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Musiquence – Design, Implementation and Validation of a Customizable Music and Reminiscence Cognitive Stimulation Platform for People with Dementia

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Abstract

Dementia is a neurodegenerative disease that affects millions of individuals worldwide and is challenging to diagnose as symptoms may only perceivable decades later. The disease leads to a gradual loss of memory, learning, orientation, language, and comprehension skills, which compromises activities of daily living. Health-related costs caused by dementia will continue to increase over the next few years; between the years 2005 and 2009, an increase of 34% (from $315 to $422 billion worldwide) was observed in treating dementia-related issues. Pharmaceutical approaches have been developed to treat dementia symptoms; unfortunately, the risk of side effects is high. For this reason, non-pharmaceutical methods such as music and reminiscence therapies have gained acceptance as patients with dementia positively respond to such approaches even at later stages of the disease. Nevertheless, further research is needed to understand how music and reminiscence therapy should be used and to quantify their impact on individuals with dementia. The development of serious games has gained attention as an alternative approach to stimulate patients. However, the clinical impact that serious games have on individuals with dementia is still unclear. In this dissertation, we contribute with new knowledge regarding the usage of music and reminiscence approaches in people with dementia through a theoretical model. Based on Baddeley's working memory model, our model aims to explain how the therapeutic properties of music and reminiscence can have a beneficial effect. To test our model, we developed a novel interactive platform called *Musiquence*, in which healthcare professionals can create music and reminiscence based cognitive activities to stimulate people with dementia. In this dissertation, we present the results from several studies about the usage and effects that music and reminiscence have on such a population. We performed two studies using *Musiquence* to study the feasibility of a novel learning method based on musical feedback to aid people with dementia during task performance in virtual reality settings. Results show that participants relied more on music-based feedback during the task performance of virtual reality activities than in other forms of feedback. Also, data suggest that the music-based feedback system can improve task performance, compensating for some dementia-related deficits. We also used *Musiquence* in a longitudinal one-month-long pilot study to assess its efficacy when used for a cognitive stimulation intervention in dementia patients. The results of the study are promising. The 3 participants showed improvements in terms of general cognition, quality of life, mood, and verbal fluency.

Keywords: Music; Reminiscence; Working memory; Serious games; Therapeutic-effect; Game-customization;

Abstrato

A demência é uma doença neurodegenerativa que afeta milhões de indivíduos em todo o mundo e é difícil de diagnosticar, pois os sintomas só podem ser percecionados décadas depois. A doença leva a uma perda gradual de habilidades de memória, aprendizagem, orientação, linguagem e compreensão, que, por sua vez, compromete as atividades da vida quotidiana. Os custos de saúde causados pela demência continuarão a aumentar nos próximos anos. A título exemplificativo, no hiato compreendido entre os anos de 2005 e de 2009 foi registado um aumento de 34% (de US $ 315 para US $ 422 bilhões) nos custos de saúde relacionados com o tratamento desta doença em todo o mundo. Entretanto, foram desenvolvidas diversas abordagens farmacêuticas com vista a mitigar os efeitos da demência. Contudo, o risco de desenvolvimento de efeitos secundários continua elevado. Por esse motivo, os métodos não farmacêuticos, tal como terapia musical e de reminiscência, ganharam crescente aceitação, na medida em que os pacientes com demência têm vindo a respondem positivamente a tais abordagens, mesmo em estágios avançados da doença. No entanto, são necessários mais estudos para entender melhor como a terapia musical e de reminiscência deve ser usada e quantificar seu impacto no tratamento terapêutico de indivíduos com demência. Neste contexto, o desenvolvimento de jogos sérios foi considerado como uma abordagem alternativa para estimular as pessoas com demência. Contudo, o impacto clínico que o jogo sério tem em indivíduos com demência ainda não é claro. Deste modo, com a presente dissertação pretendemos contribuir com conhecimento novo sobre o uso da música e reminiscência em pessoas com demência, usando um modelo teórico que explica como a música e a reminiscência é benéfica para os vários componentes que compõem a memória de trabalho de Baddeley. Para testar o nosso modelo desenvolvemos uma nova plataforma chamada *Musiquence* que permite aos profissionais de saúde criar atividades baseadas na música e na reminiscência para estimular cognitivamente as pessoas com demência. Nesta dissertação apresentamos os resultados de vários estudos sobre os efeitos que a música e a reminiscência têm sobre pessoas com demência. Para o efeito, realizamos dois estudos usando o *Musiquence* para aferir a viabilidade de um novo método de aprendizagem baseado no *feedback* musical para ajudar pessoas com demência durante a execução de tarefas em ambientes de realidade virtual. Os resultados de tais estudos mostram que os participantes reagiram melhor ao *feedback* baseado em música do que em outras formas de *feedback*. Além disso, o referido sistema de *feedback* parece evidenciar a compensação de alguns défices relacionados com a demência. Do mesmo modo, também foi empregue o *Musiquence* para realizar um estudo-piloto longitudinal com a duração de um mês, tendo o mesmo obtido resultados positivos. Com efeito, os participantes do estudo mostraram melhorias em termos de cognição geral, qualidade de vida, humor e fluência verbal.

Palavra-chave: Música; Reminiscência; Memória de trabalho; Jogos sérios; Efeito - terapêutico; Personalização de jogos;

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List of Abbreviations

Virtual Reality – VR

Alzheimer's Disease – AD

Frontotemporal Dementia - FTD

Vascular Dementia - VD

Lewy-Body – LB

People with dementia – PwD

World Health Organization - WHO

Organic Dementia - OD

Non-Organic Dementia - N-OD

Information and Communication Technologies - ICT

Cognitive Stimulation Therapy - CST

Distortion Tune Test - DTT

Mini-Mental State Examination - MMSE

Serious Games - SG

Augmented Reality - AR

Design, Player Experience - DPE

Phonological Store - PS

Articulatory Rehearsal Mechanism - ARM

Research Questions - R.Q.

HTC – VIVE with Controllers - HMD w/ Controllers

HTC -VIVE - HMD

Leap Motion - LM

HTC -VIVE with Leap Motion - HTC w/ LM

Analysis and Tracking System – AnTS

System Usability Scale - SUS

Activities of Daily Living – ADL

Intrinsic Motivation Inventory – IMI

Medians - Mdn

Mean - M

Standard Deviations - SD

Beats Per Minute - BPM

Muisca Distortion - MD

Visual Distortion - VD

Comma Separated Values -.CSV

Casa de Saúde São João de Deus - CSSJD

Centro de Dia da Nazaré - CDN

Casa de Saúde Câmara Pestana - CSCP

Instrumental Activities of Daily Living - IADLs

Basic Activities of Daily Living - BADL

Quality of life - QoL

Rating Anxiety in Dementia - RAID

Alzheimer's Disease Assessment Scale - Cognitive Subscale - ADAS-Cog

Symbol Research - SR

Digit-Symbol Coding - DSC

Weschler Adult Intelligence Scale - WAIS III

Inventário de Avaliação Funcional de Adultos e Idosos – IAFA

Kettler Laurent Thierrau – KLT

Chapter 1 – Introduction

1 Introduction

1.1 Motivation

Dementia is a degenerative neurocognitive disorder that leads to deficits in cognition and consequently affects behavioral and functional domains [1]–[3]. It impairs cognitive abilities such as memory (explicit memory), learning, orientation, language, vision-related problems, anxiety, irritability comprehension, gait and balance related issues, and judgment [1], [2], [4]–[8]. Dementia is an umbrella term that comprises a variety of subtypes according to their etiology.

Some forms of dementia are due to organic causes - organic dementia (OD) - such as Vascular Dementia (VD) [9], Frontotemporal Dementia (FTD) [10], Lewy Body (LB) [11], Alzheimer's disease (AD) [2] and mixed dementia [12], while others result from non-organic causes (also known as non-organic dementia (N-OD)), such as substance use disorders (alcohol abuse) and psychiatric disorders such as schizophrenia) [13].

The N-OD affects the brain differently, giving rise to, and often unpredictable, patterns of cognitive impairment. For example, regarding N-OD, alcohol use disorders have a diffuse and non-specific impact on cognition [14], [15]. Still, Stavro, Pelletier, and Potvin on a meta-analysis found that N-OD pathology could cause significant impairments on eleven cognitive domains: verbal fluency/language, processing speed, working memory, attention, problem-solving/executive functions, inhibition/impulsivity, verbal learning, verbal memory, visual learning, visual memory and visuospatial abilities [14]. Schizophrenia, for example, has a cognitive impairment prevalence of 50% to 80%. However, there is still some disagreement on what cognitive domains are impaired. Still, literature reports that processing speed, executive functions, memory and learning, abstraction, and attention can be affected by this pathology [16], [17].

In contrast, OD tend to have patterns of cognitive impairments that provide an expected cognitive impairment course. For example, in AD, memory deficits are among the earliest signs [18], as opposed to Vascular Dementia, which is mostly characterized by precocious attention and executive deficits [9]. AD is typically detected when individuals are struggling to complete routine activities [1]. The risk factors associated with AD can be due to family history with APOE genotypes [19], vascular-related problems [20], severe head injuries [21], mild cognitive impairment [22], and deposits of Beta-Amyloid and Tau protein [23]. All these risk factors may lead to negative and long-term consequences in patients. These consequences may translate into memory loss, challenges in planning activities, or solving problems, problems in completing chores, confusion with time and space, communication problems, among others [24]. All these occurrences not only disrupt and limit the daily living of people with dementia (PwD) severely but also affect their family members.

According to the World Health Organization (WHO), Alzheimer's disease affected 35.6 million individuals in 2010 [1]. Moreover, WHO predicted that it will possibly double in the next 20 years and that it is challenging to diagnose Alzheimer's disease on time because its symptoms are only perceivable 20 or 30 years after the beginning of the degenerative process. Many caregivers suffer emotionally, physically, and psychologically due to the health conditions of their loved ones [25]. Moreover, the costs of dementia care will inevitably increase throughout the years. A report released in 2010 estimated the worldwide social costs of around $421.6 billion in 2009 [26]. These costs were based, at the time, on a population of 34.4 million individuals with dementia and informal health costs of about $142.3 billion. Portugal alone had expenses ranging between $1652.8 million and $2120.4 million in 2009 [26]. Costs were based on a population of almost 143 thousand demented individuals, a direct cost of $1296.5, and informal care costs between $356.3 million and $823,9 million [26]. In 2017, another report was released in which worldwide social costs reached $818 billion in 2015 [27].

Thus, alternative and cheaper approaches have been taken into consideration to alleviate some of the dementia care burdens. The usage of non-pharmaceutical solutions such as via information and communication technologies (ICT), music, and reminiscence related approaches have gained attention to complement pharmaceutical practices to undertake dementia-related symptoms.

1.2 Research goals

The main research goal of this dissertation is to provide new knowledge regarding the therapeutic impact that music and reminiscence have on PwD in terms of cognition, emotion, quality of life as well as stimulating long term memories and executive functions through interactive virtual reality (VR) technology during therapy sessions. To achieve the therapeutic outcomes mentioned previously, we explored the pros- and cons of a variety of "out-of-the-shelf" technologies. We ended up developing an interactive platform in which healthcare professionals can develop and customize music and reminiscence cognitive activities. The development of the activities is done through a game editor that is integrated into the platform. As activities are being created, health professionals can save these on a serialized file. Afterward, the serialized file can be uploaded and run so that PwD can interact and complete the activities in sequential order.

1.3 Research contributions

In this dissertation, we will present the following contributions:

1. **Theoretical model regarding the impact of music and reminiscence on general cognition.** Baddeley 's working memory is defined as a temporary storage system that manipulates information "*necessary to perform complex cognitive tasks such as comprehension, learning and reasoning.*" Here we will discuss how music and reminiscence will interact with individual components of Baddeley's working memory.

2. **A comparative study of interactive technologies for PwD.** We compared a set of "out-of-the-shelf" technologies and analyzed not only the pros and cons of each technology but also how patients' profiles influenced user experience while using such technologies. We also provided a set of guidelines that can help (1) engineers and developers to craft better-suited technologies for this population and (2) suggest additional setups of the technologies used to improve user experience in PwD.

3. ***Musiquence* - a platform to aid healthcare professionals to develop music and remanence cognitive activities for stimulation purposes in PwD.** Here, we developed and present a multimodal platform that aims to aid healthcare professionals in developing music and reminiscence cognitive activities for PwD during therapy sessions.

4. **A novel learning system through manipulation of musical components to aid PwD during task performance in a virtual reality context**. This learning system is based on the assumption of PwD having intact musical memory and capacity to recognize alterations of musical components such as pitch, rhythm, and a combination of pitch and rhythm.

5. **Design of an intervention providing results of the therapeutic impact of music and reminiscence therapy.** We demonstrate the results regarding the therapeutic impact that music and reminiscence have in PwD.

6. **Positive social impact.** This platform was not developed solely for research purposes. The platform can be used in different environmental settings (i.e., at home or daycare center) to enhance mood and quality-of-life as well as cognition in PwD.

Moreover, we have performed eight studies in which each study is a topic within a chapter of the dissertation. Additionally, five of the eight studies have been published in international conferences, one article is published in a journal (with impact factor 3.53), one article is under review, and two articles are in preparation. The following articles are listed below:

Published papers:

- Luis Ferreira, Sofia Cavaco, and Sergi Bermudez i Badia. 2019. A usability study with healthcare professionals of a customizable framework for reminiscence and music based cognitive activities for people with dementia. In Proceedings of the 23rd Pan-Hellenic Conference on Informatics (PCI '19). Association for Computing Machinery, New York, NY, USA, 16–23. DOI: https://doi.org/10.1145/3368640.3368654

- Ferreira, L. D. A., Cavaco, S., & i Badia, S. B. (2019, June). *Musiquence*: a framework to customize music and reminiscence cognitive stimulation activities for the dementia population. In *2019 5th Experiment International Conference (exp. at'19)* (pp. 359-364). IEEE;

- Ferreira, L. D. A., Cavaco, S., & i Badia, S. B. (2019, June). *Musiquence*: a serious game customization system for dementia. In *2019 5th Experiment International Conference (exp. at'19)* (pp. 247-248). IEEE;

- Ferreira, L., Cavaco, S., & Bermúdez i Badia, S. (2018). Feasibility Study of an Augmented Reality System for People With Dementia. Presented at the International Conference on Artificial Reality and Telexistence& Eurographics Symposioum on Virtual Environments, Cyprus;

- Ferreira, L. D. A., Cameirão, M. S., & i Badia, S. B. (2017, June). Music-based assistive feedback system for the exploration of virtual environments in individuals with dementia. In *2017 International Conference on Virtual Rehabilitation (ICVR)* (pp. 1-7). IEEE;

Published Journals:

- Ferreira, Luis Duarte Andrade, et al. "User Experience of Interactive Technologies for People With Dementia: Comparative Observational Study." JMIR Serious Games 8.3 (2020): e17565;

Under Review:

- Luis Ferreira, Mónica Spínola, Sofia Cavaco, Sergi Bermúdez. Impact of a combined Music and Reminiscence Cognitive Stimulation Program for Dementia: A pilot Study Using *Musiquence* (conference article – submitted at ACM Multimedia 2020);

Articles in preparation:

- Luis Ferreira, Monica Spínola, Joana Câmara, Sofia Cavaco, Sergi i Bermúdez. Pitch, Rhythm, and Pitch-Shift: A Novel Learning Method for People with Dementia Using Musical Feedback (journal article);

- Mónica Spínola, Joana Câmara, Luis Ferreira, Ana Lúcia, Sergi i Bermúdez. Developing a Cognitive Stimulation Program with Persons with Dementia – a Participatory Design Approach (journal article);

1.4 Dissertation outline

This dissertation is divided into seven chapters. Chapter 2 discusses the current state-of-the-art regarding music and reminiscence, dementia, serious games, and Baddeley's working memory model. Chapter 3 presents an extension to Baddeley's working memory model in which we demonstrate how music and reminiscence may have a therapeutic effect on individual components of the working memory. Also, chapter 3 presents our research proposal and research questions, which we are going to answer throughout this dissertation. To support this research, we developed *Musiquence*, a multi-modal platform that aids healthcare professionals to customize music and reminiscence based cognitive activities. In chapter 4, we discuss the development of *Musiquence*; we present several studies that involve both healthcare professionals and PwD as they share valuable information and experiences throughout each step of the platform's developing process. In chapter 5, after developing a functional platform, we present a novel learning system for people with dementia based on musical distortions. This learning system aims to assist PwD during decision making in a virtual reality context. As for chapter 6, we used *Musiquence* and performed a pilot study regarding the therapeutic impact of music and reminiscence related approaches in PwD; we present initial results of a one-month longitudinal study in which we evaluate the impact that music and reminiscence have on PwD Also, it is noteworthy to have into consideration that chapter 4, 5 and 6 present studies which aim to answer our research questions. Finally, in chapter 7, we conclude our dissertation and present ongoing studies with *Musiquence.*

Chapter 2 – State of the art

2. State of the art

In this chapter, we present the current state-of-the-art regarding (1) the usage of music and reminiscence related approaches in a cognitive stimulation context involving PwD, (2) the technologies and serious games available to stimulate people with dementia (PwD) and (3) we talk about Baddeley's working memory and how its deterioration can impact the daily life of PwD.

2.1 Cognitive stimulation with music and reminiscence

As modern medicine evolves, essential advances are made to understand and mitigate the mechanisms responsible for the neural degeneration in Alzheimer's disease. However, the development of new drugs is not only expensive but also time-consuming as it needs to go through several scientific trials before being approved for human use [28]. Also, pharmaceutical approaches often induce undesired side-effects to the patients [29], [30]. Therefore non-pharmacological approaches, such as Cognitive Stimulation Therapy (CST), are accessible interventions as CST is a well-established approach for PwD in mild to moderate stages of dementia [31], [32].

Each CST intervention can last until 14 sessions [31], [33], and is based on two assumptions. The first assumption considers that, even in advanced age, exposure to enriched environments (i.e., cognitively and socially challenging) can enhance cognitive reserve and neuroplasticity [34], [35]. Cognitive reserve is a hypothetical construct defined as the brain's ability to cope with age or neurodegenerative conditions, such as Alzheimer's disease, through the employment of two main mechanisms - neural reserve and neural compensation [36]. Epidemiological evidence suggests that education, occupational attainment, and leisure activities throughout life can impact cognitive reserve [37]. In this sense, individuals with higher educational levels and cognitively demanding occupations and leisure activities tend to have higher cognitive reserve [38]. Neuroplasticity consists of the nervous system's ability to adapt its structural organization when responding to changes in the environment [33].

The second assumption considers that PwD can benefit from cognitive stimulation if we mobilize relatively preserved cognitive functions (e.g., crystallized abilities). Table 2.1 illustrates which cognitive functions can be mobilized to stimulate PwD. Although Table 2.1 frames cognitive functions in a *play experience* context, it can still be used in other situations, such as in a therapeutic context. As we can see, cognitive functions such as "relaxation," "reminiscence," and "sensation" are still perceivable for patients even at more advanced stages; interestingly, these experiences can be obtained through music. Nevertheless, there are cognitive experiences, such as exploration, thrill, sadism, and suffering that should not be used at all as may cause traumatic or uncomfortable experiences [39]. Thus, we will focus our attention on music and reminiscence related approaches to stimulate PwD.

Table 2.1. **The table shows the play experiences that are appropriate to patients with Alzheimer's disease.** Within all experiences presented in the table below, relaxation, reminiscence, and sensation appear to be intact at more advanced stages of the disease. Adapted From - [39]

Play Experiences	Earliest Alzheimer Disease	Mild/Moderate Alzheimer disease	Advanced Alzheimer Disease
Challenge	✓	✓	×
Eroticism	✓	✓	×
Expression	✓	✓	×
Fellowship	✓	✓	×
Humour	✓	✓	×
Nurture	✓	✓	×
Relaxation	✓	✓	✓
Reminiscence	✓	✓	✓
Sensation	✓	✓	✓
Sympathy	✓	✓	×
Subversion	✓	×	×

2.1.1 Music and dementia

Archaeological findings of musical instruments sustain the hypothesis that music has been part of the human experience since the Upper Palaeolithic Era [40], [41]. Since then, it seems that music is something that comes naturally to us. Children, as early as two months, can react positively (or negatively) to such musical exposures [42]. Indeed, music may not only lead to emotional responses [43] but may also induce physical responses (such as chills) [44] and chemical responses (such as Dopamine release) [45].

Also, due to music's high processing demands [46], the brain uses different areas to process the different musical elements such as, for example, melody, harmony, and timbre [42]. Likewise, if an individual plays music, additional brain areas are activated, such as the motor cortex and cerebellum [42] [46]. Given that music appears to activate many brain areas, it seems plausible that it can also be used to induce structural brain changes. For example, scientific literature suggests that toddlers who play music regularly have more developed brain areas - the corpus callosum - compared to non-musicians [47], [48].

In recent years, therapies based on music have been taken into consideration for treatment purposes [49] [46]. Indeed, music-based therapies have been used on a variety of health conditions such as stroke [50], heart disease [51], Parkinson [52], among other conditions [53], [54], [55]. Music has been used as well in individuals with different subtypes of dementia, among which Alzheimer's Disease (AD)(see [56] for review).

Considering that patients with AD appear to have intact musical memory [57], [58], they can benefit from CST by stimulating musical memory. Studies suggest that brain mechanisms that are responsible for musical encoding are spared even at advanced stages of Alzheimer's disease [59]. For example, a fascinating case study has emerged from a former musician who was taught to play a new song with musical instruments after being diagnosed with Alzheimer's disease [60].

As PwD have a robust musical memory, they can also identify changes in music. Studies suggest that PwD can detect pitch distortions in melodies. For example, Cuddy et al. performed a single case study in which a person with advanced Alzheimer's disease had to identify distorted melodies (in terms of pitch) in the Distortion Tune Test (DTT) [58]. The results showed that the participant attained an almost perfect score (26 out of 27). Another study was conducted using DTT on twelve participants with Alzheimer's disease [57]. Results showed that participants' ability to identify pitch distortions in the DTT ranged from 35% to 100%. The ability to identify pitch distortions in melodies relates to grey-matter volume on the right temporal lobe as well as other brain regions such as the inferior and superior temporal gyrus and temporal pole [61].

Additionally, PwD may be able to identify other types of distortion besides pitch. Some studies analyzed the possibility of PwD identifying rhythmic changes melodies. For example, in a study [62], one participant diagnosed with Alzheimer's disease was able to identify rhythmic changes in the Montreal Battery for Evaluation of Amusia. At the same time, another participant (also diagnosed with Alzheimer's disease) was capable of distinguishing rhythmic changes between two sound patterns in the Seashore Rhythm Test [60]. Studies suggest that rhythmic stimuli are processed by cerebellocortical networks in the brain [63], [64]. Hence, musical interventions - such as music therapy - have been gaining consideration as a cheap and stimulating experience while not leading to any undesired side-effects [65].

According to Munro and Mount, "*Music Therapy is the controlled use of Music, its elements and their influences on the human being is to aid in the physiologic, psychologic and emotional integration of the individual during the treatment of an illness or disability*" [66]. It is known to relax patients as it stimulates the release of hormones such as melatonin [67], [68], can stimulate Autobiographical memories [69], [70], language functioning [71], can reduce anxiety/depression-related symptoms [65], [72], [73], and stimulates cognition in general [74]. The latter study suggests that singing or listening to music can provide not only cognitive stimulation (i.e., working memory, executive function, episodic memory) but also emotional wellbeing. Another interesting study from Bruer et al. reported an enhanced Mini-Mental State Examination (MMSE) scores after music therapy intervention with PwD [75].

Indeed, as music is being recognized for its therapeutic benefits, healthcare professionals at the Madeiran delegation of Alzheimer Portugal use music to stimulate PwD. We interviewed healthcare professionals (see supplementary material interview 1), and we were told that group sessions (and individual sessions if necessary) of musical activities were done with PwD once a week for one hour. We were told as well that when preparing musical sessions, healthcare professionals always take into consideration the musical preferences of their target audience. PwD usually like traditional Madeiran songs, classical music, and *fado*, which were played using different mediums such as CD's and the internet (often Youtube). To participate in musical activities, PwD use percussion instruments, sing, and dance (see Figure.2.1).

(A) (B)

Figure 2.1. **Music sessions at the Madeiran delegation of Alzheimer Portugal**. (A) Participants are playing percussion instruments. (B) Healthcare professional dancing with a participant.

During the musical sessions, unusual behaviors have been reported by healthcare professionals. For example, one participant with advanced Alzheimer's disease was able to sing and dance the lyrics of a folkloric Madeiran song called *"The chickens are crazy."* When comparing the participant's singing with the original lyrics, both participant’s singing and original lyrics matched. Moreover, healthcare professionals reported that participants were able to remember past events of their life during therapy sessions. Also, they noticed that the participants felt more relaxed and were in a better mood after the musical sessions.

2.1.2 Reminiscence and dementia

Autobiographical memories are also used in reminiscence therapy by exploiting, for example, physical objects such as photographs or other objects related to the patient's past life [76]. Autobiographical memories are remote memories based on the personal and unique life experiences of an individual [69]. There are different forms of reminiscence interventions available for different purposes, such as Simple Reminiscence, Life-Review, and Life-Review Therapy.

The main goal of *Simple Reminiscence* is to inform/teach others about the positive aspects of life. The stories are presented freely without any restrictions [77], [78]. *Life-Review* interventions´ focus is to help individuals to re-evaluate life events while integrating negative and positive experiences. Such interventions cover the individual's entire life-span and are discussed face-to-face with the person [77], [78]. Lastly, the primary purpose of Life-Review Therapy interventions is to develop a positive attitude about a person's life while reducing the revival of unpleasant events. This latter type of intervention is usually used when a person has psychological disorders such as depression [77], [78]. Positive results have been identified using life-review therapy in individual wellbeing and reduction of depressive symptoms in PwD [79]. Also, there is some evidence that reminisces therapy can improve cognition, life quality, and mood in PwD [80].

2.2 Serious games and dementia

Some novel approaches are being explored in the European funded project ISISEMB – Intelligent system for independent living and self-care of seniors with cognitive problems or mild dementia [81]. This project aims to enhance the quality of life of both carers and PwD by providing "*innovative intelligent custom services*" in private housing through information and communication technology (ICT) such as visual fall detecting systems [82]. On the other hand, the usage of serious games (SG) (or even transformational games [83]) has gained much attention in recent years.

According to Zyda, SG can be defined as "*A mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives*" [84]. Although more studies are required to assess the therapeutic outcomes of serious games [85]–[87], a variety of SG have been developed and used for a variety of medical purposes such as training and simulation [88], diagnosis and therapy [89]–[91], and education [92]. Several games with therapeutical outcomes have been designed for patients with dementia, as well [93]. Such therapeutic games were designed to stimulate not only cognitive and motor capabilities, mood, balance among other related capacities, but also to help relearn competences that might have been lost due to the long term consequences of the disease [7], [94].

Healthcare professionals at the Madeiran delegation of Alzheimer Portugal use technologies such as Nintendo Wii, tablets, and web applications to stimulate PwD. For example, when using the Nintendo Wii, PwD play Wii Sport and perform activities such as boxing, tennis, and bowling. However, we were told that PwD had difficulties in handling Nintendo's Wii controls, especially, participants who had physical and cognitive limitations (see supplementary material interview 1).

Thus, the inability to interact with digital games can lead to frustration and confusion. An interesting observation has been made by healthcare professionals when PwD were playing the tennis game. Some players were confused and did not understand that the Wii controls work as tennis rackets. Health professionals believe that if Wii controllers could be customized to look like real tennis rackets, it would be more intuitive for PwD as these are familiar objects. Also, PwD play "Wii Party," which has activities such as dancing. Here, healthcare professionals noticed more motivation as the interaction appeared to be more intuitive for PwD and ended up having fun playing.

As for the tablet, healthcare professionals used a "piano" app for a participant that likes to "imagine" playing the piano on the table when listening to music. Healthcare professionals noticed that the user was more attentive and focused while performing the task. PwD also used the tablet to watch Youtube videos.

PwD also performed activities using Lumosity, an application consisting of a set of cognitive exercises, such as, for example, numerical reasoning. Healthcare professionals noticed that participants were motivated to solve the problems and suggested that performance was better than paper-based exercises. Although it is vital to monitor the level of frustration of PwD when playing digital activities, healthcare professionals recognize the benefits that digital games can bring to PwD in terms of cognition, motivation, and physical skills.

From a technological point of view, many platform strategies have been taken into consideration to develop dementia-related therapeutic SG applications. Two main types of interaction can be used to play (and control) these games. Indirect interaction technologies require an intermediate device to translate human action into interaction with the virtual environment. For example, technologies such as PCs [94], or conventional entertainment systems like the Nintendo Wii system [95] require an intermediate device such as a keyboard or gamepads with buttons and analog sticks.

On the other hand, using direct interaction technologies, participants do not have an intermediary device to interact with the virtual environment; participants interact directly with the machines with their bodies [96]. Examples of direct technology devices are touchscreen technology [87], [97] (see [98] for review), and gesture recognition systems, for example, Leap Motion, Kinect, and Bracelet Myo [99] and augmented reality (AR) [100]. Recently, AR technologies have gained much attention to address dementia-related issues [101]. Work has been done using AR in a variety of contexts for PwD, such as in a cognitive screening tool [102] or to provide reminiscence related experiences augmented with multimedia content such as photos and videos. For instance, this technology allows the blending of real objects with virtual content on a mobile device when walking near them [100].

On a cognitive level, indirect interaction devices use more cognitive resources as it involves conscious spatial and mental translations to convert real-world movements into virtual actions [96], while direct interaction devices require less cognitive resources as there is no movement translation between the real and virtual world as opposed to indirect interaction devices [96].

A significant advantage that serious games have over traditional methods is that serious games can enhance motivation among PwD [103], which is an essential factor, especially during clinical interventions. If PwD are engaged in game-like tasks, they will focus less on the clinical aspects, which are a source of emotional stress.

However, the success of using SG by patients in general greatly depends on the resulting game experience [104]. Brian Winn developed the design, player, experience (DPE) framework (see Figure 2.2), which depicts the relationship between the designer and player's experience. The framework is quite straightforward: the designer designs the game, which is played by the player according to that player's experience. According to this framework, *Play* is mediated by experience. Thus, player's experience (social, cultural, cognitive, and experimental background) influences, consequently, the design of the game.

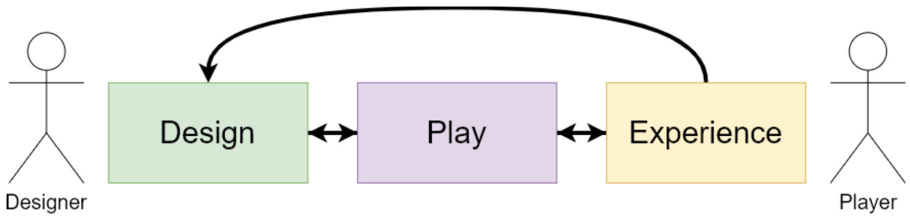

Figure 2.2.**The Design, Play, and Experience Framework.** It illustrates the interaction between game designers and players. Adapted From **[104].**

Therefore, during the prototype playtest phase, it becomes essential to validate, together with health professionals, the efficacy and effectiveness of digital systems explicitly designed for stimulation purposes with PwD (see Figure 2.3). Also, it is vital to involve PwD in the process, especially if they are the end-user. Unfortunately, many PwD are not involved in the design processes [105]; this may be because co-designing with PwD can be challenging as it requires certain levels of sensory, cognitive, and motor abilities that are affected in such population [106]. Nevertheless, PwD are still capable of sharing and expressing their needs to other people [107].

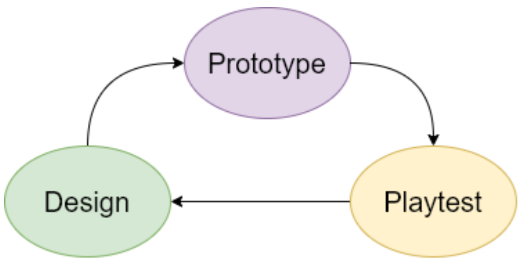

Figure 2.3. **The iterative Design Process illustrates the design process of serious games.** All games should be prototyped and play-tested with end-users, in order to guarantee that the design is central to the users' expected play experience. Adapted From [104].

The DPE framework also considers the learning process in using technological devices to play games as it can also influence the users' game experience. For example, in a recent study, R. Muri *et al.* evaluated the performance of elderly individuals on a set of technologies while performing two different tasks [108]. The study concluded that interaction with technology is dependent on the task, the user's experience, and motivation.

Moreover, the interaction with technology also depends on how intuitive both hardware and software interfaces are for PwD [103]; many high-tech technologies can overwhelm PwD on a cognitive level, which can affect the learning curve of handling technology [103], [109]. As a result, PwD will require more assistance to use technology to perform tasks [97]. One of the main issues of the SG that are currently available for PwD is that they do not follow a patient-centered design in terms of technology and digital content [101]. Also, first-time contact with novel technologies can lead to anxious behaviors [110] or even undesired side-effects such as cybersickness [111].

Another limitation of the usage of SG is the lack of interoperable systems, that is, be able to have the same game running on different technologies [103]; some technologies may be more appropriate than others for PwD. Thus, to enhance the user experience for PwD while using novel technology, additional guidelines have been suggested to help developers in designing technologies while addressing the need for PwD, such as the REAFF framework [112], [113]. The framework focus in four principles: (1) Responding (technologies should respond to the needs of PwD), (2) Enabling (technologies should improve the quality of life of PwD), (3) Augmenting (Technologies should be able to adapt the reserved skills of people with dementia) and (4) Failure Free (Technologies should be as easy to use as possible without discouraging PwD).

Another issue that needs to be considered by developers regarding the development of SG's are the costs. Developments of technology and software solutions are costly [114]. Thus, many healthcare professionals and informal caregivers may be reluctant to use SG, as these may only be useful at certain stages of dementia [115].

As stated earlier, Alzheimer's patients start to lose individual competencies as the disease progresses; their understanding of *play* will change as well. Therefore, the *"play"* experiences of SG should match the experiences that are still understandable for patients throughout the different stages of dementia [39]. Table 2.1 summarizes the different kinds of play experiences that are suitable in each stage of the disease. Although it is vital to match the play experience to the current stage of dementia, the ability to learn new information always depends upon the proper functioning of the working memory system. Thus, it is essential to be aware of the current understanding of the working memory system.

2.3 Working memory, dementia, and music

According to Baddeley, the working memory is a "*limited capacity system allowing the temporary storage and manipulation of information that is necessary to perform complex cognitive tasks such as comprehension, learning and reasoning*" [116]. According to this theory, the working memory consists of four main components [117], [118] (see Figure 2.4):

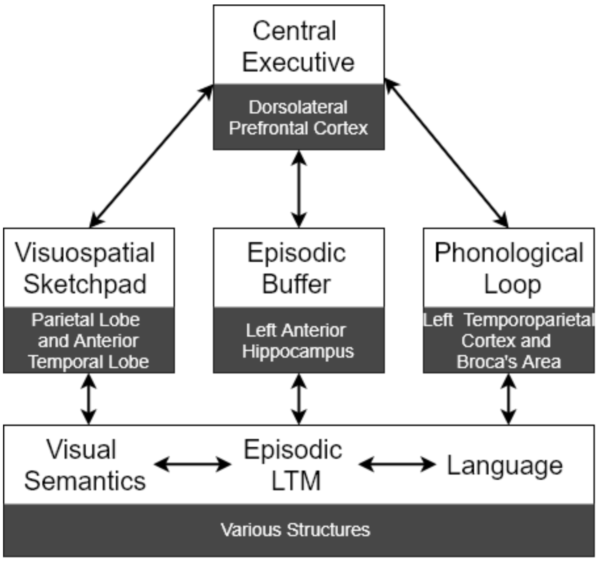

Figure 2.4. **Baddeley's working memory.** The image illustrates the theoretical model of Baddeley's working memory and how different memory systems interact with each other. Adapted From [116].

- Central Executive - Its primary purpose is to control and assign attention resources to other memory systems. It is believed that executive control involves the dorsolateral prefrontal cortex and other brain regions [117].

- Episodic Buffer – A temporary storage system gathers information from other memory systems and organizes them into an episodic representation. The episodic buffer is believed to be located in the left anterior hippocampus [119].

- Phonological Loop – It is a temporary memory that holds verbal and acoustic information. It is composed of the Phonological Store (PS) and the Articulatory Rehearsal Mechanism (ARM) [117] [118]. The PS holds speech input for a short time. However, the information can be maintained longer if it is rehearsed in the ARM. The phonological loop is believed to involve the left temporoparietal regions of the brain, including Broca's area [117].

- Visuospatial Sketchpad - A temporary memory system holds visual and spatial information. The visuospatial sketchpad is believed to be spread in the parietal lobe (for spatial information) and anterior temporal lobe (for visual information) [120].

As the disease progresses, all components of the working memory system start to deteriorate gradually [121]. It is assumed that the impairment in the acquisition of new information is due to a deficiency of the central executive or episodic buffer. It may also be possible that both are limited in Alzheimer patients. Additionally, it is still debated if the impairment of the secondary storage systems (phonological loop and visuospatial sketchpad) is dependent on the impairment of the central executive [121].

Interestingly, some studies suggest that dopamine release may modulate working memory functionality and learning capacities [122]. Experiments with transgenic mice of Alzheimer's disease suggest that the administration of dopamine enhances object recognition, which is a competence that patients struggle daily [123]. Human studies have shown that the administration of experimental dopamine-related drugs had some positive effects on cognitive performance (see review [124]). However, dopamine-related drugs may not be the only way to increase dopamine production in the human brain. Interestingly, music can also stimulate the production of dopamine [45]. To this end, we aim to explore how music and reminiscence can be used for therapeutic purposes. In the next chapter, we propose a theoretical model that explains how music and reminiscence interact with individual components of the working memory.

Chapter 3 - Research questions

In this chapter, we present our proposed model regarding the influence of music and reminiscence related approaches in Baddeley's working memory. This proposal is the foundation for our goal and research questions.

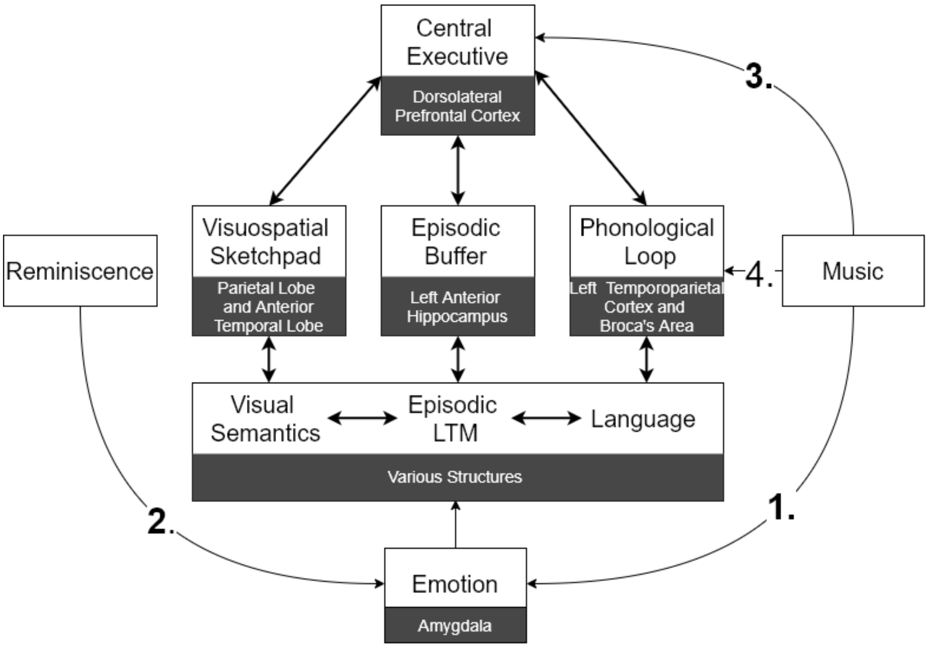

Figure 3.5. **Model depicting the working memory and music interactions**. (1.) Music and (2.) reminiscence target emotional circuits that allow the stimulation of autobiographical memories (long-term memories), may stimulate (3.) executive functions (central executive), and (4.) communication (phonological loop).

As discussed in the previous chapter, music has a positive impact on patients with dementia and may promote wellbeing as they still respond to music even at more advanced stages. Here we propose an extended model based on Baddeley's working memory model that aims to capture the relationship between musical stimuli and working memory. The connections illustrated in Figure 3.5 are explained below:

1. Music and Emotion - Preserved musical memory in patients with dementia is not unusual (see subsection 2.1.1). Moreover, the emotional aspects of music are mediated subcortically by the Amygdala [125], brain centers that are spared in the initial phases of Alzheimer's. As a result, we hypothesize that music can contribute to triggering autobiographical memories (Bottom-Up stimulation). In other words, we aim to stimulate alternative neural pathways to target lower-level structures (Emotion) to access long-term memory.

2. Reminiscence and Emotion – Similar to music, *bottom-up* stimulation can be achieved using reminiscence related approaches based on physical objects as it can arouse emotional responses in patients by generating Autobiographical memories[80].

3. Music and the Central Executive - Listening to music or singing can have a high impact on a variety of cognitive functionalities, including working memory and executive functions by stimulating the central executive [74]. We deduce that music can stimulate the reward system (dopamine) and enhance general working memory functionality, which is essential to perform everyday tasks such as learning, reasoning, and comprehension. [116].

4. Music and the Phonological Loop - Evidence shows that music can have the potential to enhance communication skills in individuals with dementia [71], [69], [70]. Thus, it may be possible that such an enhancement can be transferred daily.

In this dissertation, we hope to contribute with new knowledge in the use of music and reminiscence-based virtual reality games in health. We aim to contribute to improving patients' wellbeing by helping them to rediscover lost memories and enhance general cognition. We do this by researching the use of music and reminiscence with interactive technologies and virtual reality in therapy activities. To this end, we developed a platform that targets cognitive and emotional components based on the proposed theoretical model (Figure 3.5).

The customization of digital content is very relevant according to individual preferences in both music and reminiscence as we expect that such content will have additional influence on the patients' cognitive, emotional health, and quality of life (Figure 3.6). Hence, the musical stimuli must be associated with positive events in the patient's life as we do not intend to stimulate negative emotions.

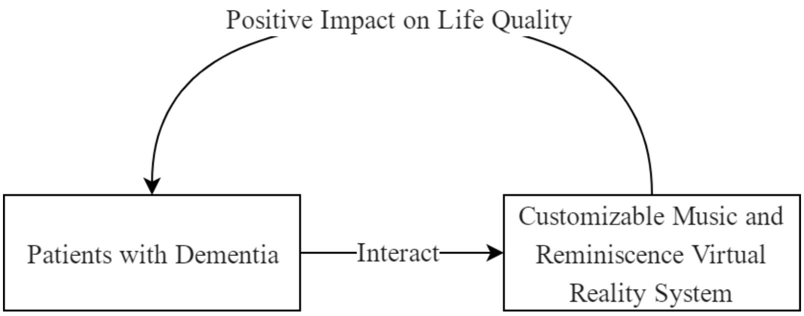

Figure 3.6. We aim to improve the quality of life of PwD by customization of music and reminiscence through a therapeutic virtual reality system.

As we proceed with this dissertation, we will answer three research questions (R.Q) and sub-questions. Patient recruitment and clinical evaluation were performed by health professionals at several places in Portugal such as the (1) Madeira Alzheimer's Association, (2) Casa de Saúde São João de Deus, (3) Centro Câmara Pestana, (4) Centro de Dia da Nazaré and (5) Centro Paroquial da Ribeira Brava, which all support this dissertation. The R.Qs. are described below.

RQ.1) How to develop a therapeutic game using technology and the benefits of music and reminiscence?

We designed music and reminiscent platform, exploiting the possible contributions of music and reminiscence on working memory based on our extension of Baddeley's Working Memory Model (Figure 3.5). To do so, we answered the following sub-questions:

1. *RQ.1.1) Which "out-of-the-shelf" technologies are more suitable for PwD?*

To answer RQ 1.1*,* we invited PwD to interact with a variety of technologies while completing a set of VR tasks to evaluate which technology is more suitable for such a population.

2. *RQ.1.2) Which interaction modalities are more intuitive for PwD?*

Here, PwD were asked to perform a variety of virtual reality tasks through different interaction modalities such as upper limb and full-body interactions, as well as through usage of physical objects. We evaluated PwD performance to assess what kind of interaction is more suitable for them.

RQ.2) Is it possible to develop a learning method through musical distortions?

We aim to create a feedback system based on musical distortion. The goal of this feedback system is to assist patients in their decision-making process while interacting with virtual reality tasks.

3. *RQ.2.1) Is Music-Based Assistive Feedback System better than Visual-Based Assistive Feedback?*

To test our hypothesis on whether PwD reacted to music – based distortion, we analyzed their performance by comparing it to an analogous feedback system based on visual distortions.

4. *RQ.2.2) Is it possible to improve performance using different musical distortions and interactions?*

Here, we further tested our hypothesis in developing a music-based assistive feedback system by introducing different distortions such as pitch, rhythm, and pitch-rhythm as well as different user inputs based on touch and distance.

RQ. 3) What is the impact on cognitive function when using our therapeutic game?

We run clinical studies together with our collaborators (Madeira delegation of the Alzheimer's Association, Casa Saúde São João de Deus, Centro Saúde Casa Pestana, Centro Dia da Nazaré and Centro Social e Paroquial de São Bento). We monitored the evolution of the participants during the experimental trials by using clinical instruments designed to assess not only cognitive, behavioral and functionality domains but also the quality of life

Chapter 4 - Developing a therapeutic game exploiting the benefits of music and reminiscence

Chapter 4 discusses and answers R.Q 1 - *How to develop a therapeutic game using technology and the benefits of music and reminiscence?* To answer this research question, we run three studies that involved the participation of health professionals and people with dementia (PwD). The goal of the first study was to evaluate the user experience of a variety of "out-of-the-shelf" technologies while performing a variety of virtual reality tasks (see section 4.1). The goal of the second study was to develop a set of AR activities and evaluate how PwD performed during task completion using different user inputs such as full-body, upper limb, and usage of real objects. Moreover, we share the opinion and concerns of health professionals regarding the usage of such technology for stimulation purposes of PwD (see section 4.2). After evaluating the data collected from the two previous studies, we developed the first functional version of the platform – *Musiquence* (see section 4.3). After developing *Musiquence*, we performed a third study that aimed to evaluate the usability and user experience of the platform. The latter study involved ten healthcare professionals from different fields (see section 4.4).

4.1 Which "out-of-the-shelf" technologies are more suitable for PwD? [1]

As Alzheimer patients lose competences throughout the stages of the disease, choosing the right task and technology for the therapeutic activities becomes a requirement that needs to be analyzed carefully. Despite the existence of several efforts at providing software recommendations to develop serious games (SG) [126]–[128], there is still a lack of usability studies that aim to understand PwD interact and accept different types of technology to perform specific tasks [105], [129]. Although elderly individuals are capable of learning and handling new technologies [130], using novel technology can lead to anxious behaviors among elderly populations [110] or lead to undesired side effects such as cybersickness [111] and fatigue [103] (see subsection 2.2).

In order to avoid such behaviors, during the prototype playtest phase, it is essential to record the feedback of each player while interacting with the game as the experience of one player may differ significantly from the experience from another player [104]. In a recent study, E. Hackner et al. analyzed how PwD perform different interaction techniques in a tablet such as a single tap, swipe, and drag-and-drop gestures [131]; the study identified several interaction issues when performing such interaction techniques and presented different solutions to avoid future problems.

Considering the reported potential of SGs as a complementary approach to stimulate PwD, the main goal of this study is to understand better how PwD accept and interact with "out-off-the-shelf" technologies, and how it influences user's game experience while performing different activities. Moreover, the study aims to find the most suitable technology to design a customizable interactive system that can exploit reminiscence and music therapy in PwD. We recruited 12 participants with

[1] This study is published at JMIR Serious Games - Ferreira, Luis Duarte Andrade, et al. "User Experience of Interactive Technologies for People With Dementia: Comparative Observational Study." JMIR Serious Games 8.3 (2020): e17565.

dementia to perform several activities with different technologies to evaluate their performance while addressing the following aspects:

- Is there a relationship between patient profile and user experience?
- Is there a relationship between user experience and direct and indirect interaction?
- Do any technologies elicit more positive or negative emotional responses?
- Overall, which technology is better suited for each task?
- Which technology is the most cost-effective?
- Which technology is less exposed to external hazards?

Following the results of our experiment, propose a set of guidelines that can help (1) engineers and developers to craft better-suited technologies for this population and (2) suggest additional set-ups of the technologies used to improve user experience in PwD.

4.1.1 Methods

Technologies used during the experiment

For each of the following technologies, we selected generic tasks that required different types of interaction, such as (1) manipulating virtual objects, (2) playing musical instruments, (3) moving virtual objects from A to B, and (4) observation of virtual environments.

To run the tasks and technologies, we used a Toshiba Satellite L850-1HZ with Windows 10 -64 Bits equipped with an AMD Radeon HD 7670 and an Intel Core i7-3630QM with 4 GB RAM. Taking into consideration that some technologies require a considerable amount of processing power, a desktop computer running Windows 10 – 64 Bits equipped with a Radeon RX 580 Series graphic card and an Intel Core 17-6700 CPU with 16 GB RAM were used. Five different interaction technologies were used in different combinations and tasks.

Indirect interaction configuration

- HTC – VIVE with controllers (HMD w/ Controllers): The HTC VIVE technology (HTC, New Taipei City, Taiwan) is a set of different technologies that includes a head-mounted display and two handheld controllers, which are equipped with a trackpad, menu button, system button, trigger button, and a grip button. Two base stations are used to track the position and movements of the participant's head and hands (Figure 4.7-A).

- Mouse: We used a standard USB powered laser Mouse (Logitech LS1 Laser Mouse, Logitech International, Switzerland). The Mouse is designed with three buttons - left, right, and a wheel button (Figure 4.7-B).

Direct interaction configurations

- HTC -VIVE (HMD): The HTC VIVE allows the usage of the Head Mounted Display (HMD) without the controllers to interact with virtual environments (Figure 4.7-A).

- Tablet: We used a Samsung 9" Android Tablet (GALAXY, Samsung, South Korea) that allows interaction inputs such as tapping and dragging (Figure 4.7-C).

- Leap Motion (LM): LM (Motion Control, San Francisco, USA) is an infrared camera-based tracking technology that allows interacting with the virtual environment with hands, fingers, and tools [55] (Figure 4.7-D).

- HTC -VIVE with LM (HTC w/ LM): We added the LM to the HTC-VIVE head-mounted display. Thus, participants can interact with the virtual environment through head movements but also with their hands (Figure 4.7-D).

- Augmented Reality (AR): For AR, we developed a projection-based set-up that requires a projector (LG Inc, South Korea) and a PSEye camera (Sony Computer Entertainment Inc, Tokyo, Japan), which were attached on a tripod. A physical object with a marker attached to it was used by the participants to interact with the virtual environment. For marker recognition, the Analysis and Tracking System (AnTS)[2] software was used, which allowed the tracking of the physical object. (Figure 4.7-F).

(A) (B) (C)

[2] Bermúdez i Badia, S. (2004-2014). AnTS (Version 2.x) [software]. Retrieved from https://neurorehabilitation.m-iti.org/tools/).

(D) (E) (F)

Figure 4.7. **Technologies used during the experimental trial.** (A) HMD with Controllers, (B) Mouse, (C) Tablet, (D) Leap Motion, (E) HMD with Leap Motion, (F) Augmented Reality.

Manipulating virtual objects

In this task, participants are required to manipulate virtual objects. For each task, we used different technologies such as LM, HMD w/ Controllers, and HMD w/ LM. The goal of each task is described below.

Leap motion. The playground was developed using the Unity 3D game engine (Unity Technologies, San Francisco) and consisted of a variety of geometrical figures (Figure 4.8). In this task, participants were required to use hand gestures such as grabbing, throwing, lifting, among others, to interact with the geometrical figures. As participants could interact and throw geometrical figures out of their field-of-view, the virtual playground could be reset by tapping the computer's space bar. The task did not have any music playing in the background, nor did it provide any additional feedback to the participant.

(A) (B)

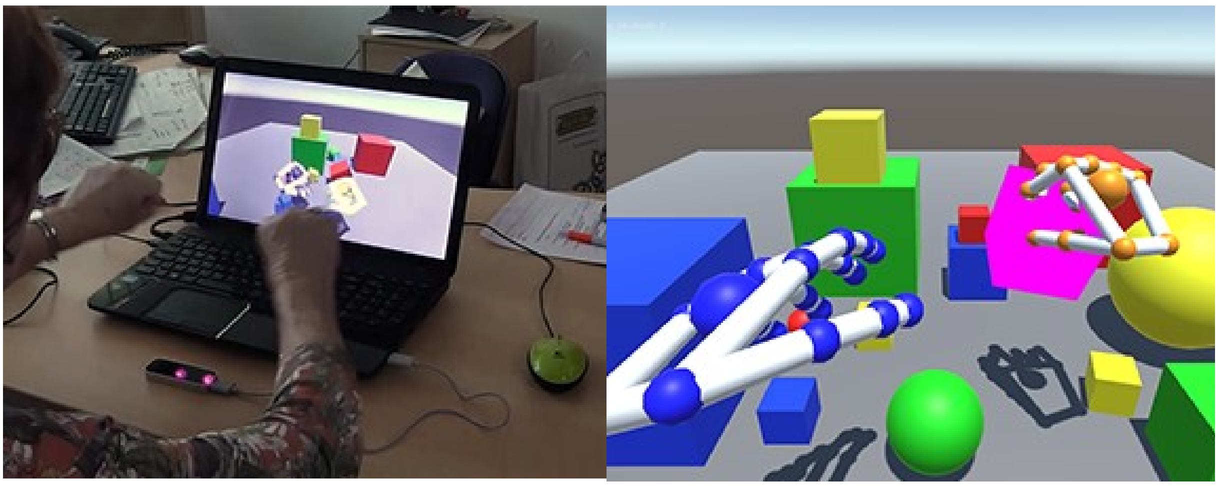

Figure 4.8. **Virtual Playground**. (A) Manipulating virtual objects tasks with hands through LM. (B) Print screen of the game. Participants had to interact freely with virtual objects.

Head-Mounted Display with controls. The goal of the task was to manipulate objects that were placed on a table in a virtual Music Bar with the HMD w/ Controllers (Figure 4.9- A). We used a game called "Jam Session" [132], which can be accessed for free on STEAM. We used several objects such as cups, a doll, a telephone, a clock, a globe, and a book (Figure 4.9 - B). All objects were placed randomly on the table. To perform the task, participants had (1) to use the controls with both hands, (2) grab objects by pressing the trigger button on the back of the controller, and (3) rotate, throw or place the object wherever they wanted. The task did not have any music playing in the background, nor did it provide any additional feedback to the participant.

(A) (B)

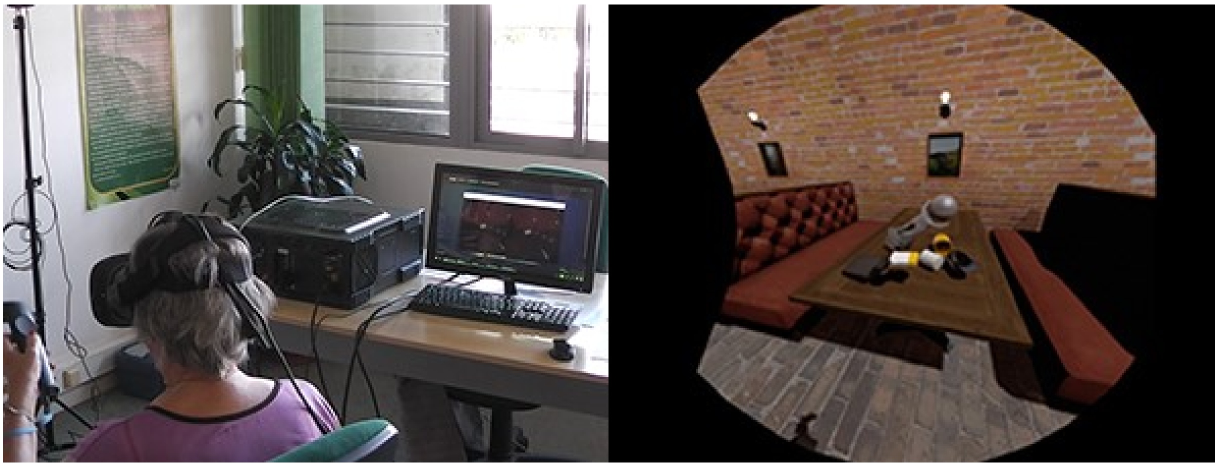

Figure 4.9. **Steam VR home** – bar table. (A) Manipulating daily objects using HMD w/ Controllers. (B) Print screen of the task. Participants had to look at and manipulate daily objects that are on the table.

Head-Mounted Display with leap motion. For this task, participants had to interact with virtual cubes using both hands while standing. (Figure 4.10- A). The game is a free demo included with the LM device [133]. The software allows the creation of different kinds of geometrical figures, such as cubes and octagons. Before the beginning of the task, we prepared the scenario by adding multiple geometrical figures in the virtual environment (Figure 4.10 - B). The goal of the task was to interact with the geometrical figures by making hand gestures such as grabbing, throwing, or pushing, among other gestures. Participants could interact with either right or left hand. Participants were positioned in the middle of the room and could move freely around the room. For security reasons, one researcher was always nearby to aid participants whenever needed. No sounds or music was played during the task, nor did it provide any additional feedback to the participant.

(A) (B)

Figure 4.10. **Blocks.** (A) Manipulating geometrical figures using hands and HMD w/ LM while standing. (B) Print screen of the game. A set of geometric figures that participants manipulate

Playing musical instruments

In this task, participants are required to play musical instruments. For each task, we used different technologies, such as LM and HMD w/ Controllers. The goal of each task is described below.

Leap Motion (LM). The goal of the task was to interact with piano keyboards using hand movements (Figure 4.11– A, B). The game was a free software included in the LM device [134]. To perform the task, participants had to position their hands above the LM and interact using their fingers. There was no new music playing in the background.

(A) (B)

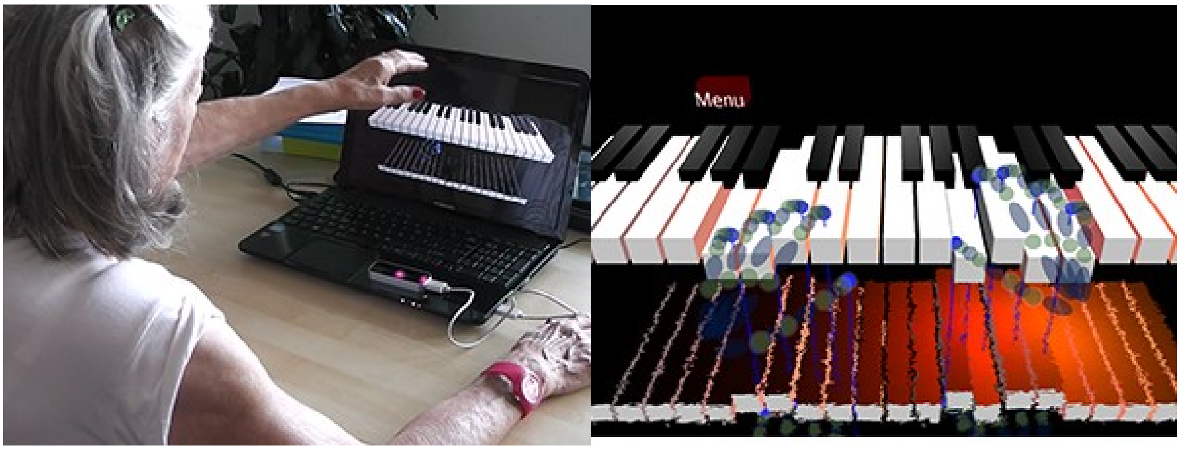

Figure 4.11. **Virtual piano for beginners.** (A) playing the piano using hands and LM. (B) Print screen of the game. The virtual piano being played with virtual hands.

Head-Mounted Display with controls (HMD w\ Controllers). We used a virtual environment with a virtual xylophone as, from an interaction perspective, it is very similar to the piano task (Figure 4.12 - A). We used the free demo "Jam Session" [132] as it has a variety of instruments, including the xylophone. The goal of the task was to interact with the xylophone while using the HMD headset and handheld controls. To initiate the task, the participant had to (1) grab the controls with both hands and (2) hit the wooden notes by doing up and down movements with the arms. When interacting with the instrument, dancing avatars would appear in front of the user (Figure 4.12 - B). Headphones were used for participants to listen to the sounds while playing the instrument. There was no new music playing in the background.

(A) (B)

Figure 4.12. **Steam VR home - Playing musical instruments**. (A) playing the xylophone using HMD w/ Controllers. (B) Print screen of the game. Wooden xylophone with wooden sticks and dancing avatars.

Moving virtual objects from A to B

In this task, participants are required to move virtual objects from one position to another (from A to B). For each task, we used different technologies, such as AR, Mouse, and Tablet. The goal of each task is described below.

Mouse. The goal of the task consisted of pairing - without any order restriction - a set of three randomly placed red squares with three randomly grey squares using a computer mouse device (Figure 4.13-A). The game was custom developed using the Unity 3D game engine. To complete the task, the participant had (1) to select a red square by pressing the left mouse button (the square becomes green after selection) and (2) select an available grey square by pressing gain the left mouse button. The right and wheel buttons were deactivated. Audio feedback was provided with "Very Good!" whenever the participant paired all squares.

Different shades of grey and a black border were used to facilitate distinguishing squares in case of overlapping positions (Figure 4.13 - B). If necessary, the researcher could rearrange the square's positions by tapping the computer's space bar.

(A) (B)

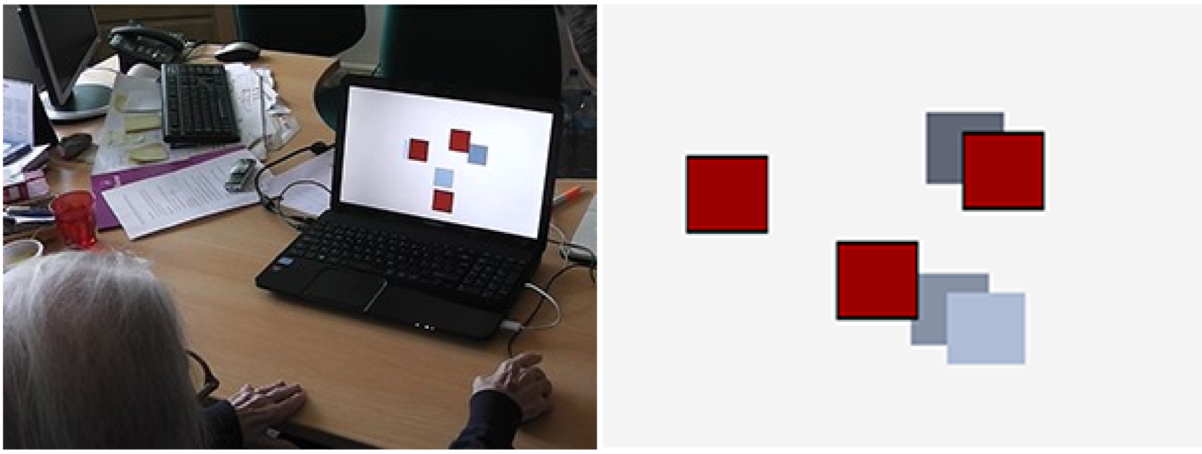

Figure 4.13. **Connecting Squares**. (A) Participants are trying to match red squares to grey squares. (B) Print screen of the game. A set of randomly distributed squares.

Tablet. In contrast to the previous task using the Mouse, the goal of this task was to capture a set of randomly placed red spheres (Figure 4.14 - A). The game was developed using Unity 3D. To complete the task, participants had to (1) drag a grey container to a red sphere, (2) wait four seconds to attach the sphere to the container, and (3) drag the container with the sphere attached to it to a black rotating target (Figure 4.14 - B). A countdown sound would provide feedback during the 4-second countdown. After that, the red sphere would become green. Additionally, the participant was rewarded with audio feedback - "Very Good"- when all spheres were captured.

(A) (B)

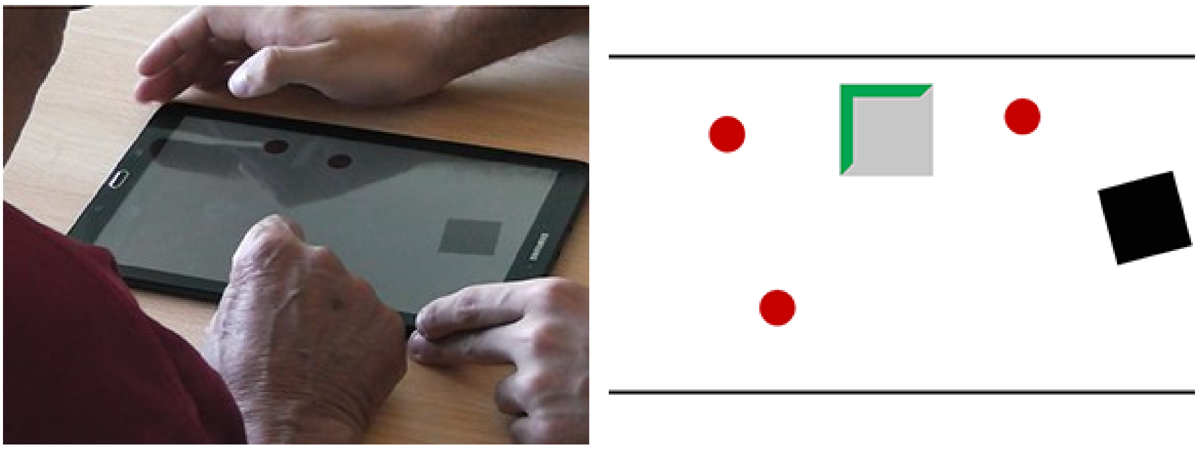

Figure 4.14. **Dragging spheres with a Tablet**(A) Participants are collecting red spheres using a grey container and dragging these with the finger to a black rotating square. (B) Print screen of the game. A set of randomly distributed red spheres, a grey container with the activated timer (in green), and a black rotating target

Augmented reality (AR). For this technology, we used the same task as developed for the Tablet. However, in this case, participants had to drag a physical object with a grey virtual container attached to it to collect the red spheres and bring them to the black rotating target (Figure 4.15 - A, B).

(A) (B)

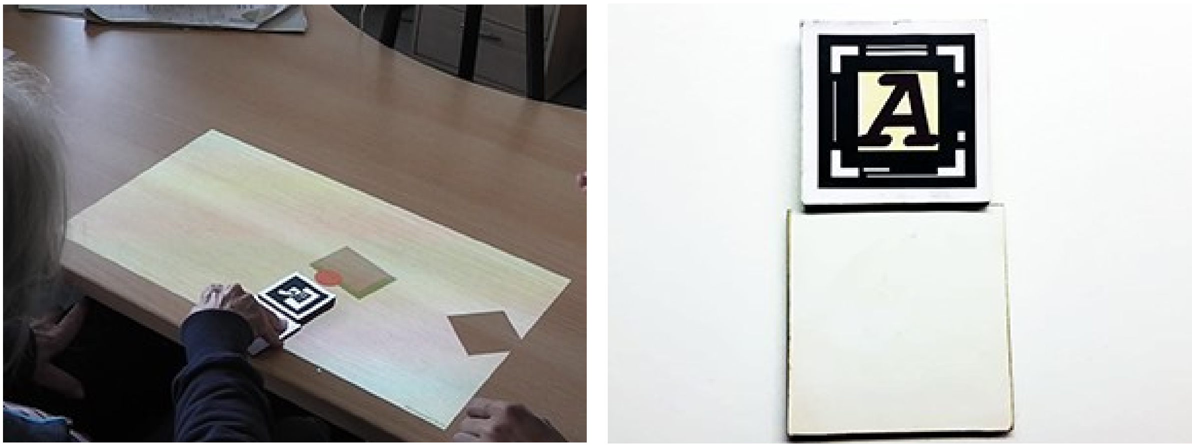

Figure 4.15. **Dragging spheres with AR.** (A) Participants are collecting red spheres using a physical object. (B) Physical objects that participants use to interact with the spheres.

Observation

In this task, participants are required to observe virtual reality-based scenarios. For each task, we used the HMD. The goal of each task is described below.

Head-mounted display (HMD). In this case, participants were seated on a chair while wearing the HMD device. We invited participants to explore virtual worlds by moving their heads freely. We used two different tasks to evaluate participants' performance.

- *Static scenario - Exploring the forest.* In this task, we used a virtual forest that was developed in the Unity game engine (Figure 4.16-A). It has virtual elements such as trees, grass, and clouds (among other elements) as well as audible elements such as birds, insects, and wind (Figure 4.16-B). The windy sound effect, combined with the animation of virtual elements, offered dynamism to the scenario by providing the illusion that the virtual elements were moving due to the wind. The goal of this task was to report and describe as many elements as possible.

(A) (B)

Figure 4.16. **Observing virtual environments: Virtual Forrest.** (A) Participants observe a virtual forest using the HMD. (B) Screenshot of the game displaying a virtual forest with trees, grass, and sound.

- *Dynamic scenario - Exploring Ghost Ship.* This task is a short virtual video of a pirate ship navigating in the Caribbean Sea. The video scenario has "natural" elements such as rocks, small buildings, and highly detailed pirate ships (Figure 4.17-B). The game can be accessed for free on STEAM [135]. When the video begins, a virtual camera automatically moves on a predefined path while rotating on its axis to show places of interest to the viewer. Generic music background plays in the background accompanying participants' journey. Participants are free to move their head to explore the virtual environment. The goal of the task is to describe and report as many virtual elements as possible to the researchers.

(A) (B)

Figure 4.17. **Observing virtual environments: Ghost Ship.** (A) Participants observe an interactive video using the HMD. (B) Screenshot of the Ghost ship sailing in the Caribbean Sea.

4.1.2 Procedure

A within-subject experimental design was used to allow all participants to interact with all technologies and tasks. Each week, different technologies and tasks were randomly introduced. Participants were required to complete tasks such as manipulating virtual objects, moving virtual objects from A to B, observation of virtual scenarios, and playing musical instruments. Participants were seated in a quiet room and accompanied by two researchers and a health professional when needed.

During the experiment, patients sat in front of a table in a silent room of the Madeiran delegation of the Portuguese Alzheimer's Association (except when performing the task requiring the HMD w/ LM, which in this case were standing up). Two researchers were present in the room; one researcher was responsible for filming and taking notes of the participants' performance, while the other researcher interacted with the participants during the experimental trial. The video recordings allowed us to analyze participants' behaviors and study their verbal responses throughout the experiment. The camera was placed behind the shoulders of the participants to conceal their faces and protect their identity. In the case of participants in more intermediate stages of dementia, a health professional was also present to guarantee their wellbeing and aid researchers during the intervention.

During the experiment, the following protocol was used. (1) Before initiating the task, researchers instructed participants on how to use a specific technology to complete a task. (2) Each task had a maximum duration of 15 minutes, and participants could repeat tasks if desired. (3) During the task, participants were encouraged to think aloud and could ask for help at any time. All interventions by the researchers were annotated for later analysis

4.1.3 Instruments

To address our RQs, we relied on direct observations, and behavioral and verbal responses extracted from the video recordings. To analyze the video recordings, we used Adobe Premiere CC 2017.1.2 release version for coding. This video editing tool allows us to tag, comment, and export annotations in .CSV (Comma Separated Files) files. The video analysis went through 2 phases. In the first phase, two researchers performed independent video analyses by tagging and annotating events in the video files. In the second phase, the information gathered by both researchers was compared and checked for consistency. In case of disagreement, a third researcher was invited to disambiguate.

To analyze participants' user experience with a given technology or in each task, we counted the number of issues identified. The issues were grouped into (1) assistance provided by researchers, (2) perception issues, (3) comprehension issues, (4) interaction issues, and (5) discomfort that participants felt. These are described in detail below:

- Assistance Provided - We counted the number of times participants required assistance from the researchers. We also considered the assistance provided by therapists if they were present during the experimental session.

- Comprehension Issues – We counted all issues identified regarding the participant's general understanding of how to perform the tasks.

- Perception Issues – We considered (1) visual perception issues whenever participants had difficulties in visualizing and correctly identifying game elements during user experience and (2) sensory issues whenever participants had difficulties in hearing and identifying sounds correctly. For (3) tactile issues, we counted the number of times that participants complained of not feeling any physical feedback of the technology during the user experience (i.e., lack of vibration and not finding the correct button) and number of times participants were expected to interact with the virtual environment in the same way as in a real-life scenario (i.e., expecting to be able to physically touch and feel a virtual object when interacting with it).

- Interaction Issues – We considered issues such as (1) controlling the interface (i.e., clicking incorrect buttons to fulfill a task), (2) controlling the software (i.e., triggering wrong software functionalities) and when (3) the participants physically misused the interface (i.e., grabbing the leap motion).

- Discomfort – We counted the number of times participants felt distressed (i.e., fatigue, cybersickness, balance issues).

Additionally, we studied emotional responses (positive and negative). That is, we countered the number of positive emotions (i.e., laughter) and negative emotions (i.e., frustration). We also counted the number of software issues (i.e., undesirable features or "bugs") that occurred during the experiment. For RQ.5, we excluded the software issues as these are explicitly related to actual software and not to the technology *per se.*

Finally, we calculated the number of times that the equipment was exposed to external hazards – equipment at risk. For example, we counted the number of times the equipment was at risk of falling to the ground during user experience.

4.1.4 Participants

We recruited 12 participants (mean age 75,08 ± 8,07 - three male, nine female). This was a convenience sample, and the recruitment of the participants was performed by psychologists at the

Madeiran delegation of the Portuguese Alzheimer's Association (Table 4.2). Participants were eligible if they: (1) could use upper limbs independently, (2) had an intact hearing, and (3) were in the initial or intermediate stages of dementia. For the last inclusion criteria, we relied on the clinical information available and did not perform any further assessments. The study was approved by the board of the association and followed standard procedures for research with human participants. Before the beginning of the experimental trial, all participants (or legal guardians) signed an informed consent, and permission was granted to film the sessions. After signing the consent form, participants were briefed about (1) the activity objectives, and (2) how to handle the technologies. Also, participants were informed that they could drop out of the experimental trial at any time.

We defined patients' profiles based on their Mini-Mental State Examination (MMSE) [136] scores, age, and years of schooling. The MMSE scores were assessed before the participation of the experimental trial. Only 5 of the participants reported previous experience with technology. For example, participant 1 had experience using a Tablet, while participants 11 and 12 had experience with PC. Participants 5 and 7 had experience in handling both PC and Tablet.

Table 4.2. **Participants' Demographics**

Participant	Gender	Age	MMSE	Schooling	Diagnostic
1	Female	70	25	4th year	Alzheimer's disease
2	Female	85	19	4th year	Alzheimer's disease
3	Female	78	18	3rd year	Vascular dementia
4	Male	81	17	- [a]	Alzheimer's disease
5	Male	67	24	5th year	Frontotemporal dementia
6	Female	74	12	3rd year	Alzheimer's disease
7	Female	71	14	4th year	Alzheimer's disease
8	Male	82	21	4th year	Lewy Body dementia
9	Female	65	11	6th year	Alzheimer's disease
10	Female	88	10	12th year	Alzheimer's disease & Parkinson disease
11	Female	77	26	4th year	Alzheimer's disease
12	Female	63	11	12th year	Frontotemporal dementia
Mean ± SD	-	75,08 ± 8,07	17,33 ± 5,79	5,55 ± 3,30	-

[a] Participant 4 does not have any formal schooling

4.1.5 Results

Data were analyzed using the Statistical Package for the Social Sciences 24 (SPSS.24). For each dependent variable, the normality of the distribution was assessed with the one-sample Kolmogorov-

Smirnov test. Because most distributions deviated from normality, non-parametric statistical tests were used for the analysis. Descriptive results are presented as medians and interquartile ranges (Mdn ± IQR). For assessing the impact of experimental conditions, the Friedman test was used. For posthoc pairwise comparisons, the Wilcoxon signed ranks test was used. The significance level was established at an α of 0.05. Bonferroni correction was used to account for multiple comparisons. We used Bonferroni as well when analyzing which combinations of technologies and tasks minimized feasibility performance (RQ.4), and when analyzing which technology was exposed less to external hazards. For non-parametric correlations, we used Spearman's rank correlation coefficient.

Of the 12 participants, not all completed all tasks. Participants 1, 2, 3, 7, 11, and 12 completed all ten experimental conditions. Participants 9 and 10 withdraw from the experiment, and participants 4, 5, 6, and 8 were not able to complete all tasks. Consequently, only nine datasets were considered for the playground activity with LM; 10 datasets were considered for condition LM (piano activity), Tablet, and PC. For AR and Observation (exploring forest), 11 datasets were considered, while seven were considered for condition Observation (exploring ghost ship), playing musical instruments, and manipulating virtual objects with both HTC w/ Controllers and HTC w/ LM respectively. Also, some video recordings were corrupted, which did not allow us to computerize the number of issues; instead, we relied on the written notes taken during the experimental trial.

Is there a relationship between the patient's profile and task performance?

We studied the relationship between patients' profiles when considering each performance domain and each technology separately (Supplementary Material, Table 1). We found a positive correlation between patients' MMSE and perception related issues when using LM (r_s = .652, n = 10, p = 0.041). We also found a significant and negative correlation between participants MMSE and the number of assistances provided (r_s = -.744, n = 11, p = 0.009) when using AR technology. Also, participants' years of schooling correlated negatively (r_s = -.615, n = 11, p= 0.044) with perception issues in the AR set-up. Concerning the Tablet, we found a significant negative correlation of the MMSE with both comprehension (r_s = -.726, n = 10, p = 0.017) and interaction issues (r_s = -.642, n = 10, p= 0.045). Lastly, for the HMD w/ LM, we identified a negative correlation of the MMSE scores with the number of assistances provided (r_s = -.802, n = 7, p= 0.03). Figure 4.18 shows the correlation plots for some of the stronger associations. However, the significances mentioned previously do not endure if adjusted for multiple testing using Bonferroni correction

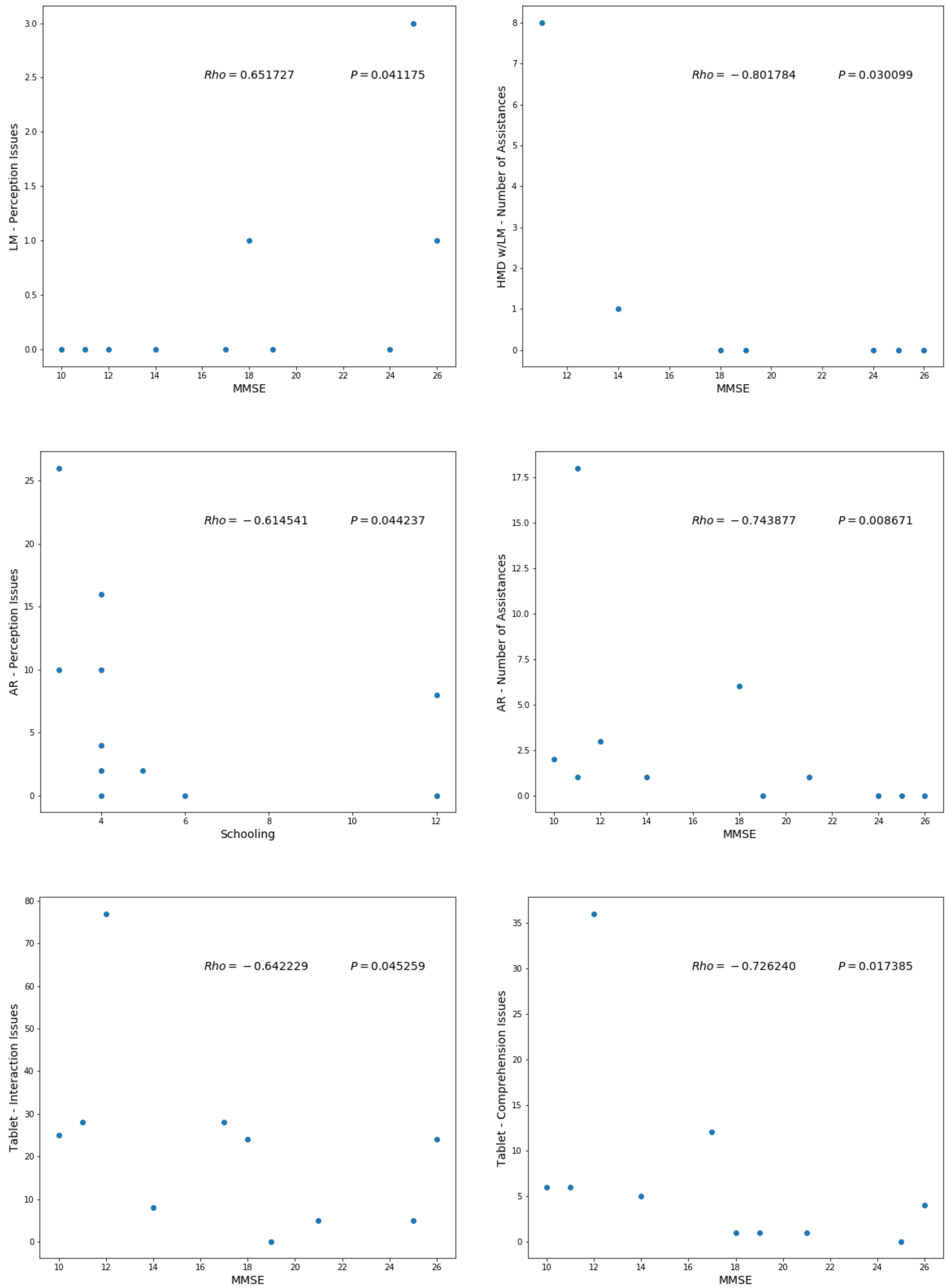

Figure 4.18. **Scatter plots correlation.** Scatter plots of patients' profile variables and the number of issues identified among different technologies.

Finally, to understand the relationship between patient profile and performance, we ran a Spearman correlation analysis considering patients' profile – MMSE, age, schooling - and the total number of issues identified (during user experience) – assistance provided, comprehension issues, interaction issues, perception issues, and discomfort. This analysis did not identify statistically significant correlations of user experience and patient profile (Supplementary Material, Table 2).

To identify if there are any specific tasks or technologies where cognitive profile may play a role, we repeated the analysis on each task (playing musical instruments, manipulating virtual objects, moving objects from A to B, Observation), and each type of technology (LM, HMD, AR, Tablet, PC, HMD w/ Controllers, and HMD w/ LM). Again, we did not find any significant correlations for either task type or technology (Supplementary Material, Tables 3 and 4).

When considering performance scores by the individual performance domains (that is assistance provided, emotion, discomfort as well as comprehension, interaction, and perception issues), we also found no direct association with the patient's cognitive profile (Supplementary Material, Table 5).

Is there a relationship between user experience and direct and indirect interaction?

We examined whether there is a difference in participants' user experience while using direct (LM, AR, Tablet, HMD w/ LM, HMD) or indirect interaction technologies (HMD w/ Controllers, Mouse). In general, participants required less assistance and were able to understand better how to use direct interaction technologies. More concretely, participants required significantly more assistance using indirect interaction devices (Mdn = 3.00 ± 12.00) than using direct interaction devices (Mdn = 1.70 ± 7.00), $Z = -2.666$, $p=0.008$, $r = -0.6$. Moreover, participants had significantly more comprehension issues with indirect interaction (Mdn =4.00 ± 5.50) than with the direct one (Mdn = 2.00 ± 2.77), $Z = -2.601$, $r = -0.6$, $p=0.009$. No statistically differences were found in interaction issues (Mdn = 8.50), perception issues (Mdn = 1.50) and discomfort (Mdn = 0.40).

Does any technology elicit more positive of negative emotional responses?

We evaluated participants' overall emotional responses while using each technology. For this analysis, we considered the number of positive minus the number of negative emotional reactions identified in the video analysis. There were no statistical differences between emotional responses and technologies used ($\chi2(6) = 7.07$, $p= 0.31$).

Which technology is better suited for each task?

We analyzed which combinations of technologies and tasks minimized the identified performance and maximized positive emotional reactions. When tasks were grouped by the technology used, participants' comprehension ($\chi2(6) = 23.14$, $p = 0.001$), interaction ($\chi2(6) = 19.60$, $p = 0.003$) and discomfort ($\chi2(6) = 22.99$, $p = 0.001$) were significantly impacted by technology, but not number of assistance (Mdn = 2.00) and perception issues (Mdn = 1.00). A posthoc analysis did not reveal any significant pairwise differences. Table 4.3. shows the ranking of technology in terms of issues.

Table 4.3. **Ranking of technologies according to performance domains**

Rank	Comprehension issues	Interaction issues	Discomfort
1st	HMD (0.00 ± 0.00)	HMD (0.00 ± 0.00)	Mouse (0.00 ±0.00) AR (0.00 ± 0.00)
2nd	HMD w/ LM (0.00 ± 1.00)	AR (2.00 ± 7.00)	-[a]
3rd	HMD w/ Controllers (1.00 ± 5.00)	HMD w/ LM (4.00 ± 6.00)	Tablet (0.00 ± 0.50)
4th	LM (1.50 ± 2.50)	HMD w/ Controllers (6.00 ± 11.00)	HMD (0.00 ± 1.00)
5th	AR (2.00 ± 3.00)	Mouse (8.50 ± 14.50)	HMD w/ Controllers (0.00 ± 4.00)
6th	Tablet (4.50 ± 6.50)	LM (9.50 ± 8.25)	LM (1.00 ± 3.25)
7th	Mouse (5.00 ± 5.25)	Tablet (24.00 ± 23.00)	HMD w/ LM (1.00 ± 5.00)

[a] Following a standard competition ranking, there is no device ranking second.

Playing musical instruments

For this task, we used LM and HMD w/Controllers, and participants played two virtual musical instruments – a piano and a xylophone. Participants showed more perception issues while using the HMD w/ Controllers (Mdn = 1.00 ± 9.00) than when using LM (Mdn = 0.00 ± 0.00), Z = -2.226, r =-0.6, p= 0.03. No other differences between technologies were found.

Manipulating virtual objects

For this task, participants used the LM, HMD w/ LM, and HMD w/ Controllers to manipulate a variety of virtual objects. Participants performance differed significantly regarding software issues ($\chi^2(2) = 6.320$, p = 0.042) and equipment at risk ($\chi^2(2) = 6.500$, p =0.039). We did not find differences regarding assistance (Mdn = 1.00), emotional responses (Mdn = -1.00), comprehension (Mdn = 0.00), perception (Mdn = 0.00) and interaction (Mdn = 5.00) issues, as well as discomfort (Mdn = 1.00). Posthoc analysis revealed no significant pairwise differences among conditions. Table 4.4 shows a ranking of technologies in the domains in which significant differences were identified. Overall, the combination of HMD w/ Controllers shows a more stable performance in this task

Table 4.4. **Ranking of participants performance to manipulate objects**

Rank	Software issues	Equipment at risk
1st	HMD w/ Controllers (0.00 ± 0.00)	LM (0.00 ± 0.00)
		HMD w/ Controllers (0.00 ± 0.00)
2nd	HMD w/ LM (1.00 ± 3.00)	-[a]
3rd	LM (1.00 ± 5.00)	HMD w/ LM (1.00 ± 1.00)

[a] Following a standard competition ranking, there is no device ranking second.

Moving objects from A to B

For this task, participants used Tablet, AR, and Mouse devices to move objects from A to B. We found a significant effect of technology in software issues ($\chi2(2) = 13.000$, $p = 0.002$), but not in assistance (Mdn = 2.00), emotional responses (Mdn = 1.00), comprehension (Mdn = 4.00), interaction (Mdn = 8.00) and perception issues (Mdn = 2.00) and discomfort (Mdn = 0.00). The technology that raised more software issues was AR (2.00 ± 3.00), followed by Tablet (0.50 ± 1.25) and Mouse (0.00 ± 0.00). However, no significant pairwise differences were found among them.

Observation

In this task, we studied the impact of two modalities, static vs. moving content on HMD. Participants explored two different environments – a virtual forest and an interactive video. No differences were identified between the two modalities. Table 4.5 summarizes the findings, reporting the most appropriate technologies by task – Manipulating virtual objects, Moving virtual objects from A to B, Playing Musical instruments, and Observation.

Table 4.5. **Suitable technologies for each task.** Colour intensity represents the total number of issues (the lower the intensity, the lower the number of errors) and × - represents technologies that have not been used to perform that given task.

Task	Mouse	Tablet	LM	HMD	HMD w/ LM	AR	HMD w/ Controllers
Manipulating virtual objects	×	×		×		×	
Playing musical instruments	×	×		×	×	×	

Moving virtual objects from A to B			×	×	×		×
Observation static	×	×	×		×	×	×
Observation interactive video	×	×	×		×	×	×

Which technology is the most cost-effective?

One critical factor that may limit the adoption of interactive technologies in this area is their cost. Hence, it is essential to perform a cost-effectiveness analysis to inform therapists and caregivers on the implications of their technological choices in terms of costs and outcomes. In this study, the most expensive technologies were HMD w/ LM (€578.99 [US $661.76]) and AR (€523.54 [US $598.38]), whereas the cheapest ones were the mouse (€16.99 [US $19.42]), LM (€79.99 [US $91.42]), and Tablet (€79.99 [US $91.42]). HMD (€499.00 [US $570.33]), and HMD w/ controllers (€499.00 [US $570.33]) technology presented a moderate cost. Regarding the (accumulated) identified issues during the study, HMD (46) and HMD w/ LM (51) had the least issues, while Tablet presented the most performance issues (433). Technologies such as Mouse (209), HMD w/ Controllers (158), LM (166), and AR (193) presented intermediate performance issues. A cost-effectiveness analysis aims to find the right balance that minimizes both cost and number of issues (Figure 4.19).

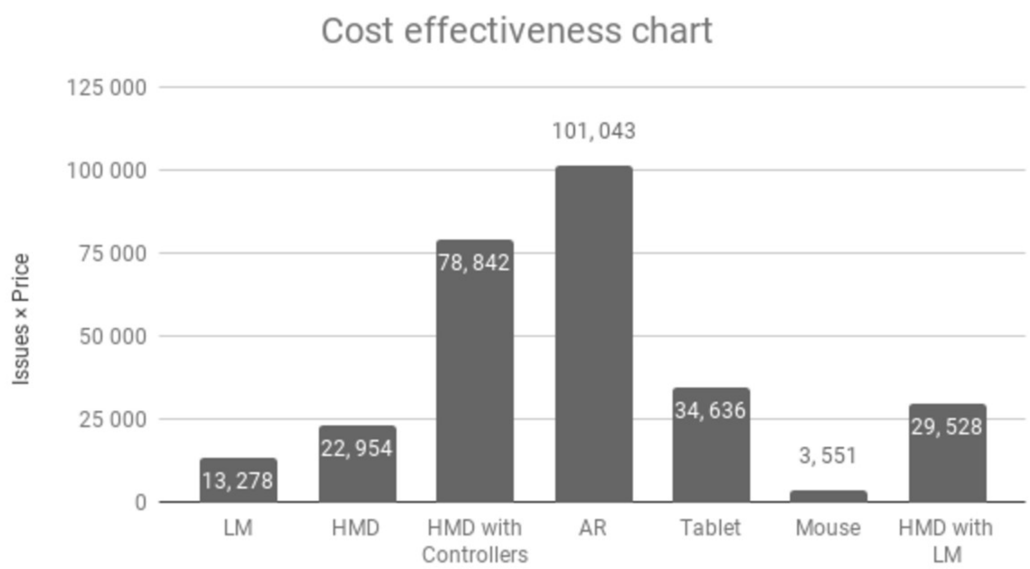

Figure 4.19. **Relationship between performance issues that emerged while performing tasks with different technologies and purchase costs of technology**. The price (euros) was that of the equipment when it was purchased.

We multiplied the number of issues with the purchase price of each technology to calculate the cost efficiency of each technology. The results are presented as the absolute value between identified issues and costs. As we can see in Figure 4.19, the most cost-efficient technology is Mouse device, while the technology that is least cost-efficient is AR

Which technology is less exposed to external hazards?

With all the technologies used in this study, we analyzed how they were exposed to risks that could damage the equipment. We found a statistical effect, but very modest, of the type of technology ($\chi2(6) = 15.882$, $p = 0.014$). The technology that led to higher risk situations was the HMD w/ LM (1.00 ± 1.00). However, posthoc pairwise comparisons revealed no significant differences among technologies.

4.1.6 Discussion

Comprehension. The technology that ranked best in comprehension was the HMD, whereas technologies that scored worse were Mouse and Tablet, respectively. This is probably due to the simplicity of the interaction with HMD – participants do only need to move their heads to interact with the virtual environments. However, when using the Mouse, participants showed great difficulties in understanding how to use it. Most of the difficulties were related to the mapping of the Mouse, and sometimes participants lost sight of the Mouse cursor. Participants also had difficulties in interacting with the buttons, being many times distracted by the Mouse wheel, as it is the most salient button of the device. Participants tended to rotate and click it instead of using the actual Mouse buttons. Some participants tried to rotate the Mouse wheel forward and backward to move the Mouse cursor up and down on the screen. Such behaviors even occurred in participants that had previous professional experience with it. For example, participant 12 had previous and professional experience using the Mouse yet was unsuccessful. As a result, the participant cried, and the experiment had to be stopped. Thus, it becomes crucial to develop intuitive interfaces in order not to overwhelm participants in understanding how to use technology to complete virtual tasks [103] (see section 2.2).

Interaction. In terms of interaction, the HMD was again ranked the highest. Participants presented issues with the Tablet's interface, mostly due to the multi-touch control. When using multi-touch control, participants would tend to rest their hands on the tablet surface and trigger undesired functions that would prevent them from achieving their goal. Once more, an intuitive software interface is vital to enhance performance in PwD [103] (see section 2.2). As our Tablet was not fixed on the table, it also moved around as participants interacted with it. A better set-up would have the Tablet fixed on a surface such as in [131]. Despite these issues, overall, participants were able to perform the task gracefully.

Discomfort. Concerning discomfort, participants complained the most when using the LM and HMD w/ LM. For example, Participants 1, 2, 10, and 11 reported fatigue while using LM. Indeed, to interact with the LM, participants' arms need to be moving in the air, leading to muscle fatigue. In the case of the HMD w/ LM, only participants 5 did not report any discomfort. The remaining participants reported fatigue, cybersickness, and balance difficulties. Although the HMD alone did not trigger major issues, participants 6 and 3 felt nauseated, and participant 12 reported cybersickness after the virtual video task. Participant 6 complained about the heat generated by the headset. In general, cybersickness and fatigue are some of the negative aspects identified in the scientific literature regarding the usage of technology, while balance related issues are associated with the negative consequences of dementia [7], [103], [111] (see section 2.2).

Effect of patient profile. We found that the participants' profile does influence the usage of technology. We found a negative and significant correlation between MMSE and the number of assistances provided with AR and HMD w/ LM. In the case of AR technology, we found a significant effect on the level of schooling and the number of perception issues that arouse in the experiment. We also saw that a low level of schooling and the lack of experience with novel technology could lead to confusion (or even anxiety) [110]. For example, participant 3 was confused when instructed to move the red spheres that were projected on the table: "*How can I catch the spheres if they are fixed on a table?*". Concerning the usage of the Tablet, we found a significant correlation between MMSE and both comprehension and interaction issues. This is likely to be due to the multi-touch feature. Some participants failed to understand that by placing the whole hand on the screen of the Tablet, multi-touch is triggered. Other issues identified, such as (1) activating the menu buttons of the Tablet involuntarily, (2) dragging the Tablet involuntarily while interacting with the virtual objects, (3) forgetting to wait the selection time and (4) forgetting the task rules. Finally, we found a positive and significant correlation between MMSE and the number of perception issues while using LM. We observed that participants with high MMSE scores were able to interact with technology easily and for longer, which allowed researchers to identify perception issues during user experience, in contrast to participants with lower MMSE scores who struggled to begin a given task. Similar results were found in the study [109] (see section 2.2), which found that individuals with higher cognitive deficits had more difficulties in using smart house technology than individuals with lower cognitive deficits. Also, performance may depend on other variables, such as motivation and experience [137] (see section 2.2).

Direct vs. indirect interaction. Participants required more assistance statistically and had more difficulties in understanding how to use indirect interaction devices. These require more cognitive resources [96] (see section 2.2) and, in a population with cognitive deficits, may hinder performance during the completion of the tasks [109] (see section 2.2). Conversely, direct interaction devices require less cognitive resources and, consistent with our observations, participants had fewer complications in using such technologies as they are more intuitive and straightforward to interact with virtual content. Some participants, such as participant 1 and participant 11, were able to use both direct and indirect interaction technologies with minor problems. However, it is important to take into consideration that these participants have higher MMSE scores, and that participant 11 had experience in using Mouse technology.

*Emotional responses***.** Participants, in general, did not show many emotional responses when using the studied technologies. However, some interesting reactions were observed. For example, participant 1 was very happy when she was able to grab a cube while using the HMD w/ LM and said, "*oh good ... what a funny thing ... it is so beautiful* ". The same participant showed pride while playing the xylophone with the HMD w/ Controllers and said that it was a shame that the people in the room could not hear her playing as it was a beautiful song. Participant 11 enjoyed exploring virtual environments with the HMD. She repeatedly said "*very beautiful*" in both the Exploring the forest and Exploring ghost ship.

Playing Musical Instruments. Here, participants used the LM and HMD w/ Controllers to play virtual instruments and showed more perception issues while using the HMD w/ Controllers than LM. Most of the issues identified were visual, auditory, and tactile related. For example, participant 12 complained that she did not hear the xylophones (yet, she confirmed during the experience that she heard the sounds). The same participant reported as well that she was not able to see anything for several times. Also, participant 3 complained that she was not able to see or reach the musical instruments (despite being within the participant's arms range).

Manipulating virtual objects. In this task, participants used the LM, HMD w/ LM, and HMD w/ Controllers to manipulate virtual objects. We found differences regarding software issues and equipment at risk. In general, the best technology is HMD w/ Controllers. Although there were no statistically significant perception issues, participant 12 raised most visual related problems as she had difficulties in identifying the virtual objects in the virtual environments, including the digital representation of her hand. Participant 3 complained because she was expecting to "physically" grab the virtual objects. Regarding software issues, the HMD w/ Controllers scored first place as it did present minor issues.

In contrast, LM technology scored the worst (last place). As participants tried to grab virtual objects, sometimes the objects stayed attached involuntarily on participants' hands and struggled to let go of the objects. Similar behaviors were recorded while participants performed the task while using the HMD w/ LM. Participants were able to "grab" virtual objects but had more difficulties dropping them. Finally, concerning equipment at-risk situations, the HMD w/ LM triggered the more dangerous situations for the equipment. For example, as participants were performing abrupt movements with the head, the HMD was sometimes at risk of falling.

Move objects from A to B. We only found a statistical difference regarding software issues, being AR, and Tablet the ones that score the worst. AR technology had some camera tracking issues due to environmental issues such as shadows and reflections. In contrast, most of the issues related to the Tablet were due to software bugs. Despite these minor issues, all technologies performed at an acceptable level.

Observation. In this task, we did not find any statistical differences. The only issues identified related to cybersickness in both observation tasks [111] (see section 2.2).

4.1.7 Design recommendations

In this study, we observed that technology had different outcomes in terms of acceptance and performance on PwD. Although technologies have been accepted by the majority, some participants had difficulties in managing them to fulfill the tasks. Such differences in the results are greatly due to patients' profiles, which in turn influences technology configuration (direct interaction vs. indirect interaction).

Comprehensibly, most of the technologies used were not aligned with the REAFF framework, as these were not explicitly designed for taking into consideration the needs of PwD [112]. Most of the used technologies did not follow, for example, the Augmenting or Failure free principles, as participants did not complete the tasks independently. Also, it is essential to consider how to align such technologies to the remaining principles of the REAFF framework for the needs of PwD (Responding), and how technology can improve their everyday life (Enabling) (see section 2.2).

Although the technologies used are not perfectly aligned with the REAFF framework principles, they are accessible and can be used in their favor if set-up correctly. By studying the use of the different technologies and tasks by PwD, we can provide a set of recommendations for the selection and implementation of different technological solutions when working with this population. Table 4.6 addresses the main problems encountered and provides recommendations to overcome them. These recommendations can help engineers in the design of technologies for PwD and draw attention to health professionals and informal caregivers regarding potential issues that can emerge while using such technologies with this population.

Table 4.6. **Identification of problems and proposed recommendations when using technology to perform virtual tasks by PwD.**

Technology	Identified problems	Solution
Leap Motion	Grabbing/moving technology needlessly	Design a set-up where the LM is fixed and not graspable (i.e., 3D printed container or embedded onto the tabletop surface)
	Confusing virtual objects (spheres) with	Use identifiable virtual objects and representations of the hand with higher realism

	the joints of the virtual hand	
Tablet	Moving the whole Tablet involuntarily	Secure the Tablet on a table or fixed structure such that patients do not need to hold it, interact with its touch screen
	Triggering undesired touch inputs	Deactivate multi-touch and disable system buttons
Augmented Reality	Interaction with physical elements	Ergonomic design with affordances consistent with the task at hand can enhance performance.
	Tracking problems	The most common tracking problems are related to (1) shadows, (2) markers out of the camera's field of view, or (3) projection of virtual elements on markers. Solutions include using a room without direct sunlight and controlled light conditions; using lower contrast virtual elements will diminish interference of projecting on markers; use a set-up with clearly defined interaction boundaries.
Mouse	Buttons not salient	Select a computer mouse that visually clearly identifies where those buttons are. A large colored sticker or paint on a button can also be used to improve its saliency.
	Too many buttons	Most modern computer mice consist of 3 buttons and a scroll wheel. Choose a one-button mouse (i.e., Apple mouse). Disabling o mapping all mouse buttons to the same functionality will minimize the impact of choosing the wrong button.
	Mouse cursor (and other elements) too small	Increase the size of the mouse cursor and other virtual elements will enhance performance
Head-Mounted Display with Controls	Too many buttons in handheld controls	Users only see a virtual representation of the controls in the HMD. Minimum button input should be considered while the remaining buttons are disabled or mapped to the same function.
	Hitting controls against each other	Usage of only one control to interact with the virtual content when possible. Alternatively, replacing the controllers with an LM.

Head-Mounted Display with Leap Motion	Lack of haptic feedback	Complement with alternative channels to convey haptic feedback (i.e., auditory or visual)
	Cyberbersichness and balance issues	PwD need to be assessed for balance, and seating set-ups should be considered. Safety harnesses or other safety measures should be considered when standing.
Head-Mounted Display	Discomfort due to the device's heat	Use in a properly ventilated room. In case of discomfort, divide the session into multiple shorter intervals.
	Cybersickness	Virtual environments should use be designed to minimize optic flow, and incongruency between physical and virtual motion should be minimized. It can be achieved by reducing forward motion and rotations, as well as using simpler environments with fewer visual elements.

4.2 Which interaction modalities are more intuitive for PwD? [3]

In order to understand which interaction modalities are more intuitive for PwD while performing a set of AR activities, we run an experiment that used the first version of the music and reminiscence-based platform. Section 4.3 describes the platform's first version more thoroughly. We quantified performance by observing how this population completed the AR activities using different human-computer interaction techniques, such as the upper limb, full-body, as well as through the usage of real objects. Despite the issues identified in section 4.1, AR can support other human-computer interaction inputs besides the use of real objects.

Also, this study added new information to the scientific literature as it provides a more in-depth understanding regarding the feasibility, efficacy, and usability in using advanced technologies with PwD [103], [105], [129]. We also invited healthcare professionals to evaluate the system's usefulness for stimulation purposes with PwD [103]. This experiment addresses the following aspects:

- How autonomous are PwD while using the proposed system?
- How engaging is the system?
- How proficient are PwD in doing the proposed activities using errorful and errorless approaches?
- How useful is the proposed system as perceived by therapists?

4.2.1 Methods

As mentioned above, this study uses a set of activities with AR features that were created using the Unity 3D Game Engine. We use an LG PW800 projector (Life's Good, Seul) to display the activities on a table, a Dell S330w projector (Dell inc., Texas) to display activities on the floor, and a PSEye webcam. While our AR system contains several different activities, all activities have some common characteristics. They all use virtual content projected on a table surface or the floor, as well as markers and a tracking system to enable the interaction of physical objects with the virtual content.

Markers are the interactive elements that participants can interact with using their limbs or with physical objects (Figure 4.20 shows a marker under the user's hand). In order to track the markers, the Analysis and Tracking System (AnTS) was used. AnTS is a visual tracking software that can track several markers simultaneously through a webcam. Interaction can happen through the tracking of a physical object tagged with a marker or through virtual markers. In the latter case, as opposed to more

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[3] This study is published at Ferreira, L., Cavaco, S., & Bermúdez i Badia, S. (2018). Feasibility Study of an Augmented Reality System for People With Dementia. Presented at the International Conference on Artificial Reality and Telexistence & Eurographics Symposioum on Virtual Environments, Cyprus;

traditional tracking approaches, markers are not physical and attached to the limbs or interactive objects but were digitally projected on the table surface.

Figure 4.20. **Circular timer and marker.** A blue circular timer is activated after occluding the marker with the finger, full-body, or random physical objects.

Interaction can be triggered when the projected marker is occluded to the camera (by a hand, foot, or an object), and the AnTS will stop detecting it. Hence, our system supports different types of interaction: through touch (hand and feet), through untagged objects, and interactive physical markers.

The actions associated with each marker are triggered after occluding them for 4 seconds A clock-like circular timer around the marker would provide feedback on the 4 seconds selection period (Figure 4.20). To facilitate communication and the identification of the markers by the participants and the researcher during the study, we designed personalized markers and identified them with letters of the alphabet. The setup of the experiment is illustrated in Figure 4.21.

Figure 4.21. **System configuration(s).** (1) Table projection set up with a projector and a tripod. (2) Floor projection setup through a high-intensity projector and a tripod. (3) A PSEye camera is collocated with the projectors to track and identify the projected markers A, B, C, and D.

4.2.2 Activities

Using AR technology, we developed six interactive activities with different interaction modalities to target different physical abilities (i.e., gross and fine motor skills) and cognitive competencies (i.e., executive functions, attention, memory, and association). During the activities, music was played in the background. For most of the activities, well known Portuguese songs were played to entertain participants during activity performance. In this experiment, we implemented two types of approaches: errorless and errorful activities (Table 4.7).

Table 4.7. Errorless and errorful based activities

Errorless Activities	Errorful Activities
Creative Painting	Knowledge Quiz: Upper Limb
Search Object	Knowledge Quiz: Full Body
Simulation ADL	Association

We define errorless as an activity that does not provide negative feedback to remediate wrong actions and errorful as activities that provide negative feedback via audio message – "Ohh, try again"- during erroneous decision making. However, participants were congratulated after finishing each task. Below we describe the characteristics of all six activities in detail.

Activity 1. Creative Paintings

Competences trained. Memory and, fine and gross motor skills

Activity Description. This is a puzzlelike activity were participants must draw to complete a painting that is projected on a table (Figure 4.22.A). This is a two-person activity where therapists or a researcher and participants work together. For this activity, PwD can use paper, cardboard, color pencils, and a pen, or any combination. Participants must (1) draw flowers, (2) draw the national symbol of Portuguese independence, (3) draw musical instruments, and (4) draw the national flags.

Interaction. The system displays an incomplete scene on a table, and a virtual marker indicates a missing element that needs to be completed gradually with participants' creative creations. After creating a drawing or painting on paper, the participant places the paper in the position indicated by the marker. Then, a timer starts, and after 4 seconds, the scene evolves to a new one that needs to be completed with another drawing.

Activity 2. Association

Competences trained. Associative memory

Activity Description. Participants must categorize as many fruits and vegetables as possible for 5 minutes.

Interaction. A fruit or vegetable appears in the top middle, and two containers - for fruits and vegetables - are displayed on opposite sides. To drag fruits and vegetables, participants use a physical controller tagged with a marker that allows selecting virtual objects (Figure 4.22.B). Vegetables and fruits become selected after placing the controller on them for 4 seconds and then can be displaced to their corresponding container using the physical marker. Once the item is placed in a container, a new item appears.

Activity 3. Search Objects

Competences trained. Attention and memory.

*Activity Description***.** This is an exploration game where participants must find hidden virtual objects typical from Madeira Island on a map of the island. These include a typical beverage, a headpiece, a musical instrument, fruit, and traditional Madeiran bread. The goal is to find as many objects as possible in 5 minutes (Figure 4.22.C).

Interaction. The participants must use a real physical object and search for the virtual objects mentioned above. After finding an object in the map, a timer is activated, and the participant must hold it for 4 seconds to select it.

Activity 4 and 5. Knowledge Quiz (Full-Body and Hand)

Competences trained. Memory

Activity Description. Participants must select the correct answer among three possibilities. The questions were presented in written form and reinforced verbally by the researcher.

Interaction. This activity can be used with two types of interaction: selecting answers by placing a hand (Figure 4.22.D) or both feet (Figure 4.22.E) on the corresponding marker for 4 seconds. If the interaction is done with hands, the activity is projected on the table. If the interaction is performed with feet, then the activity is projected on the floor. After participants choose the correct answer, the next task is initiated after a 5-second pause.

Activity 6. Simulation Activity of Daily Living (ADL)

Competences trained. Memory and selective attention

Activity Description. This is another puzzle-like experience based on activities of daily living. This activity requires using real objects like cutlery, among other objects. We developed activities that require setting the table, add earrings to a woman's picture, shave the beard of a man, add a watch and bracelets, place objects accordingly to their colors and, finally, complete a sequence of cards in descending order.

Interaction. Participants are required to identify and place the correct physical object on a marker. Every time the participant places an object on a marker, new markers appear in the game. The system detects the presence of an object on top of the AR marker but does not identify which object it is. By doing so, therapists are not limited only to specific predetermined objects. When all objects are correctly placed in the scene, a new scene is presented until all scenes are completed (Figure 4.22.F). As this is an errorless activity, participants are assisted if they choose the wrong object.

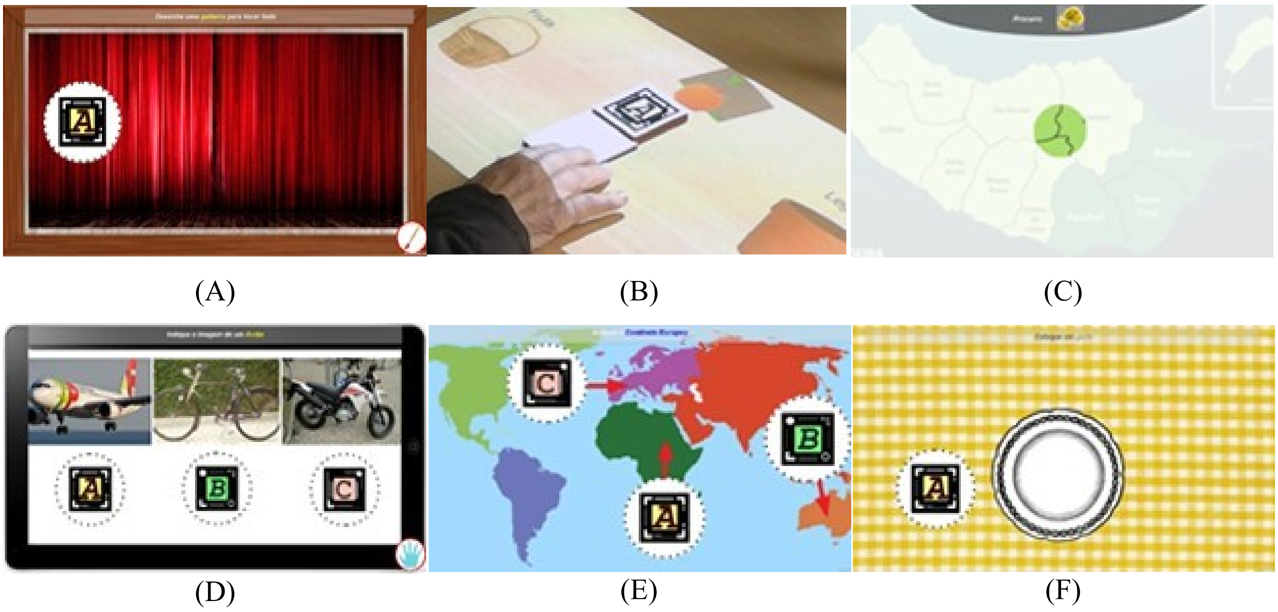

Figure 4.22. **Activities.** (A) Participants had to fill the gaps through physical drawings. (B) Participants use a physical object to interact with virtual objects in the activity and drag these to the correct container. (C) Participants had to find a variety of objects, which were only visible to the human eye through the physical device. On the top screen, a visual indicator would display the object that participants had to find. (D) Participants had to choose the correct answer among two wrong options using upper limbs. (D) Participants had to select the correct answer among two wrong answers using full-body interaction. (F) Participants had to set the table using real-life objects.

4.2.3 Participants

We recruited 7 participants (1 male) of 73.57 ± 7.87 years old from a day-care center in Funchal, Portugal. The average mini-mental examination score (MMSE) of participants was 20.57 ± 3.6. All participants included in this study were diagnosed with dementia (Alzheimer's disease, frontotemporal dementia, or vascular dementia), as presented in Table 4.8. All participants were at initial to moderate stages of dementia.

Table 4.8. **Demographic Information**. AD - Alzheimer's disease. VD– Vascular Dementia. FD– Frontotemporal Dementia.

ID	Gender	Age	Schooling	Dementia	MMSE
1	Female	78	3 Years	AD	23
2	Female	77	4 Years	AD	25
3	Female	77	4 Years	VD	17
4	Female	70	4 Years	AD	24
5	Female	85	4 Years	AD	16
6	Female	78	4 Years	AD	18
7	Male	63	4 Years	FD	21

Additionally, three health professionals also participated in the study, and a psychologist interacted with the participants while using the system. A music therapist and a psychomotricity therapist interacted with the system and evaluated it independently without participants. The psychologist is a 39-year-old male with four years of work experience. The music therapist is a 26-year-old female with one year of work experience, while the psychomotricity therapist is a 28-year-old female with 6-month work experience.

We followed a within-subjects experimental design. Participants were divided into two groups, and the activities were counterbalanced by assigning them to 2 different subsets of activities to avoid learning effects. Subset A included Creative Painting, Knowledge Quiz using upper-limb and Searching Objects, while subset B included simulations of ADL, Knowledge Quiz using full-body and Association. Each participant was randomly allocated to do A-B or B-A.

4.2.4 Procedure

Before the beginning of the experimental trial, all participants (or legal representatives) required to sign an informed consent. Additionally, we collected information regarding participants' profiles such as schooling, type of dementia, and MMSE.

The experimental sessions were filmed to compute the number of assistance and technical issues with the system. Before performing each activity, all participants had to complete a tutorial where they received instructions regarding interaction and goal.

The experimental sessions were conducted by a researcher or a psychologist from the care center. The psychologist aided whenever the participants were struggling during task completion. We consider a "task" a trial run of an activity). Taking into consideration that PwD suffer from memory loss, at the end of each activity (with several trial runs), participants were interviewed regarding their perception of autonomy and engagement during the performance of the activity.

In the second phase, the two therapists were invited to interact independently with the system and watched videos of the psychologist interacting with the participants while using the system. Then they were interviewed and asked to complete some questionnaires.

4.2.5 Instruments and metrics

To assess perceived autonomy and engagement, we performed semi-structured interviews about the participants' self- perception and compared the answers with objective data extracted from the video recordings. The answers to our questions were assessed as positive (+1), neutral (0), negative (-1), or not applicable. Additionally, we performed a correlation between MMSE and participants' engagement with the activities. To assess proficiency, we extracted three different metrics during task performance with both errorful and errorless activities:

- Time – we measured the time (in seconds) needed for participants to finish each task.
- Success rate – for the errorful based activities, we counted the number of times a participant was successful in performing each task. As for errorless based activities, we considered the success rate as 100%.
- Issues – we counted the number of technical issues that occurred for each task.

Additionally, all therapists were invited to answer a semi-structured interview regarding the interaction, difficulty, immersiveness of the system, and filled a set of questionnaires to assess not only how autonomous and engaging the system was for PwD, but also about the usefulness of the system:

- System Usability Scale (SUS) – it is a quick and low-cost 10 item Liker scale that evaluates system usability [138].
- Intrinsic Motivation Inventory (IMI) – it is a tool that evaluates the subjective experience related to an activity [139]. Within the IMI, we used the Activity Perception Questionnaire, which evaluates the participant's interest/enjoyment, value/usefulness, and perceived choice of an activity.

We also presented them with a visual analog 7 points scale that evaluated the appropriateness of the system for PwD at initial to moderated stages. This evaluates difficulty, utility, motivation, adequacy, and interest.

4.2.6 Data analysis

IBM SPSS Statistics Version 24 (IBM, New York, United States of America) was used for statistical analysis. Taking into consideration that we had a small sample size, we performed a non-parametric statistical analysis. We used the Wilcoxon signed-rank test for pairwise comparisons. Descriptive statistics are presented as medians (Mdn) and interquartile range (IQR), except for demographic data, MMSE engagement, and time spent doing the tasks, which are presented as means (M) and standard deviations (SD).

4.2.7 Results

All participants finished all activities. Participant 5, however, was excused from doing the Knowledge Quiz upper limb activity due to motor-related issues. She also participated in the Creative Painting activity, but she did contribute to the drawings. Thus, the last activity was not used to compute her performance metrics. Also, the number of overall assistance provided to participants in the Creative Painting activity was not considered in the results as it is completed with a second person.

Perceived autonomy of participants while doing the tasks

We used the participants' self-report to assess their perception of autonomy. It was reported that 45.7% of the tasks were completed autonomously, 28.6% of the tasks were completed with some help, and 25.7% of the tasks could not be completed without help. However, this perception contrasts with the data collected in the video recordings where, in general, all participants required some degree of assistance to perform the activities. We calculated the mean number of assistance provided per task. Overall, participants required, at least, one assistance per task ($M = 1.21 \pm 0.673$).

By doing a narrower analysis, the activity that required the least assistance was the Knowledge Quiz: Upper Limb task, while the activities that require the most assistance was Association and Search Objects. The activities are ranked in crescent order of number of needed assistances (Table 4.9)

Table 4.9. **Assistance provided to participants**. The activities are ranked in crescent order from least (Rank 1) to most (Rank 5) assistance provided. * asterisk indicates the tie ranking of participants responses

Rank	Interview	Rank	Observations
1	Knowledge Quiz: Upper Limb	1	Knowledge Quiz: Upper Limb
2*	Simulation ADL	2	Simulation ADL
2*	Knowledge Quiz: Full Body	3	Knowledge Quiz: Full Body
4	Association	4	Search Objects
5	Search Object	5	Association

Concerning the number of assistance provided in each task, we analyzed if there is a significant difference between assistance given in an errorful vs. errorless approach. Pairwise comparison indicated that the number of assistances provided in errorless ($Mdn = 7.50 \pm 1.5$) and errorful ($Mdn = 8.50 \pm 4.07$) based activities was not significant.

Participants engagement while doing the activities

We quantified engagement levels based on the interviews of the participants. All activities were rated as highly engaging (M = 3.6). We ranked activities engagement based on the participant's responses. The majority who did the Knowledge Quiz-Full body and Upper-limb activity felt most engaged in doing those activities while feeling less engaged with the Creative Painting activity (see Table 4.10).

Table 4.10. **Engagement Ranking**

Rank	Activity	Engagement %
1	Knowledge Quiz: Full Body	91.7
2	Knowledge Quiz: Upper Limb	91.4
3	Simulation ADL	88.6
4	Association	82.9
5	Search Objects	81.4
6	Creative Painting	78.3

To study if there was an effect of cognitive abilities in the engagement with the system, we grouped subjects according to the top and bottom 50 percentile of MMSE scores of our sample. We observed that the engagement ratings for the top 50% were higher (M = 4.17 ± 1.13) than for the bottom 50% (M = 3.27 ± 1.49). A Spearman correlation analysis supported these differences and identified a moderate correlation (r = 0.6) between MMSE scores and the reported engagement ratings. However, there is no statistical difference ($p = 0.18$).

How proficient are PwD in doing the proposed activities using errorfull and errorless approaches

We evaluated proficiency by measuring time, success rate, and the number of issues per repetition of all activities. Within the activities performed, the Creative Painting took more time (M = 337.11 ±132.31) and Knowledge Quiz: Upper Limb the least (M = 27.31 ± 8.00).

Regarding the number of issues per repetition, the Knowledge Quiz – full-body activity presented more issues (M = 0.42) and Simulations ADL the least. The success rate of the errorful learning activities was higher on average (M = 74.14% ± 0.14). The activity that presented a higher success rate was association-task with 84.27%, while the lowest performances were 69.84% in Knowledge Quiz: upper limb and 67.34% in Knowledge Quiz: full body. Data are presented in Table 4.11.

Table 4.11. **Participants Performance**

Activity	Time	Success%	Issues/Repetition
Knowledge Quiz: Full Body	57.13	67.34	0.42
Knowledge Quiz: Upper Limb	27.31	69.84	0.19
Simulation ADL	85.73	100	0.10
Search Objects	73.63	100	0.21
Association	51.41	84.27	0.28
Creative Painting	337.11	100	0.21

To compare if the type of the activity would impact their completion time, we compared the errorless vs. the errorful activities and identified that participants spent three times more time in the errorless tasks (Mdn = 165.35 ± 76.15) than in the error-full tasks (Mdn = 41.64 ± 18.83), $Z = -2.366$, $p = 0.018$, $r = 0.6$.

How useful is the proposed system as perceived by therapists?

The system's usability from the therapist's point of view was found to be 'good' (M = 78.33 ± 14.22) according to the System Usability Scale. Additionally, therapists rated the platform as high regarding its usefulness (M = 6.4), perceived choice (M = 6.5) and enjoyment (M = 6.5). When therapists were asked about their experience with the system for a population at initial to moderate stages of dementia, there was a high acceptance. Therapists showed high interest and motivation in using the platform (M = 7.0 and 6.7, respectively). Also, therapists recognized the system utility in stimulating such a population (M = 6.7). The weaker, yet positively rated, aspects where the adequacy (M = 5.3) and difficulty (M= 4.0), suggesting that the activities can be better adapted for such population.

4.2.8 Discussion

The main goal of this experiment was to study how participants interact and succeed in fulfilling different tasks while using different human-computer interaction techniques in an AR environment. We also aimed to validate the overall AR system with therapists regarding its usefulness for stimulation purposes for PwD.

Although some of the activities discussed could have been done using touchscreen technology, in AR, it is possible to use real objects to perform the tasks. By doing so, we can capitalize on personal, realistic, and tangible objects to perform the tasks more efficiently. Another advantage of using AR-based projections is that activities can be projected on the floor and stimulate mobility to perform the tasks. Moreover, therapists showed interest in using AR technologies. For example, the psychomotricity therapist was interested in having the system in the sensory stimulation room. Also, the music therapists suggested using real size musical instruments. A similar idea was provided by the psychologist, who suggested using the floor projection to develop a piano activity in which participants could play by using the feet.

Regarding participants' self-perceived autonomy, most participants (45.7%) reported that they did not need any assistance to do the activities. Similar behaviors were observed in McCallum's study in which PwD required assistance from a second person [97] (see section 2.2). Moreover, we analyzed if there was any difference in the number of assistance provided between errorless and errorful based activities, and we did not find any statistical difference. Although the contradictory information between self-responses and researcher observations, reliability was found as both responses and observations overlap, in the sense that, the Knowledge Quiz using upper limbs requested less number of assistance. At the same time, the Searching Object and Association required more assistance from both the researcher and psychologist.

Nevertheless, it is important to notice that the number of assistance provided to each participant depends on their characteristics, such as education level, motivation, and cognitive status. However, we faced some technical difficulties with the camera during the experiment, which resulted in some data loss. It was not possible to count the number of assistance provided in some of the activities, and one interview response was missing from our recordings. Furthermore, participant no. 6 denied our request to film the study. Hence, once again, we were unable to collect the number of assistance.

Concerning the engagement of the system, our results show that participants felt very engaged in performing the activities while using the AR platform. Corroborating the participant's self- reported interviews, the psychologist, who is one of their therapists, reported that the patients enjoyed the activities and were engaged. In general, participants found the Knowledge Quiz full-body more engaging and the Creative Painting less engaging, although interesting reactions could be observed during this less enjoyed activity. For instance, during the drawing activity, participant 4 said that she felt as she had lost much weight from her shoulders, and participant 2 remembered that her mother used to be a painter. While participant 6 did not participate directly in the drawing activity because of feeling insecure, she was able to complete the tasks orally with the researcher's assistance. As an example, the first task was to enhance weather conditions to plant flowers and, when she was asked about what is necessary to achieve such conditions, the participant replied that it was necessary to have water, fertilizer, and dirt. Also, participants could be engaged through storytelling strategies; For example, in an activity of daily living, participants were told family members would visit her for dinner. The researcher/psychologist would ask, "*Which side should we put the fork? And the knife? The guests will be thirsty! What do we need to pour water in?*". König *et al* report how serious games can engage participants while doing their task, despite the activity was designed to "test" PwD in terms of interaction performance [103] (see section 2.2). To explore if the engagement was dependent on the cognitive status of the participants, we made a correlation between engagement and MMSE scores, and despite no statistical difference was found, data suggest a moderate dependency relationship between the two variables.

Concerning the proficiency of PwD in doing the proposed activities using errorful and errorless approaches, in general, there is a high success rate in performing the activities (M = 87%). If we remove errorless tasks, the performance is still very high (M = 74%), supporting the feasibility of using these tasks in this population. Indeed, PwD are still open to experiment with new activities using advanced technological tools and still be successful, as seen in [95], [140] (see section 2.2). The task with the highest performance was the Association (with M = 84.27%) while the lowest performance was the Knowledge Quiz upper–limb and full–body (M = 69.84% and M = 67.34%, respectively).

Regarding the high success rate in the Association task, it may be due to the number of assistance provided by both researcher and therapist. Many participants had to be reminded that after dragging a virtual object successfully, one must drag the physical piece to the initial position to "grab" another virtual object. Also, sometimes the therapist and researcher would ask participants if the current virtual object was either a "fruit" or a "vegetable," which the majority of participants could quickly identify. Interestingly, we observed that the full-body activities required more assistance than the upper-limb ones. This may be because the content of the task (geography related questions) may not be the most adequate for PwD; this was suggested by the psychologist who conducted the experiment. Concerning the time spent to finalize activities, the Creative Painting took longer to finish. We also found statistically significant differences between time spent in errorless and errorful conditions; errorless tasks took three times more time. One possible explanation for this is that the time needed to finish these tasks also greatly depends on education, motivation, and cognitive status. Also, it can be due to a lack of experience in doing such tasks while using a novel technology.

About the usefulness of the proposed system (as perceived by therapists), additional data were collected from 3 therapists in different fields. Overall, therapists rated the system with very good usability (78.3) in the SUS questionnaire. Likewise, their experience was highly positive, as evaluated by the Activity Perception Questionnaire.

We also asked them to fill a non–standardized questionnaire regarding the usage of such a system on a dementia population at initial and intermediate stages. Although therapists attributed a high score regarding utility, motivation, and interest, they gave lower scores regarding difficulty and adequacy. Indeed, during the interview, therapists drew our attention to the fact that some content was not very suitable for some participants. As an example, the psychologist mentioned that performing tasks using full-body was very positive. Still, a geography- related activity may not have been the most suitable choice, at least, for the participants who participated in the study.

Also, the therapist verified that some participants appeared to struggle to find a specific object, aftershave, in the ADLs simulation as it is an item that many participants are not very familiar with. These observations show that it is important to adjust the activities to the individual interests, knowledge, and needs of each person. This concern is equally shared by Hayhurst, who draws our attention to the fact that tasks may not suit all users and that there is a need for user-centered design to target the individual needs of PwD [101] (see section 2.2). Despite constructive feedback provided by the therapists, only the psychologist used the system with PwD.

4.3 Development of *Musiquence*: a customizable music and reminiscence cognitive stimulation platform [4]

In this section, we present a new therapeutic platform that aims to provide music and reminiscence cognitive activities to stimulate people with dementia (PwD). The platform, which is called *Musiquence* (that derives from the words music + sequence), is a platform that displays a sequence of music and reminiscence related activities previously customized by health professionals to be played by PwD. The design of the platform was based on the "lessons learned" of the previous studies (see section 4.1 and section 4.2). We learned that (1) using technologies is task-dependent, (2) technologies that support direct interaction modalities are preferable than indirect interaction, and (3) customization of activities to the patients' preferences is vital to enhance therapeutic outcome and engagement of PwD. The latter finding inspired us to develop an additional feature to the platform - the *Game Editor* - that allows healthcare professionals to create, design, and customize activities (i.e., images and music).

Also, the designed platform is multi-platform compatible that allows overcoming some of the technological and software-related limitations identified in state of the art (i.e., portability, lack of customization features to target individual needs in PwD [101], and inadequate interoperable systems [103] (see section 2.2). Thus, considering that many PwD may not be familiarized with modern technologies, healthcare professionals can use different technology and match these to the experience and comfort of PwD. Customizing activities to PwD interests can enhance motivation, which is vital to ensure the success of cognitive stimulation [103] (see section 2.2). For example, healthcare professionals can develop an activity that uses real objects, music, or sounds, which has a special meaning for the patient and deploy these to the most suitable technology.

Another advantage of using this platform is that healthcare professionals can present the activities as a story-telling narrative. By doing so, healthcare professionals can engage PwD in performing virtual activities. The platform can also mitigate costs; the development and maintenance of activities for PwD can be costly [114] (see section 2.2). Thus, healthcare professionals can use *Musiquence* to stimulate PwD while having full control over technology, activities, and content. Finally, this platform can be used to provide more evidence regarding the impact that music and reminisce based cognitive activities have in PwD.

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[4] The full study is published in Ferreira, L. D. A., Cavaco, S., & i Badia, S. B. (2019, June). Musiquence: a framework to customize music and reminiscence cognitive stimulation activities for the dementia population. In *2019 5th Experiment International Conference (exp. at'19)* (pp. 359-364). IEEE; and Ferreira, L. D. A., Cavaco, S., & i Badia, S. B. (2019, June). Musiquence: a serious game customization system for dementia. In *2019 5th Experiment International Conference (exp. at'19)* (pp. 247-248). IEEE;

4.3.1 *Musiquence*: Activities and interaction

The platform includes, but is not limited to, five different activities that were used and tested in the previous section (see subsection 4.2). Implementing more activities for PwD in the future is possible, thanks to its modular design. To interact with the game, participants must use their upper limbs, full-body, or the usage of real objects depending on the technology used. For example, when using an AR setup (which consists of a projector projecting on a solid surface, a PSEye camera, and an image processing software application (AnTS) that detects markers), *Musiquence* can detect any user interaction with the projected markers.

The activities went through aesthetic changes to enhance task performance in PwD. For example, in the study presented previously (see subsection 4.2), the Search Objects activity distracted participants as the map was being projected in the foreground (see Figure 4.22-C). Thus, we choose a neutral foreground to avoid further distractions. Also, in the same activity, we discarded the visual indicator (see Figure 4.22-C) that was designed to aid participants in finding the next hidden object on the map. The changes were made based on observation and feedback provided by health professionals. The activities are as follows:

- Creative Painting – In this activity, participants train skills such as memory, and fine and gross motor skills. This activity is a puzzle-like game where participants must draw to complete missing pieces of painting.
- Activities of daily living – Here, PwD train memory and divided attention. Similar to Creative Painting, it is a puzzle-like game where PwD must complete a set of chores (i.e., setting the dinner table) by adding real physical objects (i.e., cutlery).
- Search Objects activity – This activity is designed to train the attention and memory of PwD. It is an exploration game where participants must find hidden virtual objects that were only visible through a virtual magnifying glass
- Knowledge Quiz activity – This is an activity that aims to train memory in PwD. Here, participants are required to answer a question correctly by selecting the correct answer(s) among incorrect ones.
- Association activity – In this activity, PwD train associative memory. Participants are required, for example, to separate fruits from vegetables and place these in the correct containers

Figure 4.23 shows the available activities of *Musiquence* in an AR setup.

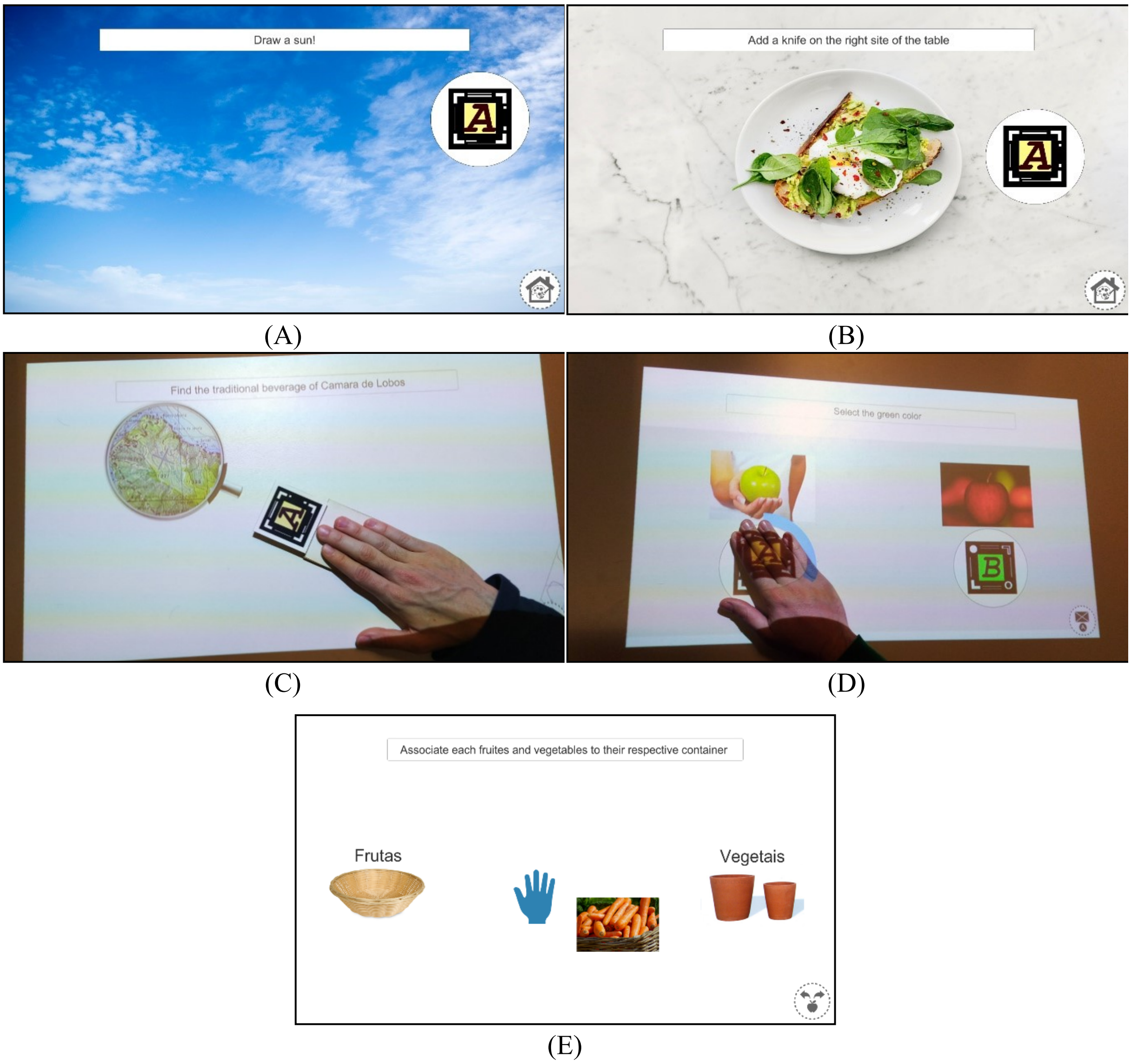


Figure 4.23. **Screenshots and projections of *Musiquence* activities using AR setup.** (A) Creative Painting. Participants must place a real drawing on the projected marker. (B) Activity of daily living. Participants must place real objects like cutlery on the marker. (C) Search Objects. Participants had to find objects that were only visible through a virtual magnifying glass using a physical wooden object with a marker attached to it. (D). Knowledge Quiz. Participants must find the correct answer by occluding the markers using upper limbs. When occluding, the response timer is triggered (E) Participants must associate, for example, images related to fruits (Frutas) or vegetables (Vegetais) to the correct container. In order to do so, participants must first "grab" the image and then drag it to the correct container using a physical object with a marker attached to it.

4.3.2 *Musiquence*: *Game Editor* and *Game Experience*

It was developed using Unity 3D and divided into two separate applications: *Game Editor* and *Game Experience*.

Game Editor. As shown in the previous section (see section 4.2), we tested a set of augmented reality-based activities that PwD had to complete using different human-computer interactions. Health professionals participated in the study to provide feedback regarding the usage of such systems for intervention purposes. Although health professionals were interested in using the platform during interventions, they were concerned about the content that was presented to the participants. Thus, we started developing a user interface for health professionals to customize activities for a dementia population. The game editor allows health professionals, relatives, and caregivers to create activities and customize these according to the participant's profile.

The editor flow is inspired by the Microsoft PowerPoint (One Microsoft Way, USA) (see Figure 4.24 A). Activities are presented as "slides" in sequential order. As new activities are added in the editor, users can:

1. change the order of activity execution;
2. eliminate activity and;
3. add a condition to finish an activity (i.e., the player must finish the activity in 1 minute before carrying on to the next activity).

For each activity, health professionals and family caregivers can:

1. Write questions;
2. Add verbal instructions;
3. Add background music;
4. Adding answers. As new answers are added, the user can add images and label them as "correct answers." Thus, the user can establish that one activity can have one or more than one correct answer. The user can also change the order to the answers by clicking the left / right arrows or delete an answer using the trash can icon.
5. Changing the response timer;
6. Manipulating the background music in terms of pitch, pitch-rhythm, and rhythm (see Figure 4.24 B and Figure 4.24 C). Manipulating music in pitch-rhythm means that musical notes are distorted in terms of both pitch and rhythm. Alternatively, pitch changes music notes only in terms of its frequency but not rhythm. Rhythm can turn the music faster or slower.
7. Preview the activities so that health professionals can see how they will appear to the end-user.

Depending on the type of activities, additional user inputs are required. For example, by previewing the Creative Painting, Activity of daily living activities, and Search Objects, users can position the markers within the limits of the game canvas (see Figure 4.24 D). Additionally, in the Search Object and Association activity, users can add additional images (see Figure 4.24-E and Figure 4.24-F). Finally, the user can export the activities as a serialized file with extension "*.musiquence" by clicking the save button (See Figure 4.24 A). Alternatively, the user can load an existing file by pressing the load button and continue editing the file (see Figure 4.24 A).

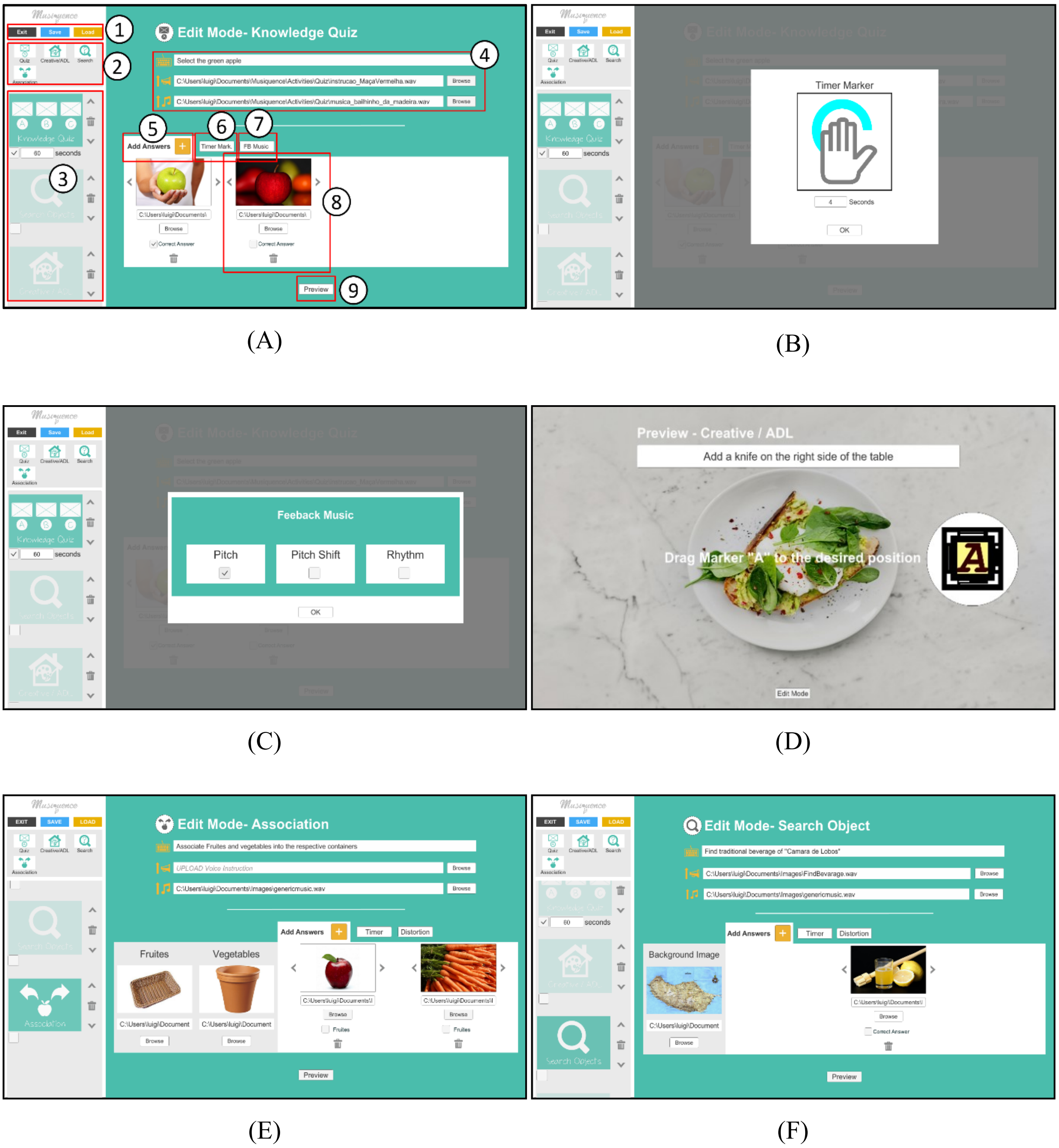


Figure 4.24. **Game *Editor*.** (A) 1. Save, Load, and Exit button. 2. Available activities – Knowledge Quiz, Search Object, Association, and Creative/ADL. 3. The sequence of activities. The up/down arrow allows the user to change the order of execution of the activities. The trash icon allows the user to delete an activity. Under each activity, the user can add a condition to finish an activity. 4. Input fields. Participants can write questions and upload verbal instructions and music. 5. Users can add answers to an activity. 6. Users can access the marker timer responses. 7. Users can manipulate musical components. 8. Answers displayed in the activity. For each answer, the user can add an image, change the order of the answers using left/right arrows, check the answer as a correct answer and delete the answer by clicking the trash can icon. 9. Users can preview the activities. (B) Marker timer. The user can adjust the response time of an answer. By default, the markers are defined as 4 seconds. (C) Musical distortion. If the activity has background music, the latter can be manipulated in terms of pitch, pitch shift, and rhythm to provide auditory feedback on current actions. (D) In the ADL, Creative Paintings, and Search Objects activities, users can preview activities and define the position of the markers within the game canvas. (E) In the association activity, the user can

define additional images to define the categories, in this case, for fruits and vegetables. (F) The user can define a general background image and object image for the Search Objects activity.

*Game Experience***.** In this application, users need to open a previously created "*.musiquence" file to run the activities. The activities will be executed in the order as established in the Game Editor. Also, the application generates a "*.CSV" (Comma Separated File) file containing data performance of PwD. For example, the file saves data such as the time required to finish a task, the number of correct and wrong answers, marker timer, and updated position of virtual objects.

In terms of software architecture, the application flow follows a state-machine implemented, which determines the sequence of events depending on the player's input (see Figure 4.25). The game's state changes according to user input. Letter "A" represents the current activity. Letter "B" represents the current question of the activity. Letter "C" represents the feedback provided to the player; if the user selects a correct answer, positive feedback – "Very Good!" is triggered. Otherwise, if incorrect, "Oh, try again" is triggered. For some of the activities presented previously in section 4.3.1, the Creative Painting, Activity of Daily Living, and Search Objects activities provide only positive feedback, while the remaining activities provide both positive and negative feedback to the player.

The arrows represent the transitions between states. These transitions only happen if certain conditions are fulfilled. For example, transition 3 occurs when the player selects an answer (user input). Transition 4 happens when the activities still have correct answers. Transition 5 occurs if all correct answers were selected and that more activities exist. Transition 6 is triggered if there are other activities, and the time to finish the activity has ended (if applicable). Transition 7 happens if all answers to all activities have been selected, and there are no more activities to be presented.

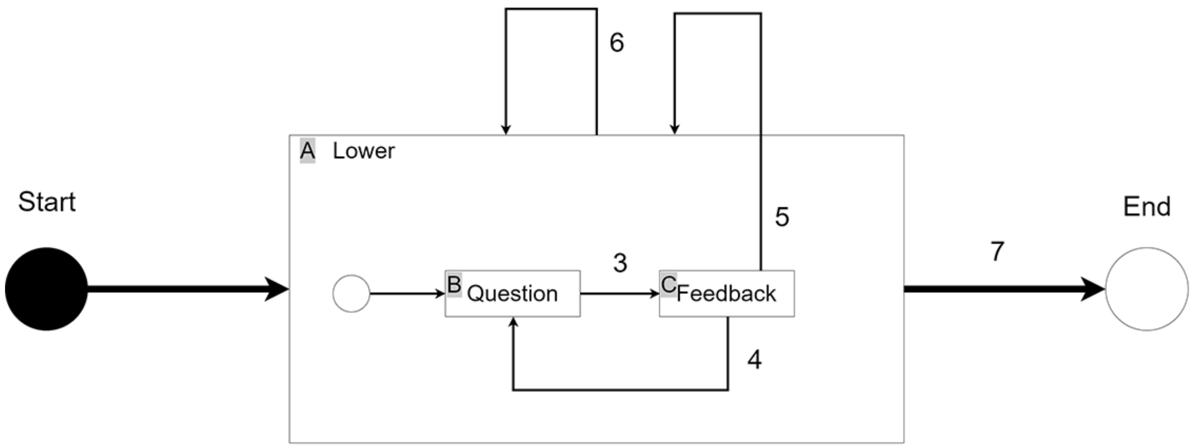
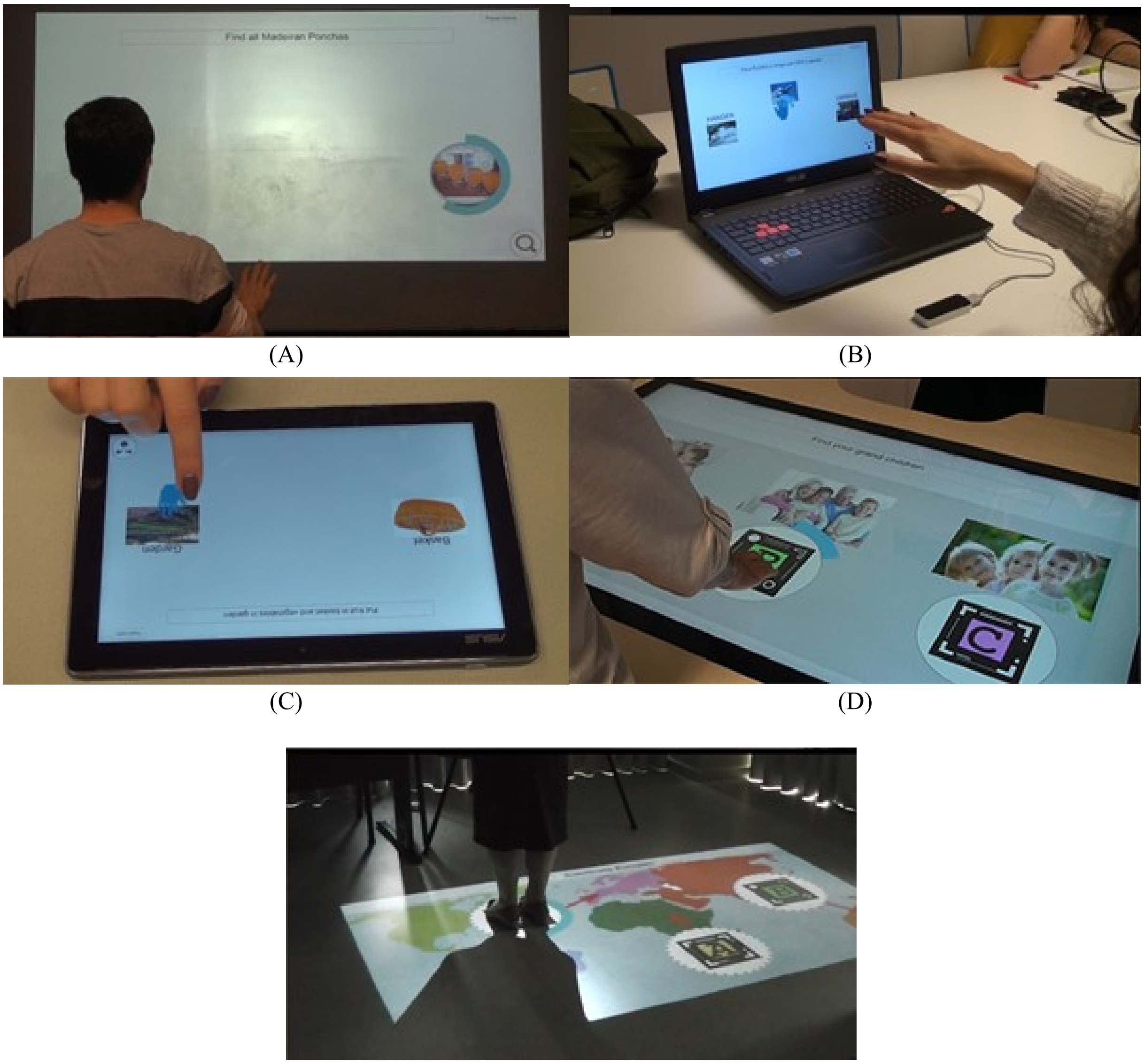


Figure 4.25**. The Game Experience application's state machine**. Letters represent states, and numbers represent transitions between states

4.3.3 *Musiquence:* Technological compatibility

Another major significant advantage in using this platform with a computer illiterate population, it is the versatility in terms of technological compatibility. The platform was designed in such a manner that it can be deployed in different platforms, such as Augmented Reality, Tablets/Interactive Tables, PC, Leap Motion, and Real Sense.

Thus, healthcare professionals can run the activities they created, using each time the technology that they consider to be the most appropriate for PwD during therapy sessions. As a result, healthcare professionals reduce the risk of adverse behaviors in PwD while reassuring therapeutic outcomes of the activities. Figure 4.26 shows the interaction with the activities presented in section 4.3.1 using different technologies.



(E)

Figure 4.26. **Using technology to interact with *Musiquence* activities**. (A) Performing Search Object activity with Real Sense through full-body and upper limb movements. (B) Performing Association activity with Leap Motion through upper limb movements. (C) Performing Association activity with a tablet through upper limb movements. (D) Performing Knowledge

Quiz activity with an interactive table using upper limb movements. (E) Performing Knowledge Quiz activity with AR using full-body movements.

4.3.4 The role of music and reminiscence in the activities

Considering the benefits previously described of using music and reminiscence in PwD (see 2.1.1), one of the main advantages of this platform is that health professionals, relatives, and caregivers can contextualize the activities by using patient-centered and meaningful content (images, music and physical objects) for participants who are diagnosed with dementia. As music is one of the most prominent features of the platform, it can be played the whole time during the activity.

Further, one of the features of *Musiquence* is that it allows the distorting of specific components of the uploaded music in terms of pitch, pitch-rhythm, and rhythm:

- Pitch: music is changed in terms of the pitch without altering Beats per Minutes (BPM).
- Rhythm: music is changed in terms of BPM.
- Pitch – Rhythm: music is changed in terms of pitch and BPM.

To generate the distortions, we used a software called FMOD which can be used in Unity 3D (https://www.fmod.com/unity). The source code of each distortion type is presented in the supplementary material (see supplementary material – Source code for musical distortions 2). The purpose of such manipulation is as a guidance system to aid PwD to avoid erroneous decision making. This feature was inspired by a single case study the experiment of Cuddy et al. [58], in which a participant diagnosed with advanced Alzheimer's disease - was able to identify melodies with erroneous pitch notes in the Distortion Tune Test (DTT) (see 2.1.1). With the proposed platform, we intend to explore further the benefits of musical distortion feedback mechanisms in PwD.

Regarding the reminiscence related aspects of the platform, due to the ease of customizing the activities and technological compatibility, the usage of photos or real objects (such as used during reminiscence therapy) to complete the activities can enhance therapeutic outcomes. An interesting technique was used during the study by both health professionals and researchers in the experiment described in section 4.2. We presented the activities in a storytelling narrative. For example, in an activity of daily living, participants were told to imagine a family event in which the dinner table had to be set-up. The researcher would ask, "*We need to put cutlery. Which side should we put the fork? And the knife? The guests will be thirsty! What do we need to pour water in?*" (see Fig22.D). Thus, by presenting context, PwD may be more prone to participate and communicate during the completion of the tasks.

4.4 A usability study with healthcare professionals using *Musiquence*[5]

Before assessing the clinical impact of music and reminiscence in PwD using the platform, we conducted a usability study with healthcare professionals to test *Musiquence*. A similar study has been conducted by *Vallejo et al*. while performing a usability study of a novel cognitive screening tool [141]. Throughout this section, we will discuss a usability study with healthcare professionals while using *Musiquence* to address the following aspects:

- How proficient where healthcare professionals in creating activities?
- How useful is the *Musiquence* Game Editor perceived by healthcare professionals to customize games for PwD?
- How mentally and physically demanding is the interface?

4.4.1 Methods

In order to evaluate the healthcare professionals' proficiency, perceived usefulness, and difficulty in handling the *Game Editor* while creating a variety of tasks, we performed a usability study of this application. The heterogeneity of the sample reflects the different backgrounds of healthcare professionals interacting with PwD in the health institution; 10 healthcare professionals (8 females and 2 males) from 25 to 42 years old from a mental health center (Casa de Saúde São João de Deus) participated in the study. The study took place at the same mental health center. All participants had experience in interacting with dementia patients. Participants' demographics are summarized in Table 4.12.

Table 4.12. **Participants Demographics**

ID	Age	Gender	Occupation	Work Experience (years)
1	28	Female	Social Educator	6
2	32	Female	Psychologist	5
3	30	Female	Nurse	1
4	25	Female	Junior Psychologist	1
5	26	Female	Psychologist	3
6	39	Male	Teacher	15

[5] The full study is published at Luis Ferreira, Sofia Cavaco, and Sergi Bermudez i Badia. 2019. A usability study with healthcare professionals of a customizable framework for reminiscence and music based cognitive activities for people with dementia. In Proceedings of the 23rd Pan-Hellenic Conference on Informatics (PCI '19). Association for Computing Machinery, New York, NY, USA, 16–23. DOI: https://doi.org/10.1145/3368640.3368654

7	29	Female	Occupational Therapist	4
8	28	Female	Nurse	4
9	42	Male	Teacher	16
10	25	Female	Psychology Student[a]	-

[a] The participant had no actual work experience but had interacted with PwD during her clinical internship

4.4.2 Procedure

Before the beginning of the experiment, all participants signed an informed consent form. During the experimental trials, participants' performance was filmed using the NVidia GeForce Experience screen recorder (Nvidia corporation, California USA).

Participants were invited, one at a time, to sit in a quiet room. In the room, only the researcher and the participant were present. The researcher read a document with instructions, and that contained contextual information and examples (for example, it illustrates why healthcare professionals may want to create a daily living activity. for PwD) and all the steps that participants must complete to finish the proposed tasks.

Before beginning the experimental trial, participants were briefed (1) regarding the purpose of the study (which was to test the customization application to develop activities for PwD), (2) were asked to think aloud throughout the completion of the task, (3) were informed where to find multimedia content in tasks that required uploading of music and images.

Additionally, participants were shown print screens (only once) with the outcome of the tasks and were asked to recreate these. We define "tasks" as assignments given to the participants by the researcher. A task can be a complex assignment, such as creating an association activity or completing a simple and more direct instruction. For example, when the researcher says, "*Write the following question for this activity: Select the red color*." The participant must write, "Select the red color." in the appropriate input field. Regarding the more complex task assignments, participants were required to create an activity from each type and interact with all features of *Musiquence* as described in subsection 4.3.2

All participants performed the activities using the same sequential order and started with the Knowledge Quiz activity. Afterward, participants were asked to save the activities in a file and upload it again to edit the activities. After uploading the file, the participant had to (1) change the order of the activities, (2) add an activity timer in one of the activities and (3) change the order of the answers in a Knowledge Quiz type activity. Participants were required to complete the tasks alone. If participants either asked for help or struggled in completing a task, the researcher would intervene by providing clues.

4.4.3 Instruments and metrics

To assess healthcare professionals' proficiency, we measured the following variables:

- The number of issues: we counted the number of issues that participants encountered during task performance. The number of issues was counted by watching the video recordings.
- Time (tasks per activity): we measured the average time (in seconds) that participants needed to finish the tasks.
- Time (tasks per editing): we measured the average time to edit the activity.

The time was manually withdrawn with a stopwatch. We started counting once the researcher finished reciting the task's instructions and stopped the time when that task was completed. To assess the perceived usefulness of the Game Editor to customize activities for PwD, we invited the participating healthcare professionals to answer some validated questionnaires:

- Intrinsic Motivation Questionnaire (IMI) [139]: IMI questionnaires evaluate users' subjective experience related to an activity. Among the available IMI questionnaires, we used the Activity Perception Questionnaire, which has a 7-point Likert scale and evaluates participants' interest/enjoyment, value/usefulness, and perceived choice of activity.

To assess how demanding the application is, we asked the participants to fill the following questionnaires:

- Nasa TLX [142]: this is a 21-point questionnaire that evaluates participants' workload in terms of mental, physical, and temporal demand, effort, performance, and frustration during an activity.
- System Usability Scale (SUS) [138], [143]: this is a 10-item Likert scale that ranges between *strongly disagree* to *strongly agree*, and that evaluates system usability.

We also performed an interview to gain a more detailed insight regarding the usefulness of *Musiquence's* Game Editor and how demanding the interface is:

- Interview: healthcare professionals answered an interview regarding (1) usage of previous technologies with PwD, (2) overall experience with the platform, (3) interest in using the platform to stimulate PwD, and (4) additional feedback regarding the overall experience. Some questions were answered with a 7-point Likert scale, while others were open questions.

4.4.4 Results

All participants finished the proposed tasks, completed the interview, and filled the validated questionnaires (see section 4.4.3). Due to technical issues, data on the number of issues for participants 6 and 7 were missing. We used IBM SPSS Statistics Version 24 (IBM, New York, United States of America) for statistical analysis. Descriptive statistics are presented as means (M) and standard deviations (SD).

How proficient where healthcare professionals in creating activities?

To evaluate the proficiency of healthcare professionals, we counted the number of issues encountered and the time needed to complete each task. The activity that led to more issues was the Knowledge Quiz type activity (M=3.25± 2.12), while the activities that led to fewer issues were the Daily Living Activity (M=0 ± 0) and the Search Objects activity (M= 0 ± 0). In the Creative Painting and Association activities, we found an average of (M=0.88 ± 1.73) and (M=0.5 ± 0.76) issues, respectively.

In terms of the time required to complete the tasks, healthcare professionals were faster to complete the daily living activity (M=43.33 ± 10.72). In contrast, the Knowledge Quiz type activity required the most time to be completed (M=95.97 ± 48.14). The time for the Search Objects activity was (M=43.70 ± 9.76), for the Creative Painting activity was (M=48.49 ± 15.70), and for the Association activity was (M=75.62 ± 20.95). Regarding the time needed to edit the file, participants required (M=128.53 ± 59.89).

How useful is the game editor perceived by healthcare professionals to customize games for PwD?

During the interview (see section 4.4.3), some participants mentioned having used technology for cognitive stimulation purposes. Three participants wrote that they used PCs with additional software such as PowerPoint to stimulate PwD with images, music, and cognitive exercises. Nevertheless, none of the participants knew a platform that supported customizing activities. As for the 7- point Likert scale in the interview, participants unanimously agreed that *Musiquence* is very useful to customize activities for PwD (M=6.70 ± 0.48). They also were generally interested in using the platform with PwD (or other pathologies) (M=6.60 ± 0.97), and, despite the results were slightly above the average, they were willing to pay for the platform (M=4.80 ± 1.75). Indeed, the Activity Perception Questionnaire revealed very high interest/enjoyment (M=6.36 ± 1.00), values/usefulness (M=5.85 ± 1.68), and perceived choice (M=5.61 ± 2.32) by the participants while using the Game Editor. During the interview, we also asked them if there was an additional feature that they would like to have on the platform. Most participants said that there was no need for additional features, yet one participant recommended to add more information regarding the "sequencing" of the activities created while another participant requested more keyboard shortcuts (i.e., press "Enter" to confirm inputs).

How demanding is the application for healthcare professionals?

By using the NASA TLX questionnaire, we evaluated how demanding the application is for participants while developing activities for PwD. Results show that the interface did not lead to any stressful experience in any of the parameters measured (M=6.24 ± 5.71). The results of each parameter measured were: Mental Demand (M=7.70 ± 5.01), Physical Demand (M=5.20 ± 6.37), Temporal Demand (M=7.40 ± 6.55), Performance (M=6.00 ± 4.69), Effort (M=8.10 ± 6.26) and Frustration (M=4.00 ± 5.25). To complement the previous questionnaire, we asked participants to rate the *Game Editor* using the SUS. The results revealed that, in general, participants rated the interface as good (M=79.75 ± 14.46) [4]. Finally, in the 7-point Likert scale in the interview, participants found that the icons and written information were self-explanatory (M=5.50 ±1.51) and that navigation of the platform was intuitive (M=5.80 ± 1.14). However, some participants mentioned in the interview that the information displayed on the platform should be in Portuguese. Although there is some margin for improvements, overall results show that the platform was precise and not demanding.

4.4.5 Discussion

The main purpose of this usability study is to ensure the proper functionality and quality of the platform's *Game Editor*. We also tried to understand if the approach of customizing activities for PwD is a viable approach for healthcare professionals.

Answering healthcare professional's proficiency, the results from the study show that, in general, participants were proficient as the Game Editor's interface led to few issues and that they were able to complete the tasks independently. As all activities share some basic functionalities described in section 4.3.2, once they completed the first few tasks, participants felt more comfortable while completing the remaining tasks. For example, two participants were able to perform the tasks before the researcher was able to finish reciting the task.

Regarding the time measured for participants' performance, the activity that required more time to complete was the Knowledge Quiz type activity, which was expected, since this was the first activity being done. Participants were still learning how to use the interface. The activity that required less time to complete was the Daily Living Activity. Although participants were relatively fast in performing the tasks, the overall time to finish an activity depends on the number of features that each activity has. Some activities required more user input than others. For example, the Association activity requires participants to upload images to identify the categories. Also, as new answers are created, participants need to associate the answers to the respective category; afterward, participants must upload an image for each answer, drag/drop, and position several of the answers in the game canvas. In contrast, the Creative Painting and Daily Living activities were more straightforward since it required the participant to create only one answer, upload an image, drag/drop, and position the answer in the game canvas.

In terms of editing the file, participants, in general, required almost 129 seconds; participants spent a significant amount of time when asked to (1) delete and to (2) add a time condition to an activity. Indeed, these two tasks led to more issues during file editing, as these features were not noticeable enough. For example, to add a time condition, participants must click on a checkbox that was displayed under a created activity. This led to confusion among participants when trying to complete the task. As for deleting an activity, participants missed the "trash" icon that was displayed on the right sight of a created activity.

Concerning the usefulness of the *Game Editor,* participants' subjective experience - as measured in the Activity Perception Questionnaire - in using the Game Editor was high. We asked participants if they had any knowledge about a platform that allows personalized content for PwD, and none of them had any knowledge of such a platform. Nevertheless, all participants agreed that the possibility of customizing activities is beneficial for interventions. Similar results of the Activity Perception Questionnaire and opinion were shared in the experiment described in section 4.2.7; therapists rated the previous version of the games with slightly higher scores in terms of interest/enjoyment (M=6.54 ± 0.78), usefulness (M=6.44 ± 0.80) and perceived choice (M=6.46 ± 1.69). The results of this study are encouraging as we are not assessing the enjoyment of the games themselves but rather the tool used to create them.

Additionally, therapists said that it is important to use appropriate content to engage PwD in performing the tasks. Indeed, participants were interested in using the platform to stimulate PwD and reported some willingness to pay for it. One participant would like to use the platform if his institution would assume the costs, while another participant reported willingness to pay the full price. Only one participant would not invest in such a platform at all. The hesitation among participants in purchasing such tools can be due to the initial and longstanding maintenance costs that reassure the proper functioning of the platform. Also, there are concerns regarding the short-term usefulness of SG as they can become inadequate over time [115] (see section 2.2).

Nevertheless, as stated in section 4.3, healthcare professionals can use *Musiquence* and adapt technology and content to the current profile of PwD. When asked whether they wished to see additional features in the platform, most participants did not feel the need for more features. However, one participant requested more information regarding the sequence of the activities while another participant said that there should be more keyboard shortcuts, such as able to press "Enter" to confirm inputs.

As for how demanding the application was, the *Game Editor's* interface was rated as "good," according to the SUS. Vallejo et al.'s study obtained identical results [141]; participants in both studies rated the interfaces as easy and straightforward to use (SUS, M = 79.75 ± 14.46 and M = 80.62 ± 11.55 respectively). Also, in both studies, the participants did not feel stressed in using the *Game Editor* according to the NASA TLX; Both interfaces were not demanding in terms of workload (Nasa - TLX, M = 6.24 ± 5.71 and M = 4.22 ± 0.53 out of 21 points respectively). A low demanding interface is essential for healthcare professionals to mitigate their workload and increase interest and motivation in using the platform to stimulate PwD. However, in our study, some participants suggested that the platform should support other languages such as Portuguese.

4.5 Chapter discussion and conclusion

Throughout chapter 4, we describe the development process of *Musiquence*, which is a platform that health professionals can use to provide music and reminiscence cognitive stimulation for PwD. In the same chapter, we aimed to answer research question *RQ.1- How to develop a therapeutic game using technology and the benefits of music and reminiscence?* To answer *RQ.1*, we addressed two sub-questions: *RQ.1.1- Which "out-of-the-shelf" technologies are more suitable for PwD?* and *RQ.1.2- Which interaction modalities are more intuitive for PwD?*

To answer *RQ.1.1- Which "out-of-the-shelf" technologies are more suitable for PwD?* We invited 12 PwD to interact with a variety of technologies, and we evaluated their user experience (see section 4.1). As participants used the technologies to perform virtual related tasks, we identified potential issues such as assistance provided, comprehension issues, perception issues, interaction issues, and discomfort. We also studied how the patient's profile would affect performance in those different tasks and technologies. Finally, we provided a set of recommendations for the selection, use, and design of virtual tasks for these technologies. Our main findings show significant effects of technology on performance regarding comprehension, interaction, and discomfort.

Overall, participants were able to complete all tasks using all technologies. However, a clear outcome of the study is that there is no absolute best technology for PwD, but this is both task and patient profile dependent. In general, the use of technologies that require direct interaction is advisable, given that cognitive performance gradually declines in PwD, as it relies on fewer cognitive resources than indirect interaction devices. We observed that cognitive skills, as assessed by the MMSE test, did influence participants' perception, comprehension, and interaction, and required more assistance. Additionally, schooling is also a factor to be considered; the lack of experience and exposure to such technologies can lead to confusion and anxiety, which interferes with user experience.

A cost-effectiveness analysis comparing price and issues identified in all technologies used suggests that the best trade-off of performance and cost is achieved with the Mouse, the most effective technology is HMD, and the most expensive one is AR. Through these insights, the experiment provides newer insights for health professionals, informal caregivers, and engineers regarding the use and design of novel technologies for PwD to (1) maximize their success in using such technologies to fulfill virtual tasks and (2) safeguard their psychological wellbeing.

In summary, participants in the study presented in section 4.1 were able to handle the technologies to complete virtual tasks. Interestingly, the overall success in using technologies by PwD depends on different variables such as patient profile, type of task, and interaction modality. Our study provides a quantitative analysis that contributes towards a better understanding of the complex relationship among those factors. Finally, by translating our findings into a set of guidelines, we hope to facilitate technological interventions and to enhance the user experience of PwD when performing virtual tasks with "out-of-the-shelf" technologies.

However, the study had some limitations. We had a small number of participants, and not all participants interacted with all technologies. Consequently, if we applied Bonferroni correction for multiple comparisons, statistical significances during posthoc analysis do not remain. Hence, a larger sample size would have provided higher statistical power for the analysis. Also, having a control group of healthy age- and sex- match participants, would have been informative to discriminate age and dementia-related issues such as perception problems. Future studies should consider adding a control group to draw additional conclusions regarding the usage of "out-of-the-shelf " technologies to perform virtual reality tasks. Nevertheless, adding a control group presented some challenges.

Firstly, we interacted with a population that cannot adequately express themselves in the same way healthy elderly do. Therefore, we had to use very time-consuming methodologies, such as independent annotation of hours of video recordings, categorization, and extraction of data so that a quantitative analysis could be performed. Consequently, we would have to use the same methodology with the control group (that would not require it), making it not feasible for us, given the time needed and available human resources. Secondly, even if we did so, our experience tells us that the two groups would not be directly comparable even if performing the same activities because PwD required constant stimulation and assistance by researchers and health professionals to understand and perform the tasks. Thirdly, the level of autonomy of PwD in performing the activities is not comparable to that of a healthy old adult.

Also, when performing the cost-effectiveness analysis, we have considered different approaches such as the normalization of costs and issues; however, we realized that the resulting values did obscure the actual relation to either cost or actual issues, making it very difficult to interpret. Moreover, we considered performing an "issues per euro" analysis; yet such an approach was also problematic since the metric favored expensive equipment. That is, the more expensive the equipment, the less the issues/cost ratio. Similarly, very cheap equipment such as the Mouse always presents a very high (comparatively) issue/cost ratio. Therefore, in the cost-effectiveness analysis, we gave the same weight to issues and cost because (1) it is fairer to compare and (2) easier to interpret.

Moreover, the usage of assessment tools should be considered for additional qualitative data analysis such as the Individually Prioritised Problem Assessment (IPPA) and the Psychosocial Impact of Assistive Devices Scale (PIADS) to evaluate how technology impacts the daily life of PwD. Finally, some video recordings were corrupted and, although we also used written notes, some level of detail may have been lost.

To answer *RQ.1.2- Which interaction modalities are more intuitive for PwD?* We developed the first version of a stimulation tool using an AR setup, which had a set of activities designed to target cognitive and physical skills (see section 4.2). The purpose of the experiment was to study how PwD interact with an AR system while performing a variety of tasks through different interactions. Overall, participants enjoyed doing the activities and were able to complete these with a high success rate.

Nevertheless, assistance was occasionally provided to participants to complete the tasks. The number of assistance given is dependent on individual characteristics, such as cognitive and physical conditions. Also, during task completion, participants were able to remember and share interesting information regarding past events of their life. This is an important finding as it suggests that the participants were engaged while doing the tasks and that the activities developed can be used for stimulation purposes. Another goal of this study is to gather information to evaluate the usefulness of the AR system for stimulation purposes in PwD at initial to intermediate stages of dementia. According to the results of the questionnaires and interviews, therapists demonstrated high interest in using the system for their therapy sessions in the future. However, therapists showed some concerns regarding the appropriateness of some of the content presented for such a population.

Consequently, in section 4.3, we added a *Game Editor* that allows health professionals to create and customize activities to the patient's needs and preferences. Also, we developed *Musiquence* as being highly platform compatible as it supports different technologies besides AR, such as PC, Tablet, Interactive Tables, Kinect, and Leap Motion. As shown in section 4.1, PwD may have difficulties in using specific technologies (i.e., lack of experience, physical/cognitive related issues, anxiety, among other reasons, see section 4.1). Thus, health professionals can transfer the same set of activities to different technologies according to the cognitive profile, experience, and comfort of PwD.

In section 4.4, after developing a complete version of *Musiquence,* we performed a usability study of the *Game Editor* with health professionals to safeguard the quality of the platform. In general, participants were efficient in completing the proposed tasks without significant problems and were fast in doing so. The *Game Editor* did not lead to any stressful experience for participants. Overall, healthcare professionals rated the usability of the Game Editor as "good," despite the language barrier and minor functionality issues. One of the significant results retrieved from the experiment is that participants recognized the usefulness of the platform to customize activities for PwD. As stated in section 2.2, most of the existing software and technology platforms follow a generalized design approach that does not take into consideration the individual needs of PwD.

To conclude chapter 4, it is essential to involve healthcare professionals and PwD throughout the design process of the platform. The input and opinions shared by both healthcare professionals and PwD led to many iterations in the platform, which resulted in a fully functional therapeutic tool that can be used as a complementary tool to aid healthcare professionals and informal caregivers during the therapy session. In the next chapter, we will present a novel learning method based on musical distortions, which is based on the principle of preserved musical memory in PwD.

Chapter 5 – Developing a novel learning method through musical distortions

Chapter 5 discusses and answers *RQ.2 - Is it possible to develop a learning method through musical distortions?* The purpose of the learning method is to mobilize crystalized competencies such as musical memory and musical processing to support people with dementia (PwD) during decision-making while completing virtual activities. To answer the research question, we used *Musiquence* and performed two studies that involved PwD. The goal of the first study was to evaluate if PwD had better performance using music-based feedback than visual-based feedback (section 5.1). The goal of the second study is to explore the feasibility of this learning approach further while using (1) different distortion mechanisms and (2) different manipulations of musical parameters such as pitch, rhythm, and pitch-rhythm (section 5.2).

5.1 Is Music-based Assistive Feedback System better than Visual-Based Feedback? [6]

Taking into consideration that participants have intact musical memory and can identify musical manipulations (see subsection 2.1.1), we developed a novel learning method based on musical distortions to assist PwD in completing VR related tasks as independently as possible. Learning methods have already been developed to assist PwD in performing activities of daily living. Learning methods such as errorless learning, trial-and-error, modelling space retrieval, and vanishing cues have been proposed ([144], [145], see [146] for review). The errorless learning approach aims to prevent errors before committing them. The trial-and-error approach allows PwD to perform errors to learn from it. As for the modelling space retrieval tactic, PwD require to learn a task sequentially and reproduce the same task after a delay. Finally, the vanishing cues technique is used to help PwD to remember names or numbers by providing a letter/numbers as cues. However, the effectiveness of each learning method and the circumstances in which they should be applied is still debated by the scientific community, and further studies are needed [146]. Some of the learning methods mentioned previously have already been applied in a virtual reality serious game that aimed to stimulate activities of daily living [94]. This case study with one AD patient provided evidence that the participant was capable of learning activities related to cooking.

Based on the above findings, we designed an experiment that tested a novel learning method based on music. To test our hypothesis on whether the music-based learning method is feasible, we developed a quiz-type game where the participants had to select correct answers to questions. The goal is to guide AD participants to the correct answer, independently of their knowledge, through music or visual distortions. A similar approach was used in an upper limb rehabilitation study that combined music with error sonification, but in healthy participants [147]. With the proposed approach, our

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[6] Full study published at: Ferreira, L. D. A., Cameirão, M. S., & i Badia, S. B. (2017, June). Music-based assistive feedback system for the exploration of virtual environments in individuals with dementia. In 2017 International Conference on Virtual Rehabilitation (ICVR) (pp. 1-7). IEEE;

participants explore a virtual task while, at the same time, the musical distortion guides them in their decision-making.

5.1.1 Methods

Musiquence **quiz-type game**

The quiz-type game was developed using *Musiquence* and run on a 9" Android Tablet (GALAXY, Samsung, South Korea). It consists of general knowledge questions that need to be answered correctly in order to progress to the next question. All answers exhibited in the game are represented as images (see Figure 5.27). Both music and visual conditions have a well- known Madeiran song called "Bailinho da Madeira," playing in the background. As for the music condition, whenever participants tapped a wrong answer, the background sound was lowered, and white noise reproduced. Regarding the visual distortions, we used the free plug-in iTween from the Unity asset store. The plug-in allowed us to manipulate image parameters such as position and speed (see Fig. 24). The speed parameter of this plugin was responsible for the intensity of the distortion. The prototype stores all responses and touch events in a .CSV (Comma Separated Values) file.

(A) (B) (C)

Figure 5.27. **Musiquence quiz-type game.** (A) – Each question has four possible answers, which are displayed below. In the shown example, participants had to indicate the image of a car. (B) Visual distortion scenario. When the answer is wrong, the image becomes distorted, allowing participants to reconsider their decision. (C) Smiley Face: additional feedback confirming that the answer is correct. If incorrect, participants were encouraged to try again

The study was organized with the following phases:

- **Tutorial Phase:** The game has a tutorial so that participants can learn the game mechanics. The tutorial begins with verbal instructions from the game's system – "Press all images for 4 seconds". Here, we taught participants that pressing an image for 4 seconds allows them to select an answer. The tutorial has four random images, and participants are required to tap all of them to continue to the next phase, the instruction phase. Also, participants can repeat the tutorial by tapping a repeat button. No background music was being played during the tutorial, and both visual and musical distortions were disabled during this phase. After selecting the four images, a button was displayed that allowed participants to continue to the next phase.

- **Instruction Phase:** In the instruction phase, participants were briefed about the game's goal. The instructions were provided by the game. If participants had any doubts regarding the game's goal, the experimenter would repeat the instructions. Both game and experimenter advised participants to pay attention to musical/visual cues. However, they were never told what these cues were, nor how and when would present themselves throughout the experience.

- **Play Phase:** Both music and visual versions have ten levels; each level has one question and four possible answers, in which only one answer is correct. Hence, the probability of selecting the wrong answer is 75%, whereas selecting the correct answer is only 25%. By making some of the questions very challenging we made sure that participants would have to rely on the music/visual distortions at some point of the experience

When starting the game, participants had to listen to a question that was introduced verbally and in written form by the game. If participants did not interact with the device for more than 15 seconds, the volume of the background music would lower, and the system would repeat the question. Next, participants had to select with the finger one of the four possible answers. While the participant's finger presses an answer, a four-second countdown (that is displayed as a pie chart) was triggered, which is displayed above the answer. During these four seconds, if the answer is wrong, musical/visual distortions are activated, allowing participants to reconsider their decision. If the participant removed the finger from the answer before the countdown reached zero, the participant would be allowed to choose an alternative answer. When the countdown reached 0, participants received additional feedback confirming whether the answer was right or wrong (see example in Figure 5.27). This feedback was presented as a human voice saying "Very Good" if correct, or "Ohhhh, Try again" if wrong. Also, wrong answers would be marked with a red border indicating that the answer is incorrect and that it was already selected.

Participants

We recruited 8 participants (three males and five females) at the Portuguese Alzheimer's Association in Madeira. All participants were at an initial to moderate stage of dementia. Participants were included if they had (1) intact upper-limp movements, (2) an intact hearing, and (3) intact comprehension skills. Table 5.13 summarizes the characteristics of each participant. One participant (nr. 4) dropped out of the study due to a health-related problem not related to the study and was not included in the analysis.

Table 5.13. **Participants Demographics**

ID	Gender	Age	Schooling (Years)	Diagnosis	MMSE[e]	Stage[f]
1	Female	76	3	VD[a]	16	Moderate
2	Male	66	5	FTD[b]	25	Mild
3	Male	73	7	FTD	26	Moderate
4	Male	81	4	LB[c]	21	Mild
5	Female	67	6	AD[d]	14	Moderate
6	Female	73	3	AD	12	Moderate
7	Female	70	4	AD	17	Moderate
8	Female	76	4	AD	27	Initial
Mean (SD)		72.75 (5.007)	4.50 (1.414)	-	19,75 (5.800)	-

[a]Vascular Dementia [b]Fronto Temporal Dementia [c]Lewy Body [d]Alzheimer's disease [e]Mini mental State Examination
[f]Based on MMSE qualitative interpretation

5.1.2 Experimental design

We used a within-subjects experimental design. The experiment had two conditions: Music Distortion (MD) and Visual Distortion (VD). In the music distortion condition, the background music was manipulated with the addition of white noise. In contrast, in the visual distortion condition, visual elements of the game became distorted through visual motion. To avoid a learning effect, we developed multiple versions of the application with different questions. In total, four versions of the application were implemented (2 sets of questions x 2 types of feedback). Before the beginning of the study, all participants were randomly assigned to perform MD-1/VD-2, MD-2/VD-1, VD-1/MD-2, or VD-2/MD-1 while keeping conditions balanced. After finishing the experiment, participants were interviewed regarding their experience of the game.

5.1.3 Procedure

All participants (or legal guardian when applicable) signed informed consent before commencing the experiment. After signing the consent, participants were seated in front of a table in a quiet room. The presence of health professionals was sometimes required to monitor participants in more advanced stages of dementia. In case of difficulties, participants received assistance, but without interfering with the purpose of the experiment. We would encourage them to look for alternative answers in order to proceed to the next level. All participants went through three phases, (1) the Tutorial phase, (2) the Instruction phase, and (3) the Play phase, as described below.

5.1.4 Statistical analysis

We used the IBM SPSS statistics version 24 (IBM, New York, United States of America) for statistical data analysis. Non-parametric methods were used as the size of our sample is small. To compare the measurements of the dependent variables in the two conditions, we used the Wilcoxon signed-rank test.

5.1.5 Interviews

After the experience, we did a short semi-structured interview about the game. The main purpose was to gather additional information regarding the overall experience of the experiment. Because we were advised by health professionals against using a questionnaire with scales with these patients, we developed questions based on Yes/No answers with follow up questions. We asked participants if they (1) were generally satisfied with the activity, (2) recognized the music playing in the background, (3) felt active during the experience, and (4) perceived the musical and visual distortion during the game. All responses were voice recorded and later transcribed.

5.1.6 Results

All seven participants finished the experimental trial. We compared (1) the number of total errors, (2) the number of partial answers, and (3) the overall time spent by the participants in each condition. Figure 5.28 illustrates the total time spent by each participant and the partial answers made by the participants in both MD and VD conditions. Performance metrics in both conditions are presented in Table 5.14 For the following analysis, we considered the total number of errors, partial answers, and total time required to solve the task in each condition.

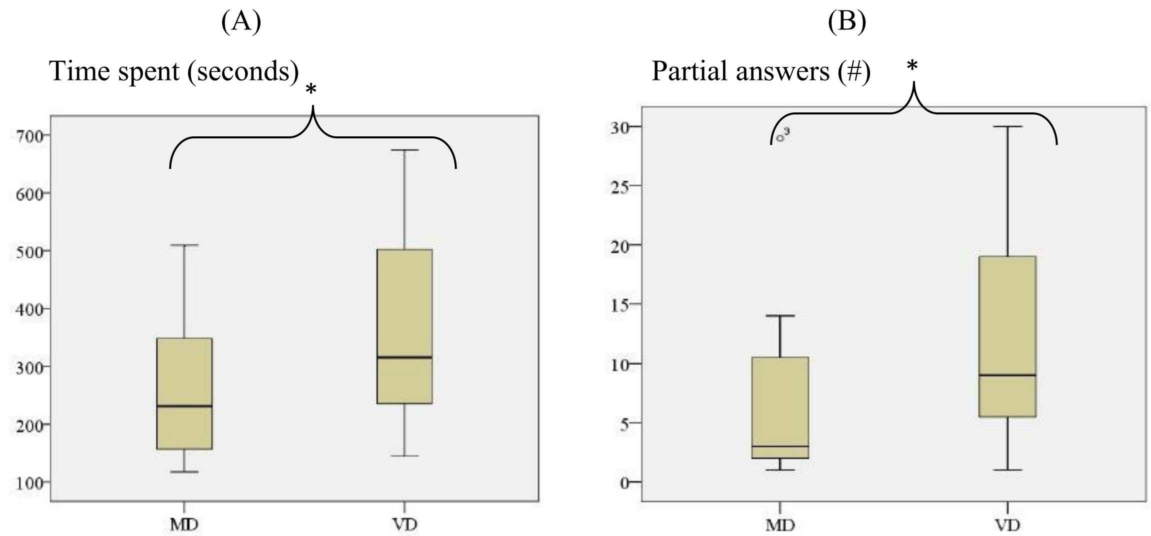


Figure 5.28. **Performance metrics.** Boxplots of (A) Total time spent in the MD and VD, and (B) Number of partial answers in the MD and VD. * indicates a statistically significant difference between conditions ($p < 0.05$).

Table 5.14. **Dependent variable measurements**

	Music Condition	**Visual Condition**
Total number of errors committed in both conditions by all the participants	45	60
Total number of partial answers committed in both condition by all the participants	58	89
Total time (seconds) needed to complete both conditions by all the participants'	1868.7	2610.4

Performance metrics

We extracted three different metrics that are used as the dependent variables in our experiment:

- **Errors:** we measured the total errors per participant in both music and visual condition in order to evaluate the performance. We have an error if these two conditions are fulfilled: (1) the answer is incorrect, and (2) the selection countdown timer reaches 0.

- **Partial Answers**: to evaluate which feedback system was more effective in preventing errors, we measured the count of partial answers per participant in both music and visual condition. We have a partial answer if the participant removes the finger from any answer before the countdown reaches 0.

- **Time:** we measured the total time (seconds) spent by each participant during both music and visual conditions. We accumulated the times for all levels of each condition, starting at the beginning of each level and stopping when participants completed the selection of the right answer.

The Wilcoxon Signed ranks test indicated that the total time necessary to complete all 10 questions in the MD condition (Mdn = 231.21 sec.) was significantly lower compared to the VD condition (Mdn = 315.627 sec.), Z = -2.197, p = 0.028, r = -0.6. However, the difference in the total number of errors made in the MD condition (Mdn = 7.0) compared to the VD condition (Mdn = 10.0) was non-significant, Z = -1.792, p = 0.073, r = -0.5. Interestingly, the number of partial answers made in the MD condition (Mdn = 3.0) was significantly lower when compared to the VD condition (Mdn = 9.0), Z = - 2.207, p = 0.027, r = -0.6.

Decision-making process

In order to assess differences in decision making due to the provided feedback, we computed the transition probabilities from game state to game state for both feedback conditions. Figure 5.29 presents all game states as a Markov chain, showing the probabilities of patients' actions depending on which state they are. For instance, Figure 5.29-A shows us that the probability of patients choosing a correct answer as the first choice in the music distortion is 46%. Similarly, when patients have previously selected a partial answer, with a 53% probability, they will perform a partial answer in the next action. Hence, this analysis allows interpreting patients' behavior in terms of the probability of their choices in a dynamic system.

Overall, we can see that the probability of answering correctly right away varies between 30-46%, of making a mistake varies between 21-26% and of partially selecting an answer is significantly higher in the VD condition (Mdn =4,0) with 49% than in the MD condition (Mdn = 2,0) with 28%, Z= -2,271, p=0.023, r=-0,5. Interestingly, we can observe that when a partial selection is performed, the probability of performing another partial selection is 53%, a behavior that is consistent with a search strategy exploiting the presented feedback.

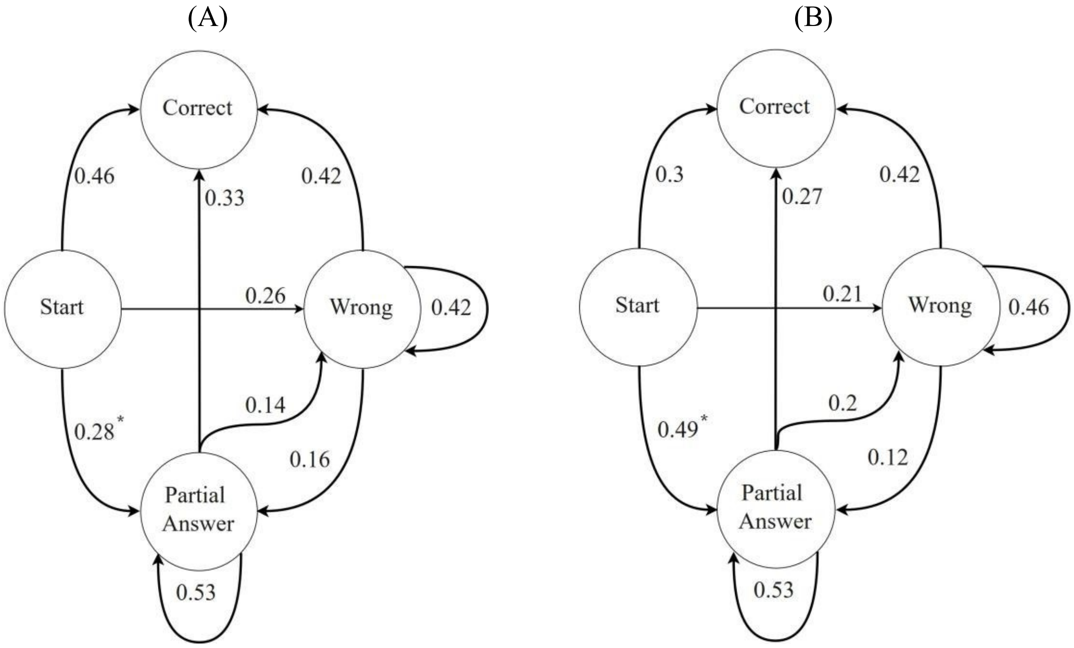


Figure 5.29. **Participants' decision making**. Markov chain representing the (A) general behavior of the participants' in the condition MD and (B) general behavior of the participants the significant difference between conditions (p < 0.05).

Interviews

When asked about their general satisfaction with the activity, all participants said that they liked the experience. When asked whether they were able to recognize the music that was playing in the background, participants number 1, 2, 5, 7, and 8 were able to remember the song's name. Also, we asked them how active they felt (if they thought the game was difficult, easy or confusing). In general, the participants reported that the overall experience was easy and not confusing. However, participants number 1 and 7 felt sometimes nervous when more difficult questions came up. Finally, we asked them if they noticed the musical and visual distortions.

Interestingly, only participant number 3 said to have noticed the distortions and was able to explain the relationship between distortions and wrong answers. Participant 5 recognized the distortions in both conditions but was not able to understand the relationship between the potential errors and the musical/visual distortions. In addition, participant 1 noticed and understood the meaning of the distortions in the music condition but not in the visual condition, while participant 7 noticed the distortion of the images but not the distortion of the music. The rest of the participants (2, 6, and 8) did not notice any distortions in either condition.

5.1.7 Discussion

Data gathered in this study supports our initial research hypothesis, as the general performance of the subjects in the music distortion condition was better than in the visual distortion condition. Despite the small sample size, we observed statistical differences in terms of time and partial answers, but not in terms of total errors committed. Moreover, the number of total errors in the visual distortion condition was also higher than in the music distortion condition, although this difference was not statistically significant. Thus, from this evidence, we can conclude that, in this particular experiment, visual distortion was not as effective as a guidance system compared to the musical distortion.

Despite the heterogeneity of our sample in terms of types of dementia and cognitive stages, when we analyze individual cases, we can observe that only participant 3 was faster in the visual distortion condition than in the music distortion condition. In terms of total errors accumulated, participant 3 made more errors in the musical distortion condition than in the visual condition. Participant 6 had the same performance in both conditions. Interestingly, regarding the number of partial answers, participant 6 made more partial answers in the visual distortion condition, while participant 2 tied. Hence, despite a clear statistical preference in favor of music, our data also suggest that this may be participant dependent. We also analyzed the participant's general behavior through a Markov diagram. Although there is only a single significant statistical difference in the decision-making process between conditions, participants in the MD condition had a higher chance to go from a partial answer to a correct answer when compared to their performance in the VD condition.

In some cases, participants were exploring all possible answers before tapping the correct answer, evidenced by a very high probability of consecutive partial answers. Thus, one possible interpretation of such behavior is that participants were developing strategies in order to find the right answer. Also, we noticed that participants in the VD condition went from a partial answer to the wrong answer more often than in the MD condition. A possible explanation for the lower effectiveness of the VD could be that the visual distortions were too intrusive, which could lead to confusion. Nevertheless, our observations indicate that sometimes participants also ignored the distortions in both conditions and selected wrong answers.

During the interview, participants reported that they did enjoy the experience and that they were, in general, comfortable playing the game. Although two participants reported feeling anxious when more challenging questions appeared, they were still capable of continuing the game. The majority was able to remember the music correctly. The majority sang the lyrics of the song during the experiment. Nevertheless, when asked about the distortions, we were surprised by the fact that only participant number 3 was able to recognize and understand the meaning of the musical and visual condition. This participant was one of the two that were not able to recognize the name of the song but still paid attention to its distortions.

It should be noted that this patient, with frontotemporal dementia, had language impairments. Sometimes this required the assistance of the health professionals to confirm his responses. Some participants partially perceived distortions. While participant 1 did perceive and understand the meaning of the distortions in the music condition, participant 7 only perceived distortions in the visual condition. The latter, when asked about her interpretation of such distortions, replied, "*It was shaking* (distorted) *because it was alive*."

It is also possible that explicit memory impairments could have interfered with the recall during the interview. Explicit memory is "*the ability to consciously and directly recall or organize recently processed information*" [8] (see section 1.1). However, it is also possible that implicit memory - which "*reflects the unconscious effects of previous experiences on subsequent task performance, without conscious recollection*" [8] - was used in our game. Thus, one possible explanation could be that participants exploited the information gathered by the distortions, but unconsciously. This would be supported by some of our observations. There were moments in which participants were exploring alternative answers before tapping the correct one without committing any errors, just partial selections. One particular case, participant 7, sometimes clearly reacted to either of the distortions presented in the musical and visual distortion conditions. Patient 7 reported, “*I do not understand why this image is shaking.*” However, the opposite was also true; there were moments in the game where participants completely ignored the distortions and committed errors.

We also noticed that some participants were sometimes confused with the audio instructions of the prototype. Whenever a participant tapped a wrong answer, the audio feedback said, "Ohhhhhhh, try again." However, some participants thought they had to select again the same answer despite a visual cue indicating that the answer was wrong. Although these were excluded from the analysis, we cannot be sure that it did not bias our results.

5.2 Is it possible to enhance performance using different musical distortions?

In order to verify if PwD can enhance performance using different musical distortions, we run a study that is an extension of the previous section (section 5.1). Considering that the proposed learning method is novel, we performed additional research exploring different types of distortion mechanisms based on tapping and distance as well as different music manipulations – pitch, rhythm, and pitch-rhythm. The study discussed in this section addresses the following aspects:

- Is there a musical distortion that was more effective?
- Is there a difference in performance per task?
- Is there a difference in performance between organic and non-organic dementia?
- Does age, schooling, and cognitive state influence task performance?

5.2.1 Methods

Technology used during the experiment

In this experiment, we used *Musiquence* configured for projection-based AR as the activities can be projected on bigger surfaces and support user inputs through real objects and upper limbs. *Musiquence* relied on AnTS, which allows the detection of physical markers. To detect the markers, we used a PSEye camera. Also, to track real-life objects', a marker can be attached to the object (see Figure 5.30 A-B). To project the game on the table, we used an Optoma projector (Optoma Corporation, Taiwan). We also covered the table with white paper to enhance visual contrast when projecting the game on the surface (see Figure 5.30 A-B).

Developed activities and improvements

For this study, we used three types of activities – Knowledge Quiz, Search Objects, and Association, as previously mentioned in subsection 4.3.1. We configured the response timer of *Musiquence* to be four seconds. We also added a new feature for the Quiz Knowledge activity, which is described below.

Knowledge Quiz activity. Participants had to select the correct answer among the three wrong answers. To finish the activity, participants had to answer 15 questions correctly. Also, when the participants selected a wrong answer, the answer would be removed from the game. Thus, we assure that participants no longer focus on the wrong answer as it happened in the previous study (see section 5.1.7).

(A) (B)

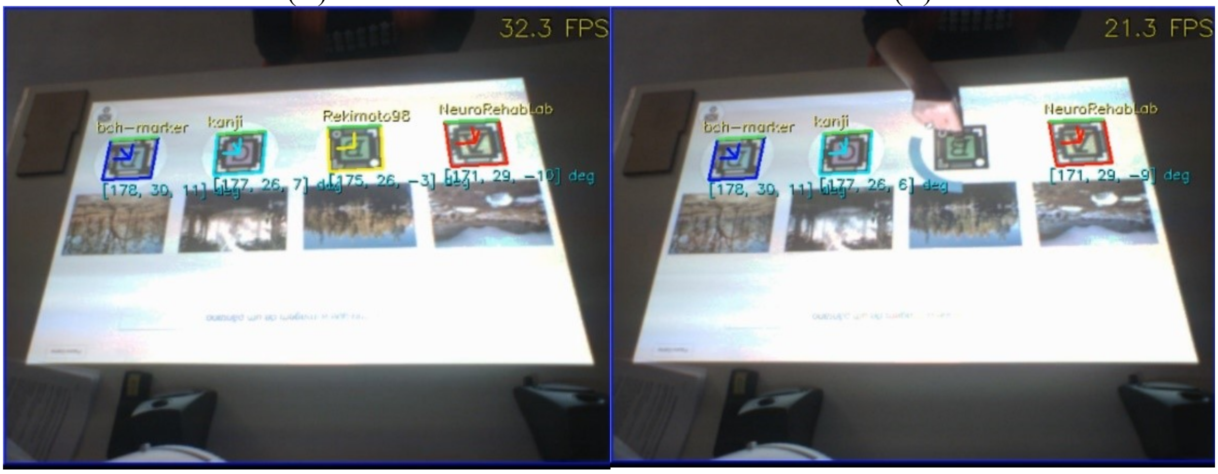


Figure 5.30. **Knowledge Quiz Activity**. (A) AnTS detecting markers (blue, green, yellow, and red) of the activity. (B) Participants occlude the markers with upper-limb movements. A 4-second timer triggered when the participant selects an answer.

Search Objects activity. Participants had to uncover 15 hidden images using a virtual magnifying glass before the end of 16 minutes (see Figure 5.31).

(A) (B)

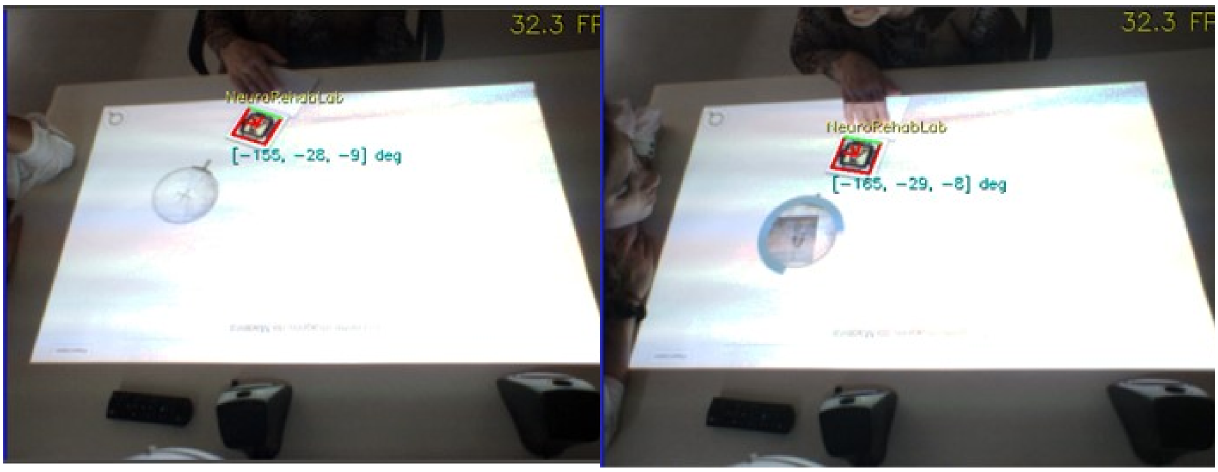


Figure 5.31. **Search Objects activity.** (A) participant searching for the hidden images through the virtual magnifying glass controlled by a wooden object with a marker that is being detected by AnTS. (B) A 4-second timer is trigged when the magnifying glass overlaps the hidden image.

Association activity. Participants had to categorize 16 images correctly to each container (see Figure 5.32)

(A) (B)

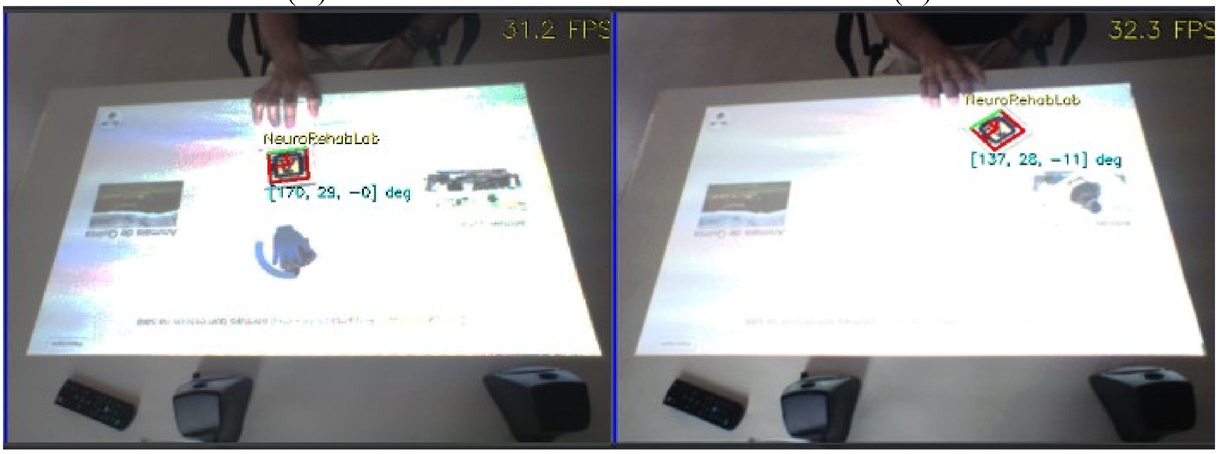


Figure 5.32. **Association Activity**. (A) A 4-second timer trigged when the "virtual hand" overlaps the image. After four seconds, the image is attached to the "virtual hand". (B) The participant is dragging the image to the correct container using the wooden piece.

We invited 18 participants to perform the study. Eight participants were from the Casa de Saúde São João de Deus (CSSJD), while the remaining 10 were from both Centro de Dia da Nazaré (CDN) and Casa de Saúde Câmara Pestana (CSCP). The participants from CSSJD were diagnosed with non-organic dementia (N-OD) (i.e., dementia due to Alcoholism abuse, see section 1.1). In contrast, participants from CDN and CSCP had organic dementia (OD) (i.e., Alzheimer's Disease, see section 1.1). The participant's demographic is shown in Table 5.15. Participants were included if they met the following eligibility criteria (1) initial to intermediate stages of dementia; (2) upper limb mobility; (3) visual and auditory acuity; and (4) intact comprehension. Participants were not admitted in the experimental trial if (1) they were in advanced stages of dementia, (2) suffer from major psychiatric disorders, (3) cannot use upper limbs independently, and (4) are bedridden.

Table 5.15. **Participants Demographics**

Organic Dementia					**Non Organic Dementia**			
ID	MMSE	Age	Schooling	Diagnosis	MMSE	Age	Schooling	Diagnosis
1	19	65	4	Frontotemporal Dementia	24	55	7	Schizophrenia
2	14	69	5	Frontotemporal Dementia	26	66	12	Undefined Psychosis
3	27	59	12	Alzheimer's disease	27	62	12	Alcoholic Amnesia
4	15	86	3	Alzheimer's disease	28	62	8	Alcoholic Amnesia
5	23	80	3	Alzheimer's disease	23	83	6	Alcohol dependence

6	17	78	4	Alzheimer's disease	24	75	4	Alcohol dependence
7	26	79	4	Alzheimer's disease	26	71	4	Alcohol dependence
8	21	79	-[a]	Alzheimer's disease	13	73	-[a]	Delirium
9	9	88	4	Dementia				
10	11	77	3	Alzheimer's disease				
M±SD	18.20 ± 6.11	76.00± 9.08	4.67 ± 3.05	-	23.88 ± 4.70	68.38 ± 8.88	7.57 ± 4.10	-

[a] Participant 8 from OD and participant 8 from N-OD do not have formal schooling.

5.2.2 Using different distortions and behaviors

In this study, we used a well-known folkloric Portuguese song - "O Malhão" – as background music. Then, we adapted *Musiquence* feedback system to add musical distortions by manipulating music in terms of pitch (pitch without changing BPM), rhythm (changing BPM only), and pitch-rhythm (pitch while changing BPM) as previously described in section 4.3.4.

In the Knowledge Quiz activity, if participants selected the wrong image during the 4 seconds, the background music became distorted. If participants deselected the answer before 4 seconds, music would normalize again. In the Search Objects activity, the higher the distance between the wooden piece and the hidden image, the higher the distortion; the music normalizes as the distance diminishes and normalizes completely when the magnifying glass overlaps the answer. As for the Association activity, the music distorts as the user drags the wooden piece to the wrong container and normalizes when approaching to the correct container.

5.2.3 Procedure

Before starting the study, we collected the most recent assessment of patients' cognitive impairment using the Mini-Mental State Examination (MMSE) [136]. We used a within-subject experimental design so that participants would be exposed to all experimental conditions. Participants were randomly exposed to activities and musical feedback modalities. For each activity (Knowledge Quiz, Search Objects, and Association), four experimental conditions were created with the following musical feedbacks: non-distortion, pitch-rhythm, pitch, and rhythm. The non-distortion condition does not have any musical distortion; it was used as a control condition to compare performance metrics with the remaining musical distortions. Also, all experimental conditions (in each activity) presented different questions and images to avoid repetition of content (see Supplementary Material Table 6, Table 7, and Table 8). The images were displayed in a 4:3 ratio format.

We used the following protocol during the experiment: (1) the researcher cannot interfere during the experiment to help the participant find the right answer, (2) if the participant requires help with a question, the researcher encourages the participant to find the right answer; and (3) the system provides the instructions of the activity. If the participant does not understand the instructions, the researcher can repeat them verbally, (4) the researcher can intervene if there is a technical problem, and (5) participants are never informed about the type nor the purpose of musical feedback. Participants were only instructed to be aware of the "sound cues."

Before the beginning of the experimental trial, participants did a tutorial session to learn the interaction mechanics of each activity. Background music was played but without any musical distortion. Also, both the researcher and two psychologists were in the room to oversee the experimental trial.

5.2.4 Instruments and metrics

To address the different aspects of this study, we used (1) log files exported from *Musiquence* and (2) direct observations through video recording; we used the Camtasia Studios Screen Recorder feature (TechSmith Corporation, USA) that allowed us to screen capture participants' performance through the PSEye webcam.

Participants' task performance was measured through the following variables from each experimental condition:

1. Time – we gathered the time (in seconds) required to finish all the tasks.

2. The number of errors committed – we counted the number of errors that participants committed in the Knowledge Quiz and Association Activity.

3. The number of images found - we counted the number of images found by the participants. This variable is only considered in the Search Objects activity.

5.2.5 Data analysis

For data analyses, we used the Statistical Package for the Social Sciences 24 (SPSS.20). Considering that we have a small sample, non-parametric statistical tests were used. Descriptive results are presented as median and Standard Deviation (Mdn ± SD). For assessing differences among experimental conditions, the Friedman test was used. For post hoc pairwise comparisons, the Wilcoxon signed ranks test was used. For the evaluation of two non-parametric independent samples, we used the Mann-Whitney U test. For non-parametric correlations, we used the Spearman's rank correlation coefficient.

5.2.6 Results

In the OD group, all participants finished all tasks, except for and ID2 (only performed the Pitch condition in the Quiz Activity), ID6 and ID7 (both partially completed the non-distortion condition of the Search Objects activity) and ID6 did not do the rhythm condition of the Search Objects activity.

Is there a musical distortion that was more effective?

We analyzed which feedback was, in general, more beneficial for both groups. When considering all tasks, the time to finish the tasks was significantly influenced by the presence of musical distortion (χ^2 (3) = 9.141, p = 0.027). Post hoc analysis revealed that participants were faster in completing the tasks in the presence of rhythm-based distortion (Mdn = 1403,271) than in the non-distortion condition (Mdn = 1828,548), (Z= -2.580, p=0.010, r = -0.4). In addition, among the distortion systems, participants were faster in completing the tasks in the pitch condition (Mdn = 1512,441) than in the pitch-rhythm condition (Mdn = 1560,645), (Z= -1.965, p= 0.049, r = -0.3).

Is there a difference in performance per task?

We analyzed each group's performance while using musical distortion. In the OD group, we found statistically significant differences in number of images found in the Search Objects activity (χ^2 (3) = 8.750, p = 0.033), number of errors committed in the Association activity (χ^2 (3) = 8.165, p = 0.043) and time to finish the tasks in the Quiz Activity (χ 2 (3) = 10.200, p = 0.017).

Post hoc analysis revealed that, in the Search Objects activity, participants found more images in the pitch condition (Mdn = 15,00) than in the non-distortion condition (Mdn = 4,00), (Z= -2.371, p= 0.018, r = -0.6). Regarding the number of errors committed in the Association activity, participants made more errors in the non-distortion condition (Mdn = 5,00) than in the rhythm condition (Mdn = 2,00), (Z= -2.124, p= 0.034, r = -0.5); also, in the same activity, participants made less errors in the rhythm condition (Mdn = 2,00) than in the pitch condition (Mdn =5,00), (Z= -2.319, p= 0.020, r = -0.5).

Lastly, in the Knowledge Quiz activity, participants were faster in the non-distortion (Mdn = 424,162) than in both pitch-rhythm (Mdn = 453.131) and pitch condition (Mdn = 388.707), (Z= -2.547, p= 0.011, r = -0.6) and (Z= -2.310, p= 0.021, r = -0.5) respectively. In the N-OD group, we did not find any statistical differences in task performance using different musical feedbacks.

Is there a difference in performance between groups?

We compared the performance of the OD and N-OD groups and found out that participants in N-OD (Mdn = 15.00) found more images than the OD group (Mdn = 4.00) in the Search Objects activity using non-distortion stimuli, U = 9.500, p = 0.006, r = -0.5. Moreover, in the Association activity, participants in the N-OD (Mdn = 345.094) where faster in finishing the tasks using pitch stimuli than in the OD (Mdn = 647.618), U = 12.000, p = 0.021, r = -0.4. Also, N-OD (Mdn = 413.461) were faster in finishing the same activity using pitch-rhythm stimuli than OD (Mdn = 672.270), U = 14.000, p = 0.034, r = -0.4

Does age, schooling, and cognitive state influence task performance?

We examined the relationship between task performance and patient profile – age, schooling, and cognitive state (MMSE) - in each musical feedback (Table 5.16). In the non-distortion condition, we found a significant correlation in all parameters except between (1) age and the number of errors committed

In the pitch - rhythm condition, we found statistical differences in all parameters except in (1) schooling and the number of images found and (2) age and the number of errors committed. In the pitch condition, we found a statistical correlation in all parameters except in (1) MMSE and the number of images found, (2) schooling and the number of images found, (3) age and the number of errors committed, and finally (4) schooling and the number of errors committed. Lastly, in the rhythm condition, we found a statistical correlation in all parameters except (1) schooling and the number of images found, (2) age and the number of errors committed, and finally (3) schooling and the number of errors committed.

Table 5.16. **Correlation between Task Performance and Patient Profile in each Experimental Condition**

		Patient Profile		
Experimental Condition	**Task Performance**	**MMSE**	**Age**	**Schooling**
Non-Distortion	Time	r_s= -.811, p<.001*, N= 17	r_s= .745, p=0.001*, N= 17	r_s= -.808, p<.001*, N=15
	Number of images found	r_s= .607, p=0.010*, N=17	r_s= -.706, p=0.002*, N=17	r_s= .623, p=0.013*, N=15
	Number of errors committed	r_s = -.658, p= .004*, N=17	r_s = .400, p= 112, N=17	r_s = -.530, p=.042*, N=15
Pitch-Rhythm	Time	r_s= -.830, p<.001*, N=17	r_s= .686, p=0.002*, N=17	r_s= -.760, p=0.001*, N=15
	Number of images found	r_s= .628, p=0.007*, N= 17	r_s= -.512, p=0.036*, N=17	r_s= .335, p=0.223, N=15
	Number of errors committed	r_s= -.779, p<.001*, N=17	r_s= .404, p=0.108, N=17	r_s= -.540, p=0.038*, N=15
Pitch	Time	r_s= -.568, p=0.014*, N=18	r_s= .695, p=0.001*, N=18	r_s= -.649, p=0.007*, N=16

	Number of images found	r_s= .225, p=0.386, N=17	r_s= -.505, p= 0.039*, N=17	r_s= .163, p=0.561, N=15
	Number of errors committed	r_s= -.765, p<.001*, N=18	r_s= .282, p=0.257, N=18	r_s= -.448, p=0.082, N=16
Rhythm	Time	r_s= -.779, p<.001*, N=17	r_s= .639, p=0.006*, N=17	r_s= -.643, p=0.010*, N=15
	Number of images found	r_s= .512, p=0.043*, N=16	r_s= -.603, p=0.013*, N=16	r_s= .380, p=0.181, N=14
	Number of errors committed	r_s = -.599, p=.011*, N=17	r_s = .216, p= .405, N=17	r_s = -.361, p= .187, N=15

(*) Statistical differences. White fields represent no statistical differences

5.2.7 Discussion

The study involved 18 PwD, of which 8 participants had dementia caused by substance abuse (non-organic), and 10 participants had dementia, such as Alzheimer's disease, due to organic causes. Both groups performed a set of activities that provided musical distortion as feedback to avoid erroneous decision making.

To assess if there is a musical distortion that was more effective, we analyzed which musical distortion had a more significant impact on participants' performance compared with non-distortion conditions. Participants finished the tasks faster in the rhythm condition than in the non-distortion condition. Also, within the musical distortions, participants were faster in completing activities using pitch than pitch-rhythm based feedback. This suggests that participants were, in general, able to use it in their benefit better to complete the tasks.

To evaluate if there is a difference in performance per task, we analyzed performance using musical distortion per task in both OD and N-OD groups. In the OD group, we have seen enhanced performance when using musical distortion compared to the non-distortion condition. In the Search Objects activity, participants did find more images using pitch than non-distortion. Similar capacities in detecting pitch-based distortions (without rhythmic changes) have been observed in the study Cuddy *et al.* [58] (see section 2.1.1), in which a person, who was diagnosed with advanced Alzheimer's disease, was able to attain (almost) perfect score in the Distortion Tune Test by identifying pitch distortions in melodies.

In the Association activity, participants in the OD group did fewer errors using rhythm-based distortions than non-distortion. Also, the same participants avoided more errors using rhythm than pitch-based distortions. These results suggest that, in general, OD participants can recognize rhythmic changes in music. Such results are consistent with a case study described by, for example, [62] in which a patient with Alzheimer's disease was able to identify rhythmic changes on the Montreal Battery for Evaluation of Amusia (see section 2.1.1). It also suggests the successful engagement of spared corticocerebellar networks that are activated during the processing of rhythmic stimuli [63], [64] (see section 2.1.1).

Surprisingly, in the Knowledge Quiz activity, participants performed better in the non-distortion condition than in the pitch-rhythm and pitch conditions. In contrast to the Search Objects and Association activities, Knowledge Quiz activity had intermittent feedback based on wrong selection, while the other activities had continuous progressive distortion feedback based on distance Consequently, our data suggest that the use of continuous progressive distortion feedback is effective. However, intermittent feedback leads to confusion. We hypothesize that most participants interpreted intermittent feedback as being the correct answer. An alternative explanation is that participants identified distortions as being something odd but were not able to react appropriately to the cues. This is consistent with the behaviors of some participants that reacted to the musical distortions by raising the hands from the marker to then returning the same on the marker.

However, some participants did notice and interpreted the sounds correctly but were not able to respond appropriately. For example, participants ID4 and ID6 from the OD group reacted to the sound and questioned the psychologist by asking, *"This is wrong, is it not?"*; participants 8 would occasionally put her hand on the marker and then raise it again.

As for the N-OD group, no differences were found in performance per task while using musical distortions, and participants were able to complete the tasks independently of the presence or absence of musical feedback. Taking into account that the N-OD group had higher MMSE scores (23.88 ± 4.70) than the OD group (18.20 ± 6.11), we hypothesize that participants in the OD group experienced more difficulties in performing the tasks and relied more on musical distortion guidance as a compensatory strategy.

Concerning the performance differences between organic and non-organic dementia, participants in the N-OD group performed, in general, better than in the OD group by finding more images in the Search Objects activity using non-feedback. Also, in the Association activity, N-OD finished the tasks faster using pitch and pitch-rhythm distortions. Again, this can be expected as participants in the N-OD presented less cognitive deficits than participants in the OD and, consequently, performed the activities more efficiently. Similar conclusions were drawn by H. Alvseike and K. Brønnick [109].

Finally, to evaluate if age, schooling, and cognitive state influence task performance, results show that music influenced participants' task performance. Our results suggest that participants with higher scores in MMSE - and consequently with less cognitive impairment - needed significantly less time to finish the activities, found more images, and committed fewer errors in the rhythm, pitch-rhythm, and non-distortion conditions. Moreover, they committed significantly fewer errors in the pitch condition. Also, older participants took significantly more time to finish the activities and found fewer images in all the conditions. Finally, higher levels of schooling significantly correlated to less time to finish the activities in all the conditions, to find more images in the non-feedback condition, and to commit fewer errors in the pitch condition.

Interestingly, if we analyze the results obtained in the pitch and rhythm condition, we can see that no statistical significance was found between age, schooling, and number errors committed. Also, we did not find a correlation in the pitch condition between cognitive state (MMSE), schooling, and the number of images found.

These results could suggest that musical distortions enhanced participants' performance by compensating some of the factors of the patients' cognitive profile that correlated with performance when no musical performance was present. Although more studies are needed, this would be consistent with some studies that suggest a positive influence of music in attention and executive functions [74] (see section 2.1.1).

5.3 Chapter discussion and conclusion

Chapter 3 intended to answer *RQ.2 Is it possible to develop a learning method through musical distortions?* To answer *RQ.2*, we had to answer the following sub-questions.

To answer *RQ.2.1 - Is Music-Based Assistive Feedback System better than Visual-Based Assistive Feedback?* We performed an experiment that studied the advantages of music distortion feedback in PwD (see section 5.1). The results of the first experiment were encouraging despite the heterogeneity and small sample.

The results of this study show that participants had better performance through music-based feedback than visual-based feedback. Overall, participants were more efficient in completing a Quiz game in the music distortion condition than in the visual condition in all measured parameters. Participants were faster and committed fewer errors, which suggests that they noticed and used to their advantage the musical distortions.

Although participants noticed the visual distortions as well, the performance was worse. One possible explanation for the worsening of performance is that it was too intrusive and led to more confusion than guidance. Interestingly, we observed both behaviors in both experimental conditions – music and visual – in which participants also behaved correctly to the feedback. Sometimes participants completely ignored the distortions, leading to errorful behaviors. Another interesting observation was that most participants did not remember hearing nor seeing the feedbacks. Such behavior was most likely due to the impairments of explicit memory, which is one of the signs of dementia (see section 1.1).

To answer *RQ.2.2 - Is it possible to improve performance using different musical distortions and interactions?* We further explored the feasibility of this learning method by performing a second experiment using different distortions and interaction modalities (section 5.2). Results show that, in general, participants' performance enhanced with musical distortion while completing the tasks. Nevertheless, the experience revealed as well that participants' cognitive profile influenced performance.

Although the N-OD performed better than the OD, patients with organic dementia enhanced performance with rhythm and pitch distortions in the Search Objects and Association activities. Results suggest that the presence of musical distortions could have compensated dementia-related deficits.

We found out that how musical distortion is presented can influence performance. For example, in the Knowledge Quiz activity, results show that participants were faster in finishing the tasks using non-distortion than pitch-rhythm and pitch. In this activity, musical distortion was presented only when the participants tapped the wrong answer as opposed to the Search Objects and Association activities, in which musical feedback was presented continuously.

Despite our findings, we identified some limitations in the study. First, although the order by which the participants performed the activities was randomized, the same activities always corresponded to the same musical distortions. For example, in the Search Objects activity, the different tasks had different backgrounds that could demand higher or lower levels of selective attention to perform and finish the task. Consequently, some conditions could be more cognitively demanding than others. Since the difficulty of all the activities could not have been equivalent, we cannot rule out the possibility of participants performing better due to the difficulty of each task and not due to the musical distortion associated with them.

Second, the use of a 4-second timer to select the answers may not have been enough time for the participants to interpret the musical distortion, acknowledge that the answer was wrong, make the decision, and initiate the behavior of changing the answer. In the Knowledge Quiz activity, several participants seemed to be aware of the distortion, and one of our participants verbally reported to think that the answer was wrong. However, they did not change the selected answer. Finally, it is challenging finding PwD with a formal diagnosis, which limited the number of participants of our study. For this reason, we included participants that were institutionalized and from outpatient care, which increased the heterogeneity of our sample.

As a future study, it would be interesting to analyze if PwD in more advanced stages can also use musical distortion as a compensatory mechanism. Also, it would be valuable to include a healthy control group for comparison. Also, it would be interesting to compare and analyze the pros and cons of the music-based learning system with other existing learning systems, such as errorless learning, errorfull learning, vanishing cues, among others.

To conclude chapter 5, the studies presented above show that it is possible to use a learning system of this nature. Participants in both studies enhanced performance using this learning method. This is the first time, as far as we know, that the advantages of music distortion feedback are studied in PwD. Nevertheless, more studies are required to explore its feasibility further.

Chapter 6 – Deployment and impact assessment of *Musiquence* on cognitive function in PwD

Chapter 6 discusses and answers the last research question of the dissertation- *RQ.3*) *What is the impact in cognitive function when using our therapeutic game?* To answer this research question, we run two studies that involved people with dementia (PwD) and healthcare professionals from several Portuguese institutions. We performed a pilot longitudinal study to assess the therapeutic impact of the cognitive stimulation program using *Musiquence.* We aim to assess cognition (e.g., attention, memory, and language), behavioral domains (e.g., anxious and depressive symptoms), functionality, and quality of life (section 6.2.). Nevertheless, to design the study, we had to gather in-depth quantitative and qualitative data regarding the personal experience and preferences of PwD past life in the context of a cognitive stimulation program (see section 6.1).

6.1 How do we create reminiscence and music-related activities?

In this participatory design study, we aim to develop a customized cognitive stimulation program for PwD to assess the impact of music and reminiscence in PwD using *Musiquence*. To develop and customize activities using the platform, we invited both formal caregivers and PwD in the creative process to uncover the needs and preferences of this clinical population. This study was done with the corporation of a clinical psychologist.

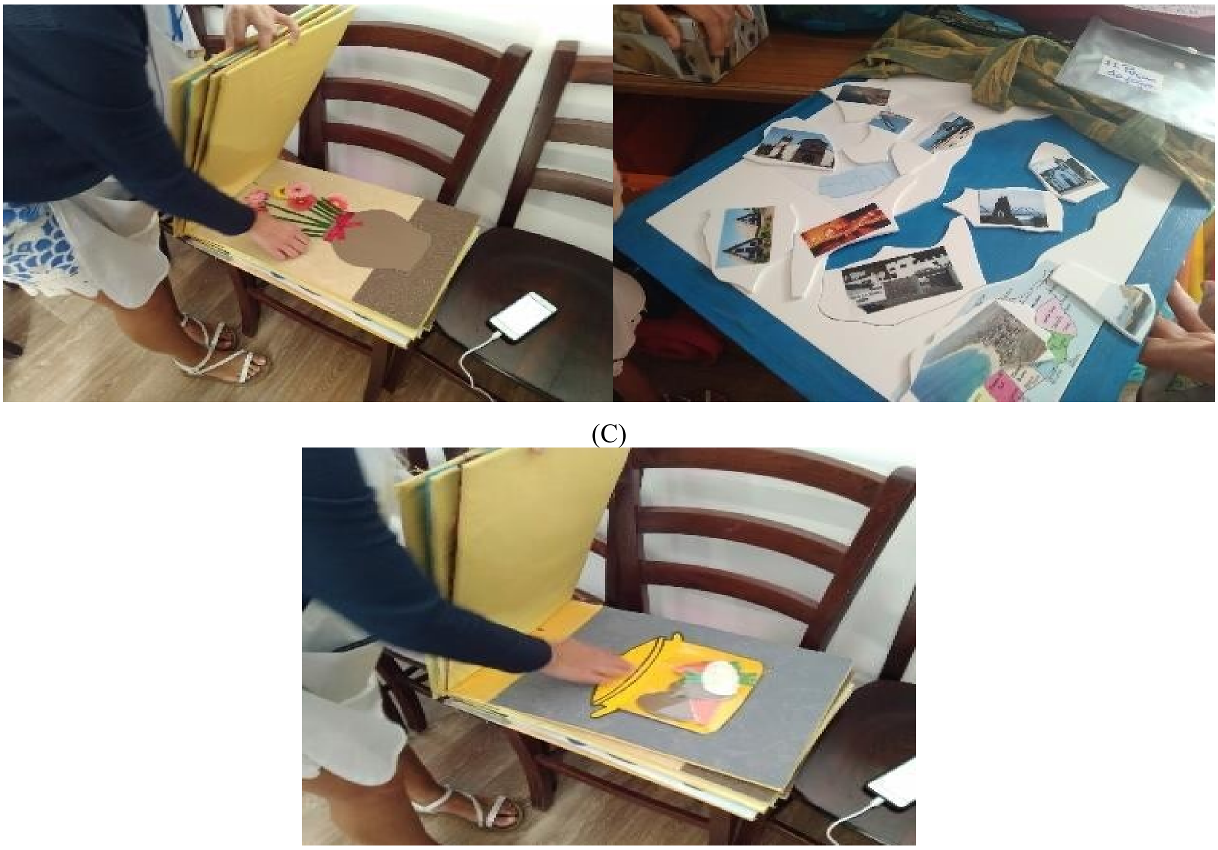
6.1.1 Methods

When confronted with the need to develop a customized clinical intervention with *Musiquence*, emerged the necessity to obtain a set of familiar and preferred themes and songs to be used as content of cognitive stimulation activities for PwD living in Centro Social e Paroquial de São Bento – Ribeira Brava. Although *Musiquence* allows individualized content personalization, within the context of a clinical intervention study, we opted to use the same content for all the study participants in order to avoid bias in assessing its impact and validity. We have followed a participatory approach with the following aims: 1) to know the most used themes and songs by formal caregivers on developing activities for PwD and 2) to find the preferential themes and songs through the active participation of PwD. Through this participatory methodology, we aim to identify the preferential themes of PwD living in Madeira-Portugal on cognitive stimulation activities and incorporate them in a longitudinal intervention with *Musiquence*.

6.1.2 Interviews with formal caregivers

Given the specificities of the target population, we approached institutions with expertise in the care of PwD in the Centro Social e Paroquial de São Bento. Through the clinical board, we had access to the professionals who regularly develop activities for PwD, which were from diverse backgrounds (such as psychologists, nurses, physiotherapists, music therapists, and occupational therapists). In total, we invited 19 formal caregivers (1 male and 18 females), with ages between 14 and 45 years old (M= 31,7 ; SD=7,17) and 12 to 17 years of formal education (M=15,33; SD=1,63) to list the most used themes and songs when developing activities for PwD. We gathered with small focus groups (4-5 elements) and asked them about the type of activities they performed with PwD, and the topics approached within those activities (Figure 6.33– (a), (b), (c)). Then, we identified a set of topics (e.g., Christmas) that originated themes (e.g., Festivities). As the presentation of several songs to order by preference could be a confusing and challenging process for PwD, leading to biased results, we decided to use the most voted songs by the formal caregivers.

(A) (B)



(C)

Figure 6.33. Themes and activities used by formal caregivers for cognitive stimulation of PwD.

6.1.3 Interviews with PwD

From the themes referred by the formal caregivers, the most voted ones were presented to 20 PwD (9 males and 11 females), with ages between 55 and 86 years old (M=74; SD=9,62) and 3 to 17 years of formal education (M=6; SD=4,18). From the 20 PwD, 15 lived in an institutional context and 5 in a community context. The most voted themes were presented to the PwD, using a combination of a written subtitle and four representative images per theme (Figure 6.34). Researchers went through all images with the PwD to ensure that every participant associated the same meaning to each image. PwD had to select every image, one by one, by order of preference. According to the order selected by PwD, a position was attributed to the images (the first was the preferred image, and the last was the least preferred) (Figure 6.35).

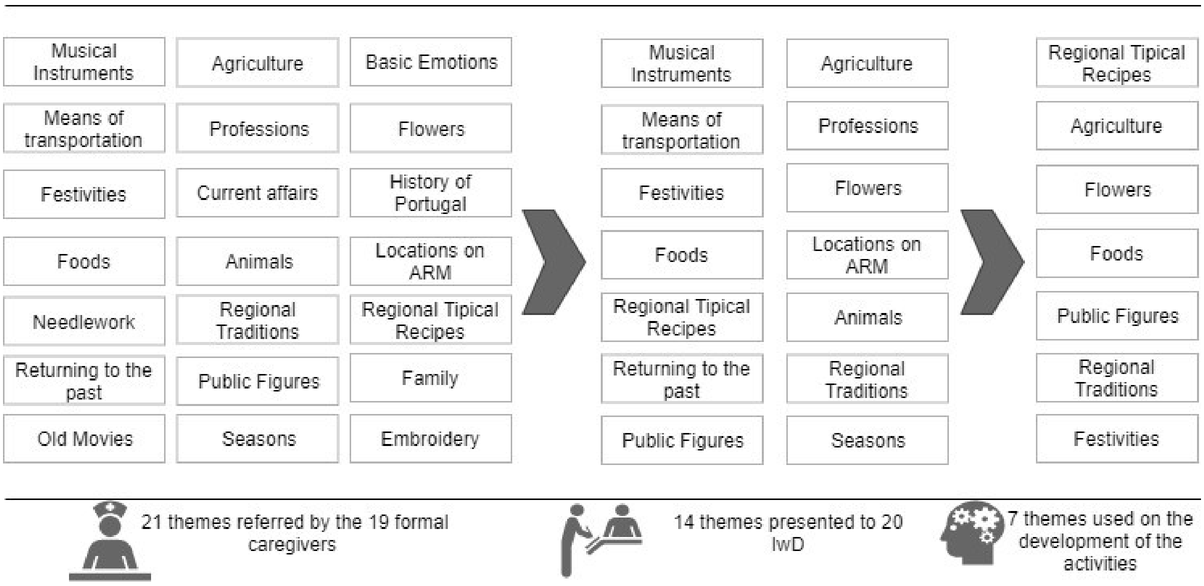


Figure 6.34. The participatory design process for the theme's selection

(A) (B)

Figure 6.35. (A) Presentation of the most mentioned themes to PwD, using verbal and visual information. (B) The Researcher went through the images together with PwD to assure that they all assigned them the right meaning.

6.1.4 Development of the Activities

To select the preferred themes, we calculated the mean and standard deviation of the positions of the four images of each theme. Then, we ranked the themes by the mean of their four representative images – lower means corresponding to the preferred themes. The duration, frequency, and periodicity of the cognitive stimulation sessions had to be spread over seven weeks (14 sessions twice a day) as recommended by other CST related studies (see section 2.1). Each week corresponded to a cycle of tasks – meaning that all the six types of activities of *Musiquence* (Reality Orientation, Creative Painting, ADL, Knowledge Quiz, Association, and Search Objects) would be performed on each cycle. Each cycle of tasks corresponded to one song, one theme, and four exercises per activity.

6.1.5 Findings

From the interviews with formal caregivers, 21 themes were mentioned as the most popular in the development of activities for PwD (Figure 6.33). From the total of 21 themes, we selected the 14 most voted to be presented to PwD, which they arranged by preference in order to reduce the poll of themes to the seven most favorites:

- public figures;
- festivities;
- regional traditions;
- flowers;
- agriculture;
- regional typical recipes and;
- foods.

These seven themes were then used to customize the content for an individual cognitive stimulation program, with each cycle of tasks corresponding to one song, one theme, and four exercises per activity. The 14 sessions were spread through seven weeks, originating seven cycles of tasks (Table 5.17).

Table 5.17. **Cycles of tasks**

Cycles	Sessions	Theme	Song
1	1 & 2	Public Figures	A Multa da Cooperativa
2	3 & 4	Festivities	Laurindinga
3	5 & 6	Regional Traditions	Ó Rosa arredonda e saia
4	7 & 8	Flowers	Nem às Paredes Confesso
5	9 & 10	Agriculture	Playback
6	11 & 12	Typical Regional Recipies	Aldeia da Roupa Branca
7	13 & 14	Foods	Olhos Castanhos

Regarding the most used songs by formal caregivers on developing and performing tasks with PwD, we reached a total of 81 songs, most of them from before the year 2000. We grouped the several mentioned songs in five broad categories:

- Regional Artists;
- Portuguese Artists;

- Folk Music;
- Eurovision, and;
- Fado;

We have selected the seven most referred songs, to match with the number of cycles of tasks. As such, each cycle of tasks corresponded to one of the most mentioned songs. The preferred theme was matched with the most voted song. The second preferred theme was matched with the second most voted song and subsequently for the remaining five cycles of tasks.

6.1.6 Discussion

Our study aimed at systematically and in an informed manner, customize the content of a cognitive stimulation program for PwD living in the Centro Social e Paroquial de São Bento – Ribeira Brava. By involving PwD in the content design, we intended to promote their engagement in the development of a cognitive stimulation program. Personalizing cognitive stimulation content according to PwD needs, preferences, and previous experiences, are of utmost relevance as it can enhance the effects of reminiscence therapy. By using familiar and favorite content, based on reminiscence principles, the impact of this program might promote broader cognitive, behavioral, and quality of life benefits.

Participatory designs are of crucial importance on the development of technologies and contents, in particular for populations with particular needs. However, although participatory approaches can contribute to the customization of content, there are still difficulties, mostly due to the deficits associated with dementia, that need to be overcome in the field of cognitive interventions with PwD. More specifically, populations such as PwD are not always able to provide the sought information explicitly. Hence, a close collaboration between the researchers, formal caregivers, and PwD is required to successfully unveil information that reflects the perspectives and preferences of PwD, which can help to assure their engagement and motivation when performing the intervention. In this case, we opted to customize for the Centro Social e Paroquial de São Bento – Ribeira Brava population and not for each individual as the individual customization of the content could bias the comparison between the performance of the different participants.

Interviews with Formal Caregivers

Currently, there is still a considerable lack of human resources to develop occupational activities for PwD. Commonly, there is only one formal caregiver for several PwD, which makes it difficult to personalize activities and closely supervise their performance. This was one of the reasons that potentiated the use of a customization platform – *Musiquence* - for our cognitive stimulation program to a specific population - individuals from Centro Social e Paroquial de São Bento – Ribeira Brava with ages between 55 and 86 years old.

During the interviews, formal caregivers referred to having difficulties developing customized content for cognitive stimulation activities in a group environment when using traditional methods (such as puzzles, scrambled words, mazes). Usually, these groups have PwD with similar ages, that experienced similar paths, especially in our insular context. Finding these everyday experiences was our starting point to customize the content to be generalized to all the clinical intervention participants

Interviews with PwD

As the researcher went through all the images with the PwD, it was very common for them to recall specific memories from their past. When asked to select the favorite image, in general, it was difficult for them to choose one, as several images reminded them of some personal experience. Nevertheless, we managed to make group customization, including themes that were meaningful to every participant, which was one of our greater achievements. Hence, although the cognitive deficits caused by dementia syndrome can affect the ability of PwD to express their wills and preferences, we found it was possible to include this population when developing the content for cognitive stimulation activities. PwD reported enjoying the task and value having a role in the activities design process

6.2 What is the impact in cognitive function when using our therapeutic game?

Following the findings from the study discussed in the previous section (see section 6.1), we designed and ran a pilot longitudinal study regarding the impact that music and reminiscence have on people with dementia (PwD) by assessing several domains such as (1) cognition, (2) quality of life, (3) functional activities, (4) depressive and (5) anxious symptomatology. This study is discussed in detail below.

6.2.1 Methods

For this study, we opted for a projection-based augmented reality (AR) setup as it allows direct interaction input through physical objects and upper limb movements. Thus, we avoid overwhelming PwD cognitively as technologies that support direct interaction modalities require less cognitive resources as opposed to indirect interaction modalities (see section 4.1). Also, it allows presenting the activities on bigger surfaces to facilitate visualization of game elements in the activities. We used an Optoma projector, a laptop, and a tripod to display the activities on a table. A PSEye webcam and AnTS was used to detect markers that were projected on the table. To emit sound during the realization of the activities, we used two columns. Besides, to enhance the contrast between the table and projected activities, we used white paper overlay on the table. The setup is shown in Figure 6.36.

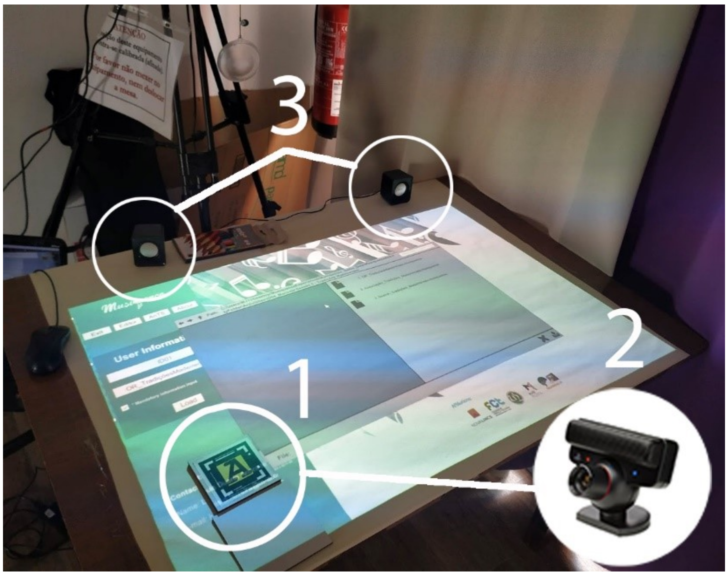


Figure 6.36. **Projection-based augmented reality system**. Projection-based augmented reality system.1). Physical object with a marker attached to it. 2) PSEye camera to track the position of the physical objects due to the marker. The camera was attached to the projector. 3) Two columns to emit the sound of the activities, such as music and feedback. The table was covered with a white sheet of paper to enhance the contrast of the virtual projection.

Musiquence **activities and improvements**

We used the activities and AR interaction modalities from *Musiquence* as described in subsection 4.3.1, which are Association, Search Objects, Activity of Daily Living, Creative Paintings, and Knowledge Quiz activities. We configured the response timer of *Musiquence* to be four seconds in all activities. Regarding the Knowledge Quiz Activity, participants are no longer required to occlude the marker to select an answer. To maintain the same interaction modalities as in the Search Objects and Association activities, participants use a physical object with a marker attached to it to complete the tasks. When the marker of the physical object is detected by *Musiquence*, a hand-shaped customized cursor is displayed in the game, which follows the participants' movements. Participants had to find the correct image among the three wrong ones. When selecting an image, a 4-second timer was triggered, and after 4 seconds, the image was selected (see Figure 5.37).

(A) (B)

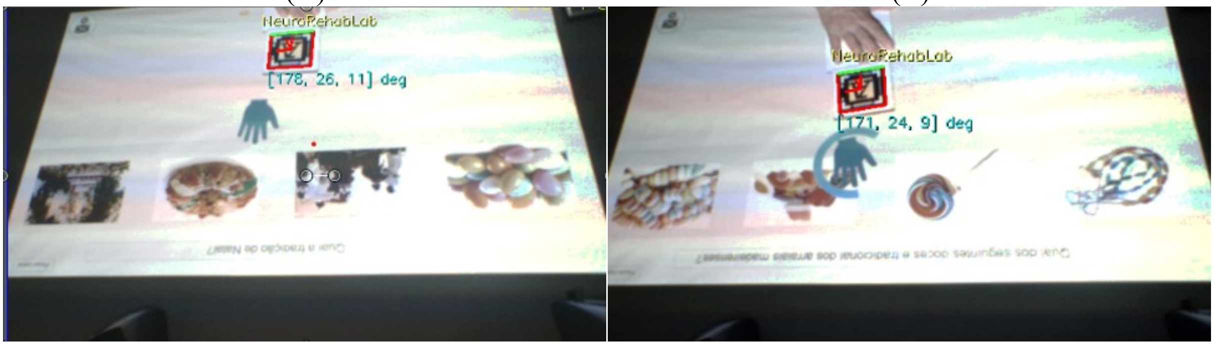


Figure 5.37. **Knowledge Quiz Activity.** (A) Participants are dragging the wooden object to the correct answer. (B) 4-second timer trigged when selecting an image.

We also made changes in the Association Activity. Now, when an image is dragged to a container, participants must wait 4 seconds to perform the association. The remaining interaction features continue the same; to interact with the images, participants use a wooden object with a marker attached to it. When participants made a correct association, a new image appears on the top center projection (see Figure 5.38).

(A) (B)

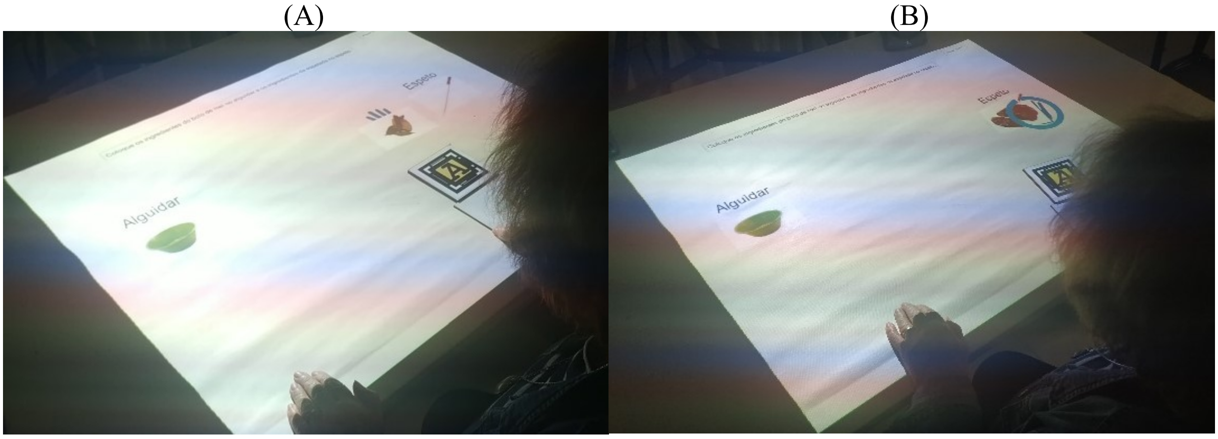


Figure 5.38.**Association Activity**. (A) participant dragging the image to the right container using the wooden object, (B) 4-second timer trigged when the image overlaps the container.

Moreover, after the participatory design approach presented in section 6.1, we decided to add a new activity to *Musiquence,* which is the Reality Orientation activity that aims to assist PwD in recollecting the present date and place. The activity provides the hours and a calendar, which update in real-time. It trains orientation related abilities (see Figure 6.39).

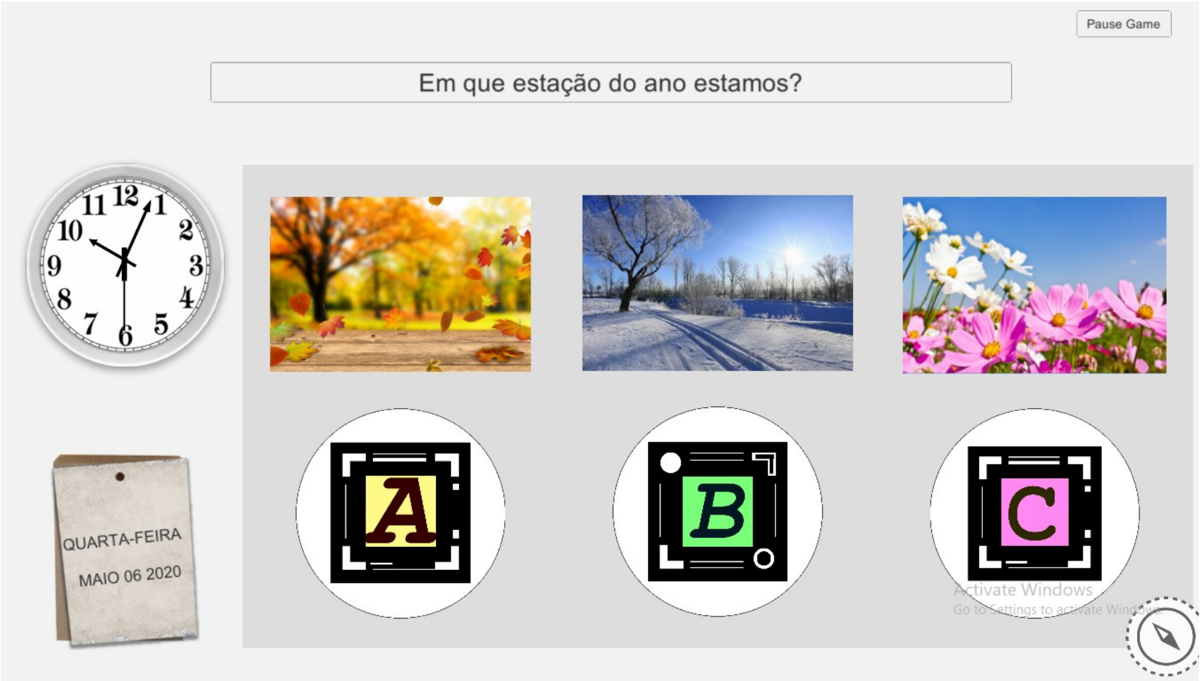


Figure 6.39. **Reality Orientation activity**. The participant must select the correct answer according to the orientation information provided. Participants must select the correct season based on the information provided by the calendar (Wednesday, May 06, 2020).

Cognitive stimulation activities using music and reminiscence

To create cognitive stimulation activities for the intervention using *Musiquence*, and following the findings discussed in section 6.1 about the general preferences of interviewed PwD in Portugal, we selected seven themes - Public Figures, Festivities, Flowers, Agriculture, Regional Typical Recipes, Foods, and Regional Traditions – and 7 Portuguese songs. Afterward, we implemented the themes using digital content such as music and images into *Musiquence*'s *Game Editor* (see section 4.3.2) to develop cognitive stimulation experiences using Knowledge Quiz, Association, Search Objects, Creative Paintings, and Activity of Daily Living. Figure 6.40 shows some of the activities developed in this study.

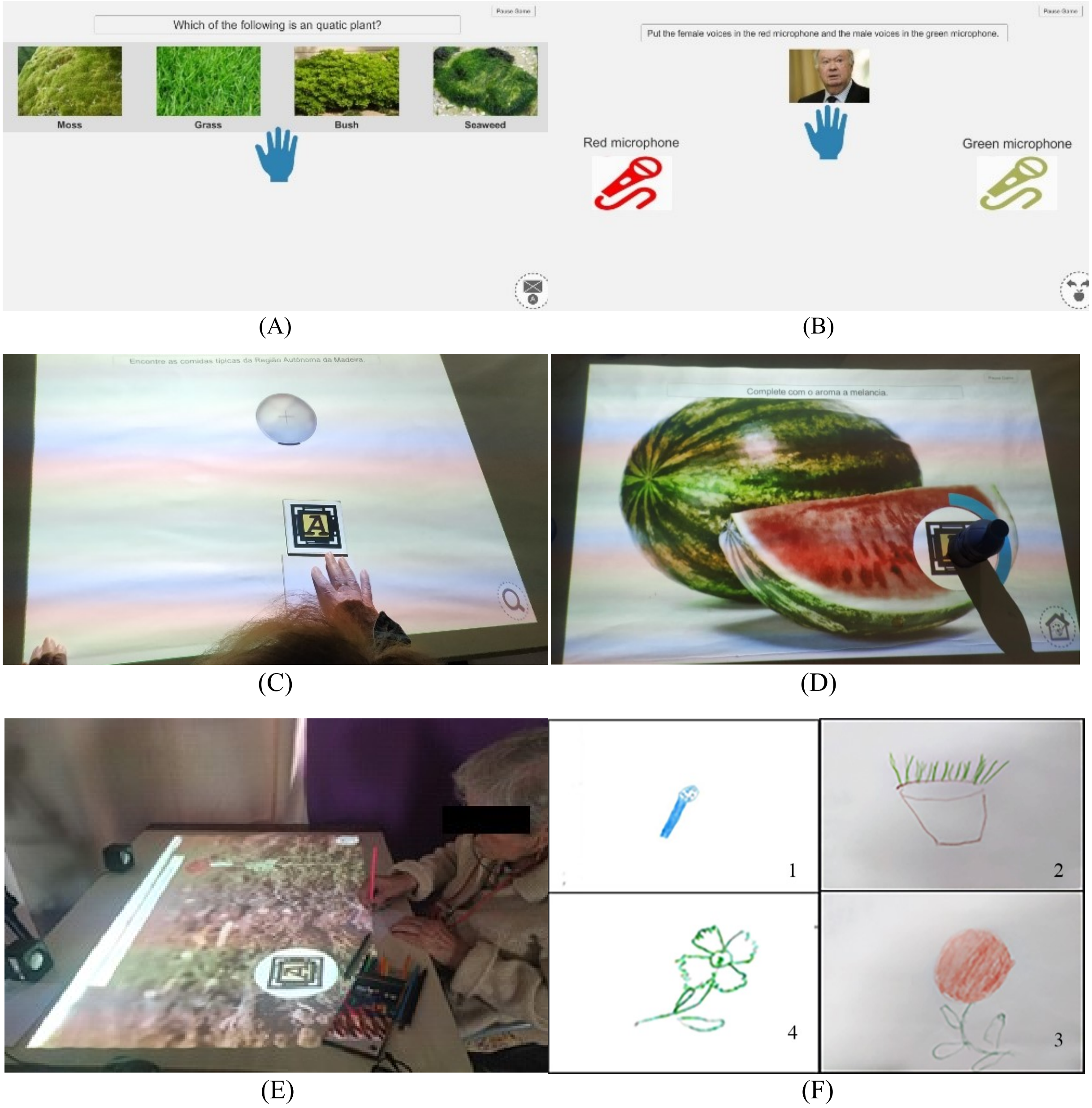


Figure 6.40. ***Musiquence*** **activities: screenshots and projections.** (A) Knowledge Quiz activity of the "Flower" theme. The participant had to select the correct answer. (B) Association activity of "Public Figures," theme. The participant had to associate the picture and drag it to the correct container. (C) Search Objects activity of the "Foods" theme. Through the virtual magnifying glass, the participant had to find images of, for example, peppers. (D)Bottles with fruit aromas in the ADL activity of the "Foods" theme. The participant had to recognize and select the correct scent of the fruit and place it on the marker. (E) Creative Painting activity of "Flowers." The participant had to draw the missing piece on a paper and place it in the marker. (F) Here, we show examples of drawings made by the participants. (1) "Microphone" drawing to complete a creative activity of the "Public Figures" theme. (2) "Wheat" drawing to complete a creative activity of the "Regional Traditions" theme. (3) "Clover" drawing to complete a creative activity of the "Flowers" theme. (4) "Carnation" drawing to complete a creative activity of the "Festivities" theme.

6.2.2 Participants demographics

Participants were eligible if (1) they were between initial or intermediate stages of dementia, (2) they were able to use superior limbs independently, (3) good hearing ability, and (4) good comprehension skills. Participants did not participate if (1) they are at advanced stages of dementia, (2) if they have diagnoses of previous psychiatric disorders (except for mild to moderate depressive symptoms), (3) if participants are not able to use upper limbs to perform the tasks and (4) if they are bedridden. Participants were recruited from different healthcare centers. Participants 1 and 2 were from the Centro Social e Paroquial da Ribeira Brava (nursing home), while participant 3 was recruited from Centro de Dia Lugar de Memórias (daycare center). The assessment and intervention sessions were performed at the same place where participants were staying.

Here we report an intervention with 3 participants with ages ranging from 76 to 86. The demographic information of PwD is shown in Table 5.18.

Table 5.18. **PwD Demographics**

ID	Diagnosis	MMSE*	Gender	Age	Schooling
1	Vascular Dementia	14	Female	86	3
2	Lewy-Body Dementia	26	Female	76	3
3	Alzheimer's Disease	23	Female	80	3

* MMSE values obtained before initiation of the study

6.2.3 Procedure

Participants were invited to be seated, one at a time, in a quiet room. Before beginning the study, participants had to sign a formal consent. The duration of the experimental trial was based on the CST principle [31] (see section 2.1); that is, we performed 14 bi-weekly sessions between 30 to 45 minutes, spread over seven weeks and each week corresponded to a cycle of tasks (i.e., one of each task available in *Musiquence*), a song, and a theme. All the participants performed all the tasks in a randomized order. A psychologist was present during all sessions. The experimental sessions were filmed to be later used as complementary data. In the first session and second sessions, a certified psychologist performed the pre neuropsychological assessment (as described in section 6.2.4). In the next session, PwD were invited again to sit in a quiet room to perform the customized music and reminiscence-based cognitive stimulation program using *Musiquence*. The psychologist re-assessed PwD after finishing the intervention sessions (see subsection 6.2.4).

6.2.4 Instruments and metrics

To evaluate the impact of the customized music and reminiscence-based cognitive stimulation program for PwD, we defined a neuropsychological assessment protocol to assess cognition (e.g., language), quality of life, functionality, and, depressive and anxious symptomatology. PwD were assessed before the intervention (pre), immediately after the intervention (post) and will be assessed three months after the intervention (follow-up). The assessment protocol was divided into two sessions of approximately 30 minutes each. To not overload PwD, the assessment of the quality of life, functionality and, depressive and anxious symptomatology was based on the health professionals' perception. To assess cognition, we used the following instruments:

- MMSE – The MMSE is a 30-point cognitive screening tool that assesses six domains: orientation (time and place), retention, attention and calculation, recall, language, and constructive ability. Higher scores relate to lower deficits [136].

- Alzheimer's Disease Assessment Scale - Cognitive Subscale (ADAS-Cog) – is a brief battery with a 50-score maximum that assesses word recall, naming, commands, constructional praxis, ideational praxis, orientation (time and place), spoken language ability, word-finding difficulty and comprehension of oral language. Higher scores relate to higher deficits [148].

- Kettler Laurent Thierrau (KLT) – it is a divided attention assessment tool that has 12 lines with 20 squares in which each square differs in the orientation of an exterior line. The participants had four minutes to select as many squares as possible. The selection is based on three examples that are presented on the top of the sheet. The total provides a dispersion index, and Higher scores relate to higher deficits [149].

- "Symbol Research" (SR) and "Digit-Symbol Coding" (DSC) – Subtests of the Weschler Adult Intelligence Scale (WAIS-III) –SR measures information processing speed and visual perception. The total is obtained by the subtraction of the errors to the number of hits. DSC measures the speed of processing and executive functioning. Its total is obtained by a total of hits. Higher scores relate to lower deficits [150].

- Semantic and Phonemic Verbal Fluency Test – In semantic fluency, the participant has one minute to say the maximum number of words belonging to each category: foods that can be found in the supermarket and animals. In phonemic fluency, the participant has one minute to say the maximum number of words that begin with each letter: "M," "P," and "R." It assesses processing speed, language production, and executive functions, and the higher the number of words, the better the participant's performance. Higher scores relate to lower deficits [151].

To assess the quality of life (QoL) of participants, we used the Quality of Life-Alzheimer's Disease scale (QoL-AD). It is a 13-item QoL assessment scale developed for individuals with cognitive deficits. Allows the assessment of the QoL through self-perception and perceived by the caregiver. Higher scores relate to greater perceived quality of life [152].

Regarding the assessments of functional activities, we used the Inventário de Avaliação Funcional de Adultos e Idosos (IAFAI). It is a Portuguese assessment tool that measures Basic Activities of Daily Living (BADLs) and Instrumental Activities of Daily Living (IADLs) (advanced IADLs and familiar IADLs), providing a total of functional inability to each of them. IAFAI also provides information about the nature of the inability - if it is either cognitive, emotional, or physical [153]. Higher results relate to greater functional inability.

For assessing depressive symptomatology, we used the Cornell Scale for Depression in Dementia. It is a 19-item scale developed to assess major depression symptomatology in people with dementia perceived by the caregiver [154]. The maximum score is 38 points, and higher scores relate to higher levels of depressive symptomatology.

Finally, to assess the anxiety symptomatology of the participants, we used the Rating Anxiety in Dementia (RAID) scale. It is an 18-item clinical rating scale developed to assess anxious symptomatology in people with dementia as perceived by the caregiver [155]. The maximum score is 54, and higher scores relate to higher levels of symptomatology

6.2.5 Results

All three participants finished all the sessions in the seven weeks. To evaluate the impact of our customized music and reminiscence-based cognitive stimulation program on cognition, we used the following assessment tools: MMSE, ADAS-Cog, KLT, WAIS-III, and Semantic and Phonemic Verbal Fluency Test. As dementia is a neurodegenerative pathology that leads to the progressive loss of cognitive abilities, it is expected for PwD to perform progressively worse in each assessment. Hence, improvement or even maintenance of the PwD's performance in cognitive assessment measures is a positive sign of the therapeutic effects of cognitive stimulation.

Table 5.19. **Pre and Post results of neuropsychological assessments**

ID	MMSE		ADAS-Cog		QoL-AD		KLT		WAIS III				Semantic Verbal Fluency Test				Phonemic Verbal Fluency Test					
									Symbol research		Digit-Symbol Coding		Animals		Foods		M		P		R	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
1	14	**15**	25	**20**	32	23	98.89	**94.45**	5	4	7	5	7	**10**	12	**14**	2	**3**	7	5	4	4
2	26	**27**	14	**10**	30	**36**	97.78	100	7	6	5	**7**	9	9	11	9	2	**3**	6	6	5	5
3	23	23	24	**23**	37	**41**	95.56	100	7	6	8	**10**	7	**10**	15	11	4	**7**	12	10	7	7

Bold values represent improvements between pre and post-assessment.

Assessment of General cognition

Regarding general cognition, as assessed by the MMSE, participants 1 and 2 scored higher in the post-assessment, compared to the pre-assessment results. In the ADAS-COG, participants 1 and 2 demonstrated fewer deficits. Participant 3 maintained the results as assessed by the MMES while improving in the ADAS-COG assessment. The results are shown in Table 5.19.

Assessment of divided attention

For divided attention, as assessed by the KLT, only participant 1 enhanced performance and, participants 2 and 3 presented higher scores of dispersion index. Regarding SR, all participants had lower scores in the post-assessment, comparing to the pre-assessment. In DSC, participants 2 and 3 had scored higher from pre to post-assessment and, participant 1 had scored less. The results are shown in Table 5.19.

Assessment of verbal fluency

As for verbal fluency, as assessed by in the Semantic Verbal Fluency Test, Participant 1 was able to mention a higher number of both animals and foods from pre to post-assessment. Participant 2 mentioned the same number of animals in pre and post-assessments and mentioned a lower number of foods. Participant 3 mentioned more animals but fewer foods in the post-assessment, comparing to the pre-assessment. To complement the Semantic Verbal Fluency Test, we used the Phonetic Verbal Fluency Test. The results show that participants 1, 2, and 3 were able to mention a higher number of words starting with "M" in one minute. Considering words starting with "P," participants 1 and 3 mentioned fewer words in post-assessment, and participant 2 mentioned the same number of words in both assessments. All the participants mentioned the same number of words starting with the letter "R" in pre- and post-assessments. The results are shown in Table 5.19.

Assessment of quality-of-life

To assess the impact of our intervention in QoL, we used the QoL-AD assessment tool that was filled by both the PwD and healthcare professionals. Regarding PwD's, participants 2 and 3 improved their self-perceived QoL, and participant 1 worsen. According to healthcare professionals' evaluation, the QoL of participants 1 and 2 improved, while participant 3 did not express any changes. The results are shown in Table 5.20.

Table 5.20. **Pre and Post results of the QoL-AD assessment tool as perceived by health professionals**

ID	Quality of Life-Alzheimer's Disease	
	Pre	Post
1	27	**30**
2	28	**29**
3	24	24

Bold values represent improvements between pre and post-assessment.

Assessment of functional abilities

To measure the impact of the intervention in the participants' functional abilities such as basic and instrumental activities of daily living, we used the IAFAI assessment tool, which is filled by a healthcare professional. Since the cognitive stimulation program included activities stimulating executive functioning and activities of daily living, we were interested to understand to which extend these activities transferred to the PwD's ability to function every day. The results show that all participants' post-results of functional capacities worsened compared to the pre-results. The results are summarized in Table 5.21.

Table 5.21. **Pre and Post results of the IAFAI assessment tool as perceived by health professionals**

ID	Inventário de Avaliação Funcional de Adultos e Idosos	
	Pre	Post
1	67.68	73.53
2	30	37.83
3	60.49	62.53

Assessment of depressive symptomatology

In order to assess the impact of our intervention in depressive symptomatology, healthcare professionals filled the Cornell Scale for Depression in Dementia. Overall, the results show that participants 1 and 2 reduced depressive symptoms, while participant 3 showed an increase in depressive symptomatology. The results are shown in Table 5.22.

Table 5.22. **Pre and Post results of the Cornell Scale for Depression in Dementia as perceived by health professionals**

ID	Cornell Scale for Depression in Dementia	
	Pre	Post
1	8	**6**
2	5	**4**
3	12	16

Bold values represent improvements between pre and post-assessment.

Assessment of anxious symptomatology

Finally, to assess the impact of our experimental trial in anxious symptomatology, healthcare professionals filled the RAID assessment tool. Results show that participants 1 and 3 reduced anxiety symptoms, while participant 2 remained stable. The results are shown in Table 5.23.

Table 5.23. **Pre and Post results of the RAID scale as perceived by health professionals**

ID	Rating Anxiety in Dementia	
	Pre	Post
1	13	**11**
2	10	10
3	25	**19**

Bold values represent improvements between pre and post-assessment.

6.2.6 Discussion

Here, we present the results of a pilot longitudinal study that quantifies the impact of a customized cognitive stimulation program using *Musiquence* in PwD. Overall, the results obtained in this study are very promising. The combination of customized music and reminiscence elements in a game-like context seems to have a positive impact on participants' wellbeing.

In our customized cognitive stimulation program, we aimed to potentiate the effect of reminiscence and music by developing our cognitive stimulation activities based on a participatory design approach in which we collected the favorite themes and songs of PwD (see section 6.1). This set of activities, incorporated on *Musiquence*, aimed to stimulate general cognition. Also, we analyzed not only specific domains commonly affected by this disease, such as language, executive functioning, and attention, but also its larger impact on the PwD's life through the assessment of QoL, Functionality and, depressive and anxious symptomatology.

Considering our general cognition assessment measures (MMSE and ADAS-Cog), the results are promising. Firstly, none of our participants had worse results on post-assessment, comparing to pre-assessment, and secondly, two of our participants improved. Since dementia is characterized by an exponential decline of cognitive functioning, even the steadiness of general cognition is a positive outcome. Interestingly, participants 1 and 2, that improved their results both on MMSE and ADAS-Cog were living in a nursing home while participant 3, who maintained the results on these measures, was in a daycare facility. A possible explanation for such results is that participants at daycare facilities perform several activities during the day and then return to their home while nursing home residents usually have fewer occupational activities, which can result in a lack of cognitive stimulation.

This contrast in the participants' daily routine suggests that PwD that are less stimulated can benefit more from a structured cognitive intervention. Similar results regarding enhanced cognition using occupational activities (i.e., music-based intervention) have been reported by Särkämö et al. [74] (see subsection 2.1.1). Also, Bruer et al. reported improvements in MMSE scores the morning after music-related interventions [75] (see section 2.1.1). Additionally, studies show that reminiscence related approaches can enhance cognition in PwD [80].

Regarding the impact of our program in specific cognitive domains, results were not even. For example, when taking into consideration divided attention, assessed by KLT. Although divided attention was never the main stimulated domain, several of our activities (Association and Knowledge Quiz) demanded some level of this ability. In general, all our participants showed high dispersion index results, which translates in a severe difficulty of paying attention to more than one stimuli at a time. Even though participant 1 improved its performance, the obtained attentional dispersion index result was still very high (94,45 out of 100), meaning that the person was not able to maintain the attention during activity performance.

Similarly, all our participants worsened their performance on SR, but participants 2 and 3 improved on DSC. The main difference between these two subtests of WAIS-III relies on the fact that SR demands visual perception abilities, as participants need to discriminate between abstract symbols. Throughout the performance of our activities, participants only had to discriminate familiar, meaningful stimuli. Although these results point to visual perception abilities deficits, we did not observe difficulties from our participants in discriminating the stimuli presented.

As for language, our participants improved or maintained their performance in most of our semantic and phonemic verbal fluency assessment measures. Although language aspects were not directly stimulated in any of our activities, communication was present in all our sessions through the Reality Orientation activity (performed every session, before the cognitive stimulation activities). On the other activities (i.e., Quiz Knowledge, Association, and Search Objects), it was frequent for the participants to verbally answer and justify their answers before taking action on *Musiquence*. Similar reports regarding the improvements of verbal fluency after musical activities in PwD were verified by Brotons et al. [71] (see subsection 2.1.1). Hence, combining music and reminiscence approaches in a serious game could be beneficial to achieve linguistic outcomes.

Considering self-perceived QoL, participant 1 was the only one to report worse perceived QoL in the post-assessment, comparing to the pre-assessment. The participant reported having less physical health, energy, worse living conditions, memory, family relationships, friendship, and general life. On the other hand, participants 2 and 3 referred better self-perceived physical health, life in general, ability to perform ADLs, ability to do enjoyable activities, and life as a whole. To complement participants' self-perceived QoL, we asked health professionals not only to evaluate participants' QoL, but also other aspects such as functional abilities and, depressive and anxious symptomatology using the QoL-AD, IAFAI, Cornell Scale for Depression in Dementia and RAID.

Regarding the QoL of the participants perceived by health professionals, results suggest improvements in participants' general life quality. Such results can be attributed due to reduced symptomatology of depression and anxiety-related behaviors. Indeed, using music and reminiscence related approaches have been shown to reduce depression and anxiety in PwD, as reported by McDermott et al. [73], Ueda et al. [65], and Guetin et al. [72] (see section 2.1.1).

Despite these encouraging data, all participants worsened in terms of functional activities (IAFAI). Although our cognitive stimulation activities included ADL training with *Musiquence*, this outcome is not surprising as none of our participants is currently autonomous in performing ADLs. Especially in the case of participants 1 and 2, which for safety reasons are provided with assistance to perform BADLs (such as bathing) and IADLs (such as meal preparation and financial management). Concomitantly, these participants showed higher functional inability between pre and post-assessments compared to participant 3.

Additional behavioral changes of PwD have been observed during the intervention. For example, in the first sessions, participants, in general, showed difficulties in manipulating the physical object with the marker attached. The marker could not be covered, or else the system (AnTS) would not be able to track it. Throughout the sessions, all our participants learned how to use the physical object without covering the marker, and, in the last sessions, they would do it autonomously, showing some signs of practice learning.

Another interesting finding was that all participants could recognize the psychologist that performed the cognitive stimulation intervention, even though they only meet during the intervention. Participants associated the psychologist as the person using the computer, although the majority could not remember the content, neither the type of activities performed. Participants reported enjoying performing the activities since the content was familiar to them. Commonly, participants would recall specific memories when performing the activities (e.g., participant 3 recognized a TV host in the activities involving "Public Figures," since it was a TV host she used to watch daily). Participants were also very receptive to the songs used in the activities. All participants sang during activity performance while recalling memories. For example, when playing the song "Mula da Cooperativa" (which is a song with a humoristic connotation), participant 1 would laugh, referring that her kids used to sing this song when they were younger.

6.3 Chapter discussion and conclusion

Chapter 6 aims to answer *R.Q3 - What is the impact of Musiquence on cognitive function?* First, in order to customize and tailor our cognitive intervention for the pilot longitudinal study, it was necessary to find music and themes that were commonly known by PwD in Portugal. Thus, in section 6.1, we presented a participatory design study to gather information regarding musical and thematic preferences. To that end, we invited PwD and healthcare professionals from different health institutions to provide us with insights regarding the usage of music and reminiscence content for the Madeiran population. By involving PwD in the development process of content for the cognitive stimulation activities, we intended to take advantage of reminiscence and promote their interest, participation, and engagement throughout the intervention program.

Although communication with PwD was more challenging than healthcare professionals, they were still able to communicate their needs and preferences to the researchers (see subsection 2.2). Involving health care professionals and PwD in the development process has revealed an essential step to ensure the quality and success in developing cognitive stimulation activities for PwD. After analyzing the data collected from the participatory design study, we implemented the cognitive training using *Musiquence* to study its impact on PwD.

We performed a pilot longitudinal study, and the results are promising. Our findings are in line with our proposal (see Chapter 3 - Research question). We were able to develop a platform – *Musiquence* – that targets different components of the working memory to (1) improve patient's quality of life and wellbeing by helping them to rediscover lost memories, (2) enhance general cognition, (3) enhance verbal communication and (4) mood. We gathered evidence that PwD improved in terms of general cognition, mood, quality of life, and verbal fluency while using *Musiquence*.

Despite positive results, we did not find functional improvements among participants. Such results were predictable as none of the participants in the study perform ADL and BADL daily

Chapter 7 – Conclusion and future work

This dissertation is an effort towards assessing the therapeutic impact of non-pharmacological solutions based on interactive media that exploit music and reminiscence in a dementia population. We focused our attention on the working memory, which according to Baddeley, is a *"temporary storage system* (that) *allows manipulation of information that is necessary to perform complex cognitive tasks such as comprehension, learning and reasoning."* The inability in dementia to manipulate information is assumed to be caused by a deterioration of the working memory. The disruption begins in the central executive and progresses to other memory systems, such as the phonological loop, visuospatial sketchpad, and episodic buffer. The central executive has a vital role in the working memory as it is responsible for allocating attentional resources to temporary storage systems such as the phonological loop, visuospatial sketchpad, and episodic buffer. These systems are responsible for adding and retrieving information from long-term memory. Thus, if the central executive is no longer able to direct attentional resources to other storage systems, the processing and manipulation of information are also limited, and storage and retravel of information from the long-term memory is scarce.

In this dissertation, we proposed a theoretical model that exploits music and reminiscence to stimulate not only long-term memories but also the phonological loop and central executive, based on the premise that by ameliorating general cognition and stimulating positive memories in PwD, quality of life can be enhanced. Scientific studies have been published regarding the beneficial effects that music and reminiscence have on cognition, communication, memory, and quality-of-life in PwD. However, the literature is ambiguous regarding the short- and long-term effects of music and reminiscence therapy. To test our theoretical model, we developed *Musiquence*, which is a music and reminiscence cognitive stimulation platform for PwD.

Following an iterative and participatory design strategy, we learned valuable lessons that allowed us to develop *Musiquence*. For example, by inviting PwD to interact with a variety of "out-of-the-shelf" technologies, we were able to quantitatively assess PwD performance with interactive technologies and gain new insights regarding the pros and cons of each technology, and how cognitive status influences user experience. We found, in general, that technologies supporting direct interaction were better than indirect interaction.

Consequently, we decided to explore the use of AR technology for *Musiquence*, adding support for a variety of user different direct interaction via upper limbs, full-body, and real objects. We also designed interactive cognitive activities such as a Knowledge Quiz, Search Objects, Association, ADL, and Creative Paintings activities, which aim to stimulate memory, associative memory, attention, selective attention and, fine and gross motor skills in PwD. In general, PwD were successful in completing the activities, although assistance was sometimes required. We also gathered the perception of healthcare professionals regarding the platform and its use. Healthcare professionals were interested in using the platform for stimulation purposes in PwD between initial to intermediate stages of dementia.

Nevertheless, healthcare professionals expressed the need to be able to adapt the cognitive stimulation content for this population. Customizing activities to PwD interests can enhance motivation, which is essential to ensure the success of cognitive stimulation. For example, healthcare professionals can develop an activity that uses real objects, music, which has a special meaning for the patient. Consequently, we developed the *Musiquence Game Editor,* which allows healthcare professionals to have full control of the creation, customization of the activities, as well as the type of interaction modality and technology of choice.

An important novelty of the platform is that it allows overcoming some of the technological and software-related limitations identified in state of the art (i.e., lack of customization features to target individual needs in PwD, and inadequate inter-operable systems). Another advantage of using this platform is that healthcare professionals can present the activities as a story-telling narrative. By doing so, healthcare professionals can engage PwD in performing virtual daily activities. Moreover, considering that many PwD may not be familiarized with modern technology, healthcare professionals can develop activities according to the PwD skills and experience as the platform is compatible with multiple interfaces and interaction modalities. The platform can also mitigate costs; the development and maintenance of activities for PwD with physical elements are time-consuming and can be costly as they need to be redesigned continuously to match the specific profile of each individual. Thus, with *Musiquence*, health professionals can quickly and easily design endless cognitive stimulation activities that match the competences and interests of PwD throughout the various stages of the disease.

After developing a fully functional *Musiquence* prototype, we began to explore ways of using music to support learning, and also its effects and those of reminiscence in PwD. Thus, we studied the feasibility of developing a learning method based on musical distortions. The underlying idea is to mobilize crystallized abilities, that is, cognitive functions that are still present in the induvial, which, in this case, is musical memory and the ability to identify manipulations in music. Indeed, scientific literature shows that PwD can process and identify changes in musical excerpts in terms of pitch and rhythm. In a first experiment, we analyzed the behavior of PwD when being exposed to 2 different feedbacks systems (musical and visual distortion) while performing a quiz-like activity. Preliminary results showed that participants, in general, performed better when exposed to musical distortions. Through this study, we concluded that PwD (1) were able to identify musical distortions and that the use of (2) visual-based distortions may be too intrusive, leading to more erroneous responses. Hence, we performed another experiment in which we exclusively studied musical distortions. In this study, we had two groups, one with organic dementia (for example, Alzheimer's disease) and another with non-organic dementia (for example, dementia induced by substance abuse). We redesigned *Musiquence* tasks - the Knowledge Quiz, Association, and Search Objects activities - to provide auditory feedback in terms of pitch, rhythm and, a combination of pitch and rhythm musical distortions. Results showed that (1) both groups, in general, had enhanced performance when auditory feedback through distortions was present, especially through pitch and rhythm, (2) the group with organic dementia had better performance using distortion than non-organic dementia, and (3) musical distortions appear to enhance performance and to compensate to some extent some of the patients' deficits. Both studies suggest that it is feasible to use a music-distortion based feedback method for learning as PwD can process and interpret musical distortions and use it to their benefit, as it mobilizes crystallized abilities present throughout the different stages of dementia.

Finally, we analyzed the impact of music and reminiscence on PwD. Before beginning the study, we prepared the activities by collecting data about the general preferences of PwD through a participatory process. The data collected was based on information provided by both healthcare professionals and PwD. This is important as we wanted to assure that PwD can establish a positive connection between the activities and personal experiences of their personal life. After designing the content of the cognitive stimulation activities, we performed a longitudinal pilot study with 3 participants diagnosed with dementia. Results were promising and are in line with our hypothesis (see Chapter 3 - Research questions). In general, participants improved general cognition, quality of life, mood, and verbal fluency. Also, participants in the study were able to remember past events of their life.

To summarize, this dissertation results support the feasibility of *Musiquence* to deliver compelling music and reminiscence cognitive stimulation activities through direct interaction and music distortion feedback, suggesting that it stimulates the phonological loop, long-term memories, and general cognition and that enhancing these components may have led to better mood and quality of life among PwD. Thus, with the existence of *Musiquence*, we hope that healthcare professionals and informal caregivers become better equipped to address the ever-increasing needs of PwD.

As future work, we aim to extend the longitudinal study by recruiting more participants to provide further evidence on the efficacy of *Musiquence* in PwD. Moreover, we will collect follow-up data to assess the long-lasting effects that the *Musiquence* has on such populations 3 and 6 months after the cognitive intervention. When finalized, we aim to make the *Musiquence* platform publicly available so that health professionals and caregivers have, at their disposal, a novel tool to provide cognitive stimulation and, consequently, enhanced wellbeing to their patients suffering from any form of dementia. Also, this platform can be further used by the scientific community not only to provide more evidence regarding the impact that music and cognitive reminiscence games have in PwD, but as a general-purpose cognitive stimulation platform.

Also, considering the versatility of *Musiquence* with different interfaces and highly customizable in terms of content, it is currently being tested with the elderly, delivering simultaneous physical exercise and cognitive training.

Furthermore, with the existence of *Musiquence*, new research opportunities are open that aim to contribute even more to science. Firstly, it would be interesting to compare the therapeutic effects of music-based cognitive intervention in different dementia-related pathologies, such as Alzheimer's disease, frontotemporal dementia, vascular-dementia, Lewy-Body dementia. Considering that diverse types of dementia affect the brain differently, new insights can be made regarding the therapeutic outcome of music-based cognitive interventions. Secondly, more studies should be performed regarding the feasibility of music-based feedback in different environmental contexts besides the virtual environment. For example, it would be interesting to use such a system in an intelligent-home setting to support the decision making of PwD during activities of daily living.

Another interesting future output of this work would be performing a comparative study between digital and traditional music and reminiscence based cognitive activities to assess the pros and cons of each approach. Thus, healthcare professionals can perform informed decisions when preparing therapy sessions for PwD. Additionally, more information should be gathered and shared publicly to the public when developing customized cognitive stimulation programs in different cultures. This can lead to the development of more guidelines to augment the impact of music and reminiscence based cognitive activities when using *Musiquence*.

Lastly, it would be valuable to make *Musiquence* compatible with other technologies such as eye-gaze [156] to assess the impact of cognition, mood, and quality of life of personalized music and reminiscence stimulation program in bedridden individuals with minimized upper-limb mobility. Many individuals in bedridden situations may not receive the necessary cognitive stimulation, which could lead to improved quality of life and mood.

8 References

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Supplementary Material

Table 1. Correlation between participants profile, performance and technology

(*) statistical significance.

	Leap Motion				
Participants Profile	Assistance	Comprehension	Interaction	Perception	Discomfort
MMSE	r_2 = -.445, n = 10, p = .197	r_2 = -.549, n = 10, p = .101	r_2 = -.152, n = 10, p = .675	**r_2 = .652*, n = 10, p = .041**	r_2 = -.057, n = 10, p = .876
Age	r_2 = -.049, n = 10, p = .894	r_2 = .362, n = 10, p = .305	r_2 = -.122, n = 10, p = .738	r_2 = -.090, n = 10, p = .805	r_2 = .374, n = 10, p = .287
Schooling	r_2 = -.058, n = 9, p = .883	r_2 = -.297, n = 9, p = .437	r_2 = -.282, n = 9, p = .462	r_2 = -.394, n = 9, p = .294	r_2 = .482, n = 9, p = .189

	HMD w/ Controls				
Participants Profile	Assistance	Comprehension	Interaction	Perception	Discomfort
MMSE	r_2 = -.617, n = 7, p = .140	r_2 = -.296, n = 7, p = .518	r_2 = -.036, n = 7, p = .939	r_2 = -.296, n = 7, p = .518	r_2 = -.438, n = 7, p = .325
Age	r_2 = -.168, n = 7, p = .718	r_2 = .259, n = 7, p = .574	r_2 = .179, n = 7, p = .702	r_2 = .259, n = 7, p = .574	r_2 = -.259, n = 7, p = .575
Schooling	r_2 = .021, n = 7, p = .965	r_2 = -.225, n = 7, p = .628	r_2 = -.453, n = 7, p = .307	r_2 = -.225, n = 7, p = .628	r_2 = -.055, n = 7, p = .907
	HMD				
Participants Profile	Assistance	Comprehension	Interaction	Perception	Discomfort
MMSE	r_2 = -.035, n = 11, p = .919	r_2 = -.419, n = 11, p = .200	r_2 = -.200, n = 11, p = .555	r_2 = -.425, n = 11, p = .193	r_2 = -.304, n = 11, p = .363
Age	r_2 = -.244, n = 11, p = .470	r_2 = -.405, n = 11, p = .217	r_2 = .000, n = 11, p = 1.000	r_2 = -.189, n = 11, p = .578	r_2 = -.249, n = 11, p = .461

Schooling	r_2 = .314 n = 10, p = .376	r_2 = .072, n = 10, p = .844	r_2 = -.482, n = 10, p = .158	r_2 = .401, n = 10, p = .251	r_2 = -.186, n = 10, p = .607

	Augmented Reality				
Participants Profile	Assistance	Comprehension	Interaction	Perception	Discomfort
MMSE	**r_2 = -.744*, n = 11, p = .009**	r_2 = -.324, n = 11, p = .331	r_2 = .196, n = 11, p = .563	r_2 = .406, n = 11, p = .215	r_2 = -.351, n = 11, p = .290
Age	r_2 = -.066, n = 11, p = .848	r_2 = -.070, n = 11, p = .837	r_2 = .078, n = 11, p = .819	r_2 = .221, n = 11, p = .513	r_2 = -.500, n = 11, p = .117
Schooling	r_2 = .035, n = 11, p = .919	r_2 = -.237, n = 11, p = .483	r_2 = -.423, n = 11, p = .195	**r_2 = -.615*, n = 11, p = .044**	r_2 = .474, n = 11, p = .140

	Tablet				
Participants Profile	Assistance	Comprehension	Interaction	Perception	Discomfort
MMSE	r_2 = -.620, n = 10, p = .056	**r_2 = -.726,* n = 10, p = .017**	**r_2 = -.642,* n = 10, p = .045**	r_2 = -.182, n = 10, p = .615	r_2 = -.261, n = 10, p = .466
Age	r_2 = -.141, n = 10, p = .697	r_2 = -.037, n = 10, p = .919	r_2 = -.220, n = 10, p = .541	r_2= .151, n = 10, p = .678	r_2 = .000, n = 10, p = 1.000
Schooling	r_2 = .066, n = 9, p = .867	r_2 = .198, n = 9, p = .610	r_2 = .033, n = 9, p = .934	r_2 = .068, n = 9, p = .863	r_2 = -.530, n = 9, p = .142

	PC				
Participants Profile	Assistance	Comprehension	Interaction	Perception	Discomfort
MMSE	r_2 = -.468, n = 10, p = .173	r_2 = .108, n = 10, p = .766	r_2 = -.367, n = 10, p = .297	r_2 = .416, n = 10, p = .232	r_2 = - n = 10, p = -
Age	r_2 = .129, n = 10, p = .723	r_2 = -.092, n = 10, p = .800	r_2 = .317, n = 10, p = .372	r_2 = -.343, n = 10, p = .332	r_2 = - n = 10, p = -

Schooling	r_2 = -.211, n = 10, p = .559	r_2 = -.575, n = 10, p = .082	r_2 = -.269, n = 10, p = .453	r_2 = .217, n = 10, p = .547	r_2 = - n = 10, p = -

	HMD w/ LM				
Participants Profile	Assistance	Comprehension	Interaction	Perception	Discomfort
MMSE	**r_2 = -.802*, n = 7, p = .030**	r_2 = .045, n = 7, p = .924	r_2 = -.464, n = 7, p = .294	r_2 = -.519, n = 7, p = .233	r_2 = -.449, n = 7, p = .312
Age	r_2 = -.535, n = 7, p = .216	r_2 = .134, n = 7, p = .775	r_2 = -.107, n = 7, p = .819	r_2 = .037, n = 7, p = .937	r_2 = -.056, n = 7, p = .905
Schooling	r_2 = .516, n = 7, p = .236	r_2 = -.172, n = 7, p = .712	r_2 = -.079, n = 7, p = .867	r_2 = .123, n = 7, p = .793	r_2 = -.206, n = 7, p = .657

Table 2. Correlations between patient profile and overall technology and activity performance

Patient Profile	Technology and Task Performance
MMSE	r_2 = -.235, n = 12, p = .463
Age	r_2 = .084, n = 12, p = .795
Schooling	r_2 = -.302, n = 11, p = .367

Table 3. Correlation between patient profile and task performance

	Tasks			
Participant Profile	Playing Musical Instruments	Manipulating Virtual Objects	Move Objects from A to B	Observation
MMSE	r_2 = -.105, n = 10, p = .774	r_2 = -.0.17, n = 9, p = .966	r_2 = -.329, n = 12, p = .296	r_2 = -.397, n = 11, p = .226
Age	r_2 = .197, n = 10, p = .586	r_2 = -.277, n = 9, p = .470	r_2 = .070, n = 12, p = .829	r_2 = -.258, n = 11, p = .444
Schooling	r_2 = -.233, n = 9, p = .546	r_2 = -.292, n = 9, p = .445	r_2 = -.264, n = 11, p = .434	r_2 = .077, n = 10, p = .833

Table 4. Correlation between participants profile and performance with different technologies

	Technology						
Participant Profile	LM	HMD	AR	Tablet	PC	HMD w/ Controls	HMD w/ LM
MMSE	$r_2 = -.334$, n = 10, p = .345	$r_2 = -.397$, n = 11, p = .226	$r_2 = .025$, n = 11, p = .941	$r_2 = -.394$, n = 10, p = .260	$r_2 = -.284$, n = 10, p = .426	$r_2 = -.250$, n = 7, p = .589	$r_2 = -.559$, n = 7, p = .192
Age	$r_2 = -.006$, n = 10 p = .987	$r_2 = -.258$, n = 11, p = .444	$r_2 = .160$, n = 11, p = .638	$r_2 = -.164$, n = 10, p = .651	$r_2 = .177$, n = 10, p = .625	$r_2 = .036$, n = 7, p = .939	$r_2 = -.126$, n = 7, p = .788
Schooling	$r_2 = -.084$, n = 9, p = .830	$r_2 = .077$ n = 10, p = .833	$r_2 = -.439$, n = 11, p = .177	$r_2 = -.065$, n = 9, p = .869	$r_2 = -.288$, n = 10, p = .419	$r_2 = -.315$, n = 7, p = .491	$r_2 = -.0.80$, n = 7, p = .865

Table 5. Correlation between participants profile and individual performance domain

	Individual Performance domain				
Participants Profile	Assistance	Comprehension	Interaction	Perception	Discomfort
MMSE	$r_2 = -.452$, n = 12, p = .140	$r_2 = -.306$, n = 12, p = .334	$r_2 = -.217$, n = 12, p = .498	$r_2 = .067$, n = 12, p = .837	$r_2 = -.092$, n = 12, p = .776
Age	$r_2 = .028$, n = 12, p = .931	$r_2 = .004$, n = 12, p = .991	$r_2 = .175$, n = 12, p = .587	$r_2 = .179$, n = 12, p = .579	$r_2 = .046$, n = 12, p = .887
Schooling	$r_2 = -.125$, n = 11, p = .715	$r_2 = -.355$, n = 11, p = .283	$r_2 = -.388$, n = 11, p = .238	$r_2 = -.264$, n = 11, p = .433	$r_2 = -.027$, n = 11, p = .938

Table 6. Questions developed for each experimental condition in the Quiz Activity

Quiz Questions			
Non-Distortions	**Pitch**	**Pitch-Rhythm**	**Rhythm**
1- Indicate the colour red	1- Indicate the color yellow	1- Indicate the color black	1- Indicate the color white
2 - Indicate who Leonardo Da Vinci is	2 - Indicate the Mona Lisa	2 - Indicate Beethoven	2 - Indicate who is Mozart
3 - Indicate an image of the desert	3 - Indicate the image of the forest	3 - Indicate the image of a swamp	3 - Indicate a Radio
4 - Who is the Portuguese Prime Minister?	4 - Who is the current finance minister?	4 - Who is the current leader of the left political party?	4 - Who is the current leader of PSD?
5 - What is the flower that represents the 25th of April?	5 - Who sang "Vila Morena" on April 25th?	5 - Indicate Estrelicia?	5 - What image does the bailinho of Madeira represent?
6 - Indicate the singer Amalia	6 - Indicate the fado singer Mariza	6 - Indicate the singer MAX?	5 - What image does the bailinho of Madeira represent?
7 - Indicate the Statue of Liberty?	7 - Indicate Issac Newton	7 - Indicate Fernando Pessoa?	7 - Who wrote the Lusiads?
8 - Indicate the flag of Peru	8 - Indicate the Indonesian flag	8 - Indicate the country of China?	8 - Indicate the flag of Japan?
9 - Indicate the current President of the United States	9 - Indicate the current president of Brazil	9 - Indicate the current president of Angola?	9 - Indicate the current President of France?
10 - Indicate the plane	10 - Indicate the image of a car	10 - Indicate a Helicopter?	10 - Indicate a bird?
11 - Indicate the phone	11 - Indicate the image of a sardine	11 - Indicate a chair?	11 - Indicate a light bulb?
12 - Indicate an aquatic animal	12 - Indicate an animal that lives in cold environments?	12 - Indicate an animal that flies?	12 - Indicate “Ovos Moles”?
13 - Indicate the flag of Madeira Island	13 - Indicate the flag of the Azores Island	13 - Indicate the flag of Portugal?	13 - Indicate the flag of Spain?
14 - Indicate the color green	14 - What image does winter represent?	14 - Indicate the color orange?	14 - Indicate the color purple?
15 - Indicate the current president of Madeira	15 - Indicate who is the current president of the Azores?	15 - Indicate who is the vice president of Madeira?	15 - Indicate who is the vice president of the Azores?

Table 7. Images that participants need to find in the Search object activity

Finding Images in Search object activity			
Non-Distortions	**Pitch**	**Pitch-Rhythm**	**Rhythm**
Find images of Madeira	Find images of Cats	Find images of Dogs	Find images of birds

Table 8. Images that participants need to associate to the correct container in the Association Activity

Finding Images in Search object activity			
Non-Distortions	**Pitch**	**Pitch-Rhythm**	**Rhythm**
Put fruits in the basket and Vegetables in the pot	Put men's clothes in the brown closet and women's clothes in the red closet	Place cars in the garage and motorbikes on the sidewalk	Place farm animals in the barn and pets in the living room

1. Interviews with healthcare professionals.

Entrevista com a Psicóloga

1ª parte - atividade musical

Luís**:** Quantas vezes por semana vocês fazem terapia musical com os pacientes?

Psicóloga**:** Depende. Temos uma vez por semana para alguns. Mas temos tido alguns têm vindo duas vezes por semana em diferentes grupos (...). E depois todas as sessões individuais (todas as pessoas têm interesse). Há uma pessoa ou outra que realmente que a parte musical não lhes diz tanto. Colocamos sempre uma música ou utilizamos a música como recurso de estimulação de variadas maneiras como um jogo para completar a letra ou para, por exemplo, trocar a ordem da letra e a pessoa tem de colocá-la por ordem. Pronto, a música acaba por ser um recurso todos os dias.

Luís**:** e a duração das sessões?

Psicóloga: Da parte de música dos grupos, cerca de uma hora. Nas sessões individuais, o habitual são os 10 minutos finais da sessão. Portanto um utente que venha a uma sessão individual e de grupo, pode ter cerca 60 a 70 minutos de música.

Luís: e que tipos de atividades musicais fazem com os pacientes?

Psicóloga: Individualmente é aquilo que estava a dizer é um recurso infindável, dá para fazer algum choque de atenção, de linguagem. No grupo, as atividades fazemos é: colocamos a música, não é, tentamos fazer com que toda a gente consiga interagir senão a cantar, pelo menos a acompanhar o ritmo através dos instrumentos.

Luís: Que tipo de músicas são utilizadas?

Psicóloga: Nós no início fazemos uma avaliação dos gostos da pessoa e também temos sempre um paragrafo para a música: tipos de música que uma pessoa goste. Fazemos um levantamento a todas as pessoas e tentamos corresponder um pouco ao gosto do grupo, mas também um pouco individual. Há pessoas que gostam de música mais clássica, por exemplo. Mas tentamos com que seja (**eclético ?). Agora, as pessoas gostam muito mais de** música **tradicional madeirense, como as** músicas **do Max, o fado também faz com que as pessoas participam imenso. Principalmente estas duas:** música **tradicional madeirense e os fados. E depois há estas pequenas variações,** música **clássica, musica portuguesa** ligeira.

Luís: E qual o médium utilizado?

Psicóloga: Utilizamos o computador: o youtube. (...) Temos CD's também, CD's que compramos, CD's que nos emprestaram, (...) Já chegamos a ir a uma radio procurar uma música que não fazíamos ideia qual era e a senhora lá conseguiu chegar. Mas é sobretudo através da concessão do computador.

Luís: As atividades musicais costumam ser maioritariamente passivo ou activo?

Psicóloga: Eu diria ativo, mas sempre que uma pessoa não esteja a cantar, pode estar a acompanhar através do ritmo ou pode ser mesmo pela forma de se expressar musicalmente. Pode não cantar, nem querer ter alguma relação com o instrumento, mas gosta simplesmente. Desta forma consegue ser sempre activo.

Luís: Os pacientes são capazes de produzir música por iniciativa própria?

Psicóloga: Alguns sim. Nalgum basta uma palavra chave. Por exemplo, há uma senhora em que falamos "domino", cantou-nos uma música sobre o domino que não conhecíamos. (...) Eu lembro-me de um caso de uma senhora que estava numa fase muito avançado (eu já contei esta história nem sei quantas vezes, mas surpreendeu-me). Ele não tinha interesse por qualquer tipo de música. Na avaliação a senhora também não conseguia, em termos de linguagem já estava muito deficitária. Mas é engraçado como uma vez eu disse qualquer coisa (não sei porque) mas disse "doidas". E ela começou a cantar a música das "Doidas estão as galinhas" com coreografia e tudo e a letra comparei com a letra que estava no Youtube, por exemplo, e tudo certinho. As vezes são essas coisas que despertam memória e as pessoas são capazes de pôr iniciativa própria. Na maioria dos casos, quando perguntamos "Que musica vamos ouvir agora?", por exemplo, ou o que gostava.... têm imensas dificuldades. Em uma fase inicial são capazes de selecionar um cantor. Agora uma música em específico são raros os utentes que consigam selecionar musica. Podem generalizar e dizer " Quero uma música da Amália ". Mas que fado? Eles têm essa dificuldade. Mas temos algumas pessoas que são capazes mesmo assim de escolher especificamente esta música ou aquela música.

Luís: E existe algum tipo de restrição para participar em atividades musicais?

Psicóloga: Eu diria que não também. Por exemplo, individualmente acompanho uma utente, e uma das principais formas de comunicação que eu tenho com ela é através da música. Através da música que ela consegue me expressar algumas emoções. Eu posso chegar, posso rir e ela sorri de volta, mas quando coloco música nota-se na face dela uma tranquilidade, um interesse, uma tentativa de comunicar comigo. Até a diference do toque dela nota-se imenso. Por isso, ela já está acamada e já perdeu completamente a linguagem verbal, mas acaba por ter aquela componente emocional muito ligada a música. Ela expressa-se imenso quando colocamos. Tive a sorte de conhecê-la antes de ela chegar a essa fase, tanto que já tinha feito uma recolha de todas as músicas que lhe interessavam e esta recolha de história da vida estava a ser bastante útil nesta fase com ela.

Luís: Os familiares costumam participar nas atividades musicais?

Psicóloga: Nós tentamos que o grupo seja principalmente para as pessoas com demência. Para terem o espaço delas. Mas os familiares são sempre convidados sempre que quiserem participar mais no fim da atividade podem sempre juntar. E já tem acontecido (...) sentar-se e acompanhar o seu familiar nos minutos finais do grupo.

Luís: E como é que vocês, profissionais de saúde, sabem que os pacientes estão a reagir positivamente às atividades musicais?

Psicóloga: É através principalmente do humor da satisfação que mostram. No fim tentamos sempre que nos deem algum feedback sobre o gostavam da sessão: o aspeto mais positivo e, também, os aspetos negativos. Vamos lá fora com o utente agradecer a presença dele, mas também tentamos fazer esta entrevista semiestruturada com a pessoa. Não temos nenhum instrumento estandardizado, mas mais através deste feedback do utente e através das reações dele da própria música; a maneira de como estão a participar, o nível do humor deles, e mesmo algum comentário menos positivo (...) perceber que é preciso mudar alguma música. Houve um senhor que, por exemplo, (...) já tenho saudades de ouvir uma música do canto "x". Isso também fez nos um pouco de reavaliação que tivemos de fazer do tipo de músicas que estivemos a colocar. Se calhar estávamos a falhar com aquela pessoa, por exemplo. É mesmo mais a nível do feedback que as pessoas nos dão.

Luís: A terapia musical consegue que capacidades?

Psicóloga: Que tipo de capacidades a música acaba por estimular, por exemplo? A memoria e, também, podemos falar das reminiscências: muitas músicas acabam por trazer de cima as tais histórias de vida que eles têm, e muitas vezes gostam de partilhar connosco. Por que razão aquela música é especial? O que lhes faz lembrar? A atenção, sem dúvida. A nível da linguagem. Existe uma linguagem muito própria para a música, não é? E isso... nota-se muitas pessoas têm dificuldades na linguagem do dia-a-dia, linguagem verbal, mas há ali aquela tal linguagem musical que tem muito mais facilidade em se exprimir. Também temos quando temos o acompanhamento através dos instrumentos podemos falar da motricidade, também. Acho que acaba por englobar várias capacidades.

Luís: E quais os benefícios para os familiares, indiretamente, com estas atividades?

Psicóloga: Indiretamente? Para além dos grupos serem para os cuidadores familiares terem tempo para eles próprios, fazerem as suas atividades do dia-a-dia. Acho que também acaba por o próprio tempo mais tranquilo, muito mais relaxado. A nível de bem-estar, muito mais satisfeitos. Se acabam por trazer benefícios ao cuidador, não é? Um familiar tranquilo, não é? Um familiar satisfeito acaba por também no dia-a-dia ser muito mais fácil de lidar para cuidador.

Luís: Com que frequência os profissionais de saúde (neste caso vocês) recorrem a música para acalmar os pacientes?

Psicóloga: Com que frequência? Muitas vezes. Temos aqui uma utente que da maneira dele relaxar mesmo é através da música. Diferentes estilos, digamos. Houve uma altura que era mesmo cantada: ponhamos uma música cantável e havia uma fase que adora assobiar. Relaxa. Ainda há puco tempo consegui com que entrasse em filme de assobiar, e ele acabou por relaxar. Vinha a assobiar, mas vimos que a música em geral pode trazer bastante tranquilidade aos utentes. As vezes começo com música no início das sessões. Em alguns utentes que estejam mais ansiosos. Portanto é com bastante frequência que utilizamos. As vezes não é para remediar uma situação. As vezes também funciona como prevenção. Um ambiente musical. As vezes ponho música clássica, tipo Mozart (...) para criar som no ambiente.

Luís: Costumam misturar músicas com outras atividades lúdicas?

Psicóloga: Sim. Há alguns jogos por exemplo, ainda hoje até estávamos a fazer isso, uns jogos mais físicos em que as pessoas tinham de acertar com a bola em um certo alvo. Falamos dos jogos sem fronteiras, por exemplo. Curiosamente todos gostavam. Fizemos a música dos jogos sem fronteiras e acho que acabou por ser uma motivação extra para o jogo. mas costumamos por sempre um pouco de música a acompanhar as outras atividades. Mesmo aqui nas sessões como estava a dizer. As vezes ponha a música a acompanhar a própria sessão. Acaba por trazer a tal tranquilidade, aquele ambiente um pouco mais relaxado e também dependendo da atividade lúdica em si também tentamos fazer com que seja uma música mais ritmada ou mais calma. Pronto, depende. Por exemplo, relaxamento também é sempre acompanhada por uma música.

Luís: Há algum melhoramento de performance cognitivo durante e depois das terapias musicais que não seria possível adquirir com a ausência da música?

Psicóloga: É difícil de avaliar essa parte. Fazemos avaliação cognitiva. As pessoas participam nas atividades de música em simultâneo com outro tipo de atividades. Portanto aqui estão todos dentro do mesmo saco. Eu diria que sim, acaba por ter mais benefícios e penso que é uma mais valia, MAS a atividade cognitiva em si que no grupo que fazemos acompanhada pela música tem sido vantagens. Na avaliação notamos algumas pessoas tiveram ligeiros melhoramentos no mini-mental, por exemplo. Agora não sei te dizer se "x" é devido a música ou se "x" vem de outras atividades. Penso que seja o contributo da música e de outras atividades.

2ª parte - Jogos Digitais

Luis- Quantas vezes por semana os pacientes jogam computador?

Psicóloga - Depende dos pacientes. Nem todos jogam, mas tento pelo menos uma vez por semana levar ali alguém a conhecer a WII. Há um utente, por exemplo, que já tem uma rotina mais ou menos estabelecida. fazemos sempre um pouco da wii (as atividades mais desportivas). Portanto, tento uma vez por semana, mas não são todos os utentes. Neste momento diria que podem ser a volta de 3, mas vamos tentar... Já utilizamos no grupo, por exemplo, e temos de explorar mais para ver até que ponto podemos utilizar mais vezes essa componente.

Luis- E quanto tempo dura?

Psicóloga - Por exemplo, este senhor tentou jogar ao bowling... uns 15 minutos cada pessoa. No grupo acabou por ser uma sessão inteira, tivemos a explorar vários jogos com as pessoas. Mas individualmente foram 15 minutos. Primeira vez foi uma hora, mas agora, para acompanhar outras atividades- 15 minutos.

Luis- E que tipos de jogos?

Psicóloga - Tem sido os jogos mais da wii sport. O Bowling, principalmente, que esta pessoa gosta imenso, o outro utente tem sido boxe e ténis. Na atividade temos a wii party e a que temos tido mais facilidade usar é uma de dança porque dá para fazer com que toda a gente acabe por participar. (...) O "Balance Corte" também acho que vai ter alguma utilidade para utilizar individualmente em algumas pessoas.

Luis- E de que maneira os pacientes interagem com os jogos?

Psicóloga - No início algumas pessoas têm muita dificuldade em perceber como é que utilizam o comando, por exemplo. Há um senhor que lhe faz muita confusão no ténis usar como se aquilo fosse uma raquete. Entretanto há sempre esta pequena orientação depois acaba por ser muito bastante lúdico; as pessoas gostam muito da interação. Agora temos sempre a tentar reorientá-los o seu bonequinho (como aquilo que lhe chamamos) "é o teu e aquilo é o meu e tem de ser utilizado como se fosse uma raquete. Temos de estar sempre a recordar aos utentes. Prontos, eles estão na fase inicial, mas têm alguma dificuldade. As pessoas com menos dificuldade e que não é necessário fazer qualquer tipo de reorientação são pessoas com défices cognitivos ligeiros. Mas eu também (...) a interação dele.… eu notei logo no início um grande interesse. Por exemplo explicou-me, deu-me imensas dicas (...) deve-lhe ter dado muita motivação a nível de participação.

Luis- Existe algum tipo de restrição para jogar?

Psicóloga - Há pessoas com mais dificuldades de mobilidade (penso eu); que tenha dificuldades cognitivos. Como estava eu a dizer acabam por, ou não, conseguir aprender a utilização. Nós tentamos fazer passo por passos, de forma muito gradual e explicar a pessoa. Mas, temos aqui pessoas que penso que é impossível a utilização deles com o comando mesmo que o nível de motricidade (os movimentos que não conseguem realizar). Já tentamos realizar, por exemplo, o Jogo da dança com essa pessoa e como ele tem muitas dificuldades de mobilidade também tivemos algumas dificuldades. Mesmo as cognitivas, são considerados bastante avançados as dificuldades e a nível mobilidade quando também com algum agravamento. Acho que são essas as principais limitações. Agora, também acho que havia coisas que podiam ser melhoradas. Sei que é difícil, mas, por exemplo, o comando faz imensa confusão jogar ténis com aquele tipo de comando. Sei que isto impossível que existem vários jogos, mas se aquilo fosse com o formato de uma raquete talvez fosse mais fácil para as pessoas aprenderem essa informação. Ou mesmo o golfe, também pode gerar alguma confusão. Por exemplo no bowling para este senhor é fácil, mas lá está porque não tem assim tantas dificuldades que não lhe permitam de aprender esta nova informação. Mas há aqui coisas que acho que não são assim tão intuitivas para as pessoas perceberem o uso daquele objeto. Neste caso do comando, acho que é a principal dificuldade.

Luis- Os pacientes conseguem jogar sozinhos?

Psicóloga - Este utente que tem défices cognitivos ligeiros, sim. Os outros enquanto não. Temos de estar sempre presentes para tentar orientar. Por exemplo, mesmo no ténis pode haver uma (escolha?) que até a pessoa faça bem, na seguinte ficam um bocado confuso o que tem de fazer agora. "Quem sou eu naquele campo?". Temos de estar sempre a recordar este tipo de informações. Agora, por exemplo, aquele jogo da dança não sei se a dança é para ser mais intuitiva, não sei, mas temos de copiar a coreografia que está a passar. É um pouco um momento divertido; há pessoas que acabam por se divertir. Acho que ai já, para quem não tem tantos problemas de mobilidade acabam por ser muito mais fácil de perceber de como fazer esse jogo, por exemplo.

Luis- E como vocês sabem que os pacientes estão a reagir positivamente aos jogos?

Psicóloga - Pelas reações emocionais que mostram. Alguns podem ficar frustrados. Ou confusos. E percebemos que as coisas não estão a correr muito bem. Temos que orientá-los. Fazer alguma pausa. E por outro lado temos a tranquilidade a jogar o facto de exprimir satisfação. Sorrir. De facto, percebemos que as pessoas estão a usufruir da maneira que queremos daquele jogo.

Luis- Os familiares costumam jogar com eles?

Psicóloga – Por enquanto não. Talvez. Por causa das estruturas individuais. Ficamos com o utente. Já aconteceu uma cuidadora jogar com o marido. Ele fica extremamente ansioso quando ela não está. E ela jogou. É para dar descanso aos familiares.

Luis – Numa sessão de jogo, quantas pausas vocês fazem?

Psicóloga – AS necessárias. Por exemplo, no ténis (falamos de uma pessoa especifica). Quando notamos que a frustração é alguma, pode chegar até as 3 pausas ou mudamos para outro jogo, por exemplo a dança que a pessoa acaba por ter mais facilidade. Mas diria no máximo 3. Depois fazemos a pausa com outro jogo. Depois tentamos o ténis mais tarde para ver se consegue iniciar outra vez o jogo com mais tranquilidade.

Luis – Existe alguma contraindicação para jogar jogos de computador com os pacientes?

Psicóloga –Não. É mesmo a dificuldade em perceber "como jogo isto". AS pessoas gostam do tablet. Gostam imenso. Gostam de ir lá. A tecnologia touch, as pessoas adoram mesmo quando é simplesmente um vídeo do Youtube e apontar. É uma novidade para eles positiva. Não traz outros constrangimentos.

Luis – Os pacientes conseguem distinguir realidade de ficção dos jogos?

Psicóloga – Com os utentes com quem jogamos sim (sabem distinguir realidade de ficção). Por isso as vezes tem dificuldade em perceber qual é o boneco que estão a jogar. Mas não tem havido confusão a este nível.

Luis- E que melhoramentos os jogos podem induzir nos pacientes?

Psicóloga – A nível cognitivo, penso muitos. A nível físico. Tem uma componente física muito interessante a nível de habilidade motoras. É uma mais valia na wii. Nos outros, os jogos da tablet. A nível de memoria é interessante. Por causa das imagens mais aliciantes, mais motivadores e acaba por aumentar a motivação acaba por influenciar o desempenho bastante. Isso vai acabar por ter algum reflexo no desempenho dela, nas tarefas de memoria e atenção. Conseguem por estar muito mais aliciantes as vezes com algum material como papel. Não quero dizer que sejam desinteressantes até conseguimos fazer melhor. Por exemplo até falei disso hoje a alguém. Um senhor que chega aqui e houve uma música que gosta de tocar com os dedos na mesa como se fosse um piano. Arranjamos no tablet uma aplicação com as teclas do piano. Ele toca e acaba por estar mais focado na tarefa, muito mais atento. Acaba por a nível de memoria depois tenta escutar uma música e tentar corresponder (é uma pessoa com alguns conhecimentos musicais). Por isso, as novas tecnologias acabam por ter. talvez… por serem mais aliciantes da maneira como foram construídos pode dar mais motivação as pessoas. E poderá ter reflexo mais positivos no desempenho das tarefas de memoria, de atenção. Raciocínio numérico há jogos engraçados. Por exemplo o lumosity? Ele tem jogos de raciocínio numérico que por exemplo o número de pássaros que uma pessoa está a contar. E talvez por ser algo continuo a acontecer, traga alguma motivação a pessoa. Traga um pouco de adrenalina, pois tem de contar mais rapidamente, também é preciso ter cuidado com a frustração, mas notamos que o desempenho tem mais sucesso do que numa folha.

Entrevista com a Psicólogo

1ª parte - atividade musical

Luis: Este questionário está dividido em dois, em música terapia e jogos virtuais. vamos começar por música terapia.

pergunta número 1 - Quantas vezes por semana fazem terapia musical com os pacientes?

Psicólogo: É uma vez. Fazemos uma vez por semana. neste caso não podemos considerar propriamente música terapia porque não somos psicoterapeutas. Não somos terapeutas musicais. Só que (e a Carla também não) nós chamamos mais animação musical porque não somos mesmo propriamente peritos, mas para eles, pensamos que funciona da mesma forma. Depois para além disso utilizamos também a música no fim das sessões individuais. Vem cá uma pessoa faz uma sessão individual e no final antes dela ir embora nós também damos-lhe sempre uma musica perguntamos que tipo de musica ela quer ouvir ou qual o cantor que ela gosta. Isto normalmente é mais no início quando queremos conhecer as pessoas nós então perguntamos quais os cantores, quais as músicas preferidas delas e depois a medida que as sessões vão avançando fazemos as sessões individualmente e no final para relaxarem um bocadinho e para saírem daqui alegres, pomos uma musica do interesse deles. Portanto, temos a músico terapia, sim, mas também temos um (peça?) musical por cada sessão individual.

Luis. E quantas sessões (horas) em que os pacientes participam nas actividades?

Psicólogo: A sessão em grupo é uma hora que é a sexta feira. A sessão individual demora 2 a 3 minutos que é a duração de uma música.

Luis: Que tipos de atividades musicais fazem com os pacientes?

Psicólogo: Nas sessões em grupo utilizamos os instrumentos. As músicas muitas vezes são do interesse deles. De vez em quando podemos utilizar uma música que talvez não é conhecida por todos porque temos, por exemplo, o caso daquela senhora que fala mais venezuelana (ela viveu muitos anos lá) podemos por uma música que seja do agrado dela. O "La Co Caracha", poe exemplo, que pusemos hoje, a primeira vez que que fomos buscar essa música foi porque sabíamos que ela gostava dessa música de vez em quando agora temos uma ou outra musica mais latina que sabemos que é do interesse dela. Tirando isso, temos o Max (toda a gente conhece e normalmente gostam), fados da Amália, as músicas madeirenses mais populares (bailinho da Madeira, ponha aqui o seu pezinho,). Eles gostam.

Luis: Que tipos de Médium vocês utilizam para estas actividades?

Psicólogo: Normalmente, ou cantamos nós, sozinhos, se por exemplo o bailinho da Madeira a partida não e necessário (cantamos todos). Na maior parte das vezes recorremos a internet (youtube).

Pode haver situações em que não há música no youtube e então nós utilizamos o radio e CD's com as músicas. Algumas músicas tradicionais madeirenses temos em CD. Também temos algumas músicas de Natal pois não encontramos muitos na internet (musicais mesmo tradicionais madeirenses). Mas na maior parte das vezes é mesmo retirado da internet. Aquilo que acontece também é que, por exemplo, posso conhecer a música (a letra) mas a outra pessoa não conhece. Quando é em grupo, os gostos não são iguais para todos. Então trazemos sempre a letra das canções e as vezes temos que retirar da internet ou quando não há na internet (muitas músicas populares não existem na internet), então nós começamos a ouvir a música e começamos a passar a mão a letra para depois apresentar.

Luis: As atividades são maioritariamente passivas ou ativos?

Psicólogo: Eles tocam e normalmente cantam. Pode haver um caso em que uma pessoa possa ser um bocadinho mais apática. Hoje por exemplo temos um caso de uma senhora que parecia um bocado mais apática, mas mesmo assim cantou um bocadinho. Temos, não neste grupo, um senhor que está num estado um bocado mais avançado, mas no que toca a música é excelente. Ele participa mesmo: canta muito. eu acho que não se pode dizer que nenhum deles seja passivo; ou a tocar nós por acaso temos uma senhora que diz que não canta, mas a nível de tocar instrumento, é impecável!

Luis: Os pacientes são capazes de tocar música por iniciativa própria?

Psicólogo: Se eles conhecerem a música sim. Nós temos um senhor por exemplo, que começa a assobiar/cantar. Ou perguntam qual a música que querem ouvir. Mas maioritariamente eles dizem o que gostam de ouvir.

Luis: Existe algum tipo de restrição para participar em atividades musicais?

Psicólogo: Aquilo que fazemos sempre no início é a avaliação da pessoa para ver se a podemos incluir no grupo ou não. Há pessoas que não gostam de estar incluídas em grupo. Depois de vermos se a pessoa pode trabalhar em grupo (isto também depende da evolução da doença. Há pessoas está num estado muito avançado e talvez não seja tão capaz de frequentar o grupo). Mesmo assim temos uma pessoa que não frequenta este grupo, mas, de qualquer forma, é convidada de vir a musica porque lá está, a musica é um bocado diferente e a pessoa se calhar poderia ter uma participação mais ativa mesmo, porque em grupo fica mais ansioso mas quando fazemos uma atividade musical ele gosta. Tirando isso a partir do momento em que esteja integrado no grupo, só mesmo quando não quiser (o paciente), não há restrições.

Luis: Os familiares costumam participar?

Psicólogo: Não. Fazemos mesmo só com os utentes. Há um caso de uma senhora que (...) está num estado mais avançado e um familiar assiste por questões de segurança.

Luis: Como vocês sabem que os pacientes estão a reagir positivamente a música?

Psicólogo: Pela participação, expressão facial, pela expressão corporal e depois muitas vezes eles próprios dizem que estão a gostar.

Luis: Houve algum caso em que reagiram negativamente a música?

Psicólogo: Que eu me recorde, não. Pode haver uma situação que, vamos supor que temos 6 a 7 pessoas, se calhar pode haver uma música que não seja do agrado de uma determinada pessoa e ela diz que não gosta desta música. São casos pontuais, mas normalmente nem isso acontece.

Luis: nem reagiram agressivamente?

Psicólogo: Não, nunca. A nível de agressividade, nunca. Pode é dizer "ai não gosto muito desta musica", mas isso é muito raro porque lá está, nós temos o cudado de saber mais ou menos quais as musicas que se enquadram naquelas pessoas. Mas agora, a nível de agressividade nunca.

Luis: Que capacidades conseguem atingir nos pacientes?

Psicólogo: Reminiscências. Isso é muito importante, porque há casos de pessoas que estão muito esquecidas, mesmo com coisas mais passadas. Só que a nível de música a maior parte daquilo está lá (reagem sempre positivamente). Depois existe convívio, relaxamento, há associabilização(?) entre todos, depois há o movimento (motricidade), alivia ansiedade. É muito completo.

Luis: Os familiares ganham algum benefício disto? das terapias musicais?

Psicólogo: Com os familiares fazemos outras atividades. Até agora, música tem sido apenas usada para os utentes com demência.

Luis: Com que frequência os profissionais de saúde recorrem a música para acalmar os pacientes?

Psicólogo: Desde que estejam ansiosos, sempre! Nem todos que frequentam a casa, ficam ansiosos. Mas temos, e estamos a falar de um caso particular, temos um senhor que já está em um estado um bocado mais avançado que chega cá um bocado ansioso e pomos-lhe música e ele reage muito bem. Quando paramos a música e ele fica ansioso, nos voltamos a pôr uma musica e ele, na maior parte das vezes, reage bem (ele participa mesmo: canta, vai batendo na mesa).

Luis: Já alguma vez misturaram outras atividades lúdicas com música?

Psicólogo: Por vezes, nem sempre. Mas por vezes podemos por uma música de fundo. Não é uma regra, mas por exemplo estamos a fazer uma atividade e pode haver uma música.

Luis: E existe algum melhoramento cognitivo que não seria possível sem música?

Psicólogo: Pelo menos nos traze-los a realidade. Há casos em que a pessoa anda um bocadinho perdido e não consegue reagir a nada, e com a música vemos que a pessoa está ali e que ainda tem lembranças do seu passado. E ao ouvir aquelas músicas ela pode ser capaz de associar isso a alguma historia (penso eu) e isso é positivo.

2ª parte - Jogos Digitais

Luis - Quantas vezes por semana os pacientes costumam jogar?

Psicólogo: Nem todos jogaram e apenas participei uma vez. Mas para já foi usada poucas vezes.

Luis - Quanto tempo dura uma sessão de vídeo jogo?

Psicólogo: Naquela que participei, correu bem. O senhor participou. O outro não tanto pois a nível motor tem muito mais dificuldades. Mas houve um senhor que até.. ele pode fazer uma confusão em entender que os movimentos daqui (realidade) é respondido ali (televisão). Mas acabou por correr, não digo bem, bem, mas razoável.

Luis - Que tipos de jogo conseguem interagir?

Psicólogo: Pois, aquilo que eu joguei com ele foi ténis. mas não me recordo muito bem. E o outro foi boxe.

Luis - E como interagiram com estes jogos?

Psicólogo: Foi de pé.

Luis - E existe alguma restrição para eles jogarem?

Psicólogo: Não. Desde que gostem.

Luis - E eles costumam jogar sozinhos?

Psicólogo: Comigo isso não aconteceu. Agora talvez no futuro sim.

Luis - E como sabem que respondem positivamente aos jogos?

Psicólogo: E reportando apenas daquele dia. Da mesma forma como a música. Eles próprios podem dar feedback e pela motivação, e interesse claro!

Luis - Os familiares costumam participar?

Psicólogo: Pelo menos da vez que participei, não.

Luis - E em uma sessão de jogos costumam fazer pausas?

Psicólogo: Não.

Luis - Alguma contraindicação?

Psicólogo - Não.

Luis - Eles conseguem distinguir realidade em ficção dos jogos?

Psicólogo - Pois. Essa é a tal questão que estava a falar a pouco. Não sei responder a essa questão. Mas como disse notei alguma dificuldade em perceber o paciente que fazer o movimento aqui (realidade) é reproduzido ali (televisão). Mas para já não sei responder a essa questão. Mas alguns eu penso que sim.

Luis - e que melhoramentos podem os jogos induzir?

Psicólogo - Os mesmos que a música. Basicamente. Mas para a maior parte isto (os jogos) é uma novidade para muita gente.

Entrevista com a Médica

1ª parte - atividades musicais

Luis: Quantas vezes por semana fazem terapia musical com os pacientes?

Médica: só uma.

Luis: E a duração?

Médica: Mais ou menos uma hora.

Luis: Que tipo de atividades musicais fazem com os pacientes?

Médica: Cantamos, fazemos a estimulação com alguns instrumentos de percussão que é o que temos acesso mais facilmente e dançamos também.

Luis: E qual o tipo que costumam usar?

Médica: O tipo de música? Sim, usamos músicas da altura deles quando eram uns bocadinhos mais novos que são as músicas que preservam na memoria. E, pronto vamos tentando perceber quais as músicas que eles gostam mais, eles próprios dão sugestões de músicas de que se lembram. Muitas delas as vezes nem conhecemos, mas vamos procurar e, pronto, é isso.

Luis: E qual o médium mais utilizados nestas catividades?

Médica: Usamos o computador como suporte auditivo. É mais fácil. E temos também ajuda de um voluntário que toca bandolim e nos ajuda também a fazer suporte musical.

Luis: As atividades musicais costumam ser maioritariamente ativos ou passivos?

Médica: Eles as vezes ficam no mundo deles e param de tocar e cantar. O nosso objetivo e cantar sempre que eles estejam sempre no máximo a cantar e tocar também.

Luis: Os pacientes conseguem tocar música por iniciativa própria?

Médica: São, muitas das vezes são. Quando eles próprios, ás vezes, no inicio não estão tão estimulados mas depois ao longo das sessões desinibam-se, e eles próprios percutem sons no intervalo das musicas, vão buscar musicas que estão na cabeça deles e começam a cantar, e ai conseguimos, como estava a dizer há um bocadinho, podemos descobrir algumas musicas que eles se lembram, e as vezes insistimos para eles cantarem, e eles conseguem cantar uma grande parte da musica. E sim, eles têm essa capacidade. Eles precisam de ser estimulados, mas têm muita música na cabeça.

Luis: Existe algum tipo de restrição para participar em atividades musicais?

Médica: Eu acho que não. Por exemplo, se for um paciente que tem dificuldades de locomoção, ou que esteja em uma cadeira de rodas, ele não vai conseguir participar na dança, mas podemos sempre estimular ao cantar e tocar para ele. Há sempre estímulo. Mesmo que eles não conseguem participar. No entanto, como a capacidade musical é a última que eles perdem, é possível estimular mesmo quando não conseguem falar.

Luis: Os familiares costumam participar em atividades musicais?

Médica: Nestas normalmente não estão presentes, mas quando eles vêm buscar mais cedo, eles colaboram na atividade.

Luis: E como vocês sabem que os pacientes estão a reagir positivamente às atividades musicais?

Médica: O objetivo é sempre fazê-los interagir o máximo possível. É sempre positivo mesmo quando estejam calados. A música está sempre a entrar na cabeça e a estimular alguma coisa. Está sempre a estimular a memoria, está sempre a fazê-los pensar... está sempre a haver alguma conceção positiva. Mesmo quando não participem muito ou ativamente durante a sessão ou durante período, às vezes eles estão em um dia em que estão mais caladinhos e mais paradinhos, é sempre positivo estarem na sessão. Mesmo assim, é cada vez mais positivo se conseguirem cantar mesmo quando estão olhando para a letra, porque muito das vezes eles se lembram da música e conseguem cantar. Depois, é ainda mais positivo conseguirem acompanhar a letra. Se conseguirem pegar em um instrumento e acompanhar com a percussão. E quando lhes pedimos para dançar se eles colaborarem podem também dançar. Mas das quaisquer das maneiras em que eles não consigam executar todas as atividades, digamos assim, é sempre positivo de eles estarem presentes e a estarem a ouvir música, porque são estimulados.

Luis: E estas atividades musicais conseguem que capacidades?

Médica: O que conseguem? Nós não sabemos propriamente muito bem. Mas, pensamos que, se pensarmos por partes, conseguimos ao eles a estarem a ouvir músicas que fizeram parte da vida deles, estimulamos memória no fundo, não é? Estimulamos um bocadinho a capacidade de produzir pensamentos e raciocínios. Depois tentamos fazer uma estimulação cognitiva também ao facultarmos a letra da música para eles poderem seguir. Há músicas que, por exemplo, que não conhecem tanto do que outros, mas o facto de estarem a ouvir a música, seguirem a letra e lerem as palavras faz também uma estimulação cognitiva importante. depois, nós também tentamos fazer estimulação sensitiva e motora com a própria participação dos instrumentos de percussão, com a massagem de relaxamento no final, com a dança. Portanto, eu acho, e do pouco que vejo, pois, a nossa amostra é bastante pequenina, não podemos extrapolar para grandes grupos. Mas daquilo que eu vejo há um beneficio grande e há utentes em que se vê um avanço, no fundo, em que se vê ganhos e que conseguem interagir mas com os colegas, conseguem estar mais divertidos, participar mais, há pacientes que não percebem o que é um instrumento de percussão e ao longo das sessões, vão reconhecendo o instrumento e vão conseguindo acompanhar e chegam mesmo a conseguir depois acompanhar o ritmo certinho que é muito positivo. E, portanto, nós vemos alguns ganhos nestes nossos utentes. Agora era importante investir em grupos maiores para perceber mesmo os ganhos. Agora além de prevenir o avanço da doença e a perda de algumas faculdades, eu acho que mesmo assim ainda se consegue alguns ganhos.

Luis: Quais os benefícios dos familiares, indiretamente destas terapias ou destas atividades musicais?

Médica: Os benefícios nos familiares? Eu acho que os benefícios são muito grandes! Porque primeiro conseguimos ter ganhos positivos em termos cognitivos, em termos funcionais e dos movimentos deles, não é? É muito importante porque eles, no fundo, conseguem movimentar-se melhor, etc. E depois, o facto de estarem na sessão também alivia um bocadinho a presença deles em casa e os familiares conseguem descansar um bocadinho. E a estimulação positiva deles faz com que também melhore o humor, o bem-estar, e isso tudo acaba por se refletir em casa.

Luis: Costumam misturar atividades musicais com outras atividades lúdicas? Por exemplo, fazer um puzzle enquanto ouvir música?

Médica: Ah, isso é mais da parte dos psicólogos. Não sei... eles é que podem responder melhor a essa parte. Durante a sessão em que eu participo, são estas coisinhas que nós fazemos. Agora não sei o que eles fazem depois na estimulação (que eles fazem terapias de grupo e fazem terapias individuais). É o trabalho mais dos psicólogos. Nós aqui na sessão músico terapia o que nós tentamos fazer é uma mini-festa. Um mini-baile em que se possam divertir e que se possam libertar um bocadinho e que tenham aquele estímulo todo positivo. E também não exigimos muita concentração se não estarem a olhar para a letra, não faz mal. Estimulamos com a parte a interação com a percussão.

Luis: Existe algum melhoramento cognitivo durante e depois das terapias musicais que não seria possível alcançar sem a música?

Médica la: Eu acho que si. Por exemplo, não sei se reparou hoje, um senhor novo, na interação que primeiro agarrava na pandeireta e achava estranho, e depois consegue interagir e consegue fazer várias tarefas ao mesmo tempo: acompanhar a letra, cantar, estar atento ao ritmo e desenvolver a técnica de percutir com a pandeireta na mão, que no inicio não estava a perceber para que servia. Eu acho que há melhorias mesmo em uma sessão, e depois as melhorias por aquilo que tenho visto nestes utentes são acumulativas de sessão para sessão. E depois da sessão eu noto, por exemplo, por experiência própria quando boleia a minha vizinha para casa (que costuma estar nas sessões) ela vai muito mais bem-disposto. Interage muito mais do que em um dia normal em que ela está em casa sossegadinha sem estar estimulada. E já assisti um período de lucidez mantido dela ao ponto de chegar a casa e contar a filha o que se tinha feito na sessão, o que já não é normal dela. Por isso eu acredito que sim.

2. Source code for musical distortions

```
/*
* Variables
*/
private static DSP DistortionDsp;
private static DSP PitchShift;
public static Channel StreamChannel;

/*
* Pitch-Rhythm algorithm - changes the speed and pitch of music
*/
private static float _pitch;
public static float Pitch
{
       get {return _pitch; }
       set
       {      //Pitch values are limited by pitchshift characteristics
              if (value > 2.0f || value < 0.5f)
                     return;

              _pitch = value;
              StreamChannel.setPitch(_pitch);
        }
}

/*
* Pitch algorithm - changes the pitch without changing the speed of music
*/
public static void ChangeDSP(DSP_TYPE type, float value1, float value2 = 0f, float
value3 = 0f, float value4 = 0f)
        {
              //Distortion goes between 0 and 1 (max distortion)
           if (type == DSP_TYPE.DISTORTION)
           {
            Result=DistortionDsp.setParameterFloat((int)DSP_DISTORTION.LEVEL, value1);
                Debug.Log("Distortion dsp result: " + Result);
           }

           if (type == DSP_TYPE.PITCHSHIFT)
           {
              //value 1 = default value; 2.0f and 0.5f are maximum and minimum
              //values possible
                 if (value1 > 2.0f || value1 < 0.5f)
                     return;

                 PitchShift.setParameterFloat((int)DSP_PITCHSHIFT.PITCH, value1);
                 UnityEngine.Debug.Log("Pitch: " + value1);
           }
        }

/*
* Rhythm algorithm - changes the speed of music without changing pitch
*/
public static void PitchCompensation(float tempo)
{
       //This method sets the amount of compensation required depending on pitch values

   float tempoRounded = (float)Math.Round(tempo, 2);
```

```
float tempoChange = Mathf.Abs(tempo - 1);
float tempCompensation = 1f;
float tempPitch = 1f;

if (tempo > 1)
{
   tempCompensation = 1 / tempoRounded;
   tempPitch = 1 * tempoRounded;
}
else if (tempo < 1)
{
    tempCompensation = 1 / tempoRounded;
    tempPitch = 1 * tempoRounded;
   }
   else
  {
    return;
  }
    UnityEngine.Debug.Log("Pitch: " + tempPitch);
    UnityEngine.Debug.Log("Compensation: " + tempCompensation);

    Pitch = tempPitch;
    ChangeDSP(DSP_TYPE.PITCHSHIFT, tempCompensation);
  }
```

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