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RESEARCH ARTICLE

Contribution of Virtual Reality Environments and Artificial Intelligence for Alzheimer

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ABSTRACT
Alzheimer's Disease (AD) is one of the most crucial diseases of our century affecting millions of persons every year. Negative emotions such as anxiety, frustration, and apathy are common in AD patients which reduce their wellbeing significantly. Virtual Reality is a means of providing the patients with a sense of presence in an environment that isolates them from external factors able to induce negative emotions. In this goal we have developed several interactive virtual environments able to relax the patients and reduce negative emotions. Virtual travels, natural environments, music therapy, Zootherapy, discovering environments can be used to calm the patients. Artificial Intelligence can bring a valuable contribution if these environments can be modified dynamically according to brainwaves reactions. Neurofeedback techniques can be used to adapt the virtual environments in order to dynamically reduce negative emotions and foster positive emotions. We will present several examples of interactive virtual environments driven by the brain of Alzheimer's patients and able to improve their cognitive capabilities.

Keywords: Healthcare Applications, Virtual Reality, Cognitive Environments, Alzheimer's Disease, Immersive Environments, Emotions, EEG Sensors

Introduction

Alzheimer's Disease (AD) is one of the most crucial diseases of our century affecting millions of persons every year. Although some cases can be tied to genetic mutations often the early-onset familial form most cases are sporadic, and their cause is unknown. Research have revealed the role of neural damage in specific regions of the brain. The affected regions in large part involve the cortex, the limbic system and the hippocampus[1]. These regions have a crucial role in memory, emotions and higher-order functions such as attention and thought.

The most notable symptom concerns the deterioration of both short-and long-term memory. The disease also affects behavior, cognitive abilities as well as physical abilities in affected individuals. Studies have shown that AD patients often become anxious and uninterested in things that used to bring them joy [2]. Negative emotions such as anxiety, frustration, and apathy are common in AD patients which reduce their wellbeing significantly and this may aggravate their already-impaired cognitive state[3].

We believe that by intervening at the emotional level, it is possible to observe a positive influence on cognitive performances including memory tasks in AD patients. Several studies have investigated the impact of **music** on emotional response, inducing sensation of pleasure and a change of the activities of specific parts of the Brain Reward System, a network of brain structures involved in the sensation of pleasure.

On the other hand, many reports revealed benefits in using Virtual Reality (VR) with AD patients. The world in which a user is immersed provides a feeling of safety and encourages imagination. Also, the user is isolated from external factors which can induce negative emotions. There is some indication that VR intervention with computerized cognitive training can improve cognitive domains in individuals with mild cognitive impairment or AD [4,5]. Moreover, participants prefer completing cognitive training tasks in VR over its pencil-paper counterpart[6]. One of the advantages of VR is the full immersion, increasing the users 'sense of presence in the virtual environment. They believe that they are in a real world and promote their performance[7].

The objective of this paper is to see the impact of virtual environments on negative emotions of Alzheimer patient. Our hypothesis is that VR environments can reduce negative emotions, improve memory capacities and cognitive functions, providing a non pharmacological way to improve AF health conditions.

Based on these ideas, we have designed several VR environments linked to emotional assessment devices, and we have proceeded to several experiments to measure their impact on memory and cognitive improvement of Alzheimer patients. To assess the evolution of emotions we will use electroencephalogram devices (EEG). EEG is a simple and easy way to get an inside view of subjects' brain activity. Some studies showed that by using the assessment of engagement and frustration, appropriate help strategies could be provided to participants engaged in a physics-related game[8].

In the following we will present first, the advantage of music therapy offered in an immersive environment. In fact, music can provide relaxing conditions which can be improved by the feeling of immersion. Then, we will show the effect of a virtual travel on cognitive improvements. We will also present the impact of two other VR environments (Savannah and Zootherapy) which will dynamically evolve according to the emotional state of the patient's brain, driven by neurofeedback and artificial intelligence techniques.

Methods

Emotions assessment can be done using several methods. Face recognition using specialized software such as Face Reader is one way. Heart rate control or galvanic responses are other possibilities. However, they are not precise and can react with a delay. To measure the evolution of emotions electroencephalogram devices (EEG) provide a precise and fast reaction from the different parts of the brain.

In our studies, we use the Emotiv Epoc EEG headset to track emotions. The headset contains 14 electrodes spatially organized according to the International 10-20 system, moist with a saline solution. The electrodes are placed in antero-frontal (AF3, AF4, F3, F4, F7, F8), fronto-central (FC5, FC6), parietal (P7, P8), temporal (T7, T8) and occipital (O1, O2) regions with two additional reference sensors placed behind the ears. The detailed position of the measured regions is shown in Figure 1.

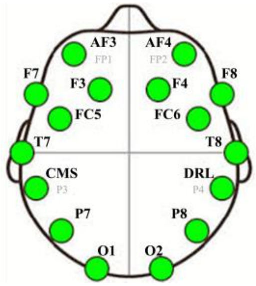

Figure 1: Emotiv headset sensors placement.

Emotiv system generates raw EEG data (in µV) with a 128Hz sampling rate as well as the five well-known frequency bands, namely Theta (4 to 8 Hz) Alpha (8 to 12Hz), low Beta (12 to 16 Hz), high Beta (16 to 25 Hz) and Gamma (25 to 45 Hz). Furthermore, the system uses internal algorithms to measure the following mental states: meditation, frustration, engagement, excitement, and valence. They were used to assess the effect of the different virtual environments on the emotions of participants.

Experimental Protocol

To study the impact of the virtual environment on attention and memory performances, we created 6 **attention and memory exercises** using Unity 3D software. For instance, in one attention exercise, we show some pictures of different items for a short period of time. Then, after each picture, four letters are presented and patients are asked to select the letter corresponding to the first letter of the presented item's name.

The following experimental protocol (Figure 2) will be used in all the VR environments, beginning (step 5) by Music therapy environment. Participants were first invited to fill the following questionnaires: The Positive and Negative Affect Schedule (PANAS) scale[9], a self-assessment of emotions, and a questionnaire on cyber-sickness[10]. Then, we equipped the participants with an EEG headset and invited them to start solving the attention and memory exercises.

Following these tests, participants were equipped with a FOVE VR headset, and the VR music therapy environment was launched. The relaxation environment lasted for about 10 minutes. Following the virtual environment, participants completed different variants of the same attention and memory exercises. Finally, the experimental session came to an end after asking the participants to once again fill the PANAS scale, cyber-sickness, AttrakDiff 2,[11] and a self-report form about the environment.

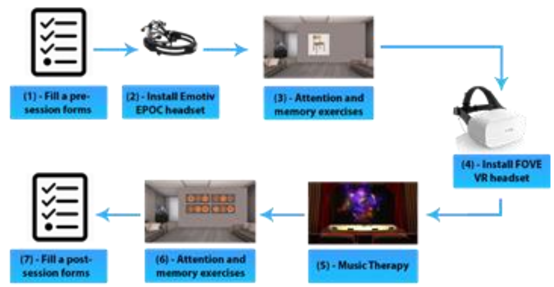

Figure 2: Experimental protocol

Figure 3 gives an example of attention exercise. the participant hears a series of numbers and is invited to replicate the sequence in the same order as presented using a numerical pad. Then, another series of numbers is presented but the participants are now invited to report numbers in the reversed order.

Figure 3: An attention exercise

Figure 4 gives an example of memory exercise in which several objects are visually or aurally presented to the participants before asking them to memorize them. After that, we present a series of objects and the participants are asked to select whether the object was seen, heard or never presented. Figure 5 shows the case where the participant answers they have seen the image of the car.

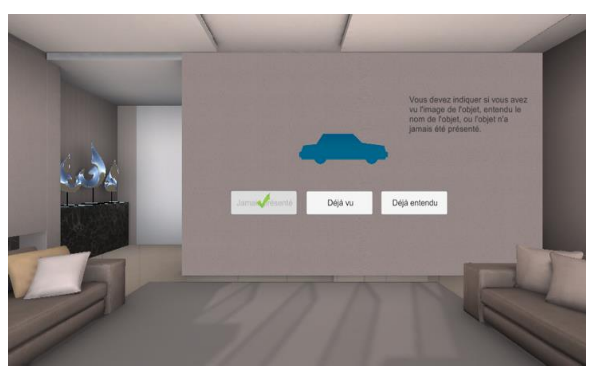

Figure 4: Memory exercise

In the next sections we will successively detail the experiments with various VR environments and the first one is built around Music therapy environment.

Music Therapy

Music is known for generating emotions which can cause changes in mood. It provides pleasure, fun or relaxation, either when actively created or when passively listened to. It has been observed that Jazz music presented to old jazzmen with memory problems leads to a positive transformation of their faces, showing a great satisfaction. They follow the rhythm, remember the tempo and offer an emotional response [12–14].

The reason of this improvement is based on the Brain Reward system, a set of connected brain structures which intervenes in the rewarding experience of stimuli, be food, sex, or music. In this structure dopamine is the main neurotransmitter, where it is both synthesized and released. This propagation reduces cortisol, a so-called stress hormone, and results in better problem-solving performances in stressful situations[15].

To generate emotions, we designed a virtual theatre (with red curtains opening at the start of the session) using Unity 3D software[16]. We virtually placed the participants in the center of the room, on a seat, where they could easily see the stage up front and dynamically rotate their head to visually explore the room (Figure 5).

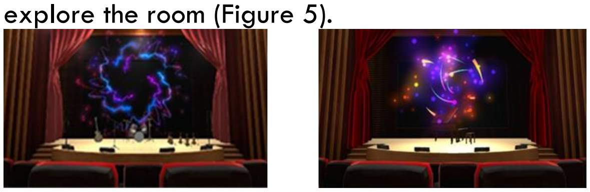

Figure 5: Scenes for two different songs from the virtual environment.

A series of eight 30 second song excerpts are sequentially presented in the following order: (1) Ave Maria by Franz Schubert, (2) Eine Klein Nachtumusik: Allegro by Mozart, (3) Ukulele by Bensound, (4) Clair De Lune by Debussy, (5) La Vie En Rose by Edith Piaf, (6) Everyday by Buddy Holly, (7) La Bamba by Ritchie Valens, and finally (8) What A Wonderful World by Louis Armstrong. Each song excerpt was clearly separated from the previous by the red curtains closing and opening. The choice of music was based on studies and theories. A portion of the songs were chosen because they contained melodies with structural features associated with anxiety reduction (i.e. slow tempo, low pitches)[17]. Another portion of the songs was selected based on their popularity in North America during the years corresponding to our participant's reminiscence bump. This refers to a time period where events and memories are more likely to be remembered.

We tested our approach on 19 participants (13 females) with subjective cognitive decline (SCD) and a mean age = 72.26 (SD = 5.82).

Results

We started by analyzing the emotions of the participants before, during and after the virtual music therapy immersion. This was done on the measure of frustration and valence extracted from the Emotiv EEG recordings. Results show that the mean frustration level before the music therapy was 0.69 (0.37 minimum and 1.00 maximum). The mean frustration level during the immersion was 0.45 (0.21 minimum and 0.78 maximum). After the immersion, the mean frustration level was 0.51 (minimum 0.23 and maximum 0.92). Figure 6 shows a boxplot of the mean frustration before, during and after the music therapy session.

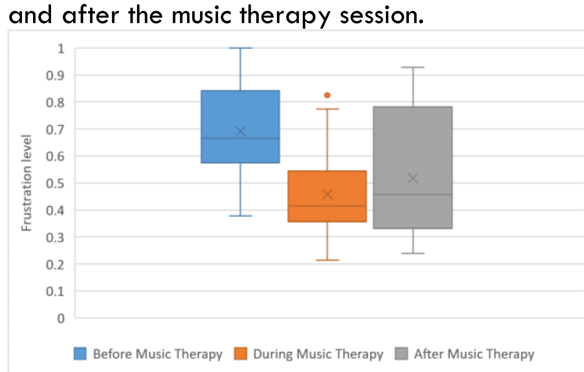

Figure 6: Boxplot of general mean frustration

For the attention exercises, results show small improvements (between 4 to 6%). However for memory exercises the improvement was between 50% to 100%.

Discussion: Results showed that following the music therapy session, participants had increased positive emotions, reduced negative emotions, slightly increased attention performance and considerably increased memory performance. **By increasing positive emotions and reducing negative emotions through the activation of the brain reward system (BRS), music improves cognitive functions.**

Using the EEG assessments in real time and a neurofeedback approach, a neurofeedback agent tracks the emotions of the participants while they listen to the eight songs, detects the song which provokes the best emotional impact and plays this song once again for a longer period of time. This allows to adapt the playlist of songs to the user to favorize the song which has the most potential effect on the participant. This means the song that has less negative effect and most positive effect on the participant's emotional state.

Virtual Travels

Over the last few years, VR started to be used in many fields due to its remarkable advantages, the major one being full immersion. In fact, VR tricks the mind of the users and increases their sense of presence in the virtual environment. It makes them believe that they are in a real world and promotes performance [7]. Therefore, VR is increasingly being seen as the most interesting way to present an environment to users.

The main advantage of virtual reality compared to other interactive environments is that the user is isolated from external visual distractions. This technology has been applied in the field of psychology to treat various disorders, including brain damage[18], anxiety disorders[19] and alleviation of fear[20]. For instance, Pedraza-Hueso et al. [21] introduced a VR system which consists of different types of exercises with which the user can train and rehabilitate several aspects including cognitive capacities.

In order to facilitate the feeling of travel in an immersive environment we designed and created an immersive virtual train using Unity3D game engine which contains a built-in physics engine able to simulate real aspects of our virtual travel[22]. This environment represents a virtual train in which the participants find a happy family sitting next to them (Figure 7) and are virtually looking through the windows to the landscape. Step 5 of Figure 2 is replaced by the virtual train.

Figure 7: Travelling into the virtual train

Results

We tested the environment on 19 participants (11 females) with SCD and a mean age = 69.68 (SD = 5.49). We used the same experimental protocol as indicated in Figure 3. We started by analyzing the emotions of the participants before, during and after the virtual train immersion. The results (Figure 8) show that the mean frustration of participants before the therapeutic train was *0.71*, (minimum *0.41* and maximum *0.96)*. The participants' mean frustration during the travel in the train was *0.51* (minimum *0.24* and maximum *0.94*). After the therapeutic train, the mean frustration was *0.53* (minimum *0.17* and maximum *0.79*). Figure 8 shows a boxplot of the mean frustration before, during and after the travel in the virtual train.

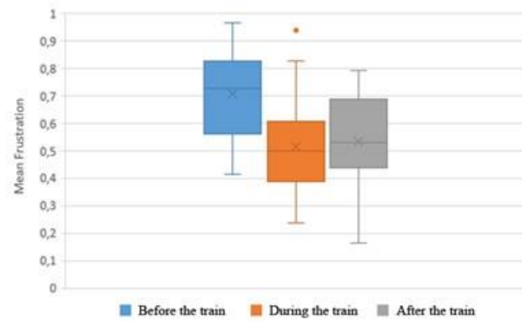

Figure 8: Reduction of frustration

Discussion: These results show a clear increase in memory performance following the virtual train and in some cases an improvement in attention abilities. Negative emotions like frustration, are reduced. A post-experience evaluation questionnaire confirmed that the virtual train is relaxing and reduces stress (73,7% participant confirmed that the virtual train is very relaxing). The questionnaire confirmed the participants' interest for this method, and their appreciation of virtual reality and its immersion effect. In fact, 89,5% of them confirmed the good aspect of immersion and 79% confirmed also that VR has a positive impact on their experience.

Virtual Savannah

Savannah is a virtual environment of African landscape, also developed in Unity 3D. Participants follow an avatar, speaking in a soft and reassuring voice, across a savannah. In a way to attract and reassure the participants, the avatar asks users how they feel. It offers succinct and straightforward explanations, both in writing and speaking, to ease the processing of information. The dominant colors are warm, the animals are peaceful, and their movement is slow. In the background, users can hear a soothing piano track at a volume low enough to appreciate the sound of each animal. Figure 9 shows the visual aspect of part of the environment.

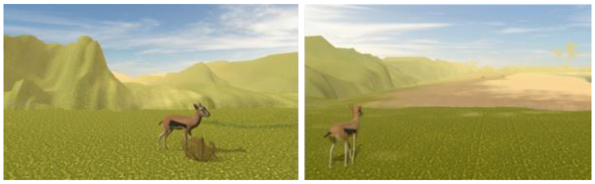

Figure 9: Virtual Savannah

Here, Artificial Intelligence plays a role on the environment. According to the emotional measures of the patient, several parameters can be adjusted. Color and light intensity are among the adjustable parameters, as light affects perception and decision making. The color of light can also stimulate learning[23] and reduce stress faster[24]. It is also possible to reduce the number of animals and change the sky and colors to provide a soothing sunset as shown in Figure 10.

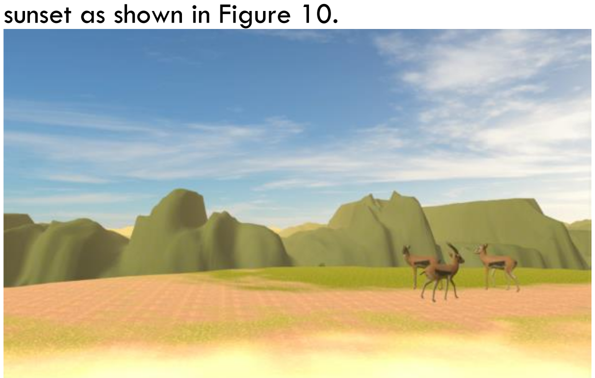

Figure 10: Automatic adjustment of parameters

The principle is based on neurofeedback effect. The parameters change according to emotional measures of frustration and according to some rules. After a cycle of measures and modifications of the parameters, the rules are updated according to a learning mechanism.

Study population: We conducted the experiments on 19 participants (12 women) with SCD and an average age = 71 years (SD = 8.39). The criteria for eligibility were: be over 60 years old, french-speaking, normal or corrected vision, normal hearing, the participant's memory is not as good as it used to be, and this worries them (self-assessment), MoCA score 20-30, no deficits in logical memory based on Wechsler Memory Scale (WMS).

Results

We analyzed the participants' level of frustration and results show that the mean frustration of participants before Virtual Savannah was 0.68 (minimum 0.24 and maximum 0.98). The participants' mean frustration during Virtual Savannah was 0.57 (minimum 0.31 and maximum 0.88). After Virtual Savannah, the mean frustration was 0.55 (minimum 0.28 and maximum 0.91). Figure 11 shows the individual frustration level for each participant before, during and after savannah.

In addition, we conducted a repeated measure ANOVA with participants' frustration level as dependent variable. Results revealed a decrease of the frustration during IST and the effect was still observed after the immersion ($p= 0.0345$ and $F= 3.7018$).

These results show that Virtual Savannah helps reduce negative emotions of participants with SCD.

We also noted that, for some participants, frustration increased during the Savannah VR. This increase may be because they could not move freely in the environment but had to follow a defined path. It may also be due to personal preferences (like the visual aspect of the environment or sounds).

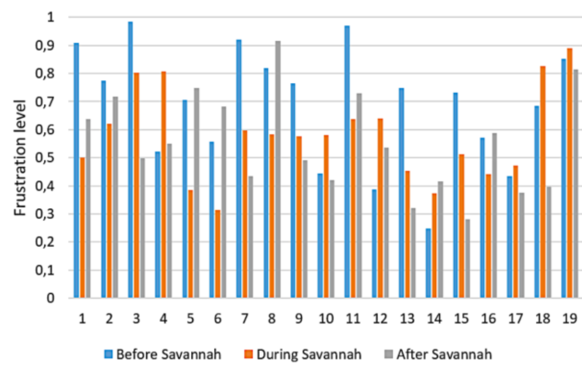

Figure 11: Improvement of emotions with Savannah

Underwater

Underwater VR is a diverse environment that we created for the relaxation based on the approach mentioned above. It has different colors of corals, rocks, sand, plants, minerals, and different kinds of fish. The number of fish, the intensity and color of the light are elements of the environment that can be changed (Figure 12).

Figure 12: Exploring underwater

No experiments were conducted in this environment but quite all the participants who tried the exploration were happy and wanted to reuse it for the fun.

Zoo Therapy

Current treatments of Alzheimer can be distributed into pharmaceutical, psychosocial and caregiving. Pet therapy (animal-assisted therapy (AAT)) is a Stimulation-oriented treatment of psychosocial, which is an interaction between humans and animals for therapeutic purposes. It can help someone recover from a health problem or mental disorder.

The most used types of AAT are dog assisted therapy and horse assisted therapy. AAT aims to improve patients' social, emotional or cognitive function. A growing body of research shows the social, psychological and physical benefits of animal-assisted therapy in health and education[25]. In aged people, AAT can be used for ameliorating agitate behaviors, psychological, occupational, social and physical disorders especially in Alzheimer and Dementia. AAT can increase social interactions by initiating decrease the agitate behaviors of patients with Alzheimer and Dementia[26]. People with Alzheimer may have an easier time decoding the simple repetitive, non-verbal actions of a dog. Animals can act as transitional objects, allowing people to first establish a bond with them and then extend this bond to people. Most of the study results revealed that AAT especially dog therapy had a "calming effect" on the patients with dementia and Alzheimer disease[27].

In the following environment (Zoo VR) we have integrated a virtual dog and a horse which can be called by the patient simply by his-her gesture recognition (Figure 13 and Figure 14). The gesture recognition module tracks hand gesture in real time[28]. The intelligent agent receives the hand gesture and users' emotions in real-time and intervene in Zoo VR by commanding animals depending on the emotions and the gestures of the users.

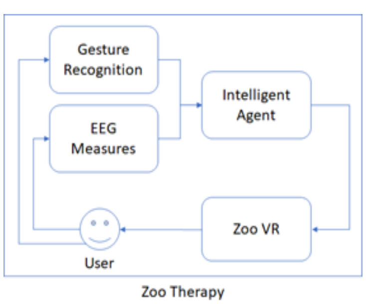

Figure 13: Zoo Therapy

So, two signals can be interpreted by the agent according to a neurofeedback approach: one from the gesture patient (Figure 13) and one from sensing the user's emotions through EEG. Users can use gestures to make animals come, walk, eat or leave. The neurofeedback system modifies animal behavior by identifying emotional changes in the user's EEG. The agent uses a rule-based system to adapt the animal's behaviour to the participants. For instance, if the frustration of the participants increases when the animal approaches them, the agent makes the animal go away.

The study population was the same as the type of population used for Savannah. Hand gestures recognition were performed by ten different subjects. We used Leap motion system and were obtained at different frame rates supported by the camera and we used the best frame rate for our experiment purpose (30 frames per second).

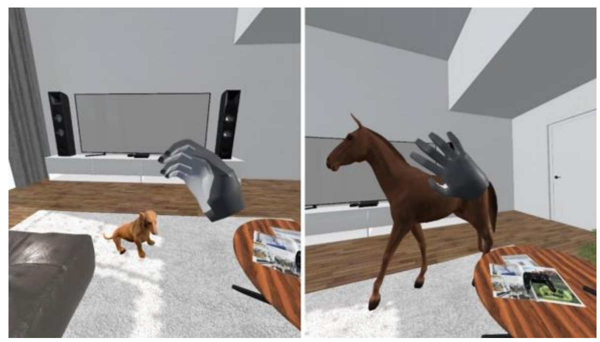

Figure 14: Interacting with the virtual animals

Due to the COVID-19 circumstances we were just able to test the system with a few participants. However, results showed that we can predict hand gestures and we might reduce negative emotions with Zoo Therapy system. Presenting several advantages compared to the introduction of real animals in room's patient such a system could be used to reduce AD symptoms.

Conclusion

Finally, we realized more than one hundred experiments within the different virtual environments. Experiments were conducted during which the participants performed cognitive and memory exercises, before and after their use of the virtual environments. Results showed that the virtual environment helps relax the participants and decreases negative emotions, most notably frustration. On the other hand, the participants' performance on the memory exercises was improved.

We can improve the memory performance and the cognitive abilities of Alzheimer patients by using immersive virtual environments which is a consequence of reducing the negative emotions. The neurofeedback approach and intelligent management of the rules which adapt the environment according to the emotion of the patients are promising avenues for non-pharmacological treatments of Alzheimer patients.

Conflicts of Interest Statement

The authors have no conflict of interest to declare.

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