MIST: A Multi-sensory Immersive Stimulation Therapy Sandbox Room

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Abstract: Multi-Sensory Stimulation Environments are a form a therapy in which a patient is exposed to a set of controlled stimuli on various sensory modalities, including visual and auditory, in order to induce some desired physical or mental state. Despite their success, these environments are still not widely known or available to everyone today. However, through the use of virtual reality, that can be made possible and even have its effects boosted thanks to the observed benefits of VR usage in conventional therapy. Thus in this work we propose a virtual reality implementation of an immersive controlled stimulation environment, customizable and adaptive to a user's response to stimulus, which can be used as a simple mobile app added to a phone VR headset. Initial experimentation with the platform has been very positive making it highly promising for a future validation of its therapeutic use.

1 INTRODUCTION

Due to the accelerated lifestyle humans have been progressively exposed to in our evolving society, stress has become a recurrent obstacle for healthy living (AIS, 2019). In addition, the growth of life expectancy and consequential development of therapy-requiring illnesses as well as the definition of developmental disorders, such as autism, places additional pressure onto an already unstable environment. Relatedly, time has become a scarce resource and the inability to balance physical/mental wellness and stress inadvertently leads to a depressive state or other spiraling issues (Beiter et al., 2015), (Menard et al., 2017). Yet, the development of readily available therapeutic tools which can both address these problems and be executed on the go has received little to no focus from the research community.

Snoezelen®, a Dutch word originating from its homologous terms *snuggle* and *snooze*, refers to a type of therapy which aims to provide controlled stimuli to a set of sensory modalities in order to induce a sense of equilibrium and relaxation during a session. The concept, known also as multi-sensory stimulation environment (MSE), ultimately attempts to reinforce executive functioning and ease communication in scenarios where such tasks are difficult to accomplish, or with people inherently dysfunctional (mentally or physically) and behaviorally impaired. In these environments, sensory stimulation may range from visual to proprioceptive and vestibular depending on the objective of the session as well as the patient's goal. MSE's claim of success rests on the observed effect of stress reduction (both physical and emotional) which leads to enhanced concentration (Ashby et al., 1995), (Hodgins and Adair, 2010), (Moore and Malinowski, 2009). Moreover, MSE may serve as an introductory means to develop cognitive cues for progressive relaxation, following the observations of (Scheufele, 2000). Overall the concept has been physically implemented for leisurely meditation settings as well as specifically for the personalized treatment of autistic patients. The observed results were generally positive as shown in (Manuel, 2000) and (Baranek, 2002).

In addition to the growing recurrence of stress patterns in human life, technology has also become a frequent cohort of our daily activities. Though they may be argued as a cause of stress and anxiety, tech appliances may also be used to combat and reduce these factors. Considering the observed success of *Snoezelen*® therapy, its implementation as an immersive virtual reality (VR) exercise evidently appears to be a a path worthwhile exploring. Consequently, its benefits would be boosted by those related with the use of

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VR technology for therapeutic purposes (Sucar et al., 2014), (Bartolomé et al., 2011). In this study we developed and validated a readily available pocket VR MSE platform, customizable on the fly to patient requirements and which can be used with the aid of a phone and corresponding VR headset.

The presented work reflects the following structure. First, Section II presents an overview of previous research on similar approaches and immersive therapeutic environments, in order to contextualize the reader on the proposed system. The platform itself is described in Section III after a summary examination of its requirements and specifications. Section IV then describes how the environment has been experimentally tested and empirically validated. An assessment and discussion of the outcome of the experiments is provided in Section V. Finally, the paper is concluded in Section VI.

2 RELATED WORK

This overview of previous works is divided in the following two subsections. To start, recent approaches to the development and use of controlled multi-sensory environments are examined in order to contextualize our system. Following that, we analyze immersive VR therapy as an alternative to conventional therapy and how its technological edge may generally provide greater benefits to patients.

2.1 Multi-sensory Environments

A simulation of a Portuguese traditional game was adapted as a MSE that focused on playfulness, while being expanded by interactive fantasy elements (Castelhano and Roque, 2015). The authors defined a set of guidelines for the design of the game that comprise the same principles of a MSE with the purpose of mediating a therapeutic intervention between an Occupational Therapist and a Child with intellectual disability.

SnoezelenCAVE, as the name suggests, is a virtual reality CAVE Snoezelen® that intends to provide therapy for Autism Spectrum Disorder (ASD), which are known to have issues on social skills, speech, self-care or job skills (Perhakaran et al., 2015). Although mental health therapies, medication or special education are the most common approaches to deal with ASD, rehabilitation centers and hospitals have been using MSEs, such as Snoezelen® rooms, to create a soothing and stimulating environment that undertake intellectual disabilities (Hogg et al., 2001; Kaplan et al., 2006; Barton et al., 2015; Anderson et al., 2011). In this way, the authors proposed a therapeutic tool that is expected to solve the immersion characteristics of the traditional Snoezelen®, while following the standardized procedures for this type of treatment.

A multi-sensory stimulation virtual environment (MSVE) for relaxation was created as a part of an exploratory case study in (Diaconu et al., 2018). The idea behind this virtual environment is that the user should explore the existing scenes while actively interacting with some of the present objects. Some of these objects are passive (non-interactable) with the principal purpose of being aesthetically pleasing, as to enhance the feeling of calmness. The authors tested their MSVE with ten individuals of a residence and development center for the disabled to provide guidelines for the future design of therapeutic tools that follow the same purpose. Extra attention should be paid off into making the controls and the environment as simple as possible, as well as being understandable and suitable for different needs of the target group.

2.2 Virtual Reality for Therapies

Virtual Reality refers to the capability of transferring individuals to ”new realities” and support experiences through sensory stimulation. Over time it has been successfully applied to a vast panoply of areas, such as military training (Baumann, 1993; Bhagat et al., 2016), social science and psychology (Bailenson et al., 2008; Wilson and Soranzo, 2015), education (Freina and Ott, 2015), or healthcare and clinical rehabilitation therapies (Chirico et al., 2016; Weiss and Katz, 2004).

Focusing on clinical rehabilitation, VR brings several advantages to the conventional therapies for patients ranging from musculo-skeletal problems, to stroke-induced paralysis, or even cognitive deficits. In fact, there are several documented advantages that endorse VR-based rehabilitation, as stated below (Sucar et al., 2014; Lafond et al., 2010; Burdea, 2003):

- Significant improvement in patients motivation and engagement with their recovery plan;
- Increased frequency and more repetitions during exercises;
- Enhanced motor (re)learning by visual stimuli;
- Possibility to provide tele-rehabilitation and require low clinical supervision (easing home use);
- Ability to track the patient’s recovery progress over time;

3 METHODOLOGY

This section overviews the steps taken during the development of our VR MSE room, encompassing requirement definition, designing and usage of room components and their actual implementation.

3.1 Design Requirements

Given the necessity of MSE rooms to induce or boost a desired state in a user while also preserving comfort and engagement, these environments must fluidly adhere to a set of rules aimed at presenting the various sensory stimuli in a controlled and adaptive fashion. As examined by (Collier and Truman, 2008), a MSE session must consider a patient's capabilities and limitations related with attention and executive functioning in addition to reducing agitation and anxiety. In terms of virtual reality, the latter can be addressed by means of shaping the environment to have a cozy mind-blanking appearance, contrastingly retaining the ability to sustain attention by means of the stimuli stemming from its components. Envisioning this, the following design guidelines were considered:

- Rounded configuration with lack of sharp edges;
- Smooth transitions between textures;
- Dim lighting;
- User adaptive surrounds;

These characteristics facilitate isolation of the immersed user from the typical barrage of real world stimuli humans are continuously exposed to. Subsequently, a patient can be progressively presented with controlled stimuli corresponding to their level of engagement, and their response measured to improve system adaptability. The general goal is to match individual needs with the selected MSE demands by adjusting perceived complexity.

Of course virtual reality relies heavily on the exposure of stimulus to the visual modality given how incorporating other sensory factors, such as tactile or olfactory, would require more complex and independent mechanisms. However, auditory stimulation is also a highly functional option which considerably enhances the immersive VR experience, besides being a major element of MSEs. Hence, integrated musical themes should as well follow some specifications:

- No abrupt or sudden variations;
- Melodic tones with little noise;
- Ideally correlate with the visual factor;

Another important aspect to consider is the need for both active and passive interactions to be possible within the MSE, enabling its use by individuals who struggle with initiating/maintaining them. Overall and considering the defined scenario, the tuning of specific components and VR artifacts then stems from the desired goals of each session. These can be many and varied, such as stimulating a patient's focus to be on a specific artifact so as to assist them in countering an attention deficit disorder, for example. Or relatedly, provide joint audio-visual stimuli to help patients link multimodal elements which they are usually unable to given some neurological condition. The world of potential applications and corresponding benefits of an MSE extends far beyond their sensory exploration leisurely use.

3.2 Component Overview

Based on the aforementioned requirements, the proposed virtual environment dynamically modifies itself by adapting a series of intervening components and concepts. Depending on this modification process, the system may incorporate a subset of all potential components, out of which the most recurring ones are:

- Shimmering Effect - Shimmering colors, changing lights and fibre optics which stimulate and hold attention. It becomes ideal for individuals with visual disabilities, as their main purpose is to break through their own personal perceptual barriers.
- Sense of Flow - The soft flow of artifacts in the room is expected to ease the relaxation process. While observing their slow chaotic flow through the wall and around the room, users undergo stimulation of their tracking capabilities. This is essential for people of all ages, specially the ones with visual processing problems.
- Bubbles/Lava - A highly common component of MSEs. In relation to the sense of flow, these provide a multi-sensory feedback and improve the ability to track motion. Applying constant effects of color change, rotation, shape morphing and movement enables perception and cognitive stimulation.
- Animated Panels - Capable of displaying a panoply of effects, ranging from infinity to common physiological illusions to simple perpetual motion. Accompanied by a relaxing soundtrack, these provide a leisurely and pleasant sensory activity which encourages introspection besides exploration of the effect.

- Adaptive Wall - The whole room envelops a pleasing experience with a focus on the most dominant theme adequate for the user. This will induce a sense of isolation and security in the user, so as to maximize comfort and confidence in the session and ease handling of sensorial stimulation. For instance, manipulating the user's perception to be just above or surrounded by water, where they can observe ripple and wave-like effects.

3.3 System Construction

Given how a MSE is composed by many distinct elements, the *Blender* software was used in order to fasten the process of 3D modeling most artifacts included in the room, following the guidelines presented above. The final model, containing all developed components as well as the configuration specifications, is loaded into the *Unity* game engine. Here, the adaptive process is implemented so as to perform the real-time modifications which follow the mentioned requirements and suit the MSE session.

The characteristic of being dynamic and able to respond to the user's needs comes from the app's inner flow, presented in Figure 1. By tracking and monitoring the user's head movements on a real-time scale, adequate visual and sound stimuli are produced on the regarding sensory inputs. Moreover, from this diagram, one can see that the main way for users to interact with the MSE room is by rotating their head and gazing something.

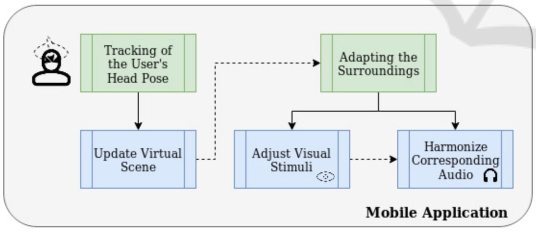

Figure 1: Overall view of the mobile application's architecture.

Considering the current computational capabilities of mobile phones nowadays, one can use their own devices as pocket personal VR platforms, able to support varied applications. The proposed portable therapeutic tool can therefore be used anywhere by a common person to relax and undergo stimulation, as well as in rehabilitation and therapy centers by healthcare professionals to aid in patient treatment. Our developed mobile app is deployable for both the Android and iOS operating systems, using phone sensors, specifically the accelerometer and gyroscope, to track the position and orientation of the user's head. Thus, any low-cost head-mounted display (HMD) with a pair of lenses and cushioning is enough for displaying the virtual environment according to the user's point of view. Considering how auditory stimulation is likewise one of the crucial components of MSE rooms, the system also expects the user to wear some type of earphones to benefit from the audio modality, ideally fully covering headphones. Plus, this is a requirement if the user intends to enhance their immersive experience during the usage of the app.

Our brain defines reality and what it believes to be real based on the collected information from our senses and perception systems. If we replace those sensory inputs with made-up information (e.g, by using an HMD and headphones), our perception of reality would change, since we would be confronted with a version of reality that isn't really there, but it would seem real. Therefore, once the users wear the HMD, they start the transportation process to a new world by acknowledging the surroundings of the displayed virtual scene. As shown in Figure 2, there is a virtual model that is considered to be a temporary representation of oneself inside the MSE room. It is expected for the user to to experience the illusion of body ownership, and consequently augment the feeling of presence inside the virtual environment (Kilteni et al., 2012).

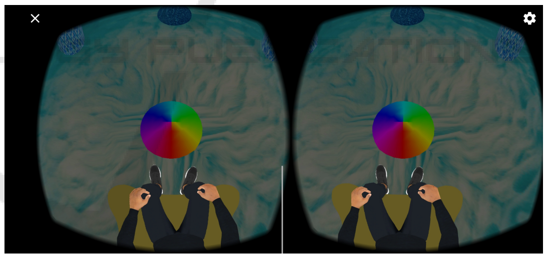

Figure 2: Self representation in the virtual environment.

As previously mentioned, the developed MSE is adaptive to the person's response in relation with the presented stimulation. Building on an initially small feedback, the room aims to amplify a desired response by means of controlled stimulation, being therefore able to acquire different shapes and characteristics. As a showcase of two different and somewhat opposing possible scenarios the room may manifest, Figure 3 shows an exemplary darker warm-feeling room while Figure 4 demonstrates a possible cooling deep dive room.

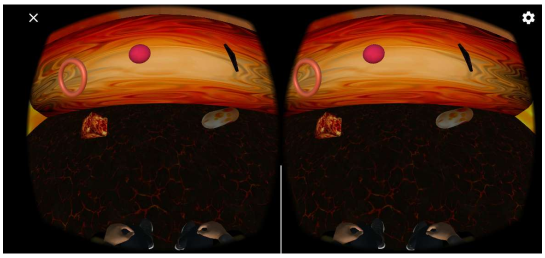

Figure 3: A warm MSE room.

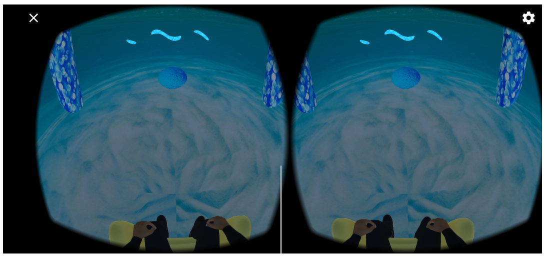

Figure 4: A cool MSE room.

4 EXPERIMENTAL RESULTS

In order to test and validate the developed MSE, it was first necessary to define a standard in which users could experience the room, for later comparison. In the adopted setting, the user sits comfortably on an armchair or sofa before launching the mobile application, requiring only the mounting of three devices: an Android or iOS smartphone, a low-cost HMD and a set of headphones. The overall experimental apparatus can be observed in figure 5, for reference.

Figure 5: User experiencing the MSE room.

The virtual environment and its effectiveness with real users was analyzed by conducting an initial study with 21 participants, the majority being personnel from the Department of Electrical and Computer Engineering at the University of Coimbra. The total amount was composed of 15 male and 6 female participants, ranging between 11 and 47 years of age. The participant distribution is shown in Figure 6. These participants had no previous knowledge concerning the developed work, simply being willing to volunteer for the experience and provide feedback on it. In order to assess the environment's effectiveness as a MSE and obtain insight on the overall immersive system, validated and adapted versions of the Positive and Negative Affect Schedule (PANAS) scales, by (Watson et al., 1988), and the Igroup Presence Questionnaire (IPQ), described in (Schubert et al., 2001), were applied. The PANAS survey was applied twice, for comparison, whilst the IPQ was given to the participants only once.

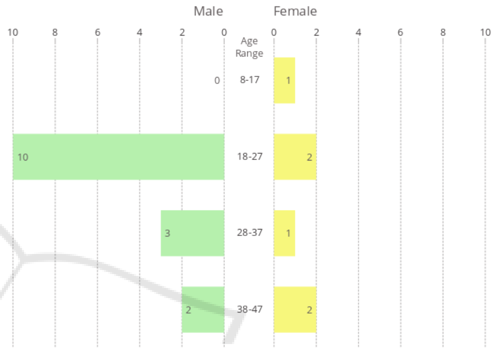

Figure 6: Distribution os participants in the experiment.

The Positive and Negative Affect Schedule (PANAS) scales was developed as a self-report questionnaire with the main purpose of providing an estimation of the individual's affective experience regarding a certain time frame. Hence, it measures two primary dimensions of mood, Positive Affect (PA) and Negative Affect (NA), based on ten internally consistent items for different time scales (e.g, "At the moment" or "This day"). PA refers to a state where the individual feels enthusiastic, active or determined, meaning that lower PA is closely associated with sadness and lethargy. On the other hand NA reflects subjective distress, being commonly correlated with feelings of anger, disgust, fear or nervousness. Thus, low NA is linked with states of calmness and serenity. The Portuguese short-version of PANAS is presented in (Galinha et al., 2014) and was employed as a mean for assessing the emotional state of the participants before and after the experience.

The Igroup Presence Questionnaire (IPQ) intends to measure the sense of presence experienced by the user in a virtual environment. Its current version aims to subjectively determine three sub-scales (spatial presence, involvement and realness), as well as to infer a second-order factor (general presence). Spatial presence refers to the sense of deeply being present in the VE, as if the user was there physically, while involvement measures the attention that the user paid to it and how embroiled they were during the experience. Experienced realism or realness aims to classify how realistic the VE is, while measuring the corresponding subjective experience. General presence can be referred to as a global analysis of the "sense of being there", and has deep loading on all the three sub-scales. An adapted and validated Portuguese version of this presence questionnaire, presented in (Vasconcelos-Raposo et al., 2016), was employed at the end of the participant's experience.

The procedure followed during the conduction of this initial study is described by the steps:

1. Briefly introduce the participant to what he/she is about to experience and take part of, as well as the involved technology.
2. Kindly request the participant to answer the Portuguese short-version of PANAS that intends to assess his/her current emotional state.
3. Aid the participant to place both the HMD and headphones properly, and let him/her experience the developed VR MSE room for five minutes.
4. After this time, the participant is expected to have been driven to a new emotional state and thus required to respond the PANAS questionnaire again.
5. In the end, to evaluate the feeling of presence, the participant is asked to answer the Portuguese validated version of the IPQ questionnaire.

4.1 Sensation Analysis

In order to extract valuable information and assess the results obtained from the first and second PANAS surveys, the SPSS software (IBMCorp, 2017) was employed. The two iterations were parallelly compared so as to draw conclusions on the effects of the proposed MSE. The majority of participants reported an increase in interest and enthusiasm, added to heightened inspiration. Concurrently, a decrease in nervousness as well as in determination and activeness was noted. Some participants mentioned a small degree of scaredness related with the ocean-like environment they were placed in (one participant suffers from Thalassophobia[1]). All in all, participants felt more motivated and encouraged after performing the experiment, while also becoming more relaxed and comfortable. It should be restated that each partaker in the experiment was asked to assess a before and after estimation of their own levels of each PANAS item sensation, ranging from low (1) to high (5). The PANAS result progression is presented in Figure 7, where the initial positive and negative affects are placed next to their final counterparts. As can be observed, there was an increase in both affects after the experiment.

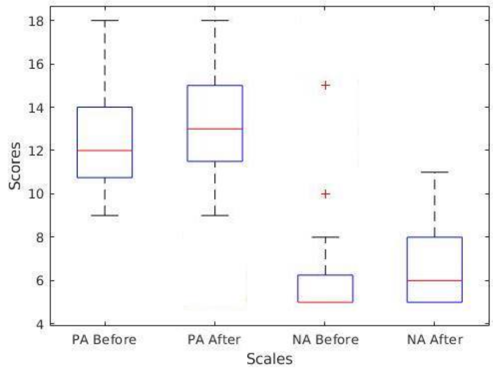

Figure 7: Panas results in terms of affective progression, according to Positive Affect (PA) and Negative Affect (NA) comparisons before and after participant immersion.

4.2 Feeling of Presence

In terms of the results stemming from the IPQ evaluation, which were obtained by resorting to SPSS as well as Excel (Microsoft, 2018), positive conclusions can be drawn such as the following. In general, participants reported being able to prescind themselves from their real world surroundings, feeling immersed within and enveloped by the virtual environment. In addition, the environment was also noted to be appealing to the participants, differing from common everyday experiences people are accustomed to. On the whole, the demonstrated room was perceived as clearly virtual and easily distinguishable from the real world, despite presence results being positive. It is important to reiterate that each participant was asked to specify their level of agreement with each of the 14 IPQ questionnaire items, ranging from 1 (strongly disagree) to 5 (strongly agree), via a *Likert* scale (Likert, 1932). The IPQ results are visually displayed in Figure 8, in the form of spatial presence (being physically present in VR), involvement (user attention level), realness (VR realism level) and general presence (overall immersion), as previously described.

In addition to the surveys, partakers were also asked to answer 4 short questions regarding their experience. From these it was observed that, even though 5 of the participants had never before been in a VR environment, all would appreciate doing one or more MSE sessions with the presented system. Fur-

[1] From *Wikipedia – Thalassophobia*: An intense and persistent fear of the sea. May include fear of being in large bodies of water, vast emptiness of the sea, sea waves and/or distance from land.

ther, no volunteer reported any sort of nausea or disorientation from being immersed in the VR room.

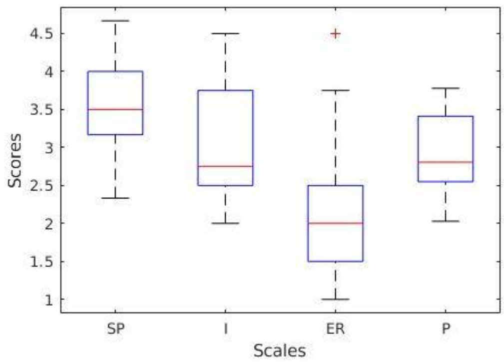

Figure 8: IPQ results in terms of Spatial Presence (SP), Involvement (I), Experience Realism (ER) and Presence (P).

Cronbach's Alpha (Cronbach, 1951), a common measure of result reliability which widely applied in psychometric testing, was also computed for the evaluated questionnaires by means of the SPSS software. Bearing in mind even higher values may be achieved by increasing the sample size of test participants, the computed values were still very acceptable, being in the 0.7 to 0.8 range. Furthermore, despite the majority of participants being male, no significant disparity was observed between male and female results in both the pre-test and post-test.

5 DISCUSSION

Considering the experimental results obtained by comparison of the initial and final iterations of the PANAS survey, it can be inferred that participants were indeed stimulated, having become more motivated to complete some assigned task thanks to undergoing a short session in the VR MSE room. Moreover the raised senses of relaxation and peacefulness while maintaining engagement, observed in the participants after the experiment, can in fact justify the application of the proposed MSE as a mental preparatory stage of therapy as proposed. Plus, it can be concluded that the developed system is adequate and provides the same benefits for both men and women. Thus the VR stimulation room's effect was validated by the obtained positive results.

Evidently there was a small increase of worry or apprehension for a group of participants. However, this group was almost solely made up of young participants within the 18-27 age range. When questioned about the scaredness increase, it was highly clear how a previous type of experiences related to thriller video games and "jump scare" scenarios was common to all and the culprit of such uneasiness. The involved participants all stated they felt a sense of false security and expected something to appear unexpectedly at some point. This, of course, may be related with the previously mentioned overstimulating and stressful society humans live in today which is causing younger generations to maintain a constant state of alert. This could also explain the observed raise in Negative Affect, given the 18-27 age range contained most of the experiment participants. Nevertheless, we believe better informing the participants on multi-sensory environments and performing further sessions could heavily attenuate this negative factor for the people who experienced it. Another related and curious serendipity was caused by one of the participants suffering from Thalassophobia, something which the authors were unaware of before starting the experiment. Given how the room was majorly a deep ocean-like environment, the user felt anxious and increasingly worried. Still, the participant finished the entire session without stopping and felt entertained by observing artifacts in the room. This is highly valuable as it shows how even patients with some degree of trauma may benefit from being immersed in a personally triggering MSE.

Differing but equally interesting interpretations of the room were described by the participants. Though the ocean/aquarium theme was common to most, with an observed ripple effect and floating/flowing objects, one compared the presented MSE to a sensory deprivation room while other felt he was floating in heaven. Another participant felt hypnotized by the room, having lost track of time, while yet a different one acknowledged to initially feel some nose discomfort (stemming from the VR glasses weight) which he forgot about as his session progressed. Some users even mentioned feeling the whole room to be rotating around them, despite this never actually happening. Lastly, all agreed sound to be a key component in their sense of immersiveness, in addition to the person avatar being present and visible. Considering these statements and how no interpretation of the room is particularly correct or incorrect, we can successfully assert its effectiveness as a MSE. A feel of stimulation was blatant in nearly all participants, following exactly what was initially intended to happen. Undoubtedly the testing carried out is limited. Due to the fact that the developed MSE was applied on volunteers only, it would be senseless to extrapolate the obtained results to patients with diverse mental pathologies as their reactions might differ from those of a healthy person. Nevertheless, the results are still positive and more than sufficient to warrant a second testing phase with actual patients and further improve the MSE. As such, preparations for such a phase are underway, ideally aiming for a clinical trial soon.

Finally, after providing valuable insight and evaluations during the development phase of the system, a final iteration of this system was presented to and validated by a clinical psychologist who considered it to be adequate for its objective, respecting the stated requirements and being safe and suitable for testing with people.

6 CONCLUSION

In this paper, we examined the requirements and specifications of multi-sensory stimulation environments (MSEs) in order to use these as an alternative to conventional therapy. A virtual reality implementation of a MSE was produced, able to run on both Android and iOS, as a platform which can be used without the need of expensive material and by anyone, including healthcare specialists for patient therapy. Following its development, the app was made available to a set of beta testers so as to have its usage and benefits be validated. Based on the analysis of the obtained responses, we were able to demonstrate how the proposed environment can in fact be beneficial for leisurely uses, engagement stimulation, and in therapy, in terms of mental preparation for treatments and by adaptive stimulation of necessary factors. In addition, insight on the platform was obtained from a therapist so as to further corroborate its use and improve it later on.

In the future, we aim to introduce the collection of biometric markers so as to more meticulously verify patient improvement, and also test the developed system on real patients ideally through clinical trials. We further intend to explore the possibility of integrating other modalities besides the visual and auditory. Specifically tactile factors can be introduced by incorporating a set of gloves in the system which can provide haptic feedback for feeling and picking up objects in VR. Some prototypes of this technology are already being developed. such as the ones introduced in (Hinchet et al., 2018) and (Perret and Vander Poorten, 2018), or the 3D printed *Sense Glove* developed by a Dutch company of the same name. Ultimately the goal would be to also provide the user with textural stimulation, besides the haptical holding feel. Integration of other modalities such as olfactory and gustatory are other potential paths of further research.

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