Adaptive Music Therapy for Alzheimer's Disease Using Virtual Reality

Alexie Byrns[1], Hamdi Ben Abdessalem[1(✉)], Marc Cuesta[2],
Marie-Andrée Bruneau[2], Sylvie Belleville[2], and Claude Frasson[1]

[1] Département d'Informatique et de Recherche Opérationnelle,
Université de Montréal, Montréal, Canada
{alexie.byrns,hamdi.ben.abdessalem}@umontreal.ca,
frasson@iro.umontreal.ca
[2] Centre de Recherche de l'Institut de Gériatrie de Montréal, Montréal, Canada
marc.cuesta@criugm.qc.ca, {marie.andree.bruneau,
sylvie.belleville}@umontreal.ca

Abstract. With Alzheimer's disease becoming more prevalent, finding effective treatment is imperative. While no pharmacological treatment has yet proven to be efficient, we explore how technology can be integrated into non-pharmacological intervention to enhance its benefits. We propose a new and unique version of Music Therapy, an already existing therapy known to be beneficial. Music therapy has been shown to improve emotions and certain cognitive functions, which is the main focus of our study. To this aim, we designed a virtual reality environment consisting of a music theatre in which participants are immersed among the audience. A meticulously chosen selection of songs is presented on stage accompanied by visual effects. Results show that the environment decreases negative emotions, increases positive emotions, and improved memory performances were observed in most participants following the immersive experience. We speculate that by improving emotions through adaptive music therapy, our environment facilitates memory recall. With virtual reality now being easily accessible and inexpensive, we believe this novel approach could help patients through the disease.

Keywords: Virtual reality · Alzheimer's disease · Music therapy · EEG · Intelligent health application · Emotions

1 Introduction

Alzheimer's disease (AD), the most common form of dementia, is rapidly becoming more prevalent as the population ages. By bringing about progressive cognitive impairment and neuropsychiatric symptoms, AD causes discomfort and suffering for both patients and caregivers. As no pharmacological treatment has yet been discovered, research has started to shift towards non-pharmacological interventions. Recent technological advances have made it easier to design non-pharmacological approaches aimed at increasing patient well-being. We believe introducing Virtual Reality (VR) in this new field of study is a promising avenue.

Indeed, VR has proven to be useful in a variety of therapeutic interventions, such as anxiety disorders and phobias [1]. Most VR environments are however unable to

evolve according to the reactions of the patient. An important characteristic of AD is that it is accompanied by negative emotions, which may have an influence on cognitive abilities and memory access [2]. Empirical and anecdotal reports have pointed towards an already-existing non-pharmacological intervention, Music Therapy (MT), as a promising avenue in helping AD patients on a psychological, behavioral and cognitive level [3, 4]. For this reason, we designed a virtual environment which combines the benefits of both VR and MT, potentially giving rise to an accessible and low-cost solution to personalized MT. To adapt the environment to the patient, our design uses a measure of the participant's emotions to make parameters of the environment adapt to the measured emotions. We focus our research on older adults with subjective cognitive decline (SCD), as these individuals progress to dementia at a higher rate than those with no subjective impression of decline and are sometimes in the early stages of the disease [5].

With these design objectives, our research questions are the following: **Q1: is it possible to reduce negative emotions through virtual music therapy?** And **Q2: is it possible to improve memory and cognitive functions through adaptive virtual music therapy?**

The rest of this paper is organized as follows. In Sect. 2, we give an overview of the characteristics of AD. In Sect. 3, we examine how music can provide a therapy for Alzheimer's disease and we present our solution of adaptive virtual reality environment. In Sect. 4, we detail the experimental procedure undertaken to validate our hypotheses. Finally, in Sect. 5 we present and discuss the obtained results.

2   Characteristics of Alzheimer's Disease

Alzheimer's disease (AD) is a neurodegenerative disease whose most notable symptom is the deterioration of both short- and long-term memory. In addition to memory impairment, the disease affects behavior, non-memory cognitive abilities and physical abilities. Much research has revealed that neural damage in specific regions of the brain plays a significant role in the symptoms of AD [6].

As patients progress in the disease, cognitive and functional abilities become significantly impaired, resulting in difficulties in decision-making, daily tasks and communication. Individuals also experience a decrease in general interest and often become apathetic. During the final stages of the disease, patients become practically incapable of communicating, have difficulty eating and display extreme apathy [7].

3   A Music Therapy Virtual Environment with Adaptation for Alzheimer's Disease

3.1   Music Therapy

Music displays great therapeutic potential for many neuropsychiatric conditions and AD is no exception. Indeed, empirical evidence suggests that music therapy (MT) can help improve cognitive, psychological and behavioral impairments induced by the disease [3, 8].

There are already many studies showing the benefits of MT for AD patients [3, 4, 8]. We propose to combine MT with a VR environment and an electroencephalogram device (EEG) able to assess the emotions felt by the participants. By focusing on the underlying neurological mechanisms which give music its therapeutic capability, we designed a new version of MT. As AD patients struggle at an emotional, cognitive, psychological and behavioral level, we target these symptoms directly.

3.2   Adaptive Virtual Reality Music Environment

Our therapeutic environment consists of a music theatre created using Unity 3D software in which the participant is immersed, facing the stage up front. Red curtains open and close as different songs are presented on stage. For each song, an appropriate selection of instruments is presented on stage, each instrument slightly animated with the music. In addition, the stage presents firework-like light visual effects taken from the Unity 3D Asset Store. These are designed to fit each individual song (Fig. 1).

Fig. 1. The virtual MT environment for two different songs.

The choice of music was based on empirical studies and theories of music [9–11]. A series of eight 30 s song excerpts are sequentially presented, accompanied by visual scenes designed with specific color shades and lightings in order to achieve the emotional purpose of the song (relaxation, engagement, etc.) [12].

In order to optimize the emotional and cognitive impact of the virtual experience, the environment was adapted to provide the most beneficial therapeutic experience to each individual participant.

4   Experiments

In order to analyze the impact of the Music Therapy environment on memory and attention performances, we created 6 attention and memory exercises using Unity 3D software.

Our approach was tested on 19 participants (13 females, 6 males) with subjective cognitive decline (SCD) and a mean age = 72.26 (SD = 5.82). The participants took part in two sessions: the first one to ensure eligibility for the study and the second one

for the actual experiment. During the pre-experimental session, participants were invited to sign a consent form and perform clinical tests to confirm diagnosis of SCD and characterize them.

The second session was the experimental session. Participants were first invited to fill questionnaires: the Positive and Negative Affect Schedule (PANAS) scale [13], a self-assessment of emotions, and a questionnaire on cyber-sickness [14]. Once completed, the participants were equipped with an EEG headset and asked to solve attention and memory exercises. Following the cognitive tests, a FOVE VR headset was installed and the VR MT began. This relaxing environment lasted for about 10 min. Following the MT, participants completed again different variants of the same attention and memory tests. Lastly, the participants were asked to once again fill up the PANAS scale, cyber-sickness, as well as AttrakDiff 2 [15].

5   Results and Discussion

The first objective of the research was to discover whether **it is possible to reduce negative emotions through virtual music therapy**. To this end, we started by analyzing the emotions from the participants before, during and after the virtual MT immersion. This   was   done using the   measurement of   frustration   extracted from the Emotiv EEG. Results show that the mean frustration level before the music therapy was 0.69. The mean frustration level during the immersion was 0.45. After the MT, the mean frustration level was 0.51 (Fig. 2).
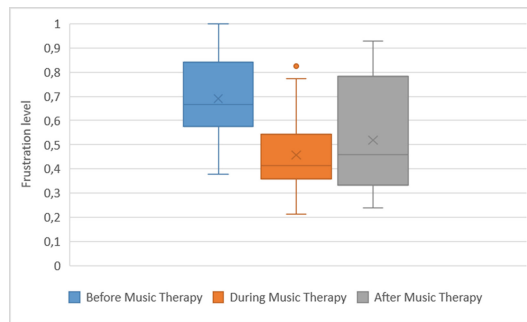

Fig. 2. Boxplot of general mean frustration

Overall, the frustration decreased when the participants were in the MT, and the positive effect on the frustration level was still observed after the MT.

The effect obtained in our first analysis lead to our second research question: **is it possible to improve memory and cognitive functions through adaptive virtual music therapy?** To this end, we analyzed performance improvements on the attention and memory exercises. Results showed small improvements on two of the three attention exercises. On exercise 1, the general mean improvement was 6.59%. On the second exercise, there was a mean improvement of 1.91%. The performance

improvement on the third exercise was 3.51%. For the fourth exercise (first memory exercise), a mean improvement of 6.14% was observed. For the fifth exercise, the mean improvement was 8.95%. Finally, the sixth exercise showed the highest improvement, reaching 36.84% improvement. Finally, we compared improvement in attention exercises with the memory exercises. These results show a large increase in memory performance following the adaptive virtual music therapy and only a small improvement in attention abilities (Fig. 3).
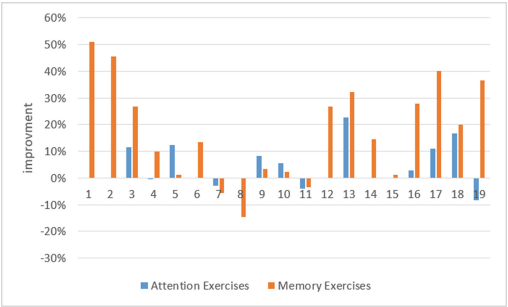

Fig. 3. Histogram of performance improvement attention compared to memory exercises.

Our first analysis confirmed that the virtual MT reduces negative emotions such as frustration. Our second and final analysis showed that reducing negative emotions through MT improved memory performances.

6   Conclusion

In this paper we presented a novel approach which could be used to improve the memory performance of subjective cognitive decline patients using adaptive virtual music therapy. Experiments were conducted during which the participants were first asked to perform attention and memory exercises, then were immersed in the music therapy environment in order to reduce negative emotions before completing a final set of exercises. The environment was built to react dynamically to the patient's emotions and change accordingly. Results showed that the virtual music therapy environment helps reduce negative emotions, most notably frustration. In addition, results showed improved memory performance on selected exercises in most participants. We speculate that the reduction of negative emotions entailed by the adaptive music therapy environment helped improve short-term memory.

References

1. Parsons, T.D., Rizzo, A.A.: Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: a meta-analysis. J. Behav. Ther. Exp. Psychiatry **39**, 250–261 (2008)

2. Cavalera, C., Pepe, A., Zurloni, V., et al.: Negative social emotions and cognition: shame, guilt and working memory impairments. Acta Physiol. **188**, 9–15 (2018)

3. Gallego, M.G., García, J.G.: Music therapy and Alzheimer's disease: cognitive, psychological, and behavioural effects. Neurol. (Engl. Ed.) **32**, 300–308 (2017)

4. Fang, R., Ye, S., Huangfu, J., Calimag, D.P.: Music therapy is a potential intervention for cognition of Alzheimer's disease: a mini-review. Transl. Neurodegener. **6**, 2 (2017). https://doi.org/10.1186/s40035-017-0073-9

5. Jessen, F., Amariglio, R.E., Van Boxtel, M., et al.: A conceptual framework for research on subjective cognitive decline in preclinical Alzheimer's disease. Alzheimer's Dement. **10**, 844–852 (2014)

6. Pini, L., Pievani, M., Bocchetta, M., et al.: Brain atrophy in Alzheimer's disease and aging. Ageing Res. Rev. **30**, 25–48 (2016)

7. Gottesman, R.T., Stern, Y.: Behavioral and psychiatric symptoms of dementia and rate of decline in Alzheimer's Disease. Front. Pharmacol. **10** (2019)

8. Ray, K.D., Mittelman, M.S.: Music therapy: a nonpharmacological approach to the care of agitation and depressive symptoms for nursing home residents with dementia. Dementia **16**, 689–710 (2017)

9. Krumhansl, C.L., Zupnick, J.A.: Cascading reminiscence bumps in popular music. Psychol. Sci. **24**, 2057–2068 (2013)

10. Belfi, A.M., Karlan, B., Tranel, D.: Music evokes vivid autobiographical memories. Memory **24**, 979–989 (2016)

11. de la Torre-Luque, A., Caparros-Gonzalez, R.A., Bastard, T., et al.: Acute stress recovery through listening to Melomics relaxing music: a randomized controlled trial. Nordic J. Music Ther. **26**, 124–141 (2017)

12. Valdez, P., Mehrabian, A.: Effects of color on emotions. J. Exp. Psychol. Gen. **123**, 394 (1994)

13. Watson, D., Clark, L.A., Tellegen, A.: Development and validation of brief measures of positive and negative affect: the PANAS scales. J. Pers. Soc. Psychol. **54**, 1063 (1988)

14. Kennedy, R.S., Lane, N.E., Berbaum, K.S., Lilienthal, M.G.: Simulator sickness questionnaire: an enhanced method for quantifying simulator sickness. Int. J. Aviat. Psychol. **3**, 203–220 (1993)

15. Lallemand, C., Koenig, V., Gronier, G., Martin, R.: Création et validation d'une version française du questionnaire AttrakDiff pour l'évaluation de l'expérience utilisateur des systèmes interactifs. Eur. Rev. Appl. Psychol. **65**, 239–252 (2015)