is purely cosmetic and does not alter the underlying system state. Instead, positive audio-visual feedback is provided to reward correct actions and reinforce user participation.

The application was purposely structured around three distinct serious games, each employing a unique interaction paradigm designed to diverge from conventional recreational gaming. These experiences serve as distinct archetypes for different engagement modalities:

- The first game emphasizes **slow-paced spatial navigation and curiosity-driven exploration** within a tranquil, controlled, and natural environment.
- The second game introduces a **cognitive, puzzle-based model** structured around logical sequencing and heightened mental demand.
- The third game utilizes a **physics-driven interaction model featuring light object manipulation** governed by realistic physical laws, fostering a tactile and intuitive form of engagement with a free range of motion.

This varied yet cohesive design accommodates diverse user preferences and prevents monotony during repeated sessions, thereby maintaining high engagement without detracting from the clinical objective.

The application itself was created using Unity, a common 3D game development software in the gaming industry, with C# as the default scripting programming language. The XR Interaction Toolkit was used for the design of the VR application, which ensures compatibility across most standard commercial VR headsets.

A few accommodations were implemented to make the application as insomnia-friendly as possible. Whereas there wasn't any personalised brightness cap to deal with the effects of blue light, the games used as little light as possible, always having a darker environment with the minimal stimuli, simulating an activated night mode across all games. Concerning the headset, the Meta Quest 3 Elite Strap was used to ensure maximum comfort and there were no signs of overheating when playing.

Each game begins with a standardized tutorial canvas that details the gameplay rules. This interface includes graphical representations of the controllers, highlighting the relevant button mappings and labels (see Fig. 2 top-right for the first game's layout).

Upon launching the application, users are presented with a main menu interface displaying the available game alternatives (see Fig. 2-left). Once a game is selected, the system transitions to a standardized tutorial canvas that details the gameplay mechanics; this interface includes graphical schematics of the controllers highlighting relevant button mappings and instructional labels (see Fig. 2-right). Clicking the "Next" button initiates the active gameplay session, which continues until the primary objective is achieved. Upon completion, a final UI canvas allows the user to return to the initial selection screen. During active gameplay, users can pause the session to access a configuration menu. This menu enables them to adjust various game parameters, terminate the session to return to the main menu, or access the help menu to re-examine the instructional rules.



Figure 2: Application workflow and user interface stages. (Top-left) Game selection menu; (Top-right) instructional tutorial interface; (Bottom-left) runtime configuration and pause menu; (Bottom-right) completion screen upon achieving the gameplay objective.



Figure 3: Core gameplay and navigation mechanics. (Top) User interaction during the harvesting of a bioluminescent mushroom. (Bottom-Left) The opened collection log displaying registered mushroom types. (Bottom-Right) Teleportation mechanism navigating the user to a designated blue target zone.

3.2 Game 1: The Mushroom forest

The first serious game, titled *The Mushroom Forest*, is a *low-pressure*, atmospheric exploration game designed to be *non-competitive* and *self-paced*. Its primary objective is *to occupy working memory and reduce the frequency of intrusive thoughts without inducing cognitive fatigue*. To minimize cognitive load, the gameplay is intentionally repetitive. Furthermore, interaction is entirely self-paced and free from external temporal pressures, allowing players to explore the virtual environment without being forced to actively pursue specific game goals.

Set in a dense, nocturnal, bioluminescent woodland, this game requires players to collect bioluminescent mushrooms scattered throughout the environment. Soft, diffuse moonlight illuminates the scene to foster a calming atmosphere that supports the transition from wakefulness to rest (see Fig. 1-right). To prevent disorientation while maintaining a sense of exploratory freedom, the terrain is bounded by natural barriers, including surrounding mountains and a river.

The player is asked to collect 10 mushrooms of each of the 16 different types and register them in a Collection Book (see Fig. 3 bottom-left) . The primary activity within the environment is the gathering of bioluminescent mushrooms. This interaction is distal and uses a ray-cast pointer that acts as an extension of the user's hands. This design choice eliminates the need for the patient to physically reach out or lean forward, which could be difficult when bedridden. This environment uses a simplified "point and select" mechanic, where the user simply directs their gaze and controller to a glowing mushroom, and once it is highlighted, it can press

the 'trigger' button to collect the mushroom. A little fade-out and scale-up animation is played before the collection book logs in the new collectable (see Fig. 3 top).

There are also blue teleportation areas scattered through the terrain that allow the user to cross the river (see Fig. 3 bottom-right). To activate them, the player needs to step on these blue points, and a message appears asking if the player would like to cross the river.

3.2.1 Auditory landscape. Auditory design plays a central role in the development of the environment, as it helps ground the user within the virtual space and promotes relaxation. These ambient sounds are used as 3D spatial audio. They exhibit similar characteristics to pink noise, which has been shown to enhance sleep stability by masking disruptive background noises in the hospital ward [Zhou et al. 2024]. Spatial audio cues dynamically respond to the user's position. For example, the river sound gradually increases in volume as the user approaches it and decreases as they move away. There is also a soft, leafy footstep sound effect every time the player teleports from one place to another, as well as an opened book sound every time the Collection Book is opened, to increase the immersive experience. All these little auditory cues function as calming confirmations instead of traditional in-game rewards.

3.3 Game 2: Tap Away

The second game is called *Tap Away* and focuses on *visuospatial stimulation and cognitive ordering*. It features a *task-focused, linear progression structure* designed to be the most cognitively engaging intervention. However, *the cognitive challenge remains bounded and non-stressful* to prevent frustration or cognitive overload. To reinforce this low-pressure environment, the game deliberately excludes any visible timers or temporal constraints.

The game places the patient in a minimalist, distraction-free space that eliminates peripheral visual noise, channelling the patient's entire attention to the task at hand. This game is about deconstructing a three-dimensional figure of cubes. Each block is marked with an arrow that indicates its trajectory, and the user must clear this block cluster in the correct order, avoiding collisions with each block. This activity aligns with the primary objective of the game, which was specifically designed to foster logical reasoning and mental rotation skills through structured gameplay.

The primary activity consists of dismantling the 3D block figure. This interaction uses a ray-cast pointer, just like the *Mushroom Forest* game, and it has the same "point and select" mechanic, maintaining consistency. The user points the controller at a specific block, and once the ray intersects with the block's collider, the block is highlighted (see Fig. 4-left), and when the trigger is pressed, the system calculates if the block's path, indicated by its arrow, is obstructed. If the path is clear, the block moves in that direction while a fade-out animation plays, but if the path is blocked, there is a subtle "wiggle" animation that helps the player see that the selected cube is locked. To solve the puzzle, the user needs to inspect the block figure from multiple angles. To do so, a rotation and zoom system was implemented, using both of the controllers' joysticks.

There is a Configuration menu button that allows users to adjust audio settings (music and sound effects), skip the current level, and track their overall progress (see Fig. 4-bottom-right).

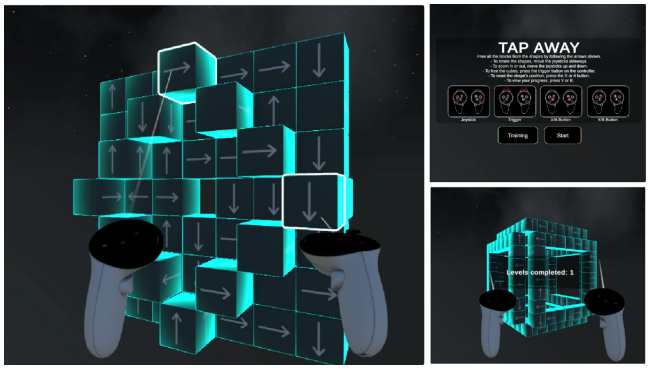


Figure 4: Overview of the application's interactive components. (Left) User interaction during the deconstruction of a 3D puzzle figure. (Top-Right) The 3D tutorial panel displaying a concise explanation of puzzle mechanics. (Bottom-Right) Progress-tracking pop-up panel displaying completed levels upon button activation.

3.3.1 Auditory landscape. The background music for this environment is a soft and melodic track to induce relaxation and sleep. The sound effects used in this game were intentionally chosen to evoke a mild ASMR (Autonomous Sensory Meridian Response) effect to provide a sense of satisfaction when an action is performed. ASMR is a sensory phenomenon in which people experience tingling sensations produced by audio and visual stimuli. These sensations can radiate to the back of the neck, the upper spine, and other areas depending on intensity, causing feelings of relaxation and comfort that have been shown to help people suffering from sleep disorders, depression, stress, and chronic pain [Hardian et al. 2020]. Three distinct sound effects were implemented to provide non-intrusive auditory feedback: one associated with successfully unlocking the cube, another indicating that the selected cube is blocked by another one, and a final sound cue as the current level is completed. These auditory effects serve a functional and emotional role, strengthening the user's actions, as well as maintaining a soothing and predictable auditory environment.

3.4 Game 3: Shape Fusion

The third game is called *Shape Fusion* and is based on a *physics interaction*. In this game, the player is placed in a simulated space with an animated nebula as a skybox to add dynamism to the scene. In this scenario, the algorithmic logic of the "2048" exponential game [Cirulli 2014] gets turned into a three-dimensional physical space. The user is presented with a spawning of geometric primitives, such as spheres and cubes, and the objective of this game is to grab and make two identical shapes collide (see Fig. 5-bottom). Upon contact, the two shapes fuse into a single, higher-tier geometry of a different color. This activity was designed to stimulate pattern recognition and executive function while executing satisfying physics interactions, keeping the user busy and engaged on the task at hand.

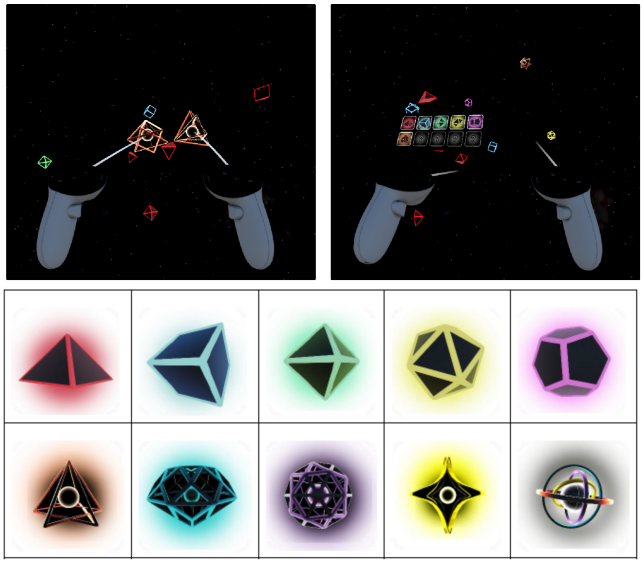


Figure 5: Overview of game interactive elements. (Top-Left) User grabbing and colliding two identical shapes. (Top-Right) Pop-up panel tracking progress and displaying completed levels upon button activation. (Bottom) The 10 geometric shapes corresponding to levels 1 through 10, ordered from upper-left to lower-right.

The primary objective of this game is to discover the 10 lost geometric shapes by merging the identical pairs, acquiring an exponential logic style, just like the 2048 game, but in 3D. This experience is the most "free" of the three of them, since in terms of limits, it has none. The pieces can be moved in all directions, which makes this environment the most dynamic one, and there is no other restriction apart from the player's movement in the space.

Once the game starts, only two pyramids, the most basic geometric figure in the game, appear at random locations, and they start to move around. Just as with the other games, the user interaction remains a distal ray-cast. To merge them, the player needs to point at them and hold the Trigger button to move them around (see Fig. 5 top-left). To move them closer or farther away in the 3D space, the joystick of the controller holding the figure needs to move up or down in a vertical motion. Once one pyramid touches the other one, a cube is created, and after that, random pyramids start spawning at different places in intervals of 3 to 5 seconds, but so as not to overwhelm the player, this spawning system has a limit of 4 pyramids at a time. The Configuration menu allows users to adjust various game settings. In addition, users can monitor their overall progress (see Fig. 5 top-right).

3.4.1 Auditory landscape. The sound effects and music for this game were kept simple, following the same design as in the previous game. Apart from the background music, there are 3 additional chimes to increase the game's immersion. The first one triggers when a new figure spawns, the second one triggers when two figures are being merged, and the third one triggers when a new geometry figure is discovered. All sounds were selected to maximise the auditory satisfaction experience, as well as to help players understand their surroundings when playing this game.

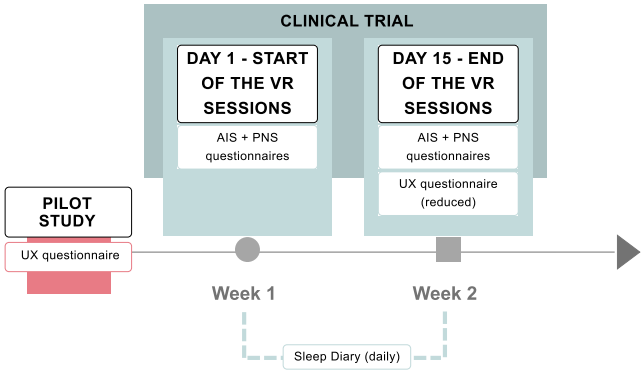


Figure 6: Experimental timeline outlining the study workflow for both cohorts.

4 Evaluation

As stated in Section 1, this evaluation assesses the feasibility of a VR application designed to mitigate sleep disorders in individuals with a spinal cord injury (SCI) undergoing inpatient rehabilitation. Fig. 6 outlines the overall experimental workflow.

Initially, an informal pilot study was conducted with a healthy cohort to evaluate user experience, specifically focusing on usability, comfort, and acceptance. This preliminary phase aimed to determine whether the application was intuitive for individuals with varying levels of technological familiarity prior to clinical deployment. Following the pilot study, the application was refined based on initial findings before beginning the clinical trial. Before starting the study, institutional consent was granted for this feasibility trial by the Guttmann Rehabilitation Hospital. Given that this work served as an internal evaluation for a Master's thesis, the institution permitted the postponement of the formal Ethics Committee application after the preliminary data could be analyzed. This approach was adopted to evaluate the initial viability of the intervention before initiating a full-scale clinical protocol. Currently, we are preparing an extended clinical trial with more patients. We have submitted a proposal to the Ethics Committee, and it has been evaluated in a first stage. The Ethics Committee has agreed on the methodology and has only required some wording changes on the forms.

4.1 Pilot Study

Experiment Design. Prior to the clinical trial, an informal pilot study evaluated user experience (UX) regarding application usability, comfort, and acceptance. Participants were permitted to test the three games in any order and for any duration without prior training. Following this open-ended session, they completed a self-reported questionnaire covering four thematic user experience categories (see Appendix A): Perceived Enjoyment (PE), Usability and Intuitiveness (UI), Sense of Immersion (SI), and Perceived Frustration (PF). Responses were scored on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree).

Participants. The study involved 20 healthy, non-clinical participants spanning an age range of 20 to 70 years. The sample comprised both VR-naive individuals and experienced users. This diverse composition was chosen to prevent experience bias and ensure the usability assessment reflected a realistic, real-world population.

4.2 Clinical Trial

Experiment Design. The primary hypothesis to evaluate is that immersing patients in a controlled, low-stimulus virtual environment can interrupt the cycles of rumination and hypervigilance characteristic of insomnia. To test this hypothesis, standard metrics—specifically the Athens Insomnia Scale (AIS) [Jahrami et al. 2023] and visual analog scales for pain intensity [Hjermstad et al. 2011]—were employed to quantitatively assess variables before and after a brief VR session.

The study was initially designed to take 8 patients (N=8) with an VR intervention of 9-10 sessions in a period of two weeks.

Each session was programmed right before going to sleep in order to maximise its effects on relaxation and sleep onset and lasted approximately 15-20 minutes. To evaluate the evolution of their sleep quality and well-being, the same Athens Insomnia Scale (AIS) questionnaire was completed at the beginning of the experiment to obtain a baseline state of their sleep, after two weeks of receiving VR therapy and then a week after that, where they were no longer subjected to the VR environment, to see if there were any changes after participation (See the AIS questionnaire in Annex 1). In addition, a sleep diary was also implemented to register the quality of every night's sleep, if there were disturbances and if they used electronic devices after VR sessions, as it can alter a person's sleep cycle. Along with standard demographic information, data regarding sleep medication use and histories of anxiety, stress, or other psychological disorders were collected at the start of the experiment.

At the beginning of each session, participants completed a brief sleep diary to study the evolution of the quality of their sleep. This diary recorded whether the patient had taken daytime naps, for how long, if they used electronic screens after the VR session and their perceived sleep quality from the previous night. Afterwards, the patients were positioned either upright or reclined at an angle of up to 45° to ensure maximum comfort and optimal gameplay. Then, they were fitted with the VR headset, and they were immersed for approximately 10 to 15 minutes in one game environment of their choice. Upon completion of all VR sessions, a subset of the UX questionnaire was administered to evaluate the patients' overall user experience.

Before starting the two-week intervention, participants attended an onboarding session to familiarize themselves with the VR headset and its control scheme. Under supervision, patients completed basic exercises using a Meta-developed tutorial to adapt to the immersive environment in a non-therapeutic setting. They also watched an instructional walkthrough video detailing the mechanics and functionalities of the three serious games. To complement this session, a informational brochure was provided to all patients, outlining the study's objectives, protocols, risk-benefit profile, and application design. This dual-approach onboarding protocol ensured informed consent and established a standardized understanding of the intervention across the entire sample.

Participants. As previously mentioned, the study was initially prepared to enrol 8 patients, but due to unforeseen circumstances, one participant had to withdraw before completing the intervention, resulting in a final sample of seven participants in total (N=7). Table 1 summarises the demographic characteristics of the study cohort. The sample consisted predominantly of male participants (6 males, 1 female) with ages ranging from 26 to 70 years. These patients were hospitalised due to a lower-body SCI, and they all had preserved upper-limb mobility and sufficient cognitive capacity to interact with the VR application. Three participants reported regular use of sleep medication, and three suffered from anxiety or other stress-related disorders.

Baseline evaluation using the Athens Insomnia Scale (AIS) confirmed that all participants met the clinical threshold for insomnia (AIS $\geq$ 6). Within the cohort, two patients presented mild insomnia (AIS 6–9), four presented moderate insomnia (AIS 10–15), and one exhibited severe insomnia (AIS $\geq$ 16). This distribution allows for an exploratory analysis of the VR system across different levels of sleep disturbance. Complementary baseline assessments using a numerical rating scale indicated mild-to-moderate pain levels among participants, with scores ranging from 3 to 6. Table 1 details the complete individual baseline and post-intervention scores. While a larger sample size would have been ideal to maximize statistical power, participant enrollment was restricted by logistical constraints typical of early-stage feasibility studies in real-world clinical settings.

4.3 Results

This section presents the findings from both studies. First, the data from the *Clinical Trial* are detailed, focusing primarily on descriptive analyses and patient clinical outcomes. Subsequently, the user experience outcomes from the *Healthy* cohort are presented alongside a comparative analysis of the corresponding metrics from the *Clinical Trial* cohort.

4.3.1 Pain levels and sleep measures evaluation. As stated above, patients were requested to report any adverse effects (e.g., discomfort, nausea, or dizziness) at the end of each session. Additionally, after completion of the two-week intervention protocol, AIS scores and pain levels were re-evaluated to measure post-intervention outcomes. According to Table 1, the two-week VR intervention yielded improvements in both sleep-related metrics and perceived pain for all participants. Notably, baseline AIS scores (ranging from 6 to 21) fell to between 2 and 7 post-intervention, indicating a uniform decrease in insomnia severity across all patients.

Notably, all participants transitioned to a lower severity category on the AIS scale following the intervention. The majority of the cohort shifted from mild, moderate, or severe baseline insomnia to post-intervention scores below the clinical threshold, indicating a clinical remission of diagnosable insomnia. All seven participants reported a positive outcome, including reduced sleep onset latency, improved sleep continuity, and enhanced perceived sleep quality. Additionally, participants noted feeling more rested upon waking,

Table 1: Baseline clinical characteristics, including use of sleep medication (Sleep M.) and anxiety diagnosis (Anx.), as well as pre- and post-intervention outcomes for the Athens Insomnia Scale (AIS) scores and pain levels (PAIN) across all participants.

	Baseline					Post-intervention	
Sex	Age	Sleep M.	Anx.	AIS	PAIN	AIS	PAIN
Male	57	No	No	7	5	3	3
Male	54	Yes	Yes	21	5	2	5
Male	35	Yes	No	10	6	3	4
Female	62	No	Yes	13	3	7	1
Male	70	Yes	No	11	5	3	2
Male	26	No	Yes	10	6	2	2
Male	31	No	No	9	6	3	5

alongside reductions in daytime sleepiness and sustained levels of diurnal alertness.

While clinical improvements were observed across the entire cohort over the two-week period, the participant with severe baseline insomnia demonstrated the most pronounced response to the therapy. At baseline, this individual presented with severe insomnia (AIS = 21) accompanied by comorbid anxiety and stress diagnoses. Following the two-week VR intervention, the participant's AIS score decreased to 2, falling well within the asymptomatic range. Furthermore, the individual reported the complete resolution of persistent daily nightmares that had been experienced for several months prior to the study, representing a clinically meaningful improvement in subjective sleep quality and psychological well-being.

Another participant also reported notable changes in sleep quality. Initially, she described a significant anxiety-related rumination that frequently interfered with sleep initiation. Following the VR sessions, she reported a substantial reduction in intrusive thoughts as well as increased feelings of relaxation and emotional well-being. However, despite these distinguished improvements, her post-intervention AIS score (AIS=7) still placed her in the mild insomnia category. Nevertheless, compared to her baseline score of 13, this still represents a noticeable improvement and shifts to a lower severity category. It is important to note that this person was also undergoing chemotherapy during the study period, which is a factor known to significantly disrupt sleep patterns and overall rest quality. A participant also diagnosed with PTSD exhibited meaningful improvements as well. Before the intervention, he used to experience frequent nocturnal awakenings beyond routine nursing care, particularly during the second half of the night, when insomnia symptoms were most severe. Although sleep medication facilitated initial sleep onset, maintaining sleep remained problematic for him. But after the VR sessions, the patient reported fewer spontaneous awakenings and an increased ability to fall back to sleep more quickly than before after nursing interventions. There was also a reduction in the need for one-hour-long naps, which were daily, due to fatigue and non-restorative sleep. This decrease in daytime drowsiness made naps no longer necessary.

Overall, all participants had a very satisfactory experience and reported positive subjective outcomes. A follow-up questionnaire was administered a week after the completion of the sessions which indicated no change in the AIS scores compared to those reported at the end of the intervention. However, three patients were discharged from the hospital by that time, which may have contributed to the sustained improvement due to being in a non-hospitalised, more familiar environment and without the routine nursing interventions. Still, the remaining participants reported that the benefits from the VR sessions persisted at least one week after completion, and they all expressed interest in continuing the sessions. In contrast, the changes reported in pain levels were more heterogeneous and less pronounced. While most patients did report a reduction in pain intensity, the magnitude was very little, and in some cases, it remained stable. This variability is not unexpected, as pain perception is influenced by multiple factors and can drastically change throughout the day, particularly in a hospital setting.

4.3.2 User experience Evaluation. As stated in Section 4, the two distinct groups of participants performed the user experience evaluation. The complete set of evaluation questions is provided in Appendix A.2. While the healthy cohort answered all questions, the patient cohort completed only a subset to prevent fatigue, as this group was required to complete multiple questionnaires. Table 2 presents the results disaggregated by group; as shown, the outcomes were highly satisfactory for both cohorts. Figure 8 presents the descriptive results for the user experience questionnaire, illustrating the percentage of responses for each question categorized by cohort.

Table 2: Mean scores and standard deviations for the user experience questionnaires for the healthy cohort (top) and the patient cohort (bottom). Columns report the results for the established categories: Perceived Enjoyment (PE), Usability and Intuitiveness (UI), Sense of Immersion (SI), and Perceived Frustration (PF). The final column presents the overall General Scoring (GS) of the application.

Pilot Study ($N = 20$)				
PE	**UI**	**SI**	**PF**	**GS**
4.2 ± 0.6	4.5 ± 0.8	4.1 ± 0.7	1.5 ± 0.7	9.0 ± 1.0
Clinical Trial ($N = 7$)				
PE	**UI**	**SI**	**PF**	**GS**
3.2 ± 0.1	4.9 ± 0.4	4.9 ± 0.2	1.1 ± 0.4	9.7 ± 0.5

In addition to the quantitative ratings, the user experience questionnaire included qualitative items to capture subjective preferences. When asked to identify their preferred game environment in the patients group, three participants selected *Tap Away*, two selected *Shape Fusion*, one chose *Mushroom Forest*, and one participant indicated no preference. The results in the general public group were slightly different. Eight people selected *Shape Fusion*, five people selected *Tap Away*, four selected *Mushroom Forest* and the remaining three had no preference between them. Interestingly, the general public picked *Shape Fusion* as their favourite one, with

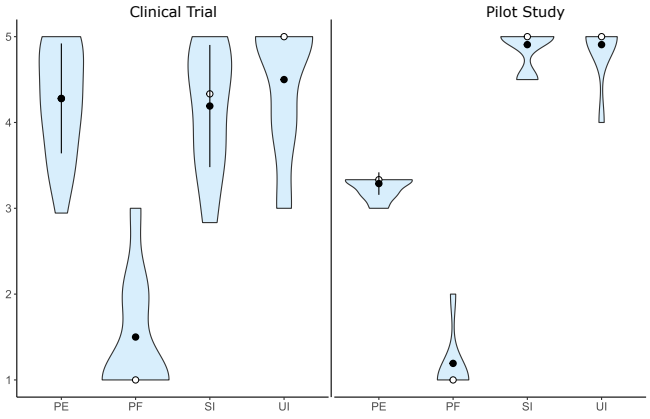


Figure 7: Violin plots of user experience categories across cohorts. Median is in white, whereas mean and standard deviation are in black.

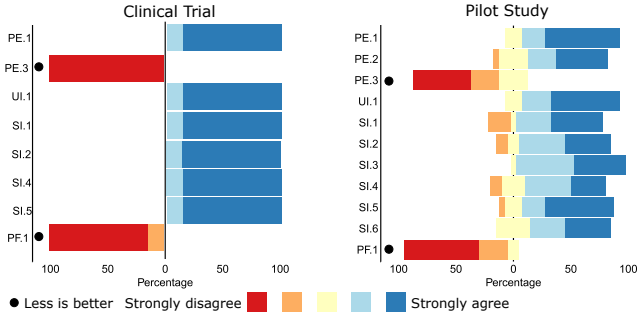


Figure 8: Agreement distribution of the questionnaire answers. The questions where a negative answer is considered good are indicated with a circle (•).

Tap Away ranking second, whereas the opposite trend was observed in the patient group. Although the sample size does not allow definitive conclusions, this divergence may be related to contextual factors, like the desire for simpler and more repetitive interaction before sleep, which aligns with the design of the *Tap Away* environment, instead of a more dynamic, livelier experience, like *Shape Fusion*.

5 Discussion

The most noticeable finding of this study is the consistent improvement in sleep-related events observed across all 7 participants during the two-week VR intervention. Although the study was not designed to assess clinical efficacy, the reduction in AIS scores suggests a significant positive trend, which should not be ignored. A particularly relevant aspect of these results is that all patients experienced a reduction of at least one clinical category in the AIS classification. Participants who initially were classified as having mild, moderate, or severe insomnia were shifted to milder forms and, in most cases, to a range considered free of insomnia. This categorical improvement reflects a transition in the severity of the symptoms that can directly impact daily functioning and perceived quality of life. It is also important to note that these improvements were observed in a very limited heterogeneous population, and still none of the patients reported any worsening of sleep symptoms, and all reported a benefit to some degree. This consistency strengthens the interpretation that the intervention was well tolerated and potentially supported rather than disrupting sleep. Complementing the reduction in AIS scores, participants' sleep diaries revealed consistent qualitative improvements. These included reduced sleep onset latency, fewer nighttime awakenings, and superior restful quality, which collectively led to diminished daytime sleepiness and improved daytime alertness. These findings suggest that the benefits extend well into daytime functioning—a perception increasingly recognized as vital in insomnia research. Consequently, from a feasible point of view rather than a clinical one, the VR intervention shows potential as a non-pharmacological tool to facilitate sleep by promoting relaxation, encouraging cognitive disengagement from ruminative thoughts, and establishing a structured pre-sleep routine.

Beyond clinical outcomes, evaluating user experience was essential to gauge the application's overall feasibility. Because the intervention requires voluntary, repeated use, assessing usability, comfort, and enjoyment is critical to ensuring long-term engagement and practical applicability in a home or clinical setting.

5.1 Experiment limitations

Some limitations must be acknowledged to contextualize the findings of this study. The primary limitation is the small sample size of the patient cohort. Consequently, the study lacks the statistical power required to generalize the clinical efficacy of the system, thereby categorizing the results as exploratory and preliminary rather than definitive evidence of therapeutic effectiveness. Secondly, this evaluation relied entirely on self-reported measures to assess sleep parameters and user experience. Although validated instruments such as the Athens Insomnia Scale were utilized, subjective questionnaires are inherently susceptible to individual perception, recall bias, and acute contextual factors. The absence of objective, physiological metrics limits the ability to cross-validate these patient-reported improvements. Furthermore, the heterogeneity of the participant population introduces confounding variables. While all patients met the core inclusion criteria, the sample exhibited substantial variance in age, concurrent medication regimens and baseline insomnia severity. While a diverse sample provides a broad perspective on application feasibility, this high variability within a small cohort makes it difficult to isolate the most effective mechanism. Finally, the two-week intervention window limits the interpretation of long-term efficacy. While this duration was sufficient to establish short-term feasibility and user acceptability, a longitudinal follow-up is required to evaluate future benefits over time.

6 Conclusions

Despite the limited sample size, the pilot study yielded consistent and encouraging outcomes. The consistent improvements observed in patient-reported sleep outcomes and the high levels of acceptance and satisfaction suggest that VR-based relaxation experiences could

be integrated into clinical routines with the required help of healthcare staff. Overall, this proposal demonstrates that virtual reality can be a promising complementary tool for non-pharmacological sleep support in hospital settings highlighting the relevance of user-centred design, comfort-oriented interaction principles, and technical robustness when developing digital interventions for vulnerable populations.

Acknowledgments

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A Questionnaires

A.1 The AIS questionnaire

(1) **Difficulty falling asleep.** Do you take a long time to fall asleep after going to bed?
- Never (0 points)
- Occasionally (1 point)
- More than three times per week (2 points)
- For at least one year (3 points)

(2) **Frequent nighttime awakenings.** Do you wake up several times during the night and have difficulty falling back asleep?
- Never (0 points)
- Occasionally (1 point)
- More than three times per week (2 points)
- For at least one year (3 points)

(3) **Early awakening without returning to sleep.** Do you wake up earlier than desired and cannot fall back asleep?
- Never (0 points)
- Occasionally (1 point)
- More than three times per week (2 points)
- For at least one year (3 points)

(4) **Insufficient total sleep duration.** Do you feel that you sleep fewer hours than you need to feel well-rested?
- Never (0 points)
- Occasionally (1 point)
- More than three times per week (2 points)
- For at least one year (3 points)

(5) **Poor overall sleep quality.** Do you feel that the quality of your sleep is not good?
- Never (0 points)
- Occasionally (1 point)
- More than three times per week (2 points)

- For at least one year (3 points)

(6) **Reduced daytime well-being.** Do you feel that your performance or general well-being is not at its best during the day?
- Never (0 points)
- Occasionally (1 point)
- More than three times per week (2 points)
- For at least one year (3 points)

(7) **Impaired daily functioning.** Do you feel that your daily energy or performance is not the same as before?
- Never (0 points)
- Occasionally (1 point)
- More than three times per week (2 points)
- For at least one year (3 points)

(8) **Excessive daytime sleepiness.** Do you feel excessively sleepy or drowsy during the day?
- Never (0 points)
- Occasionally (1 point)
- More than three times per week (2 points)
- For at least one year (3 points)

A.2 Custom user experience questionnaire

Please indicate your level of agreement with the following statements using a scale from Strongly Disagree to Strongly Agree.

Perceived Enjoyment (PE)

PE.1 I enjoyed playing the games.
PE.2 I would like to continue playing these games in the future.
PE.3 Once I learned the game mechanics, I quickly lost interest.

Usability and Intuitiveness (UI)

UI.1 The application felt intuitive, comfortable, and quick to use.

Sense of Immersion (SI)

SI.1 I forgot about my immediate surroundings while playing.
SI.2 While playing, I felt free to explore the environment.
SI.3 While playing, I felt in control of the surrounding environment.
SI.4 I felt that I was interacting with real objects in the virtual reality environment.
SI.5 I felt completely immersed in the games.
SI.6 I lost track of time while playing.

Perceived Frustration (PF)

PF.1 While playing, I felt frustrated.