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Immersive experiences for cognitive stimulation of patients in early stages of Alzheimer's disease

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- 1. Immersive experiences for cognitive stimulation of patients in early stages of Alzheimer's disease**

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Resumo

Com a esperança de vida humana a aumentar mais de 45% desde 1950, as doenças neurodegenerativas, como a Doença de Alzheimer (AD), são mais frequentemente diagnosticadas entre os idosos modernos em todo o mundo. A AD causa múltiplas cadeias de eventos no cérebro, levando à degeneração celular generalizada, perda de volume, perda de memória e declínio das funções cognitivas. Embora a DA não possa ser curada, atualmente indivíduos com sintomas ligeiros a moderados da doença podem ser submetidos a treino cognitivo. Estes métodos terapêuticos que visam a estimulação cognitiva e o atraso da progressão da AD são possíveis nas fases iniciais da doença.

As tecnologias emergentes, como a Realidade Virtual (VR), tornaram-se uma ferramenta promissora nesta área, oferecendo ambientes imersivos e seguros que podem ser adaptados às necessidades dos participantes. Este artigo apresenta o desenvolvimento de uma experiência de estimulação cognitiva baseada em VR que pode ser utilizada por pessoas para estimulação cognitiva nas fases iniciais da perturbação de défice de atenção.

Foram desenvolvidos diversos jogos de estimulação cognitiva dentro da experiência REMIND-VR, permitindo aos utilizadores interagir em segurança com os cenários simulados e as ferramentas à sua disposição, sem riscos significativos. Cada jogo estimula diversas funções cognitivas, como a memória de curto prazo, a memória espacial, o pensamento criativo e a cognição motora. Os jogos foram concebidos para eliminar o conceito de fracasso, permitindo apenas a progressão, o que atenua a frustração. Para envolver ainda mais os indivíduos, o trabalho utiliza a interação baseada no reconhecimento do movimento das mãos, resultando numa experiência mais intuitiva e acessível.

Devido a barreiras éticas, 33 participantes saudáveis participaram na avaliação da experiência de RV. As pontuações globais do Simulator Sickness Questionnaire (SSQ) indicaram uma redução na categoria de náuseas, distúrbio oculomotor e sintomas de desorientação. Isto indica um nível positivo de conforto geral, aumento da atenção e concentração, o que se reflete nas pontuações totais. O inquérito sobre RV refere que, dos 33 participantes, 87,9% reportaram

a experiência como "muito agradável", com elevada satisfação com o ambiente e vontade de melhorar o desempenho no jogo.

A experiência REMIND-VR demonstrou um elevado potencial na melhoria das funções cognitivas dos indivíduos. Apesar das várias limitações, os vários jogos foram bem recebidos, promoveram o engagement e foram recebidos positivamente. O tamanho da amostra demonstrou também que a saúde geral dos participantes não foi negativamente afetada.

Keywords: Design Centrado no Utilizador, Doença de Alzheimer, Doenças Neurodegenerativas, Estimulação Cognitiva, Experiência Imersiva, Gamificação, Jogos Sérios, Realidade Virtual, Reconhecimento de Movimentos das Mãos, Terapêutica Digital

Abstract

With human life expectancy having increased by more than 45% since 1950, neurodegenerative disorders, such as Alzheimer's Disease (AD), are more frequently diagnosed among the modern elderly of the world. AD causes multiple chain of events in the brain leading to widespread cell degeneration, loss of volume mass, memory loss and declining cognitive functions. While AD cannot be cured, presently individuals with mild to moderate symptoms of the disease can undergo cognitive training. These therapeutic methods aimed at cognitive stimulation and delaying the progression of AD are possible in the early stages of the disease.

Emerging technologies such as Virtual Reality (VR) has become a promising tool in this field, offering an immersive and safe environments that can be adapted to participant's needs. This paper presents the development of a VR based cognitive stimulation experience that can be used by people for cognitive stimulation in the early stages of AD.

Multiple cognitive stimulating games were developed within the REMIND-VR experience, allowing users to engage safely with the simulated settings and the tools at their disposal without significant risk. Each game stimulates various cognitive functions such as short-memory, spatial memory, creative thinking and motor cognition. The games were designed to eliminate the concept of failure, allowing only forward progression, which mitigates frustration. To further engage individuals, the work uses interaction based on hand movement recognition, resulting in a more intuitive and accessible experience.

Due to ethical barriers, 33 healthy participants partook in the evaluation of the VR experience. The overall scores for the Simulator Sickness Questionnaire (SSQ) indicated a reduction in category for nausea, oculomotor disturbance and disorientation symptoms. This indicates positive level of general comfort, increase in attention and concentration which is reflected on total scores. The VR survey states that out of the 33 participants, 87.9% reported the experience as 'very enjoyable' with high satisfaction of the environment and willingness to improve game performance.

The REMIND-VR experience displayed high potential in the improvement of an individual's cognitive functions. Despite the various limitations, the various games were well received, promoted engagement and were met with positive reception. The sample size also demonstrated participant's overall health not being negatively affected.

Keywords: Alzheimer's Disease, Cognitive Stimulation, Digital Therapeutics, Gamification, Hand Tracking, Immersive Experience, Neurodegenerative Disorders, Serious Games, User-Centred Design, Virtual Reality

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Abbreviations

AD = Alzheimer's disease

A β = amyloid beta

ADL = Activities of daily living CASI = Cognitive Abilities Screening Instrument

CDR = Clinical Dementia Rating

CDR-SB = Clinical Dementia Rating — Sum of Boxes

CDT = Clock Drawing Test

CESD = Center for Epidemiological Studies Depression

DST = Digit Span Test

FAB = The Frontal Assessment Battery

FICSIT-4 = Frailty and Injuries: Cooperative Studies of Intervention Techniques

GAMs = generalized additive models GDS = Geriatric Depression Scale

GDS-15 = Geriatric Depression Scale-15

HADS = Hospital Anxiety and Depression Scale

IADL = Instrumental Activities of Daily Living Scale

IL-1 = interleukin-1

IL-6 = interleukin-6

KICA = Kimberley Indigenous Cognitive Assessment

MADRS = Montgomery-Asberg Depression Rating Scale

MMSE = Mini-Mental State Examination

MMSE-DS = Mini-Mental State Examination-Dementia Screening

MoCA = Montreal Cognitive Assessment

RCF = Rey Complex Figure

SDST = Symbol digit substitution test

Short FES-I = Short Falls Efficacy Scale International

STAI = State-Trait Anxiety Inventory

SSQ = Simulator Sickness Questionnaire

STT-B = Shape Trail Test B

SWLS = Satisfaction with Life Scale

TMT = Trail Making Test
TNF- α = tumour necrosis factor-alpha
TUG = Timed Up and Go
VR = Virtual Reality
WCST = Wisconsin Card Sorting Test
WHOQOL = World Health Organization Quality of Life
WMS-III = Wechsler Memory Scale III
WMS-R = Wechsler Memory Scale Revised
ZBI = Zarit Caregiver Burden Interview

Chapter 1

Introduction

With the increment of humans' life expectancy above 45 % since 1950, neurodegenerative disorders, such as Alzheimer's disease (AD), are more frequently diagnosed among the modern elderly (United Nations, 2024). As of recent reports, AD is the most common cause of dementia, accounting for 60 %-80 % of dementia cases.

In the early stages of AD, the neurogenesis of the hippocampus displays a rapid loss of neurons, which correlates with the functional disconnection with other parts of the brain, resulting in lower cognitive functions, particularly memory processes and certain intuitive behaviours. Furthermore, with the accretion of amyloid beta ($A\beta$) from AD, the microglia activates and starts producing proinflammatory cytokines, subsequently leading to inflammation, phagocytosis and neurodegeneration (Lazarov et al., 2024; Scheltens et al., 2021).

While AD cannot be cured, presently individuals with mild to moderate symptoms of the disease can undergo cognitive training, a way to mitigate the impact of cognitive decline. Resulting in the stability of brain functions and the improvement of social functions, leading to stimulation of thinking, concentration and memory. What's more, cognitive stimulation can be enhanced through gamification to achieve improved engagement with tools such as VR (Kim, 2020; Tanmalaporn et al., 2024).

Virtual reality (VR) is a computer-generated experience that employs 3D near-eye displays and pose tracking to give the user an immersive feel of a virtual world. Considering the development of lighter, more comfortable headsets and more accessible software for people with disabilities, VR has presented itself as a promising tool for cognitive stimulation that offers an opportunity for adaptability and immersion for cognitive exercises (Scheltens et al., 2021).

What's more, recent studies have put forward that a fully immersive VR cognitive training program is feasible and usable for patients with mild cognitive dementia, resulting in improvements of mood, cognitive functions and awareness (Gamito et al., 2020; Yun et al., 2020). This approach integrates game elements into conventional mental function exercises to make them more engaging and motivating for patients.

Given these considerations, this study proposes the development of a VR based cognitive stimulation experience that can be used by people for cognitive stimulation in the early stages of AD. Using emerging technologies to promote interaction based on hand movement recognition, seeking to reduce barriers to adoption for older users, resulting in a more intuitive and accessible experience.

1.1 Motivation

The reason this work is being carried out is because of my grandfather, former professor and director of Faculdade de Ciências Sociais e Humanas, Jorge Crespo. He was a man of great knowledge and a very brilliant mind. Unfortunately, he is no longer the same person due to AD. And ever since the disease has been progressing, he has been losing more and more of his memories and the brilliant mind he once had has become increasingly distant due to the effects of the disease. This inspired me to explore ways to improve the quality of life for individuals with dementia, particularly those with Alzheimer's disease. By presenting a safe play area where they can have fun, alleviate their depression and low mood and work on their cognitive functions in order to slow their cognitive decline.

The problem that exists is the lack of a VR experience that aims to elevate the mood of an individual affected by AD, the overwhelming information of which the user has to remember when dealing with the controllers and the lack of VR experiences for these individuals. Hence, this work will address the potential and the creation of a VR experience for people with AD, mainly an experience that aims to be fun and simple and not bewilder the user's senses. To achieve this, the experience would play a sequence of games while using the current headset technology of VR to track the behaviour of the hands without a controller, removing a potential obstacle from the user's grasp, while using the headset to interact with the sense of vision and hearing.

1.2 Objectives

The main objective of this work is the creation and playtesting of an immersive VR experience to stimulate cognitive functions in patients in the early stages of dementia, mainly AD. The side

objectives of this paper are the following:

- To evaluate the limits and simplicity of an experience for people with the use of the headset hand tracking technology instead of the VR controllers.
- To create an entertaining, captivating and cognitively stimulating experience that motivates individuals to keep engaging with the aim of enabling them to stabilise their functions.
- To help people with a disease that can drastically change their lives for the worse and promote emotional well-being during the progressive stages of a disease that shifts an individual's mood toward a more sorrowful and depressive state.

1.3 Hypothesis

This paper proposes an approach and the potential to expand the limits of VR technology in the medicinal field, specifically for treatments regarding dementia (AD). Hence, this work's hypothesis is the following:

Cognitive rehabilitation therapies have the potential to be adapted to VR but their limits are evident in users. Regardless, through adaptation and fortitude, the capabilities of the digital world offer a safe space where individuals can be entertained and aided. The hypothesis tested in this study is that VR may contribute to the stabilization of cognitive functions in people in the early stages of AD. Despite limitations in clinical testing, this work highlights the potential of interactive and emotion ally safe VR experiences to complement traditional therapeutic approaches.

1.4 Document structure

This document is divided into six chapters, in which the structure is as following:

The first chapter introduces the background of the thesis, addressing the relevant topics, the motivation and the main objectives. This chapter also conveys the research hypothesis and the document structure.

Chapter 2, labelled "AD and VR", addresses the main topics of this work as sections, AD, VR and the combination of VR and therapy. It goes into detail on the relevant points and analyses the most recent works that revolve around the chosen theme. It sets the scene, points out the gaps in knowledge and acknowledges the potential of VR in treatments for AD using some games as a basis.

Chapter 3, “Methodology”, covers the work process, the chosen engine where the work will be developed, the different elements conducted into the game, the assessment criteria and data collection on users after it has been developed and is ready to be tested.

Chapter 4 addresses the clear description of the idea that will be implemented and in what manner the objective will be achieved, entitled “Proposed solution”.

Chapter 5, entitled “Results”, addresses an interpretation of the results in the context of the hypothesis and state of the art.

Finally, chapter 6 concludes the work done by summarising the main findings, addressing the contributions to the related themes and suggesting possible directions for future projects.

In the Appendix, two sections can be found. The first section labelled “Planning”, relates to the organisation of the work throughout the months until mid-June. The second section talks about the summary of an interview with a professional in the field regarding the idea of using VR for cognitive stimulation on individuals with mild AD.

Chapter 2

Alzheimer's and VR

In this section we will provide insight into AD, what happens in the brain during the disease, its different treatment options to slow down the cognitive decline, how VR functions and how it can be used for cognitive stimulations.

2.1 Alzheimer's disease

The following sections will provide relevant information regarding the study of AD, the history, pathology, clinical progression.

2.1.1 History of Alzheimer's

The history of AD includes several important milestones in the evolution of its scientific understanding.

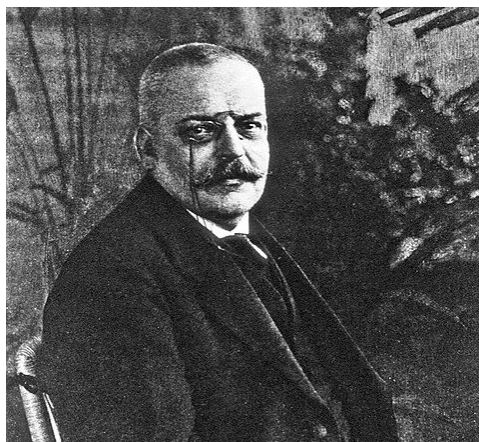


Figure 2.1: German physician Alois Alzheimer, (Alzheimer's Disease International, 1984)

In 1901, the German physician Alois Alzheimer, known linking symptoms to microscopic brain changes, documented the case of a fifty-year-old woman, Auguste D. She exhibited profound memory loss and progressive neuropsychiatric symptoms. He monitored her condition until her death in 1906, after which he first reported publicly on this case. During her autopsy, he saw dramatic shrinkage of the brain and abnormal deposits in and around nerve cells. Over the subsequent five years, eleven comparable cases were described in the medical literature, with several reports referring to the condition as Alzheimer's disease.

In 1910, German psychiatrist Emil Kraepelin, a colleague of Alois Alzheimer, formally names the term Alzheimer's Disease in the eighth edition of his book *Archives of Neurology* (Scheltens et al., 2021).

In 1976, neurologist Robert Katzman, in an editorial published in *Archives of Neurology*, characterized AD as the most frequent case of dementia and emphasized its significance as a major public health challenge (Perea et al., 2020).

In 1980, the Alzheimer's Association organisation was established to complement and stimulate the federal government (U.S.A.) efforts on AD. It has since become a leading voluntary health organization dedicated to advancing care, support services and research efforts in the field of AD (Alzheimer's Disease International, 2009).

In 1984, researchers George Glenner and Cai'ne Wong identified $A\beta$, a component of AD brain plaques. This discovery positioned beta-amyloid as a prime suspect in the investigation of mechanisms underlying neuronal damage in AD (Raut et al., 2023).

In 1986, the tau protein, another component of tangles, was identified. The second pathological hallmark of AD and another suspect in the mechanisms contributing to neuronal degeneration (Presidential Library and Museum, 1994).

In 1994, the former U.S. President Ronald Reagan publicly disclosed in an open letter with the American people that he was diagnosed with Alzheimer's disease. This announcement brought more public awareness to the disease.

In 2005, the Alzheimer's Association launches *Alzheimer's & Dementia: The Journal of the Alzheimer's Association* to enhance support at a global, interdisciplinary exchange within the Alzheimer's research community (The Alzheimer's Association, 2005).

In 2014, mortality attributable to AD was substantially underreported in death certificates. In the United States, it was estimated 500 000, significantly exceeding the fewer than 84 000 number reported on death certificates (James et al., 2014).

In August 2021, the integrity of AD research by Sylvain Lesné was raised, mainly those related to the $A\beta^*$ hypothesis. The paper in question was "A specific amyloid- β protein assembly in the brain impairs memory", published in 2006. It suggested that the $A\beta^*56$ was responsible for the memory deficits that occur in AD. An investigation was led by neuroscientist Matthew Schrag, George Perry of the University of Texas, San Antonio and John Forsayeth of the University of California, San Francisco. They concluded that the images used in the studies appeared to be manipulated, with duplicated bands and signs of digital alteration, as mentioned in the article *"Some look like 'shockingly blatant' examples of image tampering [. . .] The authors 'appeared to have composed figures by piecing together parts of photos from different experiments [. . .] The obtained experimental results might not have been the desired results, and that data might have been changed to . . . better fit a hypothesis."* (Piller, 2022).

These findings raised doubts about the validity of the $A\beta^*56$ findings and brought into question the wider reproducibility of research supporting the amyloid hypothesis, as it was based on false data. For spreading misconducted information, the paper has been retracted on June 24, 2024 (Piller, 2022).

2.1.2 The neurocognitive disorder

Symptomatology stages

AD is a neurodegenerative disease accounting for approximately 60 to 80% of all cases of dementia. As the body gets older, so does the brain and the prevalence of the disease increases. Typically beginning in individuals aged 65 to 74 years and rising significantly in those aged 85 years and older (Gamito et al., 2020).

The earliest and most frequent symptoms of the disease include difficulty recalling newly learnt information, such as recent conversations and events, indicative of short-term memory loss. Moreover, additional issues involve the completion of familiar tasks, planning, problem-solving and uncertainty with the time or place. Occasionally, people with early symptoms begin to experience difficulties carrying out daily activities (Association, 2024; Scheltens et al., 2021).

As AD progresses, symptom severity increases. Elderly individuals in the moderate stage often experience difficulties in recognizing familiar people, struggles with cognitive functions such as structuring thoughts, reading, writing and language processing. In addition, they exhibit behavioural symptoms including repetitive statements, movements, anxiety, or aggression. In advanced stages, patients typically demonstrate profound impairments in communication, reduced responsiveness to their environment, diminished conversational skills and loss of motor control. In the same vein, loss of bowel and bladder control, along with the inability to perform

everyday activities, leads to complete dependence on carers (Scheltens et al., 2021).

Moreover, as a result of the progressive neurodegeneration, the condition ultimately leads to death. It affects brain regions responsible for regulating vital physiological functions and the resulting loss of brain functions lead to complications such as dehydration, malnutrition and infections. These conditions may destabilize multiple organ systems, ultimately resulting in fatal outcomes (Rao et al., 2022).

Clinical progression

A healthy human brain is composed of tens of billions of neurons, which are fundamental cells of the brain and nervous system. As can be seen in figure 2.2, neurons are responsible for processing sensory input from the external world, transmitting motor commands to the muscles, facilitating the transformation process of information through electrical and chemical signals in the brain, between the brain, muscles, and organs. However, in AD this network area becomes impaired due to the progressive dysfunction and degeneration of neurons, resulting in significant decline in cognitive and neurological functions (Rao et al., 2022; Scheltens et al., 2021; Q. Wang et al., 2022).

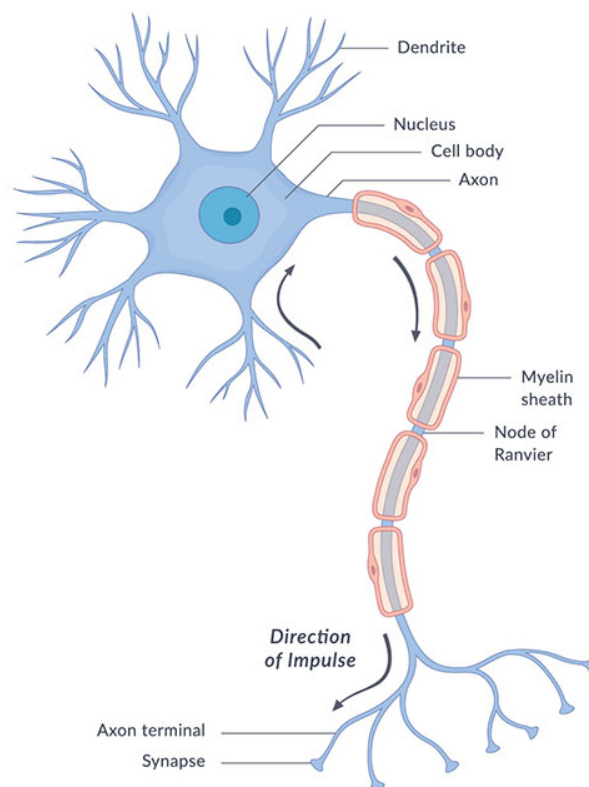


Figure 2.2: Illustration of the nucleus, cell body, dendrite, the axon leading to the axon terminal through the node of Ranvier covered by the Myelin sheath and the synapse in a healthy brain (National Institutes of Health, 2018)

Neuronal loss and gliosis in AD usually begin in the hippocampus and entorhinal cortex,

parts of the brain that play a critical role in creating memories and learning processes.

The hippocampus is a component of the limbic system, an area of the brain involved in decision-making and the consolidation of information into long-term memory. It also plays a central role in navigation through spatial memory, associating verbal and symbolic thinking into information that can be accessed during decision-making (Chen et al., 2022; Rao et al., 2022).

In addition, the entorhinal cortex is part of the allocortex, one of the two types of cerebral cortex in the brain. Located in the medial temporal lobe and serves as the main interface between the hippocampus and the neocortex. The neocortex, characterized by its set of six-layered cortex, is associated with higher-order brain functions such as sensory perception, cognition, generation of motor commands, spatial reasoning, and language. The entorhinal cortex functions as a widespread network hub for memory, spatial navigation, and temporal perception (Wagner MJ, 2020). Details of the position of the various brain parts can be seen in figure 2.3.

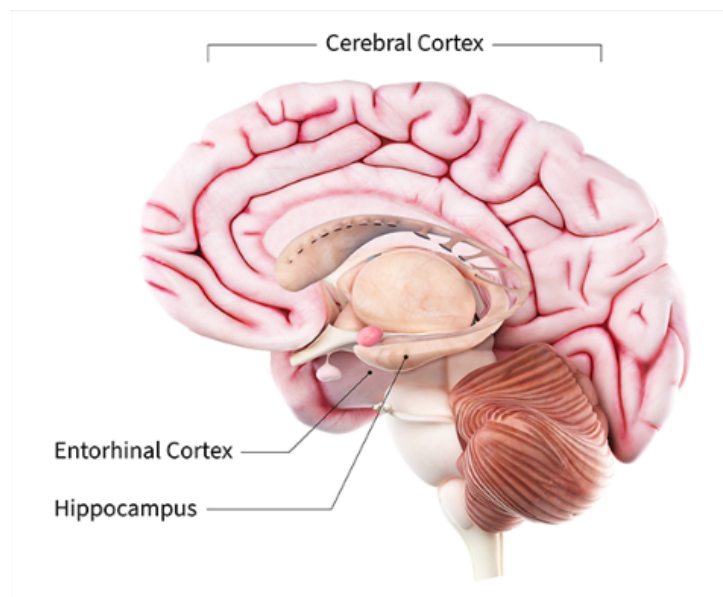


Figure 2.3: Illustration of the hippocampus and entorhinal cortex areas (National Institute of aging, 2024)

pathophysiological mechanisms

In an individual with AD, neurodegeneration begins in the second layer of the entorhinal cortex and progressively extends to the hippocampus, temporal cortex, subcortical nuclei, and frontoparietal cortex. This progression results in significant volume loss of layer tissue from the hippocampus; this atrophy disrupts neuronal connections and impairs brain function. This degeneration is believed to be associated with the accumulation of amyloid plaques and tau.

Amyloid plaques, which form in the tissue between the nerve cells, and neurofibrillary tangles initially accumulate in the entorhinal cortex and subsequently spread to the hippocampus. These

plaques consist of unusual clumps of a protein called $A\beta$, the main component of extracellular senile plaques and are associated with the degeneration of neurons and other cells. Neurofibrillary tangles are largely made up of an aggregated protein called tau which normally functions to stabilize microtubules within neurons. However, the abnormal chemical reactions originating from AD cause tau to detach from microtubules and aggregate into insoluble filaments. These filaments result in damaged neuron communication due to the created threads, eventually forming tangles that disrupt neuronal function, as illustrated in figure 2.4 (Gao et al., 2023; Lazarov et al., 2024; Mrak & Griffin, 2000; Scheltens et al., 2021). Neuronal damage is accompanied by a response from microglia, the immune cells of the central nervous system, which act to eliminate pathogens and clear damaged cells.

The microglial immune cells become activated due to elevated levels of $A\beta$, these are specialised cells that play a critical role in preserving brain health and functions (Gao et al., 2023). These specialized cells are located in the central nervous system, primarily in the brain and spinal cord. However, in AD, microglial activation contributes to producing pro-inflammatory cytokines, which promote neuroinflammation, consequently aiding the pathogenesis and the progression of the disease. Cytokines are proteins produced by various immune and non-immune cells that influence the immune system (Gao et al., 2023). Among the cytokines involved are interleukin-1 (IL-1) and interleukin-6 (IL-6), a group of signal proteins that are produced by leukocytes, white blood cells. IL-1 is an interleukin involved in inflammation and facilitates the recruitment of leukocytes with passages through blood vessel walls to areas of infections in the brain (Mrak & Griffin, 2000; Rani et al., 2023). While IL-6 is associated with the formation of neurofibrillary tangles and the upregulation of $A\beta$ precursor protein (APP), leading to cognitive decline and hippocampal deterioration (Mrak & Griffin, 2000). Furthermore, tumour necrosis factor-alpha (TNF- α) is suspected to play a role in the chronic inflammation with the synthesis of amyloid plaques and neurofibrillary tangles (Rani et al., 2023).

Considering effects of microglia, the degeneration spreads and affects a wide range of neurons including those that utilize acetylcholine, a neurotransmitter derived from acetyl coenzyme A and the nutrient choline.

Acetylcholine plays a critical role at neuromuscular junctions and is essential for the hippocampal functions. Additionally, one of those functions, particularly synaptic plasticity, is especially important in the context of memory, as it is the ability to adjust the strength of their connections, a process fundamental to the development of brain networks and the reorganisation of circuits following damage. The latter resulting in the enhancement of long-term potentiation in various regions of the hippocampus. In the same vein, another one of those functions, peculiarly synaptic transmission involves the process where a chemical signal is released from one neuron

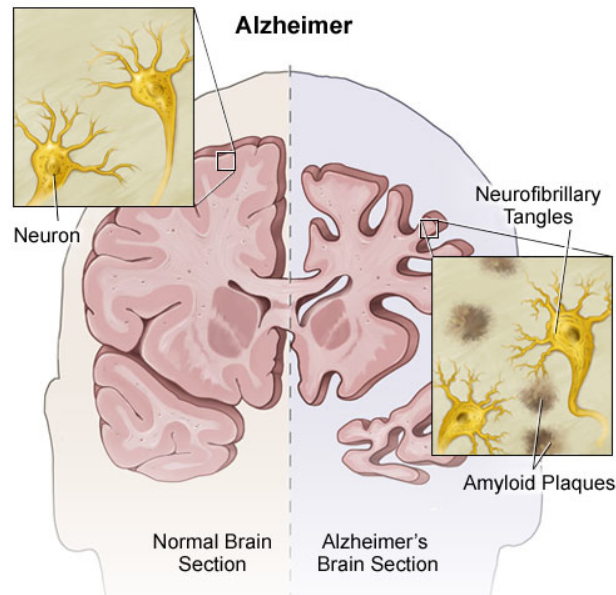


Figure 2.4: Image of a brain affected by AD (Stanford Medicine, 2022)

to other neurons or cells, which can excite, inhibits or modulates cellular activity (Chen et al., 2022; Mrak & Griffin, 2000; Prince et al., 2021; Rani et al., 2023).

The involvement of acetylcholine is significant as it contributes to the enhanced encoding of new information by promoting theta rhythm oscillations and enhancing the input strength modulated by feedback within the hippocampal circuits. In addition, it activates intrinsic cellular mechanisms for consistent spiking in the neurons of the hippocampal, which is critical for effective information encoding (Chen et al., 2022; Prince et al., 2021). In an individual with AD, the degeneration of cholinergic neurons leads to a reduction in acetylcholine levels in the brain, contributing in a progressive decline in cognitive capacities (Chen et al., 2022; Prince et al., 2021).

As neuronal damage progresses and functional impairments increase, the connections among the vast networks of neurons deteriorates, leading to a gradual dwindling of the brain. In the advanced stages of AD, this degeneration becomes extensive, resulting from significant cell death and a substantial decline in brain volume.

2.1.3 The treatments

Currently, there is no cure for AD; however, various treatments have been developed that may modify the disease's progression. The treatments are categorized into pharmacologic, which are medication-based, and non-pharmacologic approaches, which are non-drug based (Scheltens et al., 2021).

The medication	Application	Secondary effects
Donepezil (MedlinePlus, 1997a)	Every stage of AD, increases the enzyme acetylcholinesterase, which help nerve cells communicate more effectively	Nausea, diarrhea, insomnia, muscle cramps, fatigue and loss of appetite
Galantamine (MedlinePlus, 2001)	Moderate stages of AD, slows the breakdown of acetylcholine	Nausea, vomiting, diarrhea, dizziness, headache, loss of appetite and sleep disturbances
Rivastigmine (MedlinePlus, 1997b)	Moderate stages of AD, increases levels of acetylcholine	Nausea, vomiting, diarrhea, weight loss, loss of appetite, dizziness, headache and skin irritation
Memantine (MedlinePlus, 2002)	Moderate to severe stages of AD, blocks the effects of excess glutamate	Dizziness, headache, confusion, constipation and hallucinations (rare)

Table 2.1: Comparison of medications for patients with AD

The pharmacologic treatment for AD involves the use cholinesterase inhibitors. As may be seen in table 2.1, donepezil is commonly prescribed across all stages of the disease and it supports mental function by increasing the acetylcholine levels in the brain. For individuals in the mild to moderate stages, galantamine and rivastigmine medications slow the degradation of acetylcholine allowing for its accumulation and improvements of brain functions. And finally, memantine, prescribed for moderate to severe stages, by modulating glutamatergic activity. It prevents the breakdown of the neurotransmitter, the acetylcholine, by blocking the effects of excess glutamate. Unfortunately, while potentially beneficial, are associated with a range of side effects, including nausea, diarrhoea, insomnia, muscle cramps, vomiting, dizziness, and weight loss as demonstrated in table 2.1.

These medications are frequently administered in conjunction with antidepressant medications such as mirtazapine and venlafaxine to help manage associated neuropsychiatric symptoms resulting from AD, including depression, anxiety, and agitation (Scheltens et al., 2021).

A non-pharmacologic approach to AD focus on cognitive stimulation and behavioural therapy. It is suggested that a lifestyle change, such as physical activity, diet and engagement in mentally stimulating activities, are often recommended to support cognitive functions and overall well-being. Psychosocial interferences are employed to reduce negative emotions such as depression and anxiety in patients (Scheltens et al., 2021).

Furthermore, cognitive stimulation therapy, musical, dance, and exercise interventions can also address the decline through improved mood and function; these are called cognitive rehabilitation therapies.

There are a multitude of different types of approaches to rehabilitation exercises for AD, a wide range of therapies designed to delay neurological decline, manage symptoms, and improve mood; some techniques are more effective in certain stages of the disease (Stasolla et al., 2024; Xu et al., 2022).

These treatments include reminiscence therapy, which involves conversations that naturally encourages patients to recall and share past experiences without the pressure of direct questioning (Scheltens et al., 2021; Yanagida et al., 2024). It is often facilitated through the use of familiar objects, photographs, or music. Occupational therapy is another method, focusing on repeated exposure to time, place, and people to improve the understanding of the current environment (Kim, 2020; Stasolla et al., 2024).

Additionally, musical, dance, reality orientation, and exercise interventions have been demonstrated to improve cognitive function and elevate mood (Scheltens et al., 2021). Another therapeutic approach is cognitive stimulation. These are activities designed to challenge and promote various cognitive domains to promote emotional engagement and social interaction (Scheltens et al., 2021). Some of these therapies can also incorporate more engaging elements to increase participation and improve mood.

2.2 Virtual Reality

This section provides a small introduction to VR, the history of its development, how it works, and its different criteria.

2.2.1 Chronicle of VR

The idea of immersion was first introduced with stereoscopic images, as seen in figure 2.5, in which users were immersed in virtual-like environments; this lasted until the early 1900s.



Figure 2.5: Stereoscope with a Stereograph from Rome (Architectural Histories, 2016)

From 1950 to 1960, the idea of VR was explored as a concept; it was only in 1962 that Morton Heilig created the Sensorama, an arcade-style booth cabinet that combined most of the human senses using visuals, audio, wind effects, and scent dispersal ((Immersivearchive, 1962)).

In 1968, computer scientist Ivan Sutherland created “The Sword of Damocles”, the first head-mounted display based on his presented vision of the Ultimate Display in 1965, where he envisioned computer-generated worlds indistinguishable from reality. The head displays used a system to overlay computer-generated graphics into the users’ point of view ((Realityremake, 1968)).

In the 1980s, Jaron Lanier, as seen in figure 2.6, founded Virtual Planetary Laboratory (VPL) Research with the objective of improving VR hardware and software systems and popularising VR ((Virtual Reality Society, 1984)).

From 1980 to 1990, NASA developed a Virtual Visual Environment Display for astronaut training; this pushed the boundaries of visual fidelity, motion tracking, and realistic simulations, resulting in a major growth of VR ((NASA, 2001)).



Figure 2.6: Jaron Lanier, the father of VR and founder of VPL Research (Expresso, 2023)

In the early 2000s, VR re-emerged in popularity due to noteworthy advancements in domains which obstructed previous versions; this gave way to more immersive and realistic experiences ((Opase, 2024)).

In 2012, Palmer Freeman Luckey launched a Kickstarter campaign for a project called the Oculus Rift. A high-quality consumer-orientated headset, this campaign was met with success and became a critical moment for the rise of VR ((Kickstarter-Palmer Freeman Luckey, 2012)).

From 2014 to 2017, multiple VR headsets were introduced with PC-tethered, console-tethered, and mobile-tethered devices. VR headsets have since developed to be untethered and more potent, giving way for more flexible experiences ((Forbes-Moor Insights and Strategy, 2017)).

2.2.2 VR technology basis

Virtual reality is a computer-generated simulation that allows users to experience and interact with the digitally created world as if it were real; hence, they are immersed. An immersive experience is an environment that fully captivates the participant's senses, creating a perception of being part of that world. It's the concept of making the participant feel as though they are truly part of the virtual environment by blending their senses with that 3D environment.

VR is a computer-generated simulation that enables users to engage and interact with a digitally constructed environment in a manner that blends the perception of presence to that environment. An immersive experience refers to a setting that fully captivates the participant's

senses, creating a perception of being physically situated within the virtual space. This immersion is achieved by blending the user's sensory input with the characteristics of the simulated three-dimensional environment. This level of immersion is made possible through the use of specific hardware components such as VR headset, an example of a VR headset, Meta Quest 2 from Oculus can be seen in figure 2.7, controllers and motion sensors. By utilizing three-dimensional near-eye displays in concurrence with pose tracking technology, these devices deliver visual and auditory sensations that enhance the individual's sense of presence within the virtual environment (Ali et al., 2023; Wohlgenannt et al., 2020). Example of these immersive experiences are VR games, see figures 2.8 and 2.9



Figure 2.7: Picture of Meta Quest 2, a virtual reality headset including the controllers(Oculus, 2020)

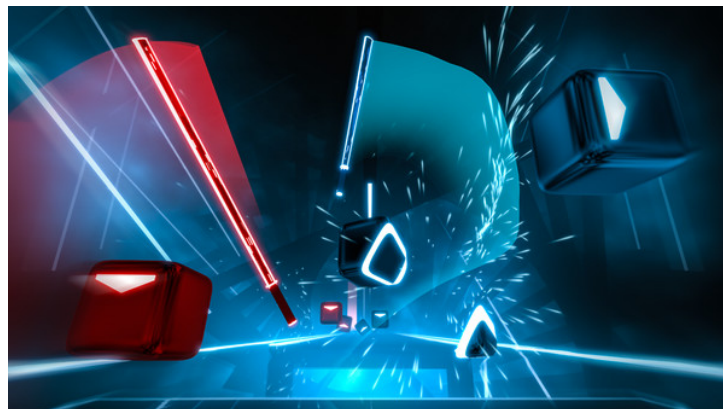


Figure 2.8: Picture of Beat Saber, an immersive VR rhythm experience where users slash flying blocks to the beat of the music with virtual sabers (Beat Saber, 2019)

Several researchers have categorized VR according to three qualification properties (Wohlgenannt et al., 2020):

1. Interaction: A highly interactive experience is synonymous with the sense of presence. This relates to the degree to which user can manipulate virtual objects and navigate through the virtual space such as in figure2.9. Higher interactivity is associated with a higher sense



Figure 2.9: Street in Half Life Alyx, an immersive VR shooter experience with physics-based puzzles (Half-Life: Alyx, 2019)

of presence.

2. Presence: A psychological feeling that is usually described as being physically somewhere in a location different from one's actual position. This is achieved by enriching an overall experience through the use of high-resolution graphics and spatial audio.
3. Immersion: This involves the degree to which people can interact and receive immediate feedback from the virtual environment resulting in a convincing alternate reality. The level of immersion can vary depending on the quality of the system, the level of objects manipulation, moving around and content of an experience such as with figure 2.8.

Given these immersive qualities, VR has recently been explored as a tool for cognitive training and therapeutic intervention in neurodegenerative disorders such as AD due to its capacity to provide a flexible environment with engaging and motivating elements for patients.

2.3 The combination of VR and therapy

This section will introduce the combination of therapeutic treatments for AD and VR immersive experiences, including their different uses, but mainly involving potential games for VR as treatments of people with AD.

2.3.1 Engaging therapeutic solutions

The gamification of cognitive rehabilitation represents an emerging solution designed to preserve and enhance the efficacy of cognitive function improvements. This approach integrates game elements into conventional mental function exercises to increase patient engagement and motivation (You et al., 2025).

Specialized solutions such as therapeutic toys and games offer various approaches to neurological deterioration decline. Considering various options such as building games, which promote cognitive function and positive emotions; puzzle games, which encourage social interaction among multiple patients while promoting beneficial techniques such as hand-eye coordination, motor function, and increasing communication. In the same vein, memory games, which provide an engaging method to exercise memory and cognition abilities; or a companion robot, which, when designed to match a familiar pet animal, may facilitate patient recall of familiar animal embodiment, as discussed in articles (Llorente et al., 2024; You et al., 2025).

What's more, traditional and modern board games have been associated with improved well-being and may contribute to slowing the disease-related impairment process.

- Chess, as shown in figure 2.10a, is a classic two-player board game in which the primary objective is to checkmate the opponent's king. The game affects various cognitive functions related to AD, including short-term and long-term memory, visuospatial memory, executive functions such as problem solving, attention, concentration and cognitive flexibility such as quickly adapting strategies as mentioned by (Pozzi et al., 2023).
- Ska, as mentioned in reference (Pozzi et al., 2023), is a traditional Thailand board game that involves complex planning and decision making. Although it holds cultural significance, it remains relatively under-documented in the academic literature. The article (Pozzi et al., 2023) suggest that Ska may improve cognitive functions, particularly memory, attention and executive functions such as problem solving and advanced planning.
- Mahjong is a traditional tile-based game that originated from China, with the main goal of forming a complete hand of 14 tiles according to rules. The game engages in a wide

variety of cognitive functions, including executive functions such as planning and cognitive flexibility, concentration, memory, focus and visuospatial memory as mentioned in (Pozzi et al., 2023).

- Go, as depicted in figure 2.10b, is an old two-player strategy board game originating in China, in which the objective is to capture territory on the board through the use of the game pieces, white and black stones. Regarding the impact in cognitive functions, the game has been analysed to influence various cognitive domains, including memory, cognitive flexibility, mood and executive functions such as abstract reasoning and problem solving. These effects are discussed in article (Pozzi et al., 2023) and summarized in table 2.6.
- In like manner, Crossword board puzzles games involve players forming interlocking words horizontally and vertically on a grid, typically guided by letter clues or tile placements. Similarly, Scrabble is a word-based board game with the objective to achieve a high score by creating valid words on a grid using available letter tiles. These types of games have been analysed to engage cognitive functions such as verbal memory, sustained attention and executive functions including problem-solving and planning. These effects are mentioned in article (Martinez et al., 2023) and summarized in table 2.7.

What's more, article (J. Wang et al., 2022) describes individuals who participated in card game sessions and demonstrated improved performance compared to individuals with no card game exposure. These findings suggest enhanced performance of cognitive functions as said by such as orientation, registration, attention, calculation, recall and language on game exposure as seen in articles (J. Wang et al., 2022), and described in table 2.7.



(a) Image of the Chess board game (Jaques London, 1795).



(b) Image of the Go board game (thebeijinger, 2023).

Figure 2.10: Board games

Similarly, tablet-based applications provide a convenient and adaptable engagement activity that can be tailored to the patient's abilities, preferences and current state of their process abilities, mental and physical function. These applications provide interactive activities that can stimulate cognitive functions and contribute to improved quality of life as mentioned in article (Tak, 2021) and table 2.7.

2.3.2 Measurement of cognitive function

The impact of the games on users have been assessed to varying degrees, depending on the measurement and study method as explained in (Pozzi et al., 2023). Tables 2.2 and 2.3 describes some of the various cognitive assessment methods conducted using several instruments mentioned in table 2.6 and 2.7.

Additionally, table 2.4 presents the assessment of depressive symptoms using a range of examination tools that were mentioned in table 2.6 and 2.7. Finally, the independence in daily tasks and quality of life of people were determined through the use of a few tests, as mentioned in 2.6 and 2.7 and described in table 2.5.

2.3.3 Noticeable games

Other engaging and entertaining solutions have also demonstrated potential benefits; examples include Simon Says, the colour-based game and the card game Concentration/Memory. Simon Says, the colour game is an electronic device that generates sequences of tones and lights, which the user attempts to replicate, as displayed in figure 2.11. With each successful repetition, the sequences become progressively lengthier and more complex, and the game concludes when the player is unable to repeat the sequence or when the time limit is reached. This game targets key cognitive functions including working memory, attention span and pattern recognition. Additionally, Simon Says presents a method to address proprioceptive engagement in an individual as mentioned in (Hojatmadani & Reed, 2022). It encourages alternative cognitive strategies such as the creation of visual patterns of the colour sequence; further inspiring alternative cognitive strategies and creative problem-solving approaches.

In the same vein, the card game Concentration displays benefits. It is a pattern recognition game that engages cognitive functions related to attention, focus and spatial perception. Players take turns attempting to find matching pairs of cards that are laid face down. If a match is found, the player collects the pair and continues; with the goal of accumulating the most pairs by the end of the game This game displays support for some cognitive skills, such as improvements in short-term and long-term memory, recall abilities and cognitive agility. Article (J. Wang et al., 2022) reinforces the nature of these types of card games can stimulate various cognitive

The assessment method	Description
Montreal Cognitive Assessment (MoCA) (Davis et al., 2021)	A test usually taken on paper or through a digital app and determines the level of mild cognitive impairment through the evaluation of multiple cognitive domains
The Trail Making Tests A and B (TMT A and B) (St-Hilaire et al., 2018)	A two-part test which evaluates visual attention and task switching by connecting numbered circles that measures visual scanning and processing speed first, followed by cognitive flexibility, working memory, and executive control
Verbal Behavioural Reasoning Test (VBRT) (Aptitude Test, 2025)	Evaluates an individual's ability to understand, analyse and reason with verbal information, depending on behaviour or practical decision-making contexts
The Mini-Mental State Examination (MMSE) (Chapman et al., 2016)	Determines general cognitive function by evaluating cognitive areas such as orientation, immediate memory, short-term memory, attention and language abilities
Kimberley Indigenous Cognitive Assessment (KICA) (LoGiudice et al., 2006)	Designed to determine cognitive impairments among older Aboriginal and Torres Strait Islander people in Australia, mainly individuals living in rural and remote area
Clinical Dementia Rating Scale - Sum of Boxes (CDR-SB) (Julayanont & DeToledo, 2022)	Estimates the severity of dementia symptoms with the use of a sum of score dependent of six cognitive domains including memory, orientation, problem solving, community affairs, home and personal care
Digit Span Test (DST) (Conductscience, 2025)	A test which measures short-term memory and working memory, by recalling forwards or backwards sequences of numbers in the correct order

Table 2.2: The different assessment methods used to determine cognitive levels of individuals who played several board games, card games and VR experiences part 1.

The assessment method	Description
The Wechsler Memory Scale, Third Edition (WMS-III) (Dori & Chelune, 2004)	Assesses various memory functions through index scores, including auditory, visual, working memory, immediate memory and delayed recall
The Wisconsin Card Sorting Test (WCST) (Labvanced, 2017)	Emeasures executive functions such as attention, cognitive flexibility such as processing speed, problem-solving, and executive control through the matching of card types
Symbol Trail Test - B (STT-B) (Tombaugh, 2004)	Conceptually similar to the TMT-B, it determines cognitive functions such as attention, processing speed and executive function by connecting circles in order without lifting a pen
Cognitive Abilities Screening Instrument (CASI) (Teng et al., 1994)	Evaluates through the usage of a 25 items across nine cognitive fields and a score range of 0 to 100. The overall cognitive functions estimated are attention, concentration, orientation, short-term memory, long-term memory, language, visual construction, abstraction and decision making
Frontal Assessment Battery (FAB) (Goh et al., 2019)	A tool designed to evaluate executive functions with a combined score and through 6 areas, which are conceptualization, mental flexibility, motor skills, inhibitory control and environmental autonomy
Clock Drawing Test (CDT) (Harbi et al., 2017)	A method used to estimate cognitive functions including attention, memory, visuospatial skills, executive function and language. The individual draws a clock with all number on a paper then set the clock hands to a specific time
Symbol Digit Substitution Test (SDST) (Gilmore et al., 2004)	It measures processing speed, attention and visual-motor coordination by asking individuals to match symbols to numbers fast and accurately

Table 2.3: The different assessment methods used to determine cognitive levels of individuals who played several board games, card games and VR experiences part 2.

The assessment method	Description
Geriatric Depression Scale (GDS) (Montorio & Izal, 1996)	It determines the depression score of an individual through mood and psychological symptoms with the use of a 15 item yes or no questionnaire. This tool was designed to assess depressive symptoms specifically in older adults.
Montgomery–Asberg Depression Rating Scale (MADRS) (Santen et al., 2009)	A 10-item clinician-rated scale that estimates, on a scale from 0 to 60, the severity of depressive episodes through the severity of depressive symptoms on an individual.
Hospital Anxiety and Depression Scale (HADS) (Brennan et al., 2010)	It is a self-report questionnaire based on 14 items divided into 2 categories, anxiety and depression and rated on a 4-point Likert scale. It estimates the severity of anxiety and depression symptoms on a person in a hospital setting.
Center for Epidemiological Studies Depression Scale (CES-D) (Cartierre et al., 2011)	Refers to a 20 item self-report questionnaire rated on a 4-point scale from 0 to 3, with a total score range from 0 to 60. It assesses depressive symptoms over the past week
State-Trait Anxiety Inventory (STAI) (Bieling et al., 1998)	It is a psychological assessment tool which determines general anxiety through two types of categories: state anxiety and trait anxiety. It consists of a 40 self-report items with 20 questions for each scale rated on a 4-point Likert scale with a total score range from 20 to 80

Table 2.4: The different assessment methods used to determine depressive levels of individuals who played several board games, card games and VR experiences.

The assessment method	Description
World Health Organization Quality of Life (WHOQOL) (Herrman et al., 1998)	Through a 5-point Likert scale, it measures the quality of life by identifying physical and psychological health, social relationships and environment. It determines the total scores for each domain on 0-100 scale
Activities of Daily Living (ADL) (Rockwood, 2007)	It determines the ability to perform self-care tasks which includes eating, bathing, dressing, toileting, continence and mobility. The total score depends on a person's performance, 1 or 0
Falls Efficacy Scale - International (FES-I) (Figueiredo & Neves, 2018)	A 16 items test rated on a 4-point Likert scale, with a scores range from 16 to 64, which assesses the level of concern of falling, regardless of whether the individual performs the activity
Frailty and Injuries: Cooperative Studies of Intervention Techniques - 4 (FICSIT-4) (Thomas et al., 2014)	A balance test scored on a 0-9 scale that measures the ability to maintain 4 progressively difficult standing positions for 10 seconds.
Timed Up and Go (TUG test) (Saunders et al., 2025)	Refers to a practical test where an individual stands up from a chair, walk 3 meters, turn, walk back, and sit down. It assesses balance and functional mobility
Instrumental Activities of Daily Living (IADL) (Mathuranath et al., 2005)	evaluates daily tasks for independent living, which include finances, shopping, cooking, and housekeeping, through 8 domains with a score range from 0 to 8
Satisfaction With Life Scale (SWLS) (Hultell & Petter Gustavsson, 2008)	A 5-item rated on a 7-point Likert scale with a total score range from 5 to 35. It estimates an individual's life satisfaction levels based on distinct settings

Table 2.5: The different assessment methods used to determine the quality of life of an individuals who played several board games, card games and VR experiences.

functions. Additionally, this is a game in which the core concept can be adapted into modified variations, such as a version of incrementing difficulty.



Figure 2.11: Picture of Simon Says game (ScienceNews, 2020).

On the other hand, more immersive approaches such as VR have been explored as a means to enhance cognitive improvement by simulating daily activities within controlled and safe virtual environments.

2.3.4 VR uses

VR represents a significant advancement in the way people engage with the digital world, it's a replica of real-world interactions through immersive experiences. It instigates the potential to transform and finds its influence across multiple industries and fields, such as gaming, entertainment, education, medical, business, retail, transportation, energy, consulting, and even sports (Bauer & Andringa, 2020; Thapa et al., 2020).

It has been suggested in an article that “*VR leverages immersive technologies to simulate interactive virtual environments or virtual worlds with which users become subjectively involved and in which they feel physically present*” (Wohlgenannt et al., 2020).

With regard to the medical field, VR has displayed itself as a motivational, engaging and entertaining approach to therapy for patients with mild cognitive impairment, an alternative activity to improve brain functions in the elderly. It has been called to attention by authors that VR cognitive exercises improve the mood and maintain brain functions, with patients displaying consistent evidence of increased attention and willingness to engage in more VR exercises (Gamito et al., 2020; Huang & Yang, 2022; Lazarov et al., 2024; Oliveira et al., 2021; Prinz et al., 2024; Tanmalaporn et al., 2024; Yun et al., 2020). The immersive nature of VR presents a highly

The game	Time	Impact	Assessment method	Reference
Chess	2 x week, 12 weeks	improvement in short term memory, improves quality of life	MoCA , TMT , VBRT, GDS, WHOQOL, MMSE	(Pozzi et al., 2023)
Go	1 x week, 15 weeks	improvement of cognitive functions, increased attention	DST , MoCA, TMT, MADRS, HADS, KICA	(Pozzi et al., 2023)
Mahjong	3 x week, 12 weeks 2/4 x week, 16 weeks	improved cognition, reduction of depression	ADL , MoCA, STT-B , MMSE , CDR-SB , GDS	(Pozzi et al., 2023)
Ska	3 x week, 16 weeks	improvement to executive functions, increase of attention	WMS III , TMT , WCST	(Pozzi et al., 2023)

Table 2.6: Comparison of board game impact on patients with cognitive function decline.

The game	Time	Impact	Assessment method	Reference
Party, quiz games	1 x week	improvement of social, thinking, improve memory	GAMs data collection	(Martinez et al., 2023)
Carcassonne	1 x week	improvement of thinking, spatial awareness, improve cognition	GAMs data collection	(Martinez et al., 2023)
Uno, Monopoly	1 x week	improve verba memory, problem solving and mental function	GAMs data collection	(Martinez et al., 2023)
Card games	unknown	improvement of memory and attention, improve cognition	MMSE	(J. Wang et al., 2022)

Table 2.7: Comparison of board game impact on patients with cognitive function decline.

flexible training environment where patients can interact safely with the environment tailored to familiar grounds, aiding memory. Simultaneously, decreasing dependence on care professionals, (Bauer & Andringa, 2020; Kruse et al., 2022; Yun et al., 2020), depressive symptoms, feelings of anxiety, and feelings of apathy (Abd-alrazaq et al., 2022; Vermeir et al., 2020).

The description of these recent experiences, alongside their objective, assessment method, session time, and different users, are shown in tables 2.8 2.9.

The participants had a mild to moderate level of AD with a mean age varying from different trials, the mean age range was from 72.5 years to 83.17 years. And different session times and periods of trial, the lower end being a single session of 30 minutes and the longer ones being an average of 10 minutes, twice per week for a duration of 3 months as described in (Gamito et al., 2020; Huang & Yang, 2022; Lazarov et al., 2024; Oliveira et al., 2021; Prinz et al., 2024; Tanmalaporn et al., 2024; Yun et al., 2020) and shown in 2.8 2.9.

2.3.5 VR experience for AD treatments

The supplement of VR experiences were tailored to reflect various themes. One involves a rural scenery featuring a harvesting and cooking game (Yun et al., 2020), while another simulates a participant's memories with photographs, music and items from the past (Huang & Yang, 2022). Furthermore, one experience follows a progressive structure, with tasks increasing in difficulty across levels (Oliveira et al., 2021). In addition, another experience consists of a series of games aimed at providing entertainment while enhancing cognitive function, which had juice-making, fireworks and memory-based activities (Thapa et al., 2020).



Figure 2.12: Scenery of the Korean rural scenery presented on (Yun et al., 2020), a VR scenario where individuals harvest and cook items has part of the VR assessment method the feasibility and usability of the test.

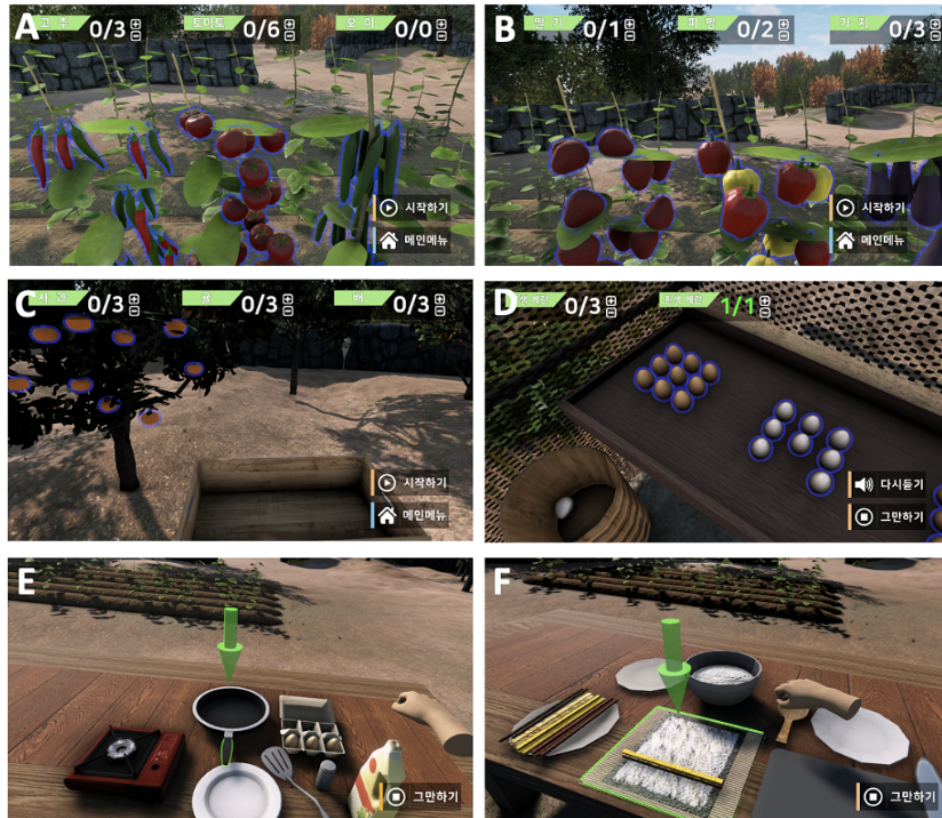


Figure 2.13: Harvest and cook games presented on (Yun et al., 2020), harvest games are aimed to improve attention and working memory whilst the cook games focus on attention, memory and executive function.

The impact of the VR experiences on users was evaluated in the articles using various assessment tools (Gamito et al., 2020; Huang & Yang, 2022; Lazarov et al., 2024; Oliveira et al., 2021; Prinz et al., 2024; Tanmalaporn et al., 2024; Yun et al., 2020). Cognitive function assessments are presented in tables 2.8 and 2.9, with detailed explanations provided in tables 2.2 and 2.3. Furthermore, table 2.4 also summarizes the tests of depressive symptoms using a range of tools previously introduced in tables 2.8 and 2.9. Finally, the assessment of quality of life of individuals, are referenced in tables 2.8 and 2.9, with detailed insight in table 2.5.

A consistent finding across these trials is the demonstrated improvement in mood among a portion of participants. This is demonstrated with willingness to engage in additional trials and VR experiences and in few cases, a temporary increase in attention span. However, certain aspects of these VR interventions can be optimized.

For instance, the design in (Yun et al., 2020) provides a solid environmental design foundation but uses a complex system setup with arm-mounted items to track finger movements, which presents obstacles within the user's personal space. The method described in (Oliveira et al., 2021) focuses on replicating daily life activities as depicted in image 2.14. Sadly, user engagement is limited and the mood impact is minimal. Creating an emotionally supportive environment is

particularly valuable for AD, as it can foster participation in activities that support the stimulation of brain functions during disease progression.



Figure 2.14: Daily life activities presented on (Oliveira et al., 2021), 9 areas are demonstrated: wardrobe, art gallery, living room, kitchen, city, store and pharmacy. Each with a different activity.

Description of VR	time	impact	Assessment method	Reference
2 player VR puzzle game	unknown	improvement of communication	unknown	(Tanmalaporn et al., 2024)
Harvest and cook games in Korean rural scenery	1 x week	positive reception and willingness to play, improved attention	self-report questionnaire, 7-point Likert-type scale, 9 items	(Yun et al., 2020)
Free roam area with relevant items	2 x week , 13 weeks	improved mood, maintained cognitive function	CASI , MMSE , CDR , CESD , ZBI	(Huang & Yang, 2022)
9 trials depicting instrumental activities of daily living	2 x week , 6 weeks	improved cognitive function	FAB , TMT , MMSE , CDT , IADL , GDS-15 , CDR	(Oliveira et al., 2021)

Table 2.8: Comparison of VR experiences and impact on individuals with cognitive decline part 1.

Description of VR	time	impact	Assessment method	Reference
City area with different task with incrementing difficulty	2 x week , 6 weeks	improved general cognition, visual memory , increased attention	FAB , TMT , WMS-R , RCF , GDS-15 , CDR , SWLS , IADL , d2 test	(Gamito et al., 2020)
Non interactive 360 degree video, 4 scenes	1 x week	no improvement to cognitive function , no decline to mood	STAI , Short FES-I , TMT-A , FICSIT-4 , TUG	(Prinz et al., 2024)
4 games, juice making, crow shooting, fireworks, memorise object positions	3 x week , 8 weeks	improved executive function , increased attention	MMSE-DS , TMT , SDST	(Thapa et al., 2020)

Table 2.9: Comparison of VR experiences and impact on individuals with cognitive decline part 2.

Chapter 3

Methodology

This section deals with the development of the VR experience and how it works, the environment built and the VR cognitive simulation games including how they work and what cognitive functions they evaluate.

3.1 Study Design

This work involved the development of multiple games within a virtual environment scenario, allowing users to engage safely with the simulated settings and the tools at their disposal without significant risk. This VR experience was designed and implemented using the Unity game engine version 2022.3.58f1; a 3D development platform created by Unity Technologies (Unity Technologies, 2025, accessed in: 10th of April 2025).

Early VR solutions typically required the use of one headset in conjunction with two hand-tracking controllers. In contrast, the present work does not make use of VR controllers, instead leverages the headset's built-in hand-tracking which has been drastically improved. By eliminating the need for external controllers, this solution reduces the complexity associated with remembering complex button configurations and equipment. The VR experience is designed to offer a low cognitive load and an emotionally supportive environment, with the goal of encouraging sustained user interaction and improvement in game performances. Progression within the experience is visually and aurally communicated through light scenario modifications.

3.2 Description of the VR Experience

This VR project, named REMIND-VR, was developed over the course of the methodology phase and subsequently refined based on initial user feedback. The resulting VR experience incorporates three games designed to stimulate cognitive functions. These activities were considered due to the research conducted in this study, as well as their suitability and practical feasibility for implementation within a VR environment, as seen in figure reffig:All games.

The created games are designed to preserve user engagement across the experience. To achieve this, the design eliminates the concept of failure; users cannot lose but only progress. This decision aims to mitigate negative emotional responses of frustration on depressive states in AD patients. This approach is intended to reduce stress, promote user engagement and enhance emotional well-being.



Figure 3.1: Picture of all the games in the virtual environment of the experience, with Simon Says on the left, Memory on the middle and Find-the-Object on the right.

3.2.1 The play-area

At the start of REMIND-VR, participants are introduced to a central hub area situated within a visually rich and serene environment, reminiscent of a garden or a field. This setting is accompanied by ambient music, which dynamically adjusts in response to the individual's interactions within the games. Additionally, a portion of the environmental 3D objects incorporates a transparent grid pattern to subtly convey the digitally constructed nature of area. Furthermore, these items are intentionally designed not to interfere with gameplay and remain unobtrusive during the participant's interaction with the different game, as can be seen in 3.2a and 3.2b.

What's more, this central area permits people to configure the games, through the selection

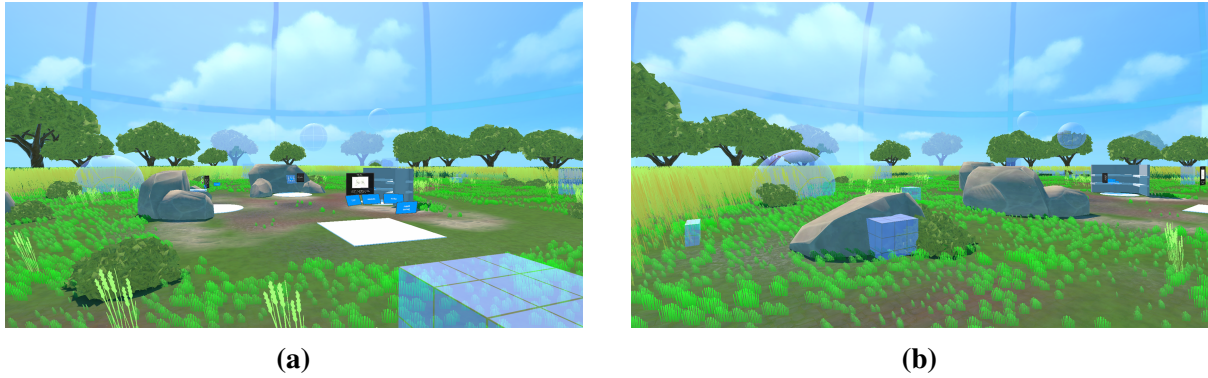


Figure 3.2: Example of the environments build in the VR experience. a) Demonstrate the overall VR experience with a peaceful atmosphere. b) Demonstrates the overall experience with gridboxes clearly visible

of various parameters with a visual interface outlining the necessary steps. The hub also features a reset button, allowing participants to reset the experience and replay any of the available games without external interference. This feature is primarily intended to restore the object positions of the third game, facilitating repeated engagement as seen in image 3.3.

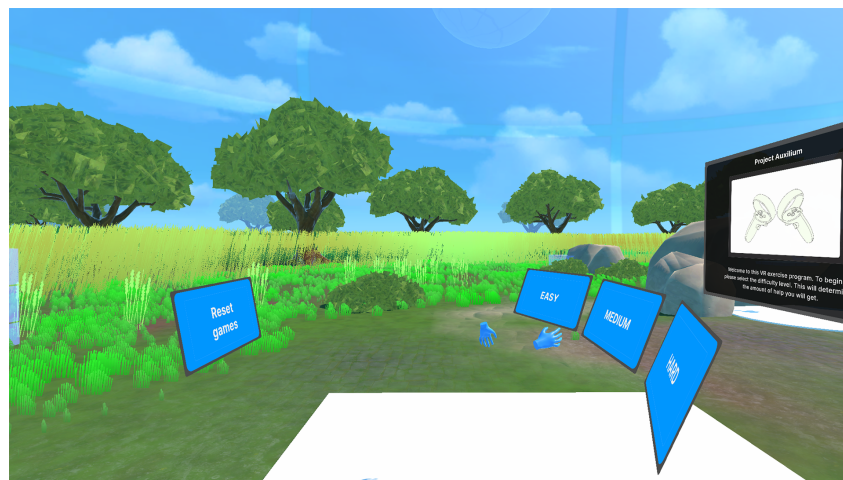


Figure 3.3: Example of the hub area with the reset button on the left and the experience parameter adjusters on the right in the VR experience.

The first interaction required of the user is the selection of the difficulty level as shown in 3.4a. This will determine the quantity of help provided, such as the frequency of hints offered throughout the games. Following this, participants can choose between two experience modes: a standard experience, where each game is played once before returning to the hub area, or a custom experience, where people can engage with a specific game of their choosing or skip specific games as shown in 3.4b and 3.5a.

Upon completing a game, users are returned to the hub, where they can view their performance metrics from their most recent attempt at each game. The first game performance is measured by the highest number of sequences successfully repeated. Additionally, the second game is

recorded as the total number of moves taken to match all card pairs, with each pair selection counted as one move. Finally, the third game performance is measured by the time taken to locate all hidden objectives. These interfaces can be seen in figures 3.4b and 3.5a.

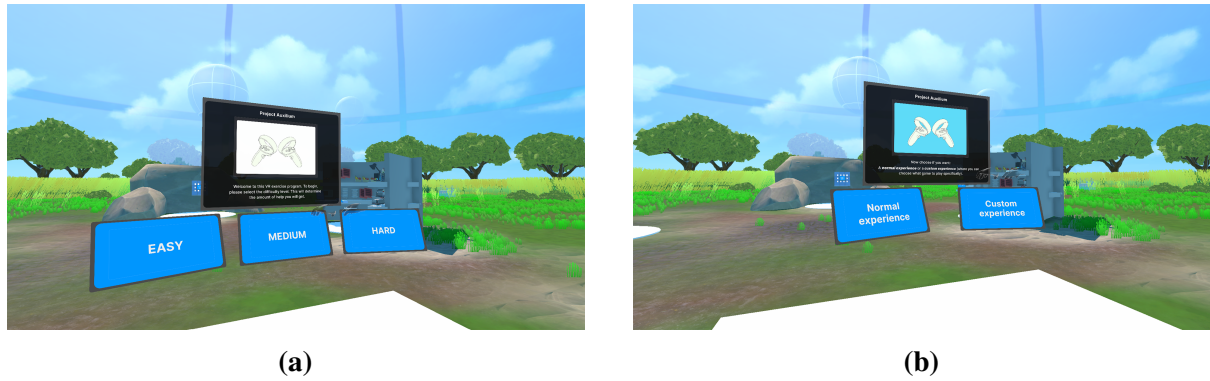


Figure 3.4: Example of hub area in its initial parameter adjustment settings. a) demonstrates the initial selection of difficulty (help) with the visual interface describing the buttons functions. b) demonstrates the following selection of experience type with the visual interface describing the available options.

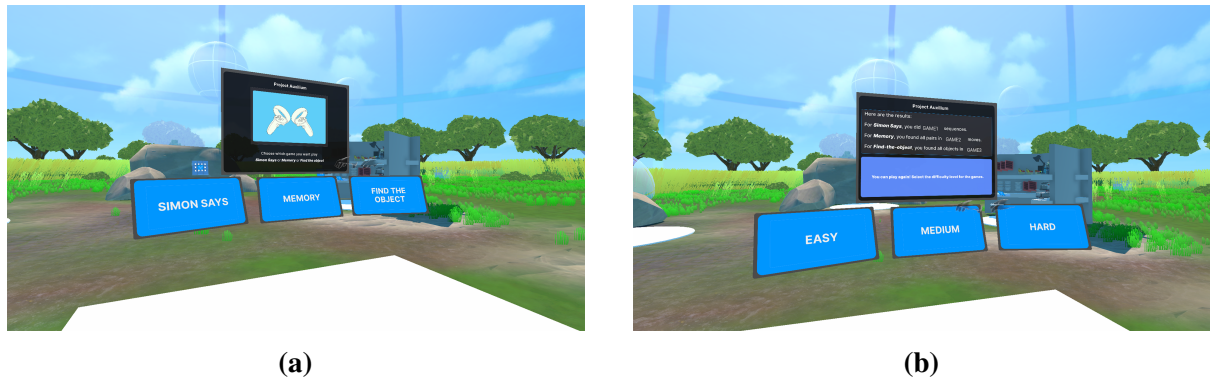


Figure 3.5: Example of hub area in its final parameter adjustment settings. a) demonstrates the selection of games with the visual interface describing the available options. b) demonstrates the initial selection of difficulty (help) with the visual interface displaying the results from previously played games.

3.3 Game Modules

3.3.1 Simon Says, the memory game

The first game is developed is **Simon Says**, the colour game, based on the illustrated figure 3.6a. In Auxilium Dimension, Simon Says presents an interface with six evenly spaced coloured buttons along with a dedicated start button. Upon activation of the start button, the game begins by displaying an initial colour sequence. The objective is to accurately replicate the sequence presented based on tones and lights. With each round, the sequence increases in length and complexity, requiring participants to recall the order using visual, spatial or auditory cues, as depicted in 3.6b. The game concludes when a presented inaccurately replicate, however no negative feedback is provided upon failure.



Figure 3.6: The environment of Simon says. a) demonstrates the initial scene the participant is confronted with. On display are the game start button, the coloured buttons, the visual instructions and the next game button. b) demonstrates an example of a person playing Simon Says. The participants can follow the sequence based on the provided colour or sounds.

This game is designed to assess short-term memory and pattern recognition abilities, as demonstrated in (Hojatmadani & Reed, 2022) but also physical performance as the buttons require movement to be pressed. The underlying objective is to encourage participants to engage attentively as they recall and reproduce sequences.

Depending on the parameters selected, people will have the option after attempting the game, to returned to the hub area to select another activity or move onwards to the next activity, instead of being presented with a failure notification, sound, interface, or r game they want to play as seen in figures 3.7a and 3.7b



Figure 3.7: Participant attempting to press the follow-up buttons of Simon says. a) demonstrates the follow-up button as “Next game” which means the settings are in normal experience. b) demonstrates the follow-up button as “Return to hub” which means the settings are in custom experience.

3.3.2 Memory, the card game

The second game is based on **Memory**, the card game. The initial interface displays a grid-based board along with a start button. When the start button is activated, the game begins and a number of cards, between four and twelve and depending on the current stage, slide in from the left of the grid board. These cards are initially face down, as shown in figure 3.8a.

The primary objective is for the participant to identify matching pairs of cards by pressing two cards, either simultaneously or subsequently. The participant must continue this process until all pairs within the current round are discovered. Each successive round increases the number of cards in the table by two, beginning with four cards and culminating in twelve cards across six rounds. The eight-card stage is repeated twice to provide the individual with additional time to mentally adjust to the progressive card count increase.

Completion of all six stages is necessary before proceeding to the next game or returning to the hub to choose an alternative game. This is to enable a better comprehension and assessment of the person performance.



Figure 3.8: The environment of Memory game a) demonstrates the initial scene the participant is confronted with. On the table are the game start button, the cards flipped down and the visual instructions. b) demonstrates an example of a participant playing the fifth round of Memory. The participant is attempting to complete the round.

This game is designed to assess the attention and memory to detail, as supported in article (J. Wang et al., 2022). Additionally, performance is evaluated based on the number of moves made, where a move consists of selecting two cards; fewer moves indicate stronger spatial memory. It emphasises visual memory, visuospatial skills, pattern recognition and critical thinking during recall of previously selected card positions within a round, assisting in short-term and working memory potential. Additionally, there is no failure in this game; it concludes once all six stages have been completed, regardless of the number of moves taken to find pairs. In the same vein, the game provides an additional button that reveals all cards temporarily without the ability to select them.

The number of times this feature can be used is determined by the parameters adjusted in the hub area during setup, as shown in 3.8b.

3.3.3 Find-the-object, recognition game

The third game is named **Find-the-Object**, a visual search task based on the "Where's Waldo?" concept, a game set within a storage closet environment. The player is presented with a grid

table an interface displaying the instructions and a start button as shown in 3.9a. Positioned behind the interface and start button is a storage closet containing two long shelves, as illustrated in figure 3.9b. Upon pressing the start button, the game begins and a variety of objects appear randomly distributed across the shelves as demonstrated in 3.9b.

The participant is then prompted an objective, to locate an objective item, a coloured ball, hidden among the surrounding objects. Furthermore, when the objective is found, the item must be grabbed and placed on the grid board for the next round to start. The game consists of three rounds, each with a different targeted item to be collected.



Figure 3.9: The environment of Find-the-Object game and the random items in the shelves. a) demonstrates the initial area the participant is confronted with. The grid table with the start button, the instructions and objective interface surrounded by the closet shelves. b) demonstrates an example of a round in Find-the-Object, where the shelves are filled with objects hiding the objective item.

Find-the-Object was designed to assess people's motor functions, emphasizing the requirement of physical interaction with the environment. This is achieved by approaching the shelves and manipulating objects to locate the objective items. In like manner, to maintain engagement and ensure continued cognitive stimulation, the positions of the non-target objects are randomized in each round. This design promotes creative thinking by determining effective methods to find objects, as seen in figures 3.10a and 3.10b.

To assist the user during the search, a help feature is included, which the level is determined by the parameters selected in the hub area during the setup process. If the participant does not locate the objective item within a set period of time, the shelf where the asked item is at would begin to display a dynamic colour-shifting shader indicating the objective location, as shown in Figure 3.10a.

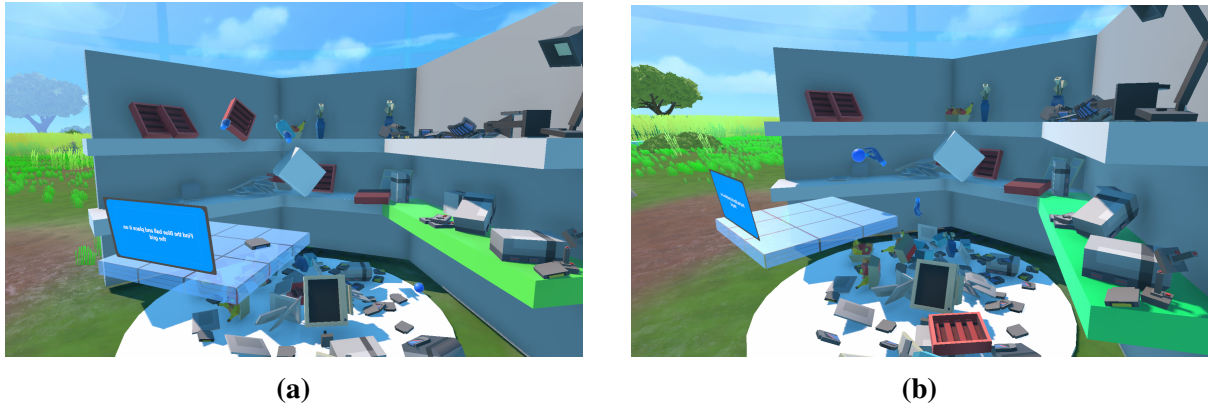


Figure 3.10: Participant playing a round of Find-the-Object game and completing the objective requested. a) demonstrates an individual playing a round of Find-the-Object by manipulating items to find the objective. b) demonstrates an individual finishing a round of Find-the-Object by placing the objective item on the grid table.

3.4 Evaluation Tools

REMIND-VR was designed to stimulate cognitive functions on people with AD; however, due to ethical reasons, it was not possible to conduct testing on individuals with mild AD. As an alternative, it was tested on at least 30 healthy participants. To determine the engagement and usability of REMIND-VR, various evaluation instruments was employed, including the simulator sickness survey and a post-experience feedback survey of the VR environment.

3.4.1 SSQ

In order to identify and measure the possible VR sickness symptoms induced by the REMIND-VR, a Simulator Sickness Questionnaire (SSQ) was employed as an assessment tool. The SSQ is a widely validated and reliable self-report 16 items survey that measures user discomfort across multiple symptom domains, including nausea, eye strain, and difficulty focusing among others, as mentioned in (Bimberg et al., 2020) and demonstrated in Appendix 6. The use of this questionnaire is important in the context of VR and AD. VR sickness can significantly impact a participant's experience and willingness to engage with immersive applications; thus, there is a need to identify, measure, and understand the symptoms of VR-induced discomfort. This chosen questionnaire would help enhance future VR work, improve the user experience, allow for different paths to mitigate the effects of VR sickness, and ensure a general acceptance and safety of current VR experience.

The SSQ categorizes symptoms into three main domains:

Nausea (N) combines the data of general discomfort, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, stomach awareness and burping.

Oculomotor disturbance (O) utilises the collected information of general discomfort, fatigue, headache, eyestrain, difficulty focusing, difficulty concentrating and blurred vision.

Disorientation (D) encompasses difficulty focusing, nausea, fullness of head, blurred vision, dizziness (eyes open), dizziness (eyes closed) and vertigo.

Each main category score is designated by the sum of individual symptom scores multiplied by a constant scaling factor. Finally, the total simulator sickness (TS) makes use of this logic but uses the three sub-scales from the main category symptoms, providing a comprehensive measure of overall simulator sickness severity.

3.4.2 Post test survey

Individuals who tested the VR experience underwent the SSQ and then evaluated the developed VR cognitive simulation experience using a self-report questionnaire based on a 5-point Likert-type scale. The initial objective of the evaluation is to determine if the built games are engaging, easy to understand, and straightforward to play; if the environment is comforting; and if the individuals could improve their performance in the different games with more creative thinking or attention to detail.

The survey is divided into two sections, the first section obtains demographic information from the participants such as the age range, the gender, the education level, the validation of colour blindness, and if the current individual has ever used VR before as seen in Appendix 6. Then the second section, consisted of the assessment of 10 items on a number of categories as seen in appendix Appendix 6: The acceptability of each game, through the understanding of the different mechanics and the difficulty of play when engaging with the tasks. The cognitive challenge, by the level of mental demand for each game. The engagement and performance improvement, by improving the performance of colour sequences for **Simon Says**, the number of moves for **Memory** and the time for finding all the requested objects associated with their creative thinking and motor functions in **Find-the-Object**. The visual and audible distinctions, such as the variety of colour and sound for Simon says buttons. The serenity satisfactoriness, through the peaceful, luscious environment and the comforting scene. And overall satisfaction for the experience. The higher the score for these items, the more positive the outcome. The survey also included additional suggestions regarding the working prototype.

3.5 Participants and Procedure

These assessment methods were carried out over a two-week period following the development of a functional prototype. The experimental protocol realized was the following: sample size chosen was simple random sampling, on a controlled settings of a laboratory at IADE, the previous campus at Santos, each trial lasted 10 minutes.

Overall, two evaluation sessions occurred. During the first session, it focused on analyse potential flaws in the various games and environment, this was a preliminary session done with 34 participants. The second session was the proper evaluation of the VR experience, evaluated on 33 individuals to determine attention span, motor function, reflexes, memory and satisfaction levels.

After engaging with the VR experience, a performance assessment was conducted to the participants by providing demographic information:

Out of the 33 participants, 30.3% were under 20 years old, 48.5% were 20-24 years old, 6.1% stated 25 to 29 years old, 6.1% said 30 to 34 years old, 3% declared 35 to 39 and 6.1% were 40 to 44 years old. Furthermore, 57.6% of users were male and 42.4% were female. Consequently, 21.9% of individuals had a high school level of education, 59.4% had a bachelo's degree level of education, 15.6% had a master's degree level of education and 3.1% possessed a PhD level of education. Subsequently, 93% of users answered that they were not colour blind, whilst 6.1% validated that they were colour blind. Finally, 78.8% of users have used VR before, while 21.2% responded that they haven't used it before.

3.6 Limitation of the Method

Several limitations of methodology design were identified in the current study, which could potentially affect interpretability of the results.

First, the non-representative population, REMIND-VR was evaluated exclusively on healthy individuals rather than the intended target population, people in the early stages AD. Due to ethical limitations, testing with the target audience was not feasible. As a result, the findings do not fully reflect the usability, accessibility or cognitive impact experience may have.

Furthermore, the lack of experimental control, the assessments did not include comparison with other cognitive stimulation methods. This absence limits the ability to make inferences or compare the designed methods effectiveness to others.

In addition, subjective assessment, which indicates that the assessment tools employed, SSQ and the user satisfaction survey, rely on self-reported data. They do not provide objective evidence of cognitive function improvement or neurological impact.

In the same vein, short duration of the tests, participants engaged with REMIND-VR for a single session lasting approximately 10 minutes. This limited exposure does not allow for the estimation of medium to long-term effects through repeated use.

And finally, technological limitations, the VR application was tested using a single headset model, the Quest 2 with hand-tracking input only. While compatible with other models, Meta Quest 3, it was not evaluated on other devices potentially limiting the hardware adaptability of the application.

Chapter 4

Proposed Solution

This section deals with the proposed solutions, the concept of the VR experience and its variations, the environment and the games and the response to feedback on the initial testing phase.

4.1 Chosen designs

The proposal developed investigates the potential of VR as a cognitive stimulation tool for AD resulting in designs choices for an optimal experience.

Three games were selected based on prior research and designed to create a safe, immersive and engaging environment for participants. These games were designed to minimize frustration and failure while promoting a continuous sense of success and progression. While targeting cognitive and motor domains, including memory, attention, visual recognition and motor skills stabilisation (Scheltens et al., 2021).

The REMIND-VR was developed using the Unity game engine, selected for its capabilities and prior experience with the platform (U. Technologies, 2025, accessed in: 10th of April 2025).

The solution proposed in this study distinguishes itself by eliminating the use of physical controllers, which are commonly employed in traditional VR systems. This choice allows for a reduction in barrier of entry, to enhance an individual's sense of presence, as suggested in (Tuena et al., 2020), and eliminating the need for physical peripherals, relying exclusively on the headset's hand-tracking capabilities as seen in figure 4.1.

The virtual environment was constructed using various 3D assets, including small and long grass, trees, boulders and a variety of ground textures, which were used to create a naturalistic and



Figure 4.1: Example of the hand tracking features of the VR headset in the REMIND-VR environment.

immersive setting reminiscent of a garden. Additionally, to maintain visual design consistency, in-game assets such as grid tables, grid spheres and grid cubes share similar visual identity, they are a reminder that the world is digital. The world also features ambient sounds of winds flowing and birds chipping alongside non-copyrighted music originating from ref 8.

Furthermore, interactable 3D buttons were designed with large dimensions to ensure visibility, readability and ease of interaction. These buttons can be triggered by a gentle touch of one finger or by a two-finger pinch gesture for quicker visual feedback.

The user interface was also intentionally designed to be large, visually distinct and aesthetically pleasing due to colour patterns, with a greater emphasis on simplicity and readability. In the same manner, written instructions for each game follows the same visual language. This is achieved through the use of bolded keywords to highlight essential information, set against a dark coloured background for improved legibility.

Finally, start game UI buttons were made visually distinct and with large dimensions to facilitate recognition. To differentiate interactive buttons from static interfaces, these buttons are labelled with the instruction “Press to Start.” All these design choices are demonstrated in figure 3.6a.

During playthrough in REMIND-VR, successful completion of a game or round triggers a reward system from the environment consisting of coordinated visual and audio feedback. The virtual world responds through visual dynamic changes: background assets including grid cubes and grid spheres enter a temporary state in which they create a visually engaging display by cycling through a range of colours, as seen in figure 4.2b. Simultaneously, the background music transitions to one of various alternate compositions. All musical selections were carefully chosen to evoke a sense of serenity and comfort, improving the REMIND-VR experience and

reinforcing positive engagement.

In addition, the absence of elements indicating whether the user won or lost to protect participants' emotional well-being raised questions about the balance between challenge and cognitive stimulation.

In the same manner, during the initial trials, it was necessary to validate the reward system and whether the absence of failure in all games contributed positively to the maintenance of cognitive functions or whether it could limit the effectiveness of the training, as seen in figure 4.2a.

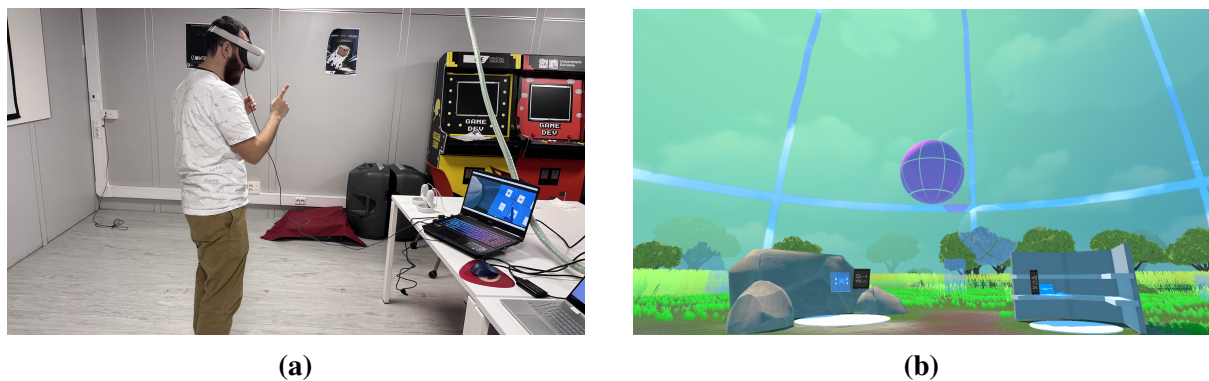


Figure 4.2: Individual playing REMIND-VR and the VR environment triggering a reward system. a) demonstrates a participant at IADE campus in Santos playing a game in the VR experience. b) demonstrates the reward system of the VR world triggering and switching 3D assets colours for a visual show.

4.2 Simon Says, the memory game

The first game is based on Simon Says, the colour game. The assigned area of the game in the digital environment consists of 6 buttons of different colours (red, blue, yellow, green, purple and orange), a start button to begin the game, an interface to explain the game mechanics and in the most recent iteration, a "next game" or "return to hub" button depending on the parameters chosen as seen in figure 3.6a.

The 3D buttons were designed to provide both visual and auditory feedback: each button highlights in a brighter shade of its originally presented colour upon sequence display and interaction, while also playing a distinct sound corresponding to a musical note on an electric piano. This visual and auditory feedback enhances participant experience and promotes easier identification of individual buttons during gameplay as seen in 4.4b.

The decision to design six coloured buttons as opposed to the original design of four buttons, as shown in figure 2.11, was made to provide a broader range of colour combinations.

This solution allows for increased variation and introduces a greater cognitive challenge for participants demonstrating higher engagement. Each button was designed to respond with both visual and auditory feedback. This is demonstrated in button highlights in a brighter shade of its original colour and a distinct musical note playback achieved through electric piano notes. This auditory and visual feedback promotes easier identification of buttons during sequence playbacks, assisting in memory identification as seen in figure 4.3.



Figure 4.3: Example of a participant, at IADE campus in Santos, attempting to replicate a 10 coloured sequence in Simon Says.

As mentioned before, there are different ways to interact with the 3D buttons; they can be interacted with by lightly pressing them with one finger, as they would show visual feedback of being pressed, or by pinching with two fingers, and each coloured button emits a different lit-up colour and a different tone when being activated for better perceptibility as seen in figure 4.4a and 4.4b.

During the development of REMIND-VR, the initial iteration of the game underwent modifications based on user feedback. The problems identified were as follows:

- The first game featured excessive spacing and suboptimal positioning of the 3D buttons which hindered memorisation of colour patterns as seen in figure 4.5a).
- Increased difficulty distinguishing between the different 3D-coloured buttons when they were illuminated and not illuminated.

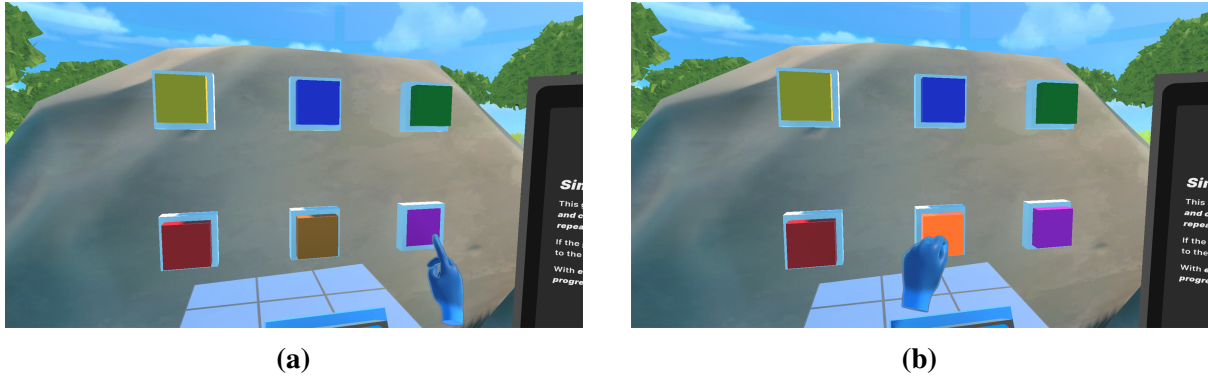


Figure 4.4: Example of a participant interacting with the 3D button in Simon Says through various methods available a) demonstrates a participant lightly pressing with the purple button in Simon Says to activate it. b) demonstrates a participant pinching with the orange button in Simon Says to activate it.

- Visual distractions while engaging with the game from dynamic environmental elements such as moving grass, cubes and spheres.
- Automatically returning to central hub or moving onwards to the next game upon unsuccessfully replicating a Simon Says colour sequence resulted in negative perception of the game

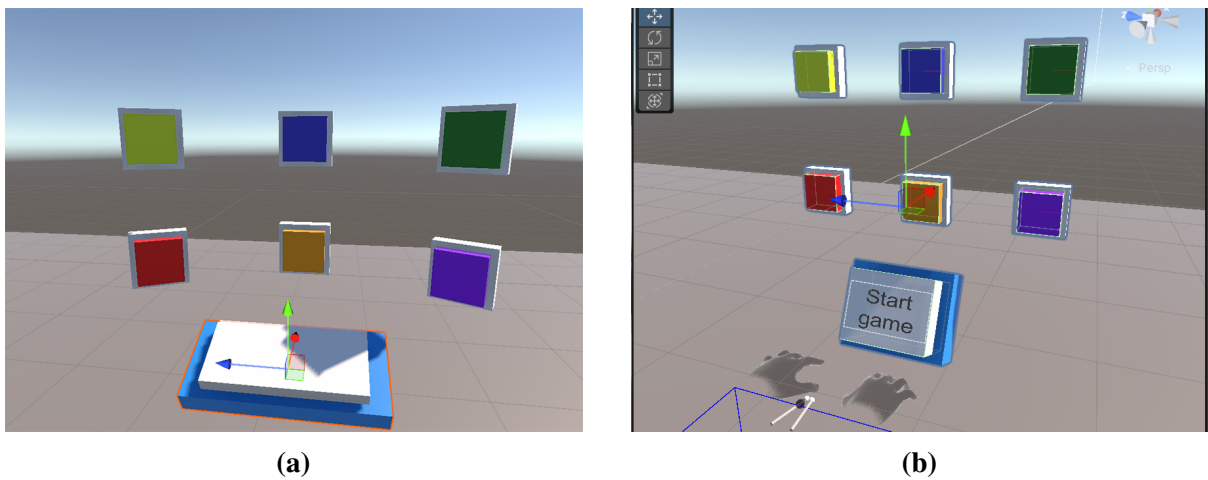


Figure 4.5: Initial iteration of Simon Says the colour game pre and post feedback in a blank environment a) demonstrates the initial Simon Says area in the blank environment, with the buttons featuring excessive spacing and suboptimal positioning b) demonstrates the initial Simon Says area in the blank environment, featuring updated narrow buttons and optimal positioning based on feedback.

The feedback received so solve the identified problems was:

- To increase the space between each coloured button and better a positioning for improved reachability.
- To modify the colour shader of each 3D button for improved visual distinguishability.

- The addition of a 3D asset in the background of the game area to reduce visual distractions from environmental elements.
- The option upon finishing to replicate sequences to select a button to return to the hub area, to move onwards to the next game or replay the first game.

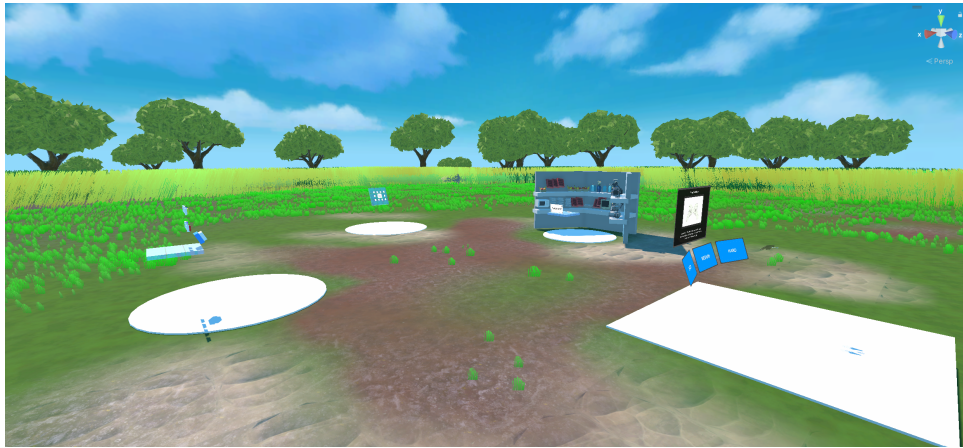


Figure 4.6: Example of initial iteration of REMIND-VR hub area in bottom right and game areas, Simon Says on left, Memory in back middle, Find-the-Object on back right without background elements to reduce visual distractions from environmental elements.

And the changes implemented were as follows:

- The narrowing of space between each 3D button for better visibility and adjusting their placements to a reachable location while still requiring slight physical movement to promote motor engagement as seen in figure 4.5b.
- Modification of colour shaders for both the non-lit and lit up versions for easier recognition as seen in figures 4.7a and 4.7b.
- The addition of a large background element, a giant boulder, positioned behind the game interface. The intention is the reduction of visual distractions from dynamic environmental assets, thereby promoting focus on memorizing the colour sequences as seen in figure 4.6.
- Finally, depending on the parameters selected while setting up the experience at the hub area, a button to move onward to the next activity and a button to return to the hub area have been implemented to give more control to the participant and reduce frustrations as seen in figures 3.7a and 3.7b.

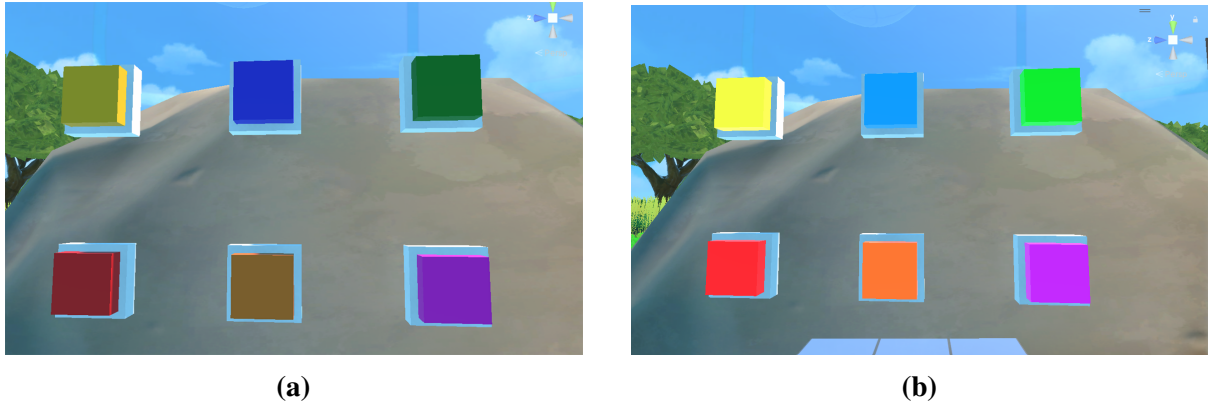


Figure 4.7: New version of Simon Says colour buttons based on feedback. a) demonstrates 6 buttons of Simon Says with new non-lit colour shaders for better distinguishability b) demonstrates the 6 lit-up buttons of Simon Says with new colour shaders for better distinguishability when highlighted in sequence replay.

4.3 Memory, the card game

The second game is based on Concentration, the card game. The assigned area of the game in the digital environment consists of a 3D grid table where the cards are placed, a start button to begin the game, an interface to explain the game rules and instructions on interactions and a help button on the bottom of the grid as seen in figure 4.8.

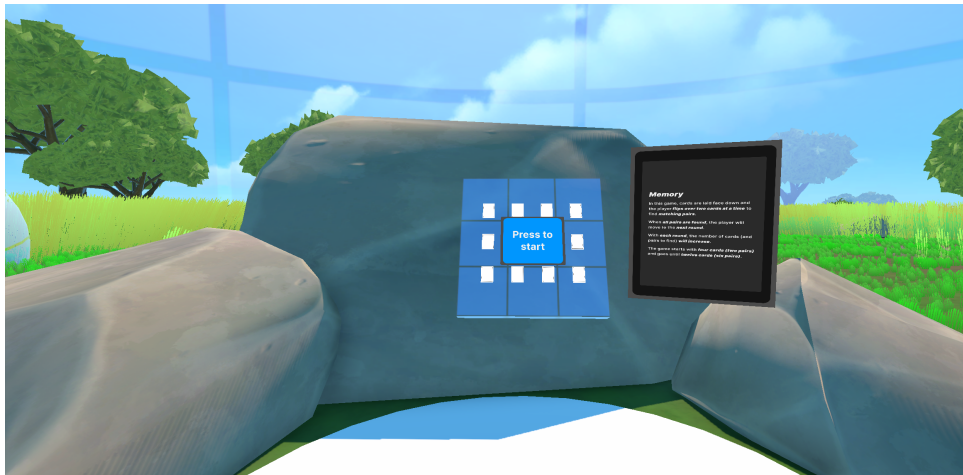


Figure 4.8: Picture of the Memory game in an initial state, featuring the 3D grid table and 12 cards flipped down, the “Start game” button and the written interface instructions.

This game includes the following pairs of cards: the gems, the suns, the trees, the teas, the moons and the knight, as seen in figure 4.9a. Additionally, at the beginning of each new round, including when game begins, all card positions are randomly shuffled. This design choice aims to introduce variability and encourages participants to form new spatial memory associations in each round, which promotes engagement.

The game’s help feature is located at the bottom of the grid board during gameplay. It features

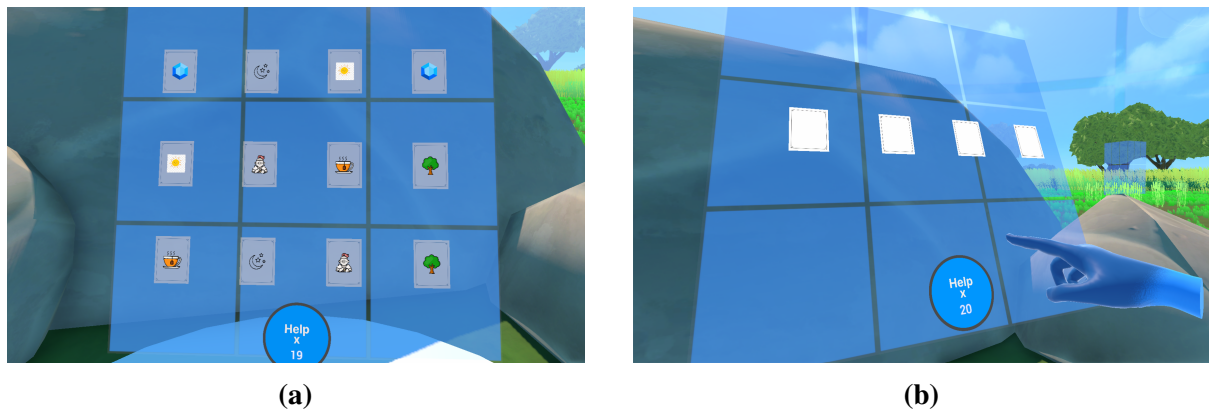


Figure 4.9: Grid board of Memory featuring the help button and different cards during playthrough. a) demonstrates all the available card pairs in the game flipped up for the participant to see and memorize b) demonstrates a participant attempting to press the help button to be able to see all card pair positions temporarily.

a limited number of uses, indicated by a visual counter on the button interface and functions to temporarily reveal all available cards of the current round without allowing interaction. The available number of tokens for this feature is determined by parameters selected in the hub area prior to the playing the game as seen in 4.9b.

During the development of REMIND-VR, the card game Memory underwent modifications based on initial user feedback. The problems identified were as follows:

- The UI designs and button layouts were overly simplistic and visually unengaging, in addition to the bad positioning of the help and start game button, as seen in the figure 4.10.
- Individuals finding themselves frequently distracted by dynamic background assets such as the moving grid spheres, shifting grid boxes, grass and reward system display as shown in figure 4.11a.
- Difficulty with UI interaction, which include cards lacking visual feedback upon selection, making it difficult to confirm card actions. Furthermore, the help button displayed interaction complexity, contributing to frustrations during gameplay.

The feedback received to address the identified problems led to the following:

- The improvement of the UI designs with more visually appealing interface and adjustments of card positioning.
- Introduction of a fixed background assets behind the grid board of game area to minimize visual distractions.
- Modification of the hitboxes of the play cards and the help button.

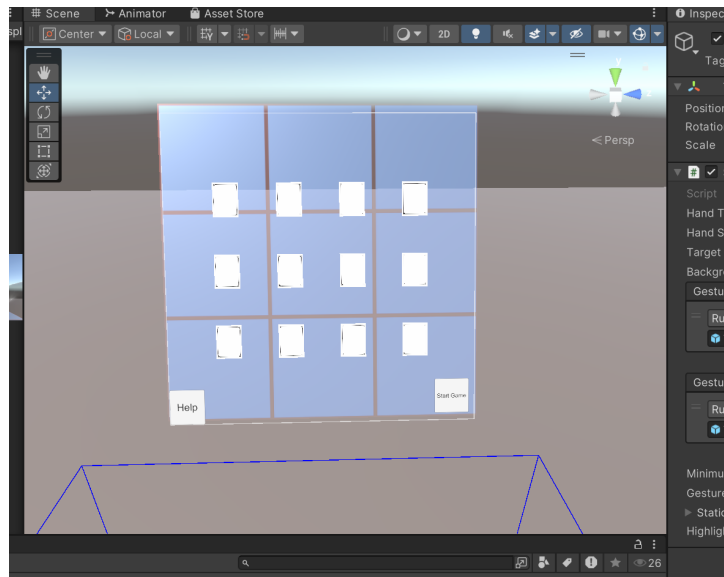


Figure 4.10: Visuals and design of the initial version of the Memory game with no environment built, featuring the cards, the help button and the start game button.



(a)



(b)

Figure 4.11: Memory game play area background changes with the grid board, instructions and start button. a) demonstrates the play area of without and background assets, allowing participants to be easily distracted by the environment visuals b) demonstrates the play area with background assets to reduce visual distractions from the dynamic 3D environment.

Finally, the changes implemented based on feedback were as follows:

- UI buttons, including the help button and start game button were redesigned with more visually appealing aesthetics. Additionally, their positions were adjusted to provide a convenient experience.
- A large 3D boulder was added as a background element behind the semi-transparent grid board interface to reduce visual distractions from the surrounding environment. The boulder was chosen to follow the environmental aesthetic as shown in figure 4.11b.
- Increased the hitbox size of the play cards and help button. Additionally adjusted the space of every card and help button in the grid table for an improved interaction, as shown in 4.9b and added visual feedback for the selection of every card.

4.4 Find-the-object, recognition game

The third game is called Find-the-Object. The assigned zone of this game in the environment includes a giant closet with two large shelves, a grid table, an interface to communicate with the user, a start button to begin the game and a written interface to explain the game mechanics and instructions as seen in figure 4.12a.

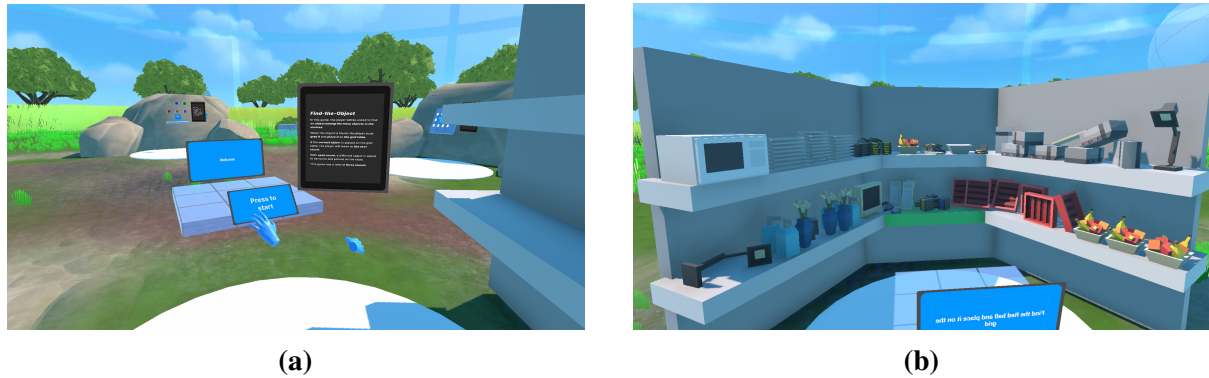


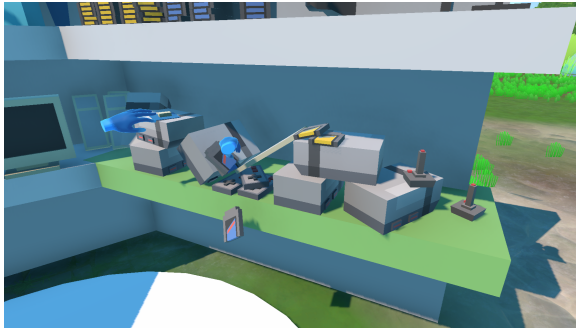
Figure 4.12: Find-the-object play area with a view from the interfaces and the overview of the shelves. a) demonstrates the play area written instructions interface, the start button, the objective interface and the grid table. b) demonstrates the overview of the play area with all shelves filled with items to hide the objective item.

At the start of every round, the objective interface communicates with the participant with written instructions. It displays the objective and specifying the item that must be located and placed on the grid table. The game ends after 3 rounds of looking for the requested object. Each round, the objective items are placed in preset locations, ensuring their appearance is not in the same preset position as in previous rounds. Similarly, supplemental items are rearranged every round to promote novelty, creative thinking and encourage sustained attention as seen in figure 4.12b.

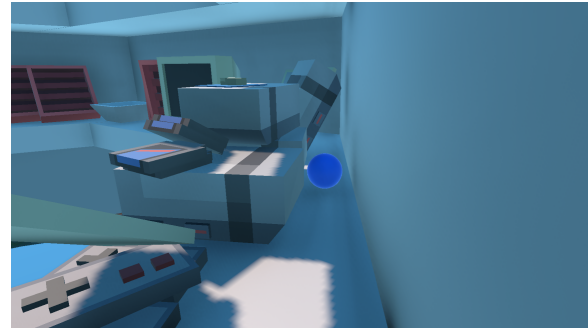
The help system associated will trigger based on a timer that is determined by the parameters chosen in the hub area when initially setting up the experience. When that invisible timer reaches zero, the shelf where the ball is hidden would highlight in a variety of green colours for visual communication. However, this system does not indicate where the ball is exactly meaning participants still have to look for it as seen in figures 4.13a and 4.13b.

During the initial version of Find-the-Object, some problems identified were as follows:

- The size of shelves and grid table based on the player. The size of the shelves and the grid table did not reflect to the player's size, as shown in figures 4.14a and 4.14b, affecting usability and comfort.
- Difficulty of regaining access to the objective items in case they fell off the shelves. These



(a)



(b)

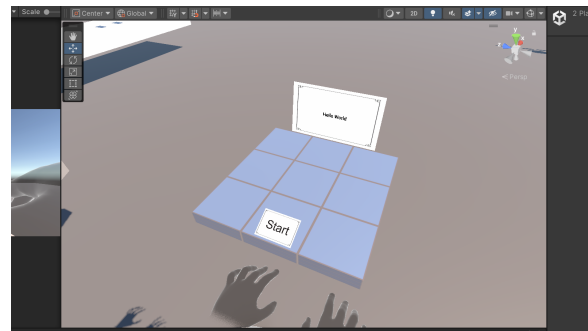
Figure 4.13: Find-the-object playthrough with a shelf highlighting and the objective item hidden behind the items. a) demonstrates an individual playing a round of Fin-the-Object by manipulating objects to find the objective b) demonstrates the objective item, the blue ball, on a hidden behind various items in a shelf.

objects would sometimes fall into unapproachable zones, hindered game progression and resulting in failure in a game where failure is deemed impossible.

- The inability to replay the third game without outside interference, breaking the flow of the experience.



(a)



(b)

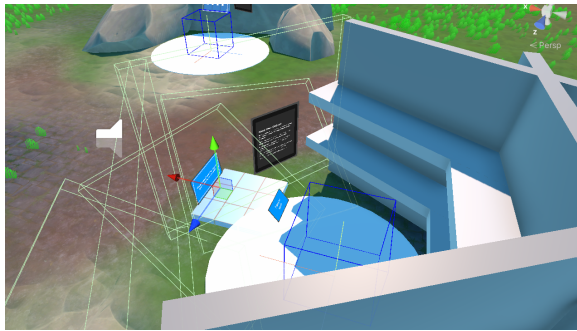
Figure 4.14: Initial built version of Find-the-object with the shelves, items and 3D grid table with an interface. a) demonstrates the Find-the-Object play area in an empty environment with the shelves filled with items and the grid table b) demonstrates the initial version of the grid table, the play game button and the objective interface instructing what to find.

The feedback received to address the identified problems led to the following:

- The size adjustment of respective shelves and interactable items.
- Addition of more invisible barriers to block items from going to inaccessible areas.
- The option of a button in the VR experience to reset the third game.

Finally, the changes implemented based on feedback were as follows:

- The 3D game elements and shelves had a size adjustment to better reflect the player size as



(a)



(b)

Figure 4.15: Modified invisible walls in Find-the-Object to bounce items back to participants and the reset button at the hub area. a) demonstrates the Find-the-Object play area with invisible walls meant to keep items in play area. b) demonstrates the “Reset games” button in the hub area to reset every game in the REMIND-VR experience.

seen in figures 4.14a and 4.14b.

- The number and position of invisible barriers were increased and strategically adjusted to prevent objects from reaching unreachable. These new measures were built with the intention of facilitating retrieval and maintaining uninterrupted gameplay as seen in figure 4.15a.
- The implementation a button in the main hub area that resets all games in the VR world so that outside interference was no longer required and ensuring a seamless continuation, as seen in figure 4.15b.

Chapter 5

Results

This section deals with the display and interpretation of the collected data from the simulator sickness questionnaire and the VR experience survey.

5.1 Results rundown

As mentioned in section, studies were conducted to evaluate the experience with at least 30 healthy individuals to gauge usability, cognitive involvement and user satisfaction. For ethical reasons, people diagnosed with Alzheimer's were not included in this initial phase. A total of 33 individuals undertook the SSQ and VR experience survey.

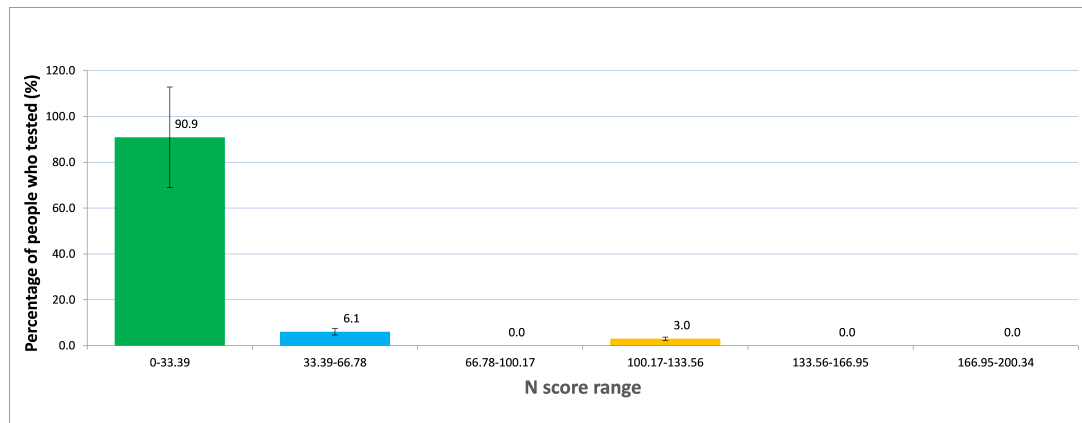
5.1.1 Simulator Sickness questionnaire

Participants were asked to provide subjective ratings of 16 individual symptoms on a scale from 0 (not at all) to 3 (severe) before and after the exposure to REMIND-VR. The 16 items allowed for an evaluation of three categories representing symptoms for nausea (N), oculomotor disturbance (O) and disorientation (D). Additionally, a total simulator sickness (TS) score can be determined by using the three sub-scales from the main category symptoms. In the SSQ, a higher score in each main category indicates a stronger presence of the main symptoms as mentioned in Bimberg et al., 2020.

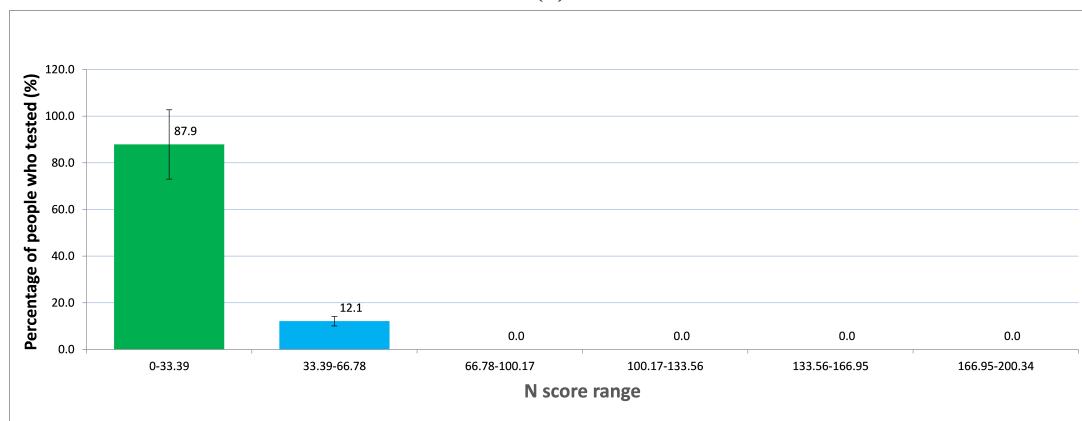
The threshold scores for N symptoms were as follows: 0 to 66.78 represents null to mild levels of symptoms, 66.78 to 133.56 designates mild to moderate levels of symptoms, and 133.56 to 200.34 portrays moderate to severe effects of N.

As observed in the histogram 5.1a, pertaining to N before the experience, 90.9 % of tester

scores ranged between 0 and 33.39, 6.1 % of individuals achieved scores between 33.39 and 66.78, and 3 % performance was rated between 100.17 and 133, with an error bar uncertainty of 24.1 %. Subsequently after the experience, 87.9 % of players achieved scores between 0 and 33.39, and 12.1 % fell within 33.39 to 66.78, with an error bar uncertainty of 16.9 % as demonstrated in the histogram 5.1b.



(a)

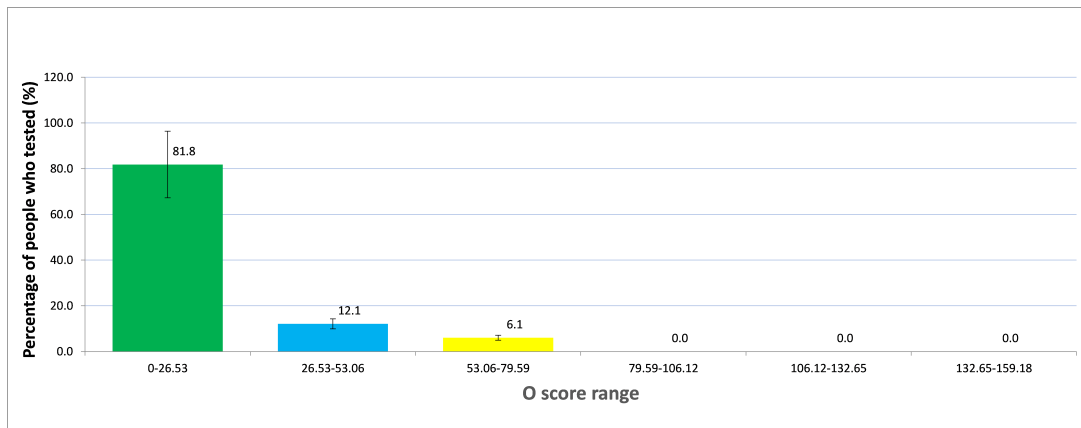


(b)

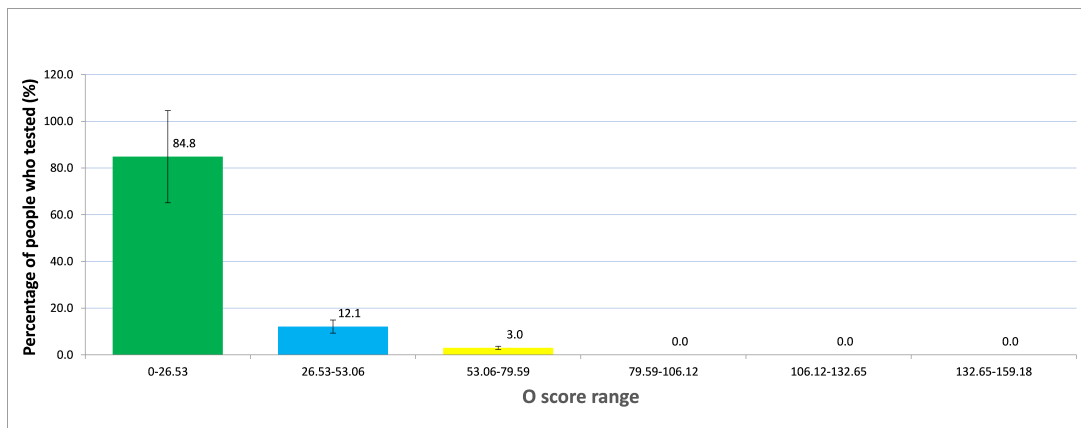
Figure 5.1: Histograms of nausea symptoms rating. (a demonstrates the data before testing VR. b) demonstrates the data after testing VR.

Following up, the O symptoms threshold scores, 0 to 53.06, represent null to mild levels of symptoms; 53.06 to 106.12 scores are associated with mild to moderate levels of symptoms; and 106.12 to 159.18 portray moderate to severe effects of O.

Histogram 5.2a displays that before trying the VR world, 81.8 % attained between 0 and 26.53, 12.1 % scored between 22.53 and 53.06, and 6.1 % were rated in-between 53.06 and 79.59 with an error bar uncertainty of 17.8 %. Thereafter, as demonstrated in histogram 5.2b, 84.8 % of players were rated within 0 to 26.53, 12.1 % of individuals got between 26.53 and 53.06, and 3 % achieved scores between 53.06 and 79.59, with an error bar uncertainty of 23.3 % after playing the games in VR.



(a)



(b)

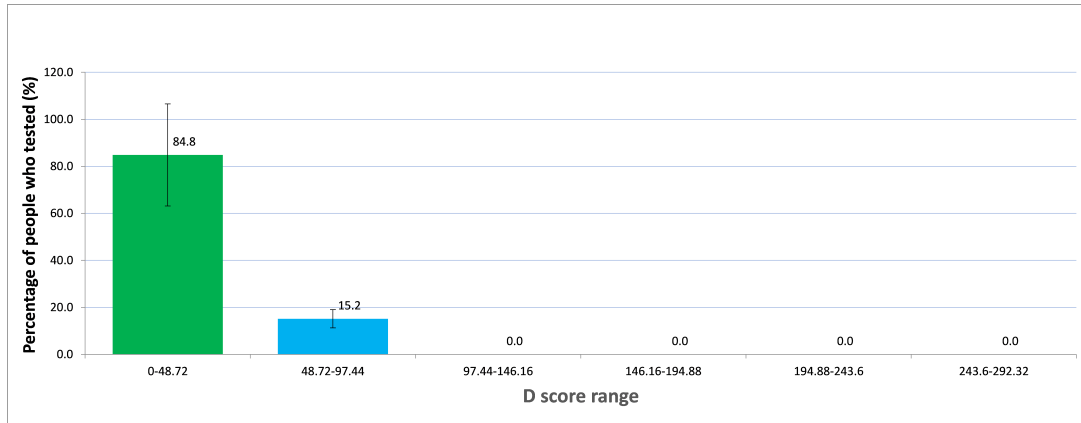
Figure 5.2: Histograms of oculomotor disturbance symptoms rating. (a demonstrates the data before testing VR. b) demonstrates the data after testing VR.

Furthermore, threshold scores for D symptoms were determined: 0 to 97.44 represents null to mild levels of symptoms, 97.44 to 194.88 designates mild to moderate levels of symptoms, and 194.88 to 292.32 portrays moderate to severe effects of D.

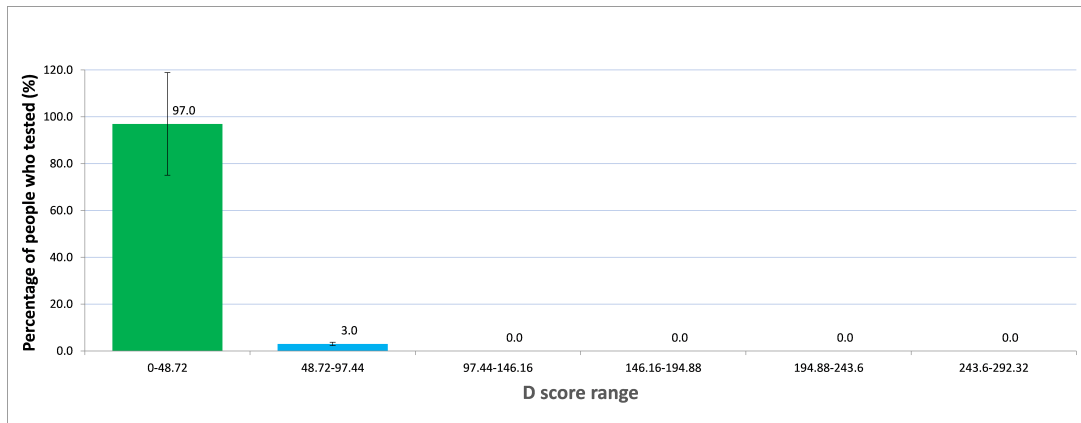
As displayed in histogram 5.3a, before attempting the experience, 84.8 % of people achieved an outcome between 0 and 48.72, and 15.2 % of testers' scores ranged between 48.72 and 94.44 with an error bar uncertainty of 25.6 %. Following a play session, 97.0 % of individuals demonstrated a sum between 0 and 48.72, and 3 % of participants fell within 48.72 to 97.44, with an error bar uncertainty of 22.6 %, as demonstrated in histogram 5.3b.

Finally, the TS score thresholds, 0 to 40.18, represent null to mild levels; 40.18 to 80.36 designates mild to moderate levels; and 80.36 to 235.62 portrays moderate to severe levels.

Before attempting the experience, 69.7 % of participants achieved a tally in the 0 to 20.9 range, 12.1 % of participants received a score between 20.9 and 40.18, 12.1 % fell within 40.18



(a)



(b)

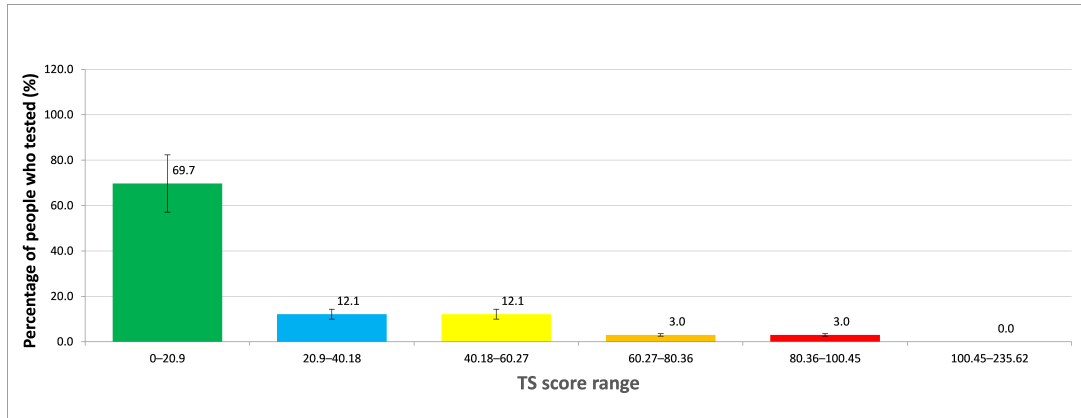
Figure 5.3: Histograms of disorientation symptoms rating. (a demonstrates the data before testing VR. b) demonstrates the data after testing VR.

to 60.27, 3 % scored in the range of 60.27 to 80.36 and 3 % got between 80.36 and 100.45 in TS points, with an error bar uncertainty of 18.1 %, as displayed in histogram 5.4a. Subsequently, histogram 5.4b shows that after a play session, 72.7 % of players scored between 0 and 20.9, 21.2 % were rated within 20.9 to 40.18, and 6.1 % fell within 40.18 to 60.27, with an error bar uncertainty of 16.7 %.

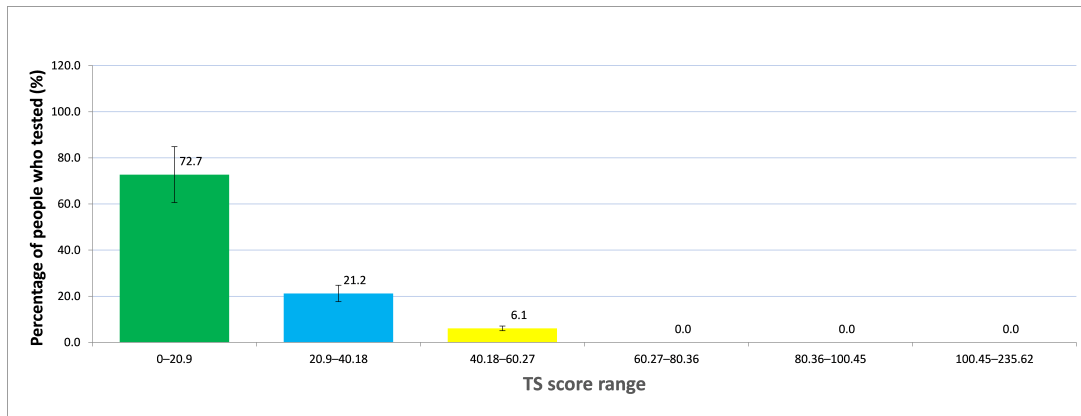
5.1.2 VR world survey overview

After engaging with the VR experience, a performance assessment was conducted to the participants by providing demographic information and opinions on the VR world and games.

The VR world survey questions were answered with a 5-point Likert scale. As demonstrated in histogram 5.5a of the assessment of the difficulty level in understanding the various games in the experience, 78.8 % of individuals responded 'very simple' (5), followed by 21.2 % who rated it 'simple' (4), with an error bar uncertainty of 1.51 %. As may be seen in the histogram 5.5b



(a)



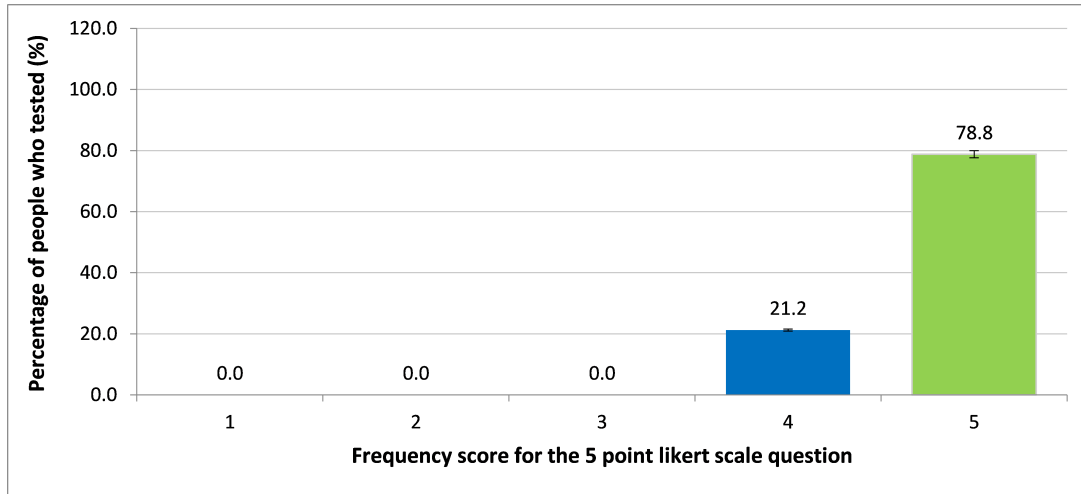
(b)

Figure 5.4: Histograms of total simulator sickness symptoms rating.(a demonstrates the data before testing VR. b) demonstrates the data after testing VR.

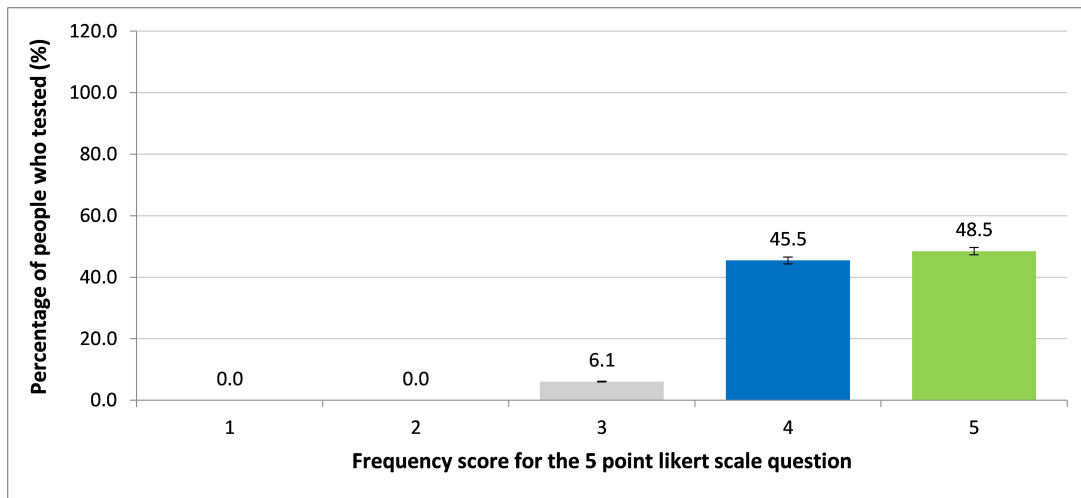
assessing the difficulty of play of all the games, 48.5 % of participants responded 'very easy' (5), followed by 45.5 % of users rating it 'easy' (4), whereas 6.1 % answered 'neutral' (3), with an error bar uncertainty of 2.42 %.

Furthermore, as depicted in the histogram 5.6a evaluating how mentally demanding the tasks were, 51.5 % of users selected 'very easy' (5), 39.4 % responded 'easy' (4), whilst 9.1 % were 'neutral' (3), with an error bar uncertainty of 2.61 %. Following up, the histogram 5.6b displays the likelihood of performance improvement in Simon Says (by achieving a better colour sequences score); 63.6 % of participants answered 'very likely' (5), 24.2 % rated 'likely' (4), and 12.1 % stated they were 'neutral' (5), with an error bar uncertainty of 2.75 %.

Subsequently, the histogram 5.7a depicts if the buttons in Simon Says were easy to distinguish visually and/or by sound; 72.7 % responded with 'very easy' (5) in addition to 27.3 % rating it 'easy' (4), with an error bar uncertainty of 1.67 %. Afterwards, players were asked about finding card pairs in the game of Concentration more efficiently (through the use of their spatial



(a)

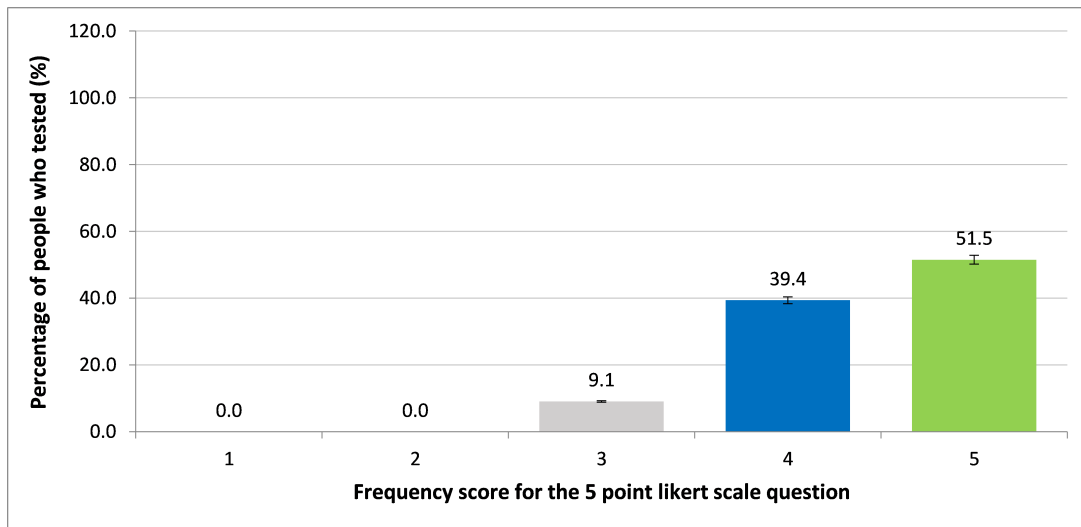


(b)

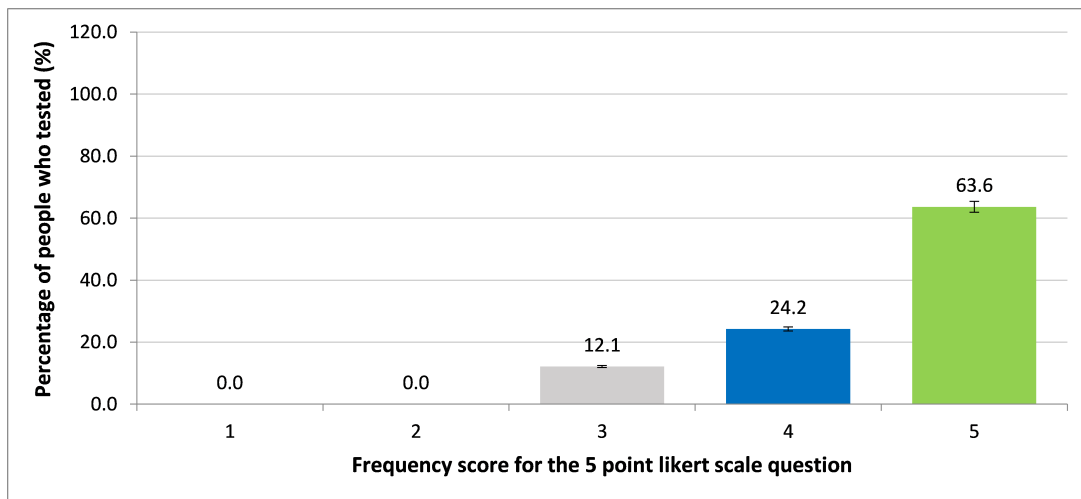
Figure 5.5: Histograms data of the VR survey a) demonstrates the histogram of the frequency rating of difficulty understanding the various games. b) demonstrates the histogram of the frequency rating of difficulty of play of the various games.

memory); considering histogram 5.7b, 45.5 % chose 'very likely' (5), with an additional 33.3 % responding 'likely' (4), although 6.1 % stated 'neutral' (3), 12.1 % choosing 'unlikely' (2) and 3 % affirming 'very unlikely' (1), with an error bar uncertainty of 4.9 %.

Following up with the performance improvements of the Find-the-object game (through the use of more creative means to find the objectives), the histogram 5.8a depicts 63.6 % stating 'very likely' (5), 21.2 % rating 'likely' (4), while 3 % chose 'neutral' (3) and 12.1 % selected 'unlikely' (2), with an error bar uncertainty of 4.09 %. As observed in histogram 5.8b, in regard to the satisfaction of the serenity of the environment, 72.7 % assessed it as 'very satisfied' (5) and 21.2 % chose 'satisfied' (4), whilst 3 % were 'neutral' (3) and 3 % stated it was 'unsatisfying' (1), with an error bar uncertainty of 3.13 %.



(a)



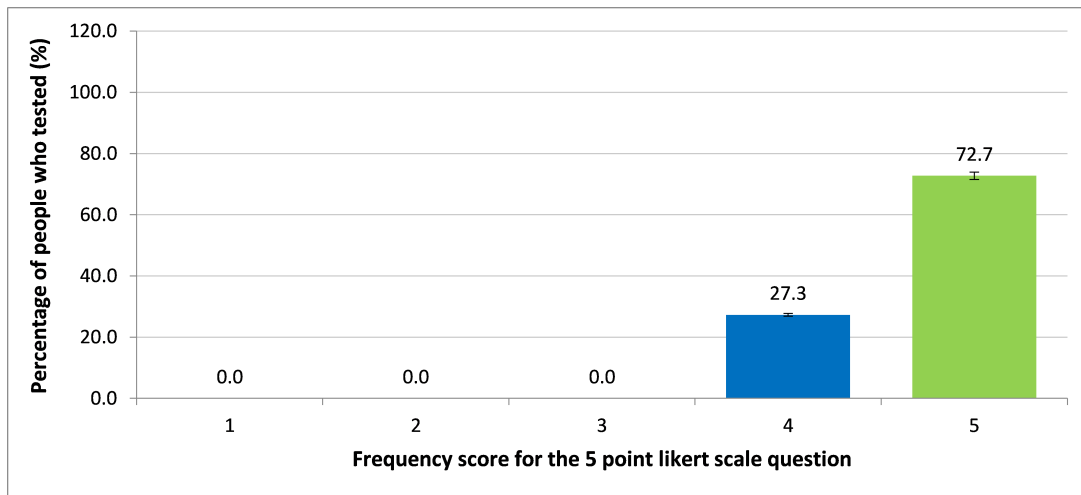
(b)

Figure 5.6: Histograms data of the VR survey. a) demonstrates the histogram of the frequency rating of mental difficulty of the various games b) demonstrates the histogram of the frequency rating of Simon Says performance improvement

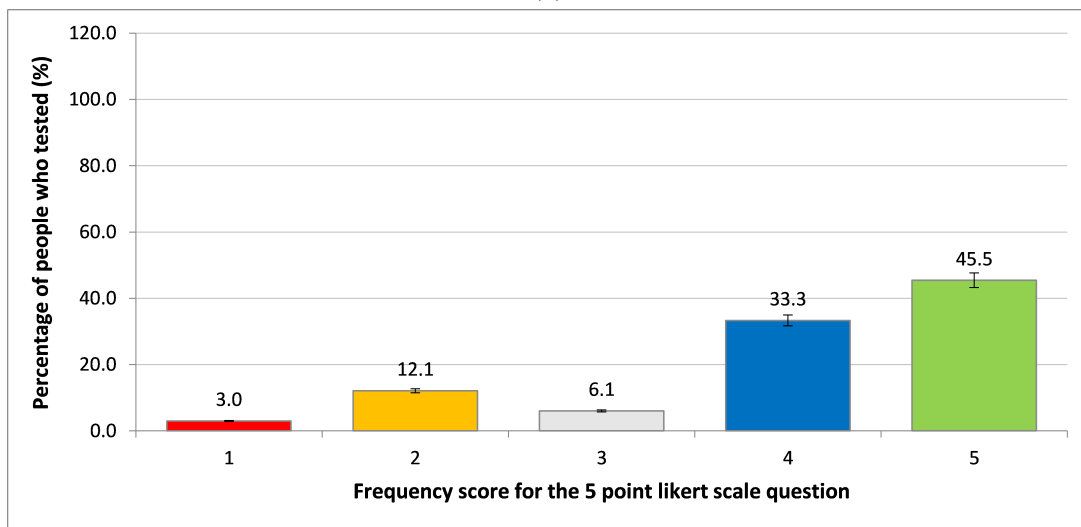
In like manner, participants were asked about the satisfaction with the comfort of the environment; histogram 5.9a displays 78.8 % stating it was 'very satisfying' (5), followed by 18.2 % selecting 'satisfying' (4), although 3 % chose 'neutral' (3), with an error bar uncertainty of 1.84 %. Finally, histogram 5.9b depicts the enjoyability of the VR experience, with 87.9 % stating it was 'very enjoyable' (5) and 12.15 % choosing 'enjoyable' (4), with an error bar uncertainty of 1.18 %.

5.1.3 Results discussion

To determine if the VR experience induced any important side effects, the results from the SSQ before testing and after testing were analysed.



(a)

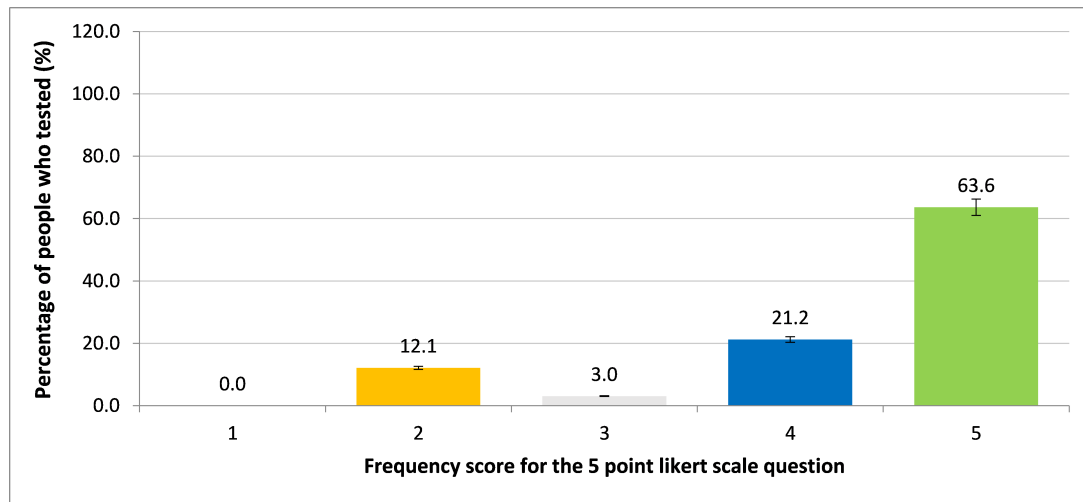


(b)

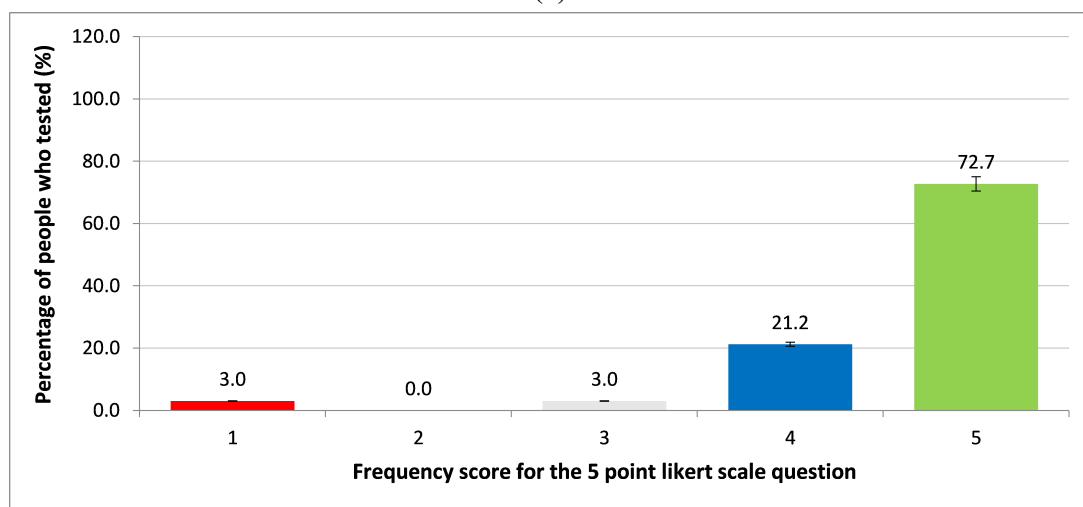
Figure 5.7: Histograms data of the VR survey. a) demonstrates the histogram of the frequency rating of audio and visual feedback of Simon Says buttons. b) demonstrates the histogram of the frequency rating of Memory game performance improvement

As observed in histogram 5.1a and histogram 5.1b which are associated with the nausea category symptoms, there is a drop in the percentage of individuals affected by 'mild to moderate' (3 % to 0 %); in contrast, the none to mild percentage of individuals has changed, '0-33.39' changed to 87.9 %, down from 90.9 %, whilst '33.39-66.78' increased from 6.1 % to 12.1 %.

This drop in percentage of individuals within the mild to moderate score ranges could be attributed to participant showing improved concentration and increased comfort comfortable. Whilst the reduction in none to neutral could be linked to participants with no prior VR experience, section 3.5 of this work reports that 21.2 % of individuals never had previous exposure VR before. It is plausible that these individuals experienced unease and discomfort; alternatively, they may have encountered sensory conflict while playing the third game.



(a)

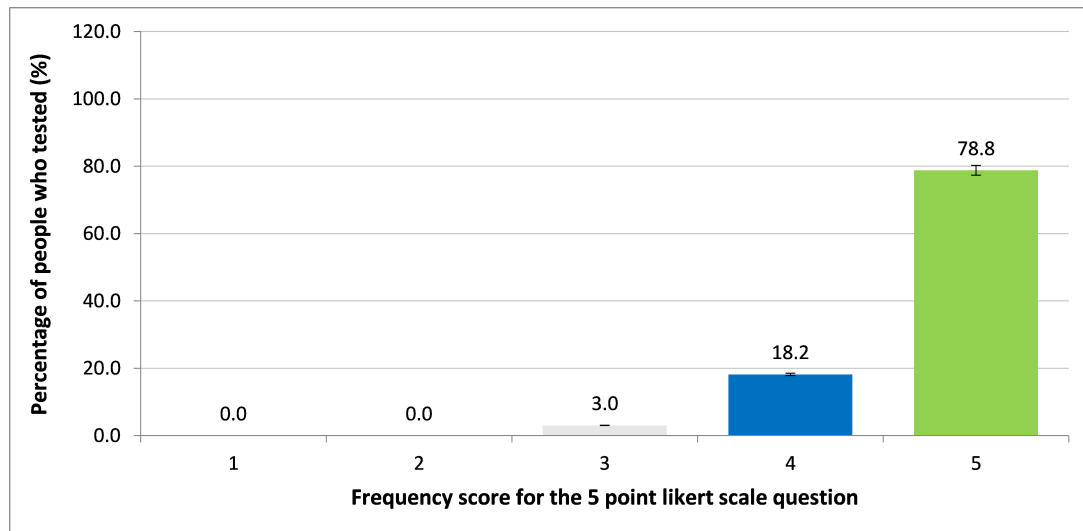


(b)

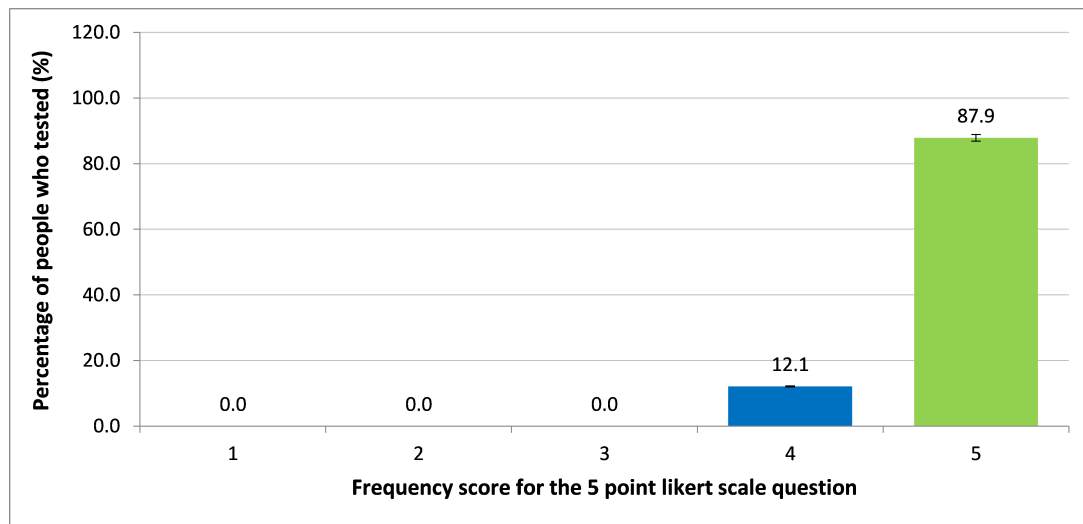
Figure 5.8: Histograms data of the VR survey. a) demonstrates the histogram of the frequency rating of Find-The-Object performance improvement. b) demonstrates the histogram of the frequency rating of the serenity of the VR environment

Furthermore, in histogram 5.2a and histogram 5.2b which are linked to oculomotor disturbance, a slight improvement of categorised symptoms can be viewed; the mild to moderate percentage of affected individuals decreased from 6.1 % to 3 % ('53.06 -79.59'); whilst the none to mild saw some positive changes, the '0-26.53' score range went from 81.8 % to 84.8 % in contrast to '26.53-53.06', which stayed at 12.1 %.

Based on the observed changes, it can be estimated that the decrease in mild to moderate and increase in none to mild percentage is due to participants, mainly those without prior VR experience, having fewer difficulties focusing or reduced fatigue levels despite playing the VR experience games in whatever order. Alternatively, it could also be due to headache intensity alleviation for the majority of users.



(a)



(b)

Figure 5.9: Histograms data of the VR survey. a) demonstrates the Histogram of the frequency rating of the comfort of the VR environment. b) Histogram of the frequency rating of enjoyability of the VR experience.

Regarding the disorientation category symptoms, histograms 5.3a and 5.3b display major improvements to individuals. None to mild score ranges improved; '0-48.72' increased from 84.8 % to 97 %, whilst '48.7-97.44' scores decreased from 15.2 % to 3 %.

These results could be interpreted in a few methods. The change in percentage of participants within '0-48.72' and '48.7-97.44' scores could reflect an improvement in fullness of head, increased focus and reduction in dizziness levels due to the simple nature of the VR experience. Additionally, participants with no prior VR experience may have not felt loss of spatial awareness or sensory mismatch throughout the activities.

Finally, the total simulator sickness score category. Considering histogram 5.4a and histogram

5.4b, there is a noticeable drop in the percentage of individuals' total simulator sickness scores: mild to moderate, '40.18 to 60.27', lowered from 12.1 % to 6.1 %, and 60.27-80.36 from 3 % to 0 %. Sequentially, moderate to severe lowered in percentage, 80.36-100.45 from 3 % to 0 %. In contrast, the none to mild percentage of individuals was altered; 0-20.9 increased from 69.7 % to 72.7 %; moreover, 20.9-40.18 increased from 12.1 % to 21.2 %.

Through this analysis of the sample size of testers, it can be considered that the VR experience doesn't affect individuals negatively; it can mildly improve nausea, oculomotor disturbance and disorientation symptoms. This estimation is the result of positive total simulator sickness scores despite a short exposure time, which can be associated with little loss of spatial awareness, improved focus and reduction of headache or fullness of head levels.

In regard to the VR self-report questionnaire based on a 5-point Likert-type scale, the results show promise for usability, cognitive involvement and user satisfaction. The initial rating of "difficulty of understanding the various games" in histogram 5.5a suggests that users found it simple enough to grasp how all the games work (78.8 % very simple and 21.2 % simple). These metrics are likely attributed to the simplicity and straightforwardness of the rules and objectives associated with the different games. Regarding the difficulty of play of the various games, histogram 5.5b indicate that the majority of participants, 48.5 % in 'very easy' and 45.5 % in 'easy', suggest that the games were easy to play, but there were individuals who were neutral about this question (6.1 %). In a similar manner, the mental demand of all the tasks, as seen in histogram 5.6a was rated undemanding, with 51.5 % suggesting it was 'very easy' and 39.4 % stating it was 'easy', although 9.1 % were neutral on the games' demands. These results are most likely due to the various methods of interaction and cognitive engagement of the various games, through the actions of pinching buttons and items, button pressing, cognitive effort tasks, problem solving and creative thinking.

As observed in histogram 5.6b, the Simon Says performance improvement suggests individuals can memorise more colour sequences (63.6 % on 'very likely' and 24.2 % on 'likely'); through the usage of visual processing, auditory patterns, pattern recognitions, focused attention, selective listening or the use of creative thinking to remember pattern sequences, although some players are undecided on whether they can improve their performance (12.1 %). Additionally, histogram 5.7a demonstrates that all the buttons in Simon Says were simple to distinguish visually and audibly, with 72.7 % stating 'very easy' and 27.3 % choosing 'easy'.

Following the Memory game performance, a portion of individuals felt confident of their abilities to find all pairs in fewer moves by using their spatial memory, short-term memory and focused attention; histogram 5.7b demonstrates the latter with 45.5 % choosing 'very likely' and

33.3 % picking 'likely'. Although 6.1 % stated 'neutral' on the potential to improve performance, a portion of individuals were not confident (12.1 % 'unlikely' and 3 % 'very unlikely').

Furthermore, histogram 5.8a indicates that a majority of individuals can improve their performance in Find-The-Object by finding the objectives faster through the use of creative thinking in regards to manipulating a great number of supplemental objects and attention to detail by looking behind oddly placed items (63.6 % stated 'very likely' and 21.2 % chose 'likely'), although a small portion were unsure of their abilities (3 % validated 'neutral' and 12.1 % selected 'unlikely').

As demonstrated in histogram 5.8b, the satisfaction with the serenity of the VR environment is predominantly positive; 72.7 % of people rated it 'very satisfying', and 21.2 % rated it 'satisfying', although there are some peculiarities: 3 % were 'neutral', and a surprising 3 % rated it 'very unsatisfying'. In the same vein, the histogram 5.9a displays that the comfort that the environment presents with its ambience, music and ambient sound is largely embraced, with 78.8 % stating 'very satisfying' and 18.2 % saying 'satisfying', albeit with the exception of a 3 % 'neutral'. The high levels of satisfactions are most likely due to the spatial presence and environmental factors which include music, ambient sounds, lighting, environmental design and overall enjoyment of the games.

And finally, as observed in histogram 5.9b, the participants were overall pleased with the experience, 87.9 % stating 'very enjoyable' and 12.1 % stating 'enjoyable'. The results show promise and validation for the sample size of an experience that can benefit people for cognitive function improvement.

Chapter 6

Conclusion

This thesis proposed the development of a VR experience aimed at cognitive stimulation in individuals at early stages of Alzheimer's disease. The system includes three interactive games focused on memory, attention, and recognition. While promoting cognitive progression, creative thinking, attention to detail and reducing feelings of frustration. By incorporating interaction through VR hand movement recognition, the experience aimed to lower adoption barriers for older users, resulting in a more intuitive and accessible experience.

Performance studies were conducted to evaluate the experience with at least 30 healthy individuals to gauge usability, cognitive involvement and user satisfaction. It was analysed that a significant portion of individuals weren't negatively affected by the VR experience. The SSQ scores indicates a reduction in category symptoms for nausea, oculomotor disturbance and disorientation. This results in improved TTS scores, 72.2 % and 21.2 % scored in 'none to mild' ranges after engaging with REMIND-VR. These scores ranges suggest a positive level of general comfort, increase in attention and concentration.

The VR survey shows that out of the 33 participants, 78.8 % stated the environment as 'very comfortable', 78.8 % rated the understanding of the various games 'very easy' and 87.9 % reported the experience as 'very enjoyable'. Additionally, a majority of participants were willing to improve their performances on each game through the use of their creative thinking, spatial, visual and auditory memory and higher focus.

The study contributes to the field by demonstrating that a non-invasive, emotionally supportive VR experience can support cognitive stimulation goals, particularly when tailored to elderly users. Additionally, the work leverages the VR headset's built-in hand-tracking feature eliminating the need for external controllers. This reduces the challenge associated with remembering complex

button configurations and equipment promoting engagement.

The expected outcome of this work based on prior research was an engaging experience with positive reception, with participants willing to play again, as referenced in article (Thapa et al., 2020) A 3D world that can offer a place to improve attention and especially mood, as referenced in articles (Thapa et al., 2020), (Gamito et al., 2020), (Huang & Yang, 2022), to engage visual memory and communication, as mentioned in article (Tanmalaporn et al., 2024), and to maintain cognitive functions, as iterated in article (Oliveira et al., 2021).

However, this study presents several limitations; the prototype's cognitive tasks, while accessible, may lack ecological validity when compared to real-world reminiscence or function-based therapies. These factors limit the immediate clinical applicability of the system. Every individual is affected differently by VR; while the results suggest that it didn't negatively affect a majority of testers, it could be the case that there are some people for whom the side effects could be of great importance.

In future work, performance studies would be conducted on people diagnosed with Alzheimer's. The data collected would assist in further improvements of the experience developed. In terms of game development, there would be an increased focus on diversifying game types, the introduction of personalized adaptations based on people's user profiles and exploring prolonged interventions in clinical contexts. Integrating biometric sensors or remote monitoring platforms opens new possibilities for cognitive training protocols guided by patient data. A future integration with AI for various outcomes: An automatic adaptation of difficulty depending on current participant's performance, this would be used in a clinical environment with integration into the therapeutic plan of institutions. And a system that would create the 3D environment based on user preferred ambient profiles to further promote memory engagement and stimuli.

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Appendix

Document 1: Planning

Immersive experiences for cognitive stimulation of patients in early stages of Alzheimer's disease

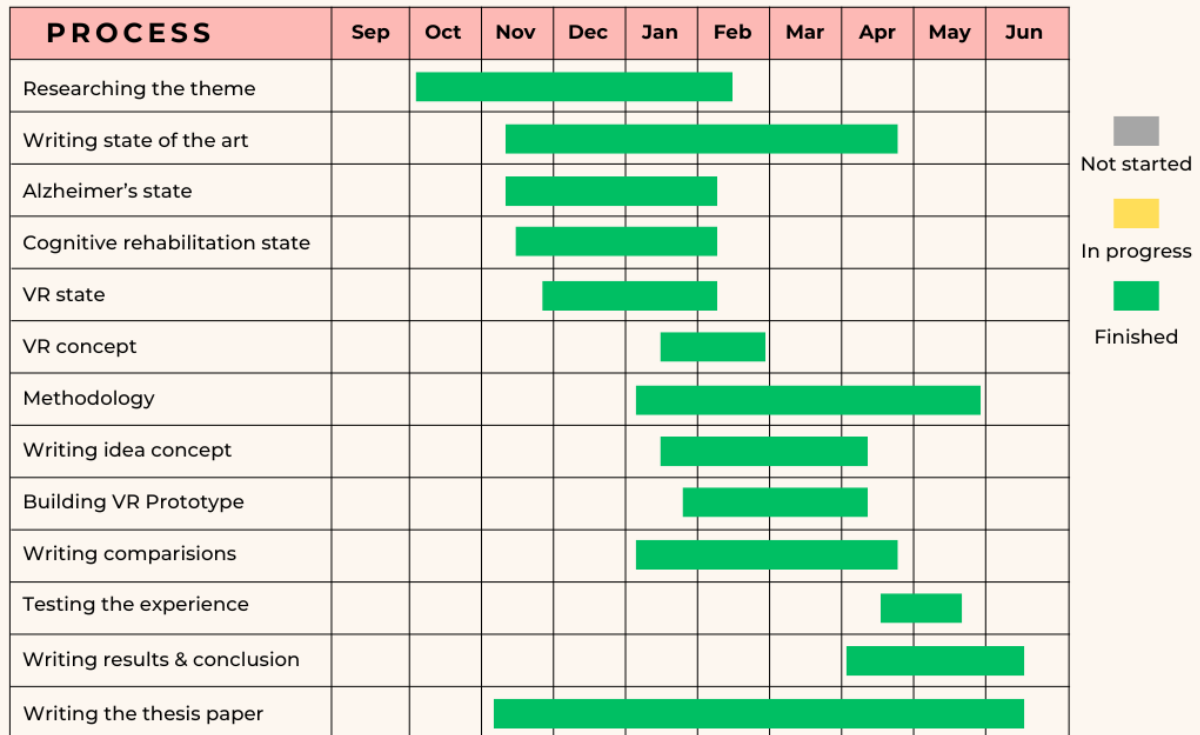


Figure 6.1: This chart shows the different stages of the development of this work.

Document 2: Interview

TA discussion was carried out with a leader, specialist in the field of biochemist research in AD, professor of biology and chemistry George Perry at the University of Texas - San Antonio, USA; who kindly agreed to elaborate on some of the view points he has of AD, the meeting took place in December 2024. The focal points discussed are as follows:

- When assisting individuals with AD, the main points to look out for are as follows: exercises (yoga, pilates, etc.), proper nutrition, maintaining a reason to be alive, and stress reduction (which helps alleviate depression).

- People with AD often experience mood swings such as aggression and depression, with the latter being a crucial concern; therefore, improving the mood of a person with AD should be the focus of a VR experience.

- A VR experience for AD patients should aim to be enjoyable and simple to raise their morale. A beneficial way to improve an experience is by employing elements from a person's distant memories, as the memories of the distant past are the last to disappear in people with AD. An example of this topic would be music; it may trigger memories from the distant past in the right scenario.

The reason to be alive can be as simple as social interaction, as the sense of connection with others can be crucial for individuals with AD, helping them feel supported and not alone.

- When dealing with a VR experience for AD patients, it is ideal to engage with multiple senses, as these can elevate an experience. However, if too many senses are interacted with, it can overwhelm the person, so focusing on two senses (hearing and sight) or three senses (hearing, sight, and touch) is the ideal scenario. Additionally, the use of hand tracking thanks to the VR headset is a viable solution, as it eliminates the need for controllers, reducing a potential problem that may overwhelm their senses.

Document 3: Virtual Reality Project Auxilium Review

Virtual reality *project Auxilium* review

Thank you for participating in this review of project Auxilium.

This is a project made for individuals with Alzheimer's disease, this is a project meant to alleviate their mood and work on their cognitive functions in order to maintain their cognitive decline. Due to ethical reasons, this project is not yet available to be tested on individuals with Alzheimer's.

Your participation is entirely voluntary, and you may choose not to answer any or all questions. The information you provide will be treated as confidential and will only be used for research and analysis. Your responses will not be shared with any third party or linked back to you individually. We value your privacy and appreciate your contribution.

Demographic Information

1. What is your age range?

Mark only one oval.

- ☐ Under 20
- ☐ 20-24
- ☐ 25-29
- ☐ 30-34
- ☐ 35-39
- ☐ 40-44
- ☐ 45-49
- ☐ 50 or older

2. What is your gender?

Mark only one oval.

- ☐ Male
- ☐ Female
- ☐ Other: _____

3. What is your education level?

Mark only one oval.

- ☐ High school (secondary education)
- ☐ Vocational / Technical school
- ☐ Bachelor's degree
- ☐ Master's degree
- ☐ PhD (Doctorate)
- ☐ Other: _____

4. Are you color blind?

Mark only one oval.

- ☐ Yes
- ☐ No
- ☐ Unknown

5. Have you ever used Virtual reality before?

Mark only one oval.

- ☐ Yes
- ☐ No

The VR experience

6. How difficult was it to **understand** the **various games** in the VR experience?*Mark only one oval.*

	1	2	3	4	5	
Very	☐	☐	☐	☐	☐	Very simple

7. How difficult was it to **play** the different games?*Mark only one oval.*

	1	2	3	4	5	
Very	☐	☐	☐	☐	☐	Very easy

8. How **mentally demanding** were **the tasks** in the games?*Mark only one oval.*

	1	2	3	4	5	
Very	☐	☐	☐	☐	☐	Very easy

9. Do you feel that you could **improve your maximum number of color sequences** in the game of **Simon Says**?*Mark only one oval.*

	1	2	3	4	5	
Very	☐	☐	☐	☐	☐	Very likely

10. Were the **buttons** in **Simon Says** easy to **distinguish visually** and by **sound**?*Mark only one oval.*

	1	2	3	4	5	
Very	☐	☐	☐	☐	☐	Very easy

11. Do you feel you could find **card pairs** more **efficiently** in the game of **Concentration**?

Mark only one oval.

	1	2	3	4	5	
Very	☐	☐	☐	☐	☐	Very likely

12. Do you feel that you can **improve your time** in the game of **Find-the-Object**?
(*Finding the items faster by any means necessary*)

Mark only one oval.

	1	2	3	4	5	
Very	☐	☐	☐	☐	☐	Very likely

13. How satisfied are you with **the serenity** (*the peaceful and untroubled play area*) the **environment** presents?

Mark only one oval.

	1	2	3	4	5	
Very	☐	☐	☐	☐	☐	Very satisfied

14. How satisfied are you with **the comfort** the **environment** presents?

Mark only one oval.

	1	2	3	4	5	
Very	☐	☐	☐	☐	☐	Very satisfied

15. Was the Virtual Reality experience enjoyable?

Mark only one oval.

1 2 3 4 5

Very ☐ ☐ ☐ ☐ ☐ Very enjoyable

16. Do you have any suggestions to improve the VR experience? (*Optional*)

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Document 4: Simulator Sickness questionnaire

Simulator Sickness questionnaire

Thank you for participating in the VR experience. Please rate the symptoms you have before and after playing or after playing the VR experience Project Auxilium

* Indicates required question

1. Select how much each symptom below is affecting you before testing. *

0 = "not at all" 1 = "mild" 2 = "moderate" 3 = "severe"

Mark only one oval per row.

	0	1	2	3
General discomfort	☐	☐	☐	☐
Fatigue	☐	☐	☐	☐
Headache	☐	☐	☐	☐
Eye strain	☐	☐	☐	☐
Difficulty focusing	☐	☐	☐	☐
Increased salivation	☐	☐	☐	☐
Sweating	☐	☐	☐	☐
Nausea	☐	☐	☐	☐
Difficulty concentrating	☐	☐	☐	☐
Fullness of head	☐	☐	☐	☐
Blurred vision	☐	☐	☐	☐
Dizziness (eyes open)	☐	☐	☐	☐
Dizziness (eyes closed)	☐	☐	☐	☐
Vertigo	☐	☐	☐	☐
Stomach awareness	☐	☐	☐	☐
Burping	☐	☐	☐	☐

After playing

2. Select how much each symptom below is affecting you after the testing. *

0 = "not at all" 1 = "mild" 2 = "moderate" 3 = "severe"

Mark only one oval per row.

	0	1	2	3
General discomfort	☐	☐	☐	☐
Fatigue	☐	☐	☐	☐
Headache	☐	☐	☐	☐
Eye strain	☐	☐	☐	☐
Difficulty focusing	☐	☐	☐	☐
Increased salivation	☐	☐	☐	☐
Sweating	☐	☐	☐	☐
Nausea	☐	☐	☐	☐
Difficulty concentrating	☐	☐	☐	☐
Fullness of head	☐	☐	☐	☐
Blurred vision	☐	☐	☐	☐
Dizziness (eyes open)	☐	☐	☐	☐
Dizziness (eyes closed)	☐	☐	☐	☐
Vertigo	☐	☐	☐	☐
Stomach awareness	☐	☐	☐	☐
Burping	☐	☐	☐	☐

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Google Forms

Document 5: ICVR 2025 conference publication

NOTIFICATION OF ACCEPTANCE

Dear João Gonçalves, João Dias and Pamela Teubig,

Paper ID:	VR2057
Paper Title:	Immersive experiences for cognitive stimulation of patients in early stages of Alzheimer's disease

Co-sponsored by Wageningen University & Research, the 11th International Conference on Virtual Reality (ICVR 2025) will be held from July 9th to 11th, 2025, in Wageningen, Netherlands.

Based on the recommendations of the reviewers and the Technical Program Committees, we are pleased to inform you that your paper identified above has been accepted for publication and presentation. You are cordially invited to present the paper at ICVR 2025 to be held from July 9th to 11th, 2025, in Wageningen, Netherlands!



ICVR 2025 list on the IEEE Conference Calendar

Submitted paper will be peer reviewed by conference committees, and accepted papers will be included in ICVR 2025 Conference Proceedings, which will be archived in IEEE Xplore, and indexed by EI Compendex, Scopus, and other indexing services.

Registration Instructions

1. Revise your paper according to the Review Comments in EasyChair system carefully.
2. Format your paper according to the Template carefully. (choose one of below to format paper)

Word: <https://icvr.org/instruct8.5x11x2.doc>

LaTeX: <https://icvr.org/ieee-latex-conference-template.zip>

3. Finish registration by below link by registration deadline.
<http://hgg922om6hjbwthb.mikecrm.com/4DtZAPf>

Notes: Please follow the instructions of the 3rd step to finish registration materials uploading before **May 20, 2025**.

The Final Conference Program will be available on the website in early July 2025. For the most updated conference information, please check the conference website at <http://www.icvr.org/>.

If you have any problem in preparing the registration documents, please feel free to contact us via icvr_conf@163.com.



Immersive experiences for cognitive stimulation of patients in early stages of Alzheimer's disease

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Abstract—Therapeutic interventions aimed at cognitive stimulation and delaying the progression of Alzheimer's disease are possible in the early stages. Virtual reality (VR) has become a promising tool in this field, offering immersive and safe environments that can be adapted to patients' needs. This article presents a solution consisting of three games that take advantage of VR to stimulate cognitive functions in individuals in the early stages of the disease, such as memory, attention, and visual recognition. The proposed solution eliminates the need for physical controllers by employing hand-tracking capabilities of the headset itself, thus promoting greater accessibility and usability for seniors. Although still in a preliminary phase, this approach demonstrates potential as a cognitive rehabilitation tool, with prospects for evaluation in clinical settings and the development of personalized functionalities.

Index Terms—Alzheimer's disease, cognitive stimulation, hand-tracking, serious games, virtual reality

I. INTRODUCTION

With the increase in human life expectancy of over 45% since 1950, neurodegenerative disorders [1], such as Alzheimer's disease (AD), are more frequently diagnosed among the modern elderly. As of recent reports, AD is the most common cause of dementia, accounting for 60-80% of dementia cases [2]. In the early stages of AD, the neurogenesis of the hippocampus displays a rapid loss of neurons, which correlates with the functional disconnection with other parts of the brain, which lowers cognitive functions, particularly memory processes and certain intuitive behaviors [3]. As amyloid beta (AB) accumulates, microglia become activated and start producing proinflammatory cytokines, leading to inflammation, phagocytosis, and neurodegeneration [4].

While AD cannot yet be cured, individuals with mild to moderate levels of the disease can undergo cognitive training, a way to mitigate the impact of cognitive decline, resulting in the stability of brain functions and the improvement of social functions, leading to stimulation of thinking, concentration, and memory [5]. Cognitive stimulation can also be gamified to enhance engagement.

Virtual reality (VR) is a computer-generated experience that employs 3D near-eye displays and pose tracking to give the user an immersive feel of a virtual world. With the development of lighter, more comfortable headsets and

more accessible software for people with disabilities, VR has presented itself as a promising tool for cognitive stimulation that offers an opportunity for adaptability and immersion for cognitive exercises [6].

Recent studies have put forward that a fully immersive VR cognitive training program is feasible and usable for patients with mild cognitive dementia [7], improving their mood, functions, and awareness [8].

The purpose of this study is to create and test an immersive VR experience for cognitive stimulation of patients in the early stages of Alzheimer's disease. Cognitive rehabilitation therapies have the potential to be adapted to VR but their limits are evident in users. Regardless, through adaptation and fortitude, the capabilities of the digital world offers a safe space where individuals can be entertained and aided; hence, VR and interactive experiences can help people with dementia, more specifically maintaining the cognitive decline in Alzheimer's disease. Despite limitations in clinical testing, this work highlights the potential of interactive and emotionally safe VR experiences to complement traditional therapeutic approaches.

Therefore, the main contributions of this work are:

- A critical synthesis of recent research on the use of virtual reality for cognitive stimulation in Alzheimer's disease, highlighting usability challenges related to traditional VR controllers;
- The design and implementation of an immersive VR prototype consisting of three serious games targeting memory, attention, and visual recognition, developed using hand-tracking interaction to enhance accessibility for older adults;
- A user-centered design approach that prioritizes emotional well-being by removing failure feedback and encouraging continuous progression;

The remainder of the document is divided as follows: Section 2, addresses the main topic of this work: the combination of VR and therapy. It analyses the most recent works that revolve around the chosen theme. It sets the scene, points out the gaps in knowledge, and acknowledges the potential of VR in treatments for AD using some games as a basis. Section 3 addresses the clear description of the idea that will

be implemented and in what manner the objective will be achieved, while section 4 addresses an interpretation of the results in the context of the hypothesis and state of the art. Finally, section 5 concludes the work done by summarising the main findings, addressing the contributions to the related themes, and suggesting possible directions for future projects.

II. RELATED WORK

In this section, the combination of therapeutic treatments for AD and VR immersive experiences will be described, including their different uses in the fields, but mainly involving potential games for VR as treatments of people with Alzheimer.

A. Engaging therapeutic solutions

The gamification of cognitive rehabilitation is an emerging solution designed to preserve and improve the effectiveness of brain function developments. This approach integrates game elements into conventional mental function exercises to make them more engaging and motivating for patients.

Solutions such as therapeutic toys and games can address neurological deterioration through various options [9], such as building games (which promote cognitive function and positive emotion), puzzle games (multiple patients playing together incentivise social communication and beneficial techniques such as hand-eye coordination, limb function, and increasing communication between patients), memory games (an engaging method to work on memory and cognition), or a companion robot (if the robot matches a certain pet animal, the patient can recall a familiar animal embodiment) [10].

Traditional board games have also been suggested to improve well-being and slow the disease-related impairment process. Games such as chess (a classic board game for two players with the objective to checkmate the opponent's king), *ska* (a traditional board game in Thailand that involves high levels of planning and decision-making), *mahjong* (a traditional tile-based game originating from China with the objective of building a complete hand of 14 tiles), or *go* (an old strategy board game between two players with the objective of capturing territory, originating in China) appear to have varying impacts on specific cognitive functions like executive functions and memory [11]. Crossword puzzles and *Scrabble* are word games that can help preserve memory and executive function of the brain in the early stages. Patients who underwent card game sessions performed better in orientation, registration, attention, calculation, recall, and language compared to those who never played, demonstrating enhanced executive functions [12]. While traditional games show potential in maintaining cognitive functions, immersive technologies may offer new levels of personalization and engagement.

Similarly, tablet applications and certain video games are a convenient and easy activity that can be adapted to the patient's abilities, preferences, and current state of their thought process abilities, mental and physical function. They provide engaging activities that can stimulate cognitive functions and improve

quality of life. Unlike mobile and tablet-based games, VR allows users to engage in fully immersive environments, which may increase cognitive load and sensory involvement.

B. Virtual Reality influence

VR represents a significant advancement in the way people engage with the digital world; it is a replica of real-world interactions through immersive experiences. It instigates the potential to transform and finds its influence across multiple industries and fields, such as gaming, entertainment, education, medicine, business, retail, transportation, energy, consulting, and even sports [7].

With regard to the medical field, VR has displayed itself as a motivational, engaging and entertaining approach to therapy for patients with mild cognitive impairment, an alternative activity to improve brain functions in the elderly. It has been called to attention by authors that VR cognitive exercises improve the mood and maintain brain functions, with patients displaying consistent evidence of increased attention and willingness to engage in more VR exercises. The immersive nature of VR presents a highly flexible training environment where patients can interact safely with the environment tailored to familiar grounds, aiding memory [8]. Simultaneously, decreasing dependence on care professionals [13], depressive symptoms, feelings of anxiety, and feelings of apathy [14].

The past experiences were tailored to different ideas; one is a rural scenery containing a harvest and cook game [7], it was evaluated with a self-report questionnaire on a 7-point Likert-type scale on 9 items. This resulted in great reception but uses a complex system attached to the arms of the players to track their finger movements; there are too many items attached to the user's personal space.

Another scenario is a progressive experience in which the difficulty of the tasks becomes more complex with each level [15], its assessment was done with multiple tests such as the IADL (Instrumental Activities of Daily Living Scale) and TMT (Trail Making Test) and displayed temporary improved cognitive function but the engagement of the users could be improved upon, and their mood is not greatly affected.

And finally, a series of games with the objective of entertaining the user while enhancing their cognitive functions (juice-making game, fireworks, and memory objects) [8], it was evaluated with multiple tests like SDST (Symbol digit substitution test) and MMSE-DS (Mini-Mental State Examination-Dementia Screening). This experience shows the potential of a VR training program for cognitive ability improvement.

The consistent part of each of these trials is that they demonstrate an improvement in mood for most of the participants. There is more willingness to attempt more trials and virtual experiences; in a few cases, a temporary increase of attention [16]. Improving an individual's mood with AD is important, as it gives way to a willingness to attempt activities that are effective in maintaining brain functions during the progression of the disease.

III. PROPOSED SOLUTION

This work will involve the creation of multiple games in a virtual environment scenario [6], an experience in which the users can interact safely with the environment and the tools at their disposal without major risk of harm. The VR experience was developed using the Unity game engine, a 3D development platform created by Unity Technologies [17].

Early VR solutions required 1 headset and 2 hand-tracking controllers to work; this work does not use VR controllers but instead uses the headset hand-tracking feature which has been drastically improved. This approach eliminates the need for users to manage physical controllers or complex input combinations (e.g., button presses).

This VR experience aims to be a fun, captivating, and cognitively stimulating experience that motivates the users to keep engaging to get better at the games. This experience will also be accompanied by visual scenario alterations to demonstrate progression or success. This is a VR project that will be built over the course of the methodology phase and improved with feedback.

The experience will be evaluated through user testing, followed by self-report questionnaires assessing attention span, motor function, reflexes, and memory. The evaluation method would be with a questionnaire on a 7-point Likert scale based on previous assessment methods done in other works revolving around this theme. This questionnaire would be carried out over a certain period of time after a working prototype version of the experience is built. It is important to note that, at this stage, the evaluation will be conducted exclusively with healthy individuals. This limitation aims to ensure safety and usability before future clinical trials with Alzheimer's patients.

The digital experience will consist of 3 games, which aim to stimulate cognitive functions; the choices of activities are based on the research conducted for this paper and their feasibility and viability for the VR experience. These games are meant to motivate the user so they keep engaging in the experience. Losing in a game would make them lose the ambition and motivation since they would feel as if they accomplished nothing, so there is no loss in this experience, only progression. The difficulty selection will determine the amount of help and the frequency of hints a user may receive throughout the different games.

A. Simon Says, the memory game

The first game is based on Simon Says, the colour game (Figure 1). The user is presented with six spaced coloured buttons so that the user moves around to interact with the respective buttons and a start game button. Once the start button is pressed, the game begins, and a sequence will initiate. The objective of this game is to repeat a sequence based on a series of tones and lights; the sequence will become progressively longer and more complex with each round as there is more to remember.

Users are expected to remember the sequences by colors or by patterns. This game tests their short-term memory and pattern recognition to see how much they can remember [18].

When the user fails to replicate the sequence, they will be moving onwards to the next game instead of being presented with a failure notification, sound, or screen. This is to ensure that the user does not feel like they have failed the game.



Fig. 1. The interface for the “Simon Says” game is based on sequential memory. In this game, the user must try to reproduce the visual and sound sequences of the colored buttons.

B. Memory, the card game

The second game is based on Memory, the card game (Figure 2). The user is presented with a board grid with a start button. Once the start button is pressed, the game begins. Four to fourteen cards (based on the stage of the level) are slid from the left and face up. The objective of this game is for the user to try to find pairs of matching cards that are placed face down, flipping two cards each time, and finding all pairs in the current round. This game tests the user's attention and memory to detail; the fewer moves they do (flipping pairs of cards), the better [12].

To help the user, there will be a button to start the game and a button to temporarily see all the cards without interacting with them; the number of times you can activate this button is dependent on the difficulty chosen.

Each stage would increase the card count by 2; it would start at 4 cards and end at 14 cards, for a total of 8 stages, with the stage of 8 cards repeating twice and the stage of 10 cards repeating twice, to give some time for the user to adapt to the increase of card numbers.

This game requires the user to finish all 8 stages for a better evaluation of their cognitive skills before moving onwards to the next game.



Fig. 2. The “Memory” game interface aims to find pairs of identical cards and promotes visual attention, working memory, and concentration.

C. Find-the-object, recognition game

The third game is a find-the-object-in-a-closet type of game; the base inspiration is Where’s Waldo. The user is presented with a grid board containing a message and a start button and a small storage closet containing a lot of random items.

Once the start button is pressed, the game begins. The display would ask the user to find a certain object. The objective of this game is for the user to try to find the asked items among all the items in the storage and place them on the grid board to confirm if the item is the asked one. There is a total of 3 rounds for 3 objects to find.

To help the user, depending on the difficulty chosen, after a certain amount of time has passed without the user finding the asked object, the shelf where the asked item is at would start to change into multiple colors to indicate where the item to pick up is.

IV. DISCUSSION

This study explores the potential of virtual reality (VR) as a tool for cognitive stimulation in individuals in the early stages of Alzheimer’s disease (AD). The three games designed—targeting memory, attention, and visual recognition—aim to provide a safe, immersive, and motivating environment, minimizing frustration and promoting a continuous sense of progress.

Compared to prior studies [10], [16], [18], the proposed solution introduces accessibility improvements by eliminating physical peripherals, relying instead on the headset’s hand-tracking capabilities. This design choice specifically addresses



Fig. 3. The “Find-the-object” game focuses on visual recognition and aims to stimulate the ability to identify and discriminate visually. The user is challenged to locate specific objects with various elements in a virtual cupboard.

the motor and cognitive limitations often observed in individuals with AD [19]. In this way, it is possible to make the experience more accessible, intuitive, and immersive.

Nevertheless, several limitations should be acknowledged. First, the current evaluation does not include individuals diagnosed with Alzheimer’s disease, which limits the generalizability of the results. Second, the assessment relies solely on subjective feedback via questionnaires, without incorporating objective cognitive metrics. Additionally, the visual clarity and gesture recognition capabilities of the system play a critical role in the user experience and require further validation.

Moreover, the absence of failure indicators, designed to protect users’ emotional well-being, raises questions about the balance between challenge and cognitive stimulation. Future studies should examine whether this design choice contributes to cognitive benefits or diminishes training effectiveness.

Despite these limitations, this work contributes to the growing body of evidence that immersive technologies can be adapted for therapeutic use in aging populations. The design principles applied here—emotional safety, accessibility, and intuitive interaction—offer a promising foundation for more personalized, clinically validated interventions.

V. CONCLUSION AND FUTURE WORK

This article proposes the development of a virtual reality-based cognitive stimulation experience that can be used by people in the early stages of Alzheimer’s disease. The solution developed includes three interactive games designed to stimulate memory, attention, and visual recognition, promoting

positive progression and minimizing feelings of frustration. Using emerging technologies such as virtual reality promotes interaction based on hand movement recognition, seeking to reduce barriers to adoption for older users, resulting in a more intuitive and accessible experience.

Although the current prototype has not yet undergone clinical trials, the results obtained from initial user testing with healthy individuals suggest strong potential for usability and engagement. The study contributes to the field by demonstrating how non-invasive, emotionally supportive VR experiences can support cognitive stimulation goals, particularly when tailored to elderly users. The expected outcome of this work based on prior research is an engaging experience with positive reception, with participants willing to play again [7]. A 3D world that can offer a place to improve attention and especially mood [8], [20], [21], to engage visual memory and communication [22] and maintain cognitive functions [15]. However, this study presents several limitations. The evaluation relied on subjective questionnaires, without incorporating objective cognitive performance metrics. Furthermore, the prototype's cognitive tasks, while accessible, may lack ecological validity when compared to real-world reminiscence or function-based therapies. These factors limit the immediate clinical applicability of the system.

In future work, performance studies will be conducted to evaluate the experience with at least 30 healthy individuals to gauge usability, cognitive involvement, and user satisfaction. For ethical reasons, people diagnosed with Alzheimer's will not be included in this initial phase. The data collected will make it possible to improve the experience developed iteratively. Also, in terms of game development, upcoming developments include the introduction of personalized adaptations based on each user's profile and exploring prolonged interventions in clinical contexts. Integrating biometric sensors or remote monitoring platforms opens new possibilities for cognitive training protocols guided by patient data.

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The IADE logo consists of the letters 'IADE' in a bold, sans-serif font. The 'I' and 'A' are connected, as are the 'D' and 'E'. The logo is white and is positioned on a black rectangular background that has a diagonal cut on its right side.

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