TÉCNICO LISBOA

Serious Games in Virtual Reality and Augmented Reality

Instrumental Activities of Daily Life using techniques of Procedural Memory

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Acknowledgments

It's with great delight that I write this chapter, which is an expression of the conclusion of this stage of my life!

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Abstract

With the increase in Average Life Expectancy a larger percentage of the population reaches higher ages. This new societal paradigm is accompanied by an increase of age-related neurodegenerative diseases like Alzheimer Disease. Even with the effort in the last few years to understand and diminish the population affected by Alzheimer Disease, no real conclusion on the causes were reached. Pharmacological interventions that aim to control the impact and progression of this neurological condition seems to be insufficient to ensure the quality of life of these patients.

This work proposes to use the new advances on Virtual Reality technology to develop a Serious Game dedicated to the teaching of the Instrumental Activities of Daily Life to Neurodegenerative disease patients, by using Implicit memory learning techniques like Errorless Learning methods, to avoid errors and allowing for better retention of procedures.

Keywords

Virtual Reality; Alzheimer's Disease; Habit Learning; Implicit Memory; Errorless Learning; Instrumental Activities of Daily Life; Procedural Memory; Serious Games.

Resumo

Com o aumento da esperança média de vida, uma maior percentagem da população atinge idades mais elevadas. Este novo paradigma faz-se acompanhar de um aumento de doenças neurodegenerativas relacionadas com idade, tal como a Doença de Alzheimer. Mesmo com o esforço nos últimos anos para compreender e diminuir a população afectada pela Doença de Alzheimer não é ainda possível concluir as suas causas. As intervenções farmacológicas que tentam controlar e impedir a progressão destes sintomas neurológicos não parecem ser suficientes para garantir qualidade de vida para estes pacientes.

Este trabalho propõe o uso dos novos avanços na tecnologica de Realidade Virtual para desenvolver um Jogo Sério dedicado para o ensino de Actividades Intrumentais da Vida Diária a pacientes com doenças Neurodegenerativas, através do uso de técnicas de ensino de Memória Implicita tal como a metodologia de Aprendizagem Sem Erros, evitando erros e permitindo uma melhor retenção da actividade aprendida.

Palavras Chave

Realidade Virtual; Doença de Alzheimer; Aprendizagem de hábitos; Memória implicita; Aprendizagem sem erros; Actividades Instrumentais da Vida Diária; Memória Processual; Jogos Sérios.

Contents

Acronyms

AD	Alzheimer's Disease
EL	Errorless Learning
IM	Implicit Memory
EM	Explicit Memory
IADL	Instrumental Activities of Daily Life
EV	Ecological Validity
VR	Virtual Reality
SG	Serious Game

1

Introduction

Contents

1.1 Motivation

In the last decades, the Average Life Expectancy has increased, making itself accompanied by a growth on the manifestation of neurodegenerative diseases, like Alzheimer. Without a pharmacologic solution, these diseases are an ever-growing problem that many studies seek to understand and compare the causes and symptoms of Alzheimer's Disease (AD) patients who are incapable of having an independent life due to the inability of being autonomous.

AD is described as a cognitive deficit which in the early stages the person is confronted with symptoms of Mild Cognitive Impairment. It is represented by a significant change in the capacities of the memory, for example difficulties at remembering appointments. People that suffer from Mild Cognitive Impairment have a high possibility of developing dementia, acting as a good predictor for therapists.

The AD is known to affect the person memory capabilities. It is recognised through deficits on the Explicit Memory (EM) in the early stages, which is composed of the episodic and semantic memory. The EM is also known as Declarative Memory. This is the ability of *"knowing how"*, which allows subjects to consciously recall events, facts and of recognizing information. The Implicit Memory (IM) also known as Non-Declarative Memory, is the ability of *"knowing that"*. It allows for the retention of processes enabling for improvements of behaviours as the subject acquires more experience. The IM is responsible for the procedural, skeletal and emotional memories. Only when the AD patient reaches advanced stages is the IM affected.

The learning challenge of AD come from the deficit of cognitive functions. The patient loses the capability to consciously recognise new information becoming unable to differentiate a mistake on is own actions, often leading to keeping capabilities without knowing *"how"*. This can be seen as if the patient treated every information as absolute truth, caused by the deficit in EM, leading to the incapability of recognising which fact is retained (see Fig. 1.1). The intact IM capabilities open up the possibility of maintaining and acquire abilities to do Instrumental Activities of Daily Life (IADL), i.e. basic and necessary activities for a normal daily life. The Procedural Memory uses this newly acquired information to create new behaviours, the accumulative capabilities of the Procedural Memory and repetitive tries strengthens the behaviour, forming experience, and allowing for the generation of habits.

AD treatment can be very hard since it involves going through a large number of sessions of repetitive and meticulous evaluation from the therapist. This treatment can eventually affect the state of mind of the patient leading to frustration. To help the treatment process of the AD patients many studies looked over the Serious Game (SG) concept, in the last few years. SG offer a controlled and consistent teaching, leading to a better interpretation of the sessions and a less stressful experience.

SG are video games aimed at health enhancement, but their main objective to have a purpose other than entertainment. For example, educational, health, and even others, while keeping in mind a more entertaining version of the serious process of practice and learning that the user will be going through.

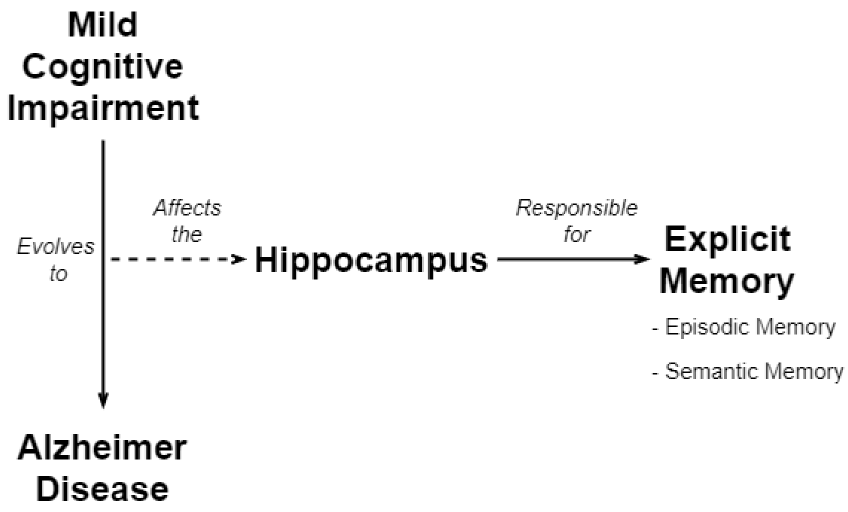

Figure 1.1: When Mild Cognitive Impairment evolves to AD the physical size of the brain shrinks, affecting the form of the hippocampus, creating a deficit in EM capabilities.

Many games started to approach health and wellness topics of the mind, e.g. Nintendo's "Big Brain Academy", and body, e.g Nintendo's "Wii Fit", working very strictly on the social and cultural context these game will be inserted.

The use of Virtual Reality (VR) allows for new perspectives over the process of rehabilitation of the patient by opening opportunities for a new and improved view of the existing treatments. By using VR, actions, as well as the environment, can have a better approximation to reality, which improves Ecological Validity (EV) and reinforces the training method. This kind of method allows exercising both the procedural and motor memory capabilities while immersed in a controlled, dynamic and personalised space.

With this in mind, this study proposes a therapy for AD where the patient goes through an intervention using a VR simulator software. This software will use Errorless Learning (EL) to ensure proper retention of the steps of the learning behaviour. It also includes some other training methods to reinforce the knowledge and the patients' ability to transfer the learned knowledge to a new environment.

Due to Covid-19 pandemic is was not possible to execute the original testing method. This method meant doing a three-month intervention with two weekly sessions where the patient would train an activity with the use of the VR solution that this study details. With this intervention, we would obtain metrics to understand the impact of this intervention method. This testing method would require close accompaniment which was not viable due to the susceptibility of the target population to the Covid-19 disease.

As an alternative, the testing method used was an online questionnaire where the participants have to play an adaptation of the VR solution. This adapted version is a Point-and-Click solution, which serves as a method to analyse the user experience and understand aspects that require improvement.

1.2 Challenges

The main challenges of this study are:

- **Embodiment** - Forget that they are in a virtual environment or where they can support themselves;
- **Exercise objects lack of mass** - During the intervention, the target audience will be training with virtual objects, which have no mass, through hand tracking;
- **Hand Tracking** - Inadequate virtualisation, provoking unusual hand movements in VR or the lack of precision when capturing fine movements;
- **Motion sickness and headaches** - The target audience is more susceptible to these symptoms, given the advanced age;
- **Technological illiteracy** - The target audience is expected not to have the knowledge of technological conventions and mechanisms used;
- **Remote tests** - Due to Covid-19, is very difficult to do tests with the target audience;
- **Implementation approach** - Ensure that the implementation follows a realistic approach of an intervention;

1.3 Objectives

The main objective of this study is to create a Simulator of IADL directed to AD Patients through a VR SG. For this purpose, the solution will use EL methodology to ensure the retention of the taught activity. The solution will also employ other methods to increase the effectiveness of the use of the SG in an intervention. Such as, the adaptation of the exercise based on Addenbrooke's Cognitive Examination, the adaptation based on the player performance on previous sessions and Block/Random practice methodology [1].

It is also the objective of this solution to be simple and iterable to support future researches.

1.4 Contributions

The main contributions of this study are:

- Allow for a AD patient to retain and obtain the capabilities to perform an IADL;

- Creation of a method of training for AD Patients that can be easily adaptable to the needs of the user;
- Open up new methods of treatment of AD Patients;
- Create a method for the therapist to understand better the performance and development of the patient during the intervention;

These contributions intend to comprise of an Artifact contribution, as defined by Wobbcrock et al. [2]. This is, a solution that combines a set of methodologies to present a new method of interaction and approach to the subject.

1.5 Outline

This document is divided into seven sections. The second chapter will explain *Related Work (see Chap. 2)* over the Alzheimer Disease, Serious Games and Virtual Reality. The third chapter presents the *Proposal (see Chap. 3)* to develop a software capable of simulating a virtual environment dedicated to the learning of new behaviours. Followed by the *Methodology (see Chap. 4)* used in the development, such as Architecture and Design of the solution. Then explain the *Implementation (see Chap. 5)* of the solution and how the questionnaire was prepared. Followed by how the solution *Evaluation (see Chap. 6)*. Finally, the *Conclusion & Future Work (see Chap. 7)*.

2

Related Work

Contents

The subject of AD has been studied over many decades, taking focus on understanding the intact capacities to understand the memory's affected parts. In more recent years newer studies started looking over the new technologies to search for new methods to treat AD.

The following subsections look over the conclusions taken over the methodologies and research done over the AD and the few technological advancements towards the treatment of cognitively impaired patients.

2.1 Alzheimer's Disease

When the population reaches higher ages, the probability of manifestation of AD increases. This said, 2% to 10% of the AD cases appear before the age of 65, doubling the proportion every 5 years after the 65 years [3]. The AD cases can be predicted by early diagnosis of Mild Cognitive Impairment, where an older adult has 3% to 19% chance of developing. From these individuals 20% to 50% have a high probability of developing dementia under 2-3 years. Overall 10% to 55% of the Mild Cognitive Impairment cases turn to dementia over 2-6 years period [3, 4].

The cases that evolve to AD can also be identified by evaluating the change of behaviour of the patients, which try to compensate for changes in life skills performance by decreasing the frequency of which they do a task. Leading to learning the behaviour of "not do" tasks they have previously performed, even if he/she likely could continue doing the task with adequate support or supervision [5].

AD affects multiple forms of memory such as EM, which is the ability to consciously and directly recall or recognise recently processed information. The EM is mainly controlled by the hippocampus and temporal lobe connections, that are essential for the formation of new episodic memories [6]. The hippocampus role is to consolidate information, ensuring that short-term memory is converted to long-term memory. The hippocampus structure can be divided into anterior, intermediate and posterior sections. The anterior hippocampus is associated with regulation effect, stress and emotions. The posterior hippocampus is responsible for cognitive function as memory and spatial learning. The intermediate part is identified but less understood [7]. When patients suffer from AD their hippocampus shrink causing a deficit in his ability, serving as a predictor of the disease which can be confirmed by comparing the volumetry of the hippocampus with the normal population. Optionally a less effective but more convenient predictor is to evaluate the medial temporal lobe atrophy score, a visual estimation of the volume of the medial temporal lobe [8].

To understand the behavioural impact of the AD many studies focused on challenges directed for specific paradigms. Small exercises with no real-life relevance that allow the analysis of the intact capabilities, [6, 9–11]. Others studies took an approach over the Activities of Daily Life [5, 12–14].

Of these approaches, the STOMP (Skill-building through Task-Oriented Motor Practice) intervention

Model is a family-centred model with a unique blend of task-oriented training delivered through motor learning principles which are: 1) practice is scheduled; 2) errors are managed in training; 3) task parameters, such as context and tools, are varied and 4) feedback is delivered. Carrie et al. [5] conclude the STOMP intervention allows for an increase in the caregiver performance and satisfaction over the sessions. From the patients perspective, the intervention is very receptive since it allowed them to feel capable of doing the tasks, even though the participants showed 70 instances of negative behaviour, going from anxiety, depression and agitation.

Another form of memory is the IM which can add new behaviours to the Procedural Memory, i.e. the incremental implicit learning of associations, to be used as a recurring behaviour when a primed cue happens, the unconscious recognition of a cue [6]. AD allows for habits to be acquired showing that over time patients can learn to associate the cues to the necessary outcomes for the execution of the habit, proving that it does not require EM in the process. Even though when applying the habit EM performance will be based on chance, while the use of IM will be very similar to healthy adults, in same age stage. By training AD patients their performance can go from 50% to 70% [10]. The AD patients might not reach a normal level of learning but they show the capability of learning without awareness, i.e. through repeated exposure of the procedure [6].

The capabilities of the IM can also allow categorisation of the information. Such as, an event can be learned through IM where the medial temporal lobe is not used. To prove this, Andrea et al. [11] conducted a series of sessions where patients were asked to categorise a set of pictures between *"High Similarity"*, *"Low Similarity"* and *"No Training"* categories. Registering that the control groups outperformed the AD groups, but concluding that AD used implicit learning during training and sessions, showing that on small data sets the capability is more efficient without training.

Debra et al. [15] examined the association of AD with IM, by measuring repetition priming, i.e. response improvement on repeated presentation of stimuli, by going through a category-exemplar, word-identification and picture naming tests. These tests resulted in low measurements of EM usage where higher neuropathology levels meant lower levels of IM as patients approximated to death. Demonstrating good preservation of priming also stating that some forms of repetition priming are more vulnerable to AD. For example, when doing and exercise of picture-naming 25% of the patients did not prime while on an exercise of word-identification only 5% did not prime. From these, conceptual and category-exemplar priming impairment seems to be related to AD while the same wasn't identified in perceptual and word-identification priming.

It has been proven that AD patients can, and do preserve, the capability of retaining implicit knowledge, through Procedural Memory, until later stages of the disease [10]. Even if AD patients have many difficulties recalling what/how/when they did a task, this can lead to serious learning problems by allowing them to keep doing the same mistake over and over again. Meaning that the patient can still learn new processes even if the capability of discerning a mistake from a correct step is unexisting.

To understand the retained capabilities of the AD patients some studies presented tests like [6, 9]:

- **Maze Test** - Where blindfolded patients had to trace a complex pathway;
- **Rotor-Pursuit task** - Where patients had to maintain contact between a hand-held stylus and a rotating spot;
- **Serial Reaction-Time task** - Patients had to respond as fast as possible when a stimulus appeared in one of four places by pressing a response key;
- **Pattern Learning task** - Based on Serial Reaction-Time task, patients produce pen-cursor movements toward targets presented in a specific pattern;
- **Mirror-Tracing task** - Do a task while the patient is viewing his performance through a mirror;
- **Puzzle-Assembly task** - Patient is requested to assemble a puzzle;

To mitigate the consequences of learning an error, a focus in IM teaching techniques appeared for example like EL and sensorimotor learning, known to be useful in learning and retaining information in mild AD patients [6]. The EL objective is to avoid mistakes, by providing a cue immediately after an instruction is given to ensure the person knows the action he must do, consequently avoiding mistakes. Some of the methods (see Fig. 2.1) used by EL are Vanishing Cues, causing the answer to progressively disappear, and Spaced Retrieval, where the cue for the answer is given after a increasing interval of time. [16].

Oposite to EL there is Trial and Error Learning, or Errorful Learning. Both these learning methods can also be divided in two subjects *Effortless* and *Effortful* (see Fig. 2.2).

The Trial and Error Learning approach ensures that the patient fails by forcing a guess before the right answer is given. In an effortless version, the patient is asked a question and it is given some answers making the patient guess, for example, "Guess what instrument am I thinking? Piano, Guitar or Flute?", an effortful approach of this exercise would be to not present any answers. This approach allows for better retention of the knowledge by provoking the repeated requests of information from long-term memory but to fulfil its role requires the capabilities of the EM, requiring that the patient confirms and discard the errors to decide to retain the correct information. To avoid the patient from learning bad habits the EL is used by teaching only the correct behaviour.

Both methods should have the ability to improve the daily life quality of the patients. On a performance basis, the Trial and Error Learning and EL have very similar performances, EL tend to show bigger improvements in early sessions but matching Trial and Error Learning in future sessions. On the other hand, the therapists show more confidence in EL [18].

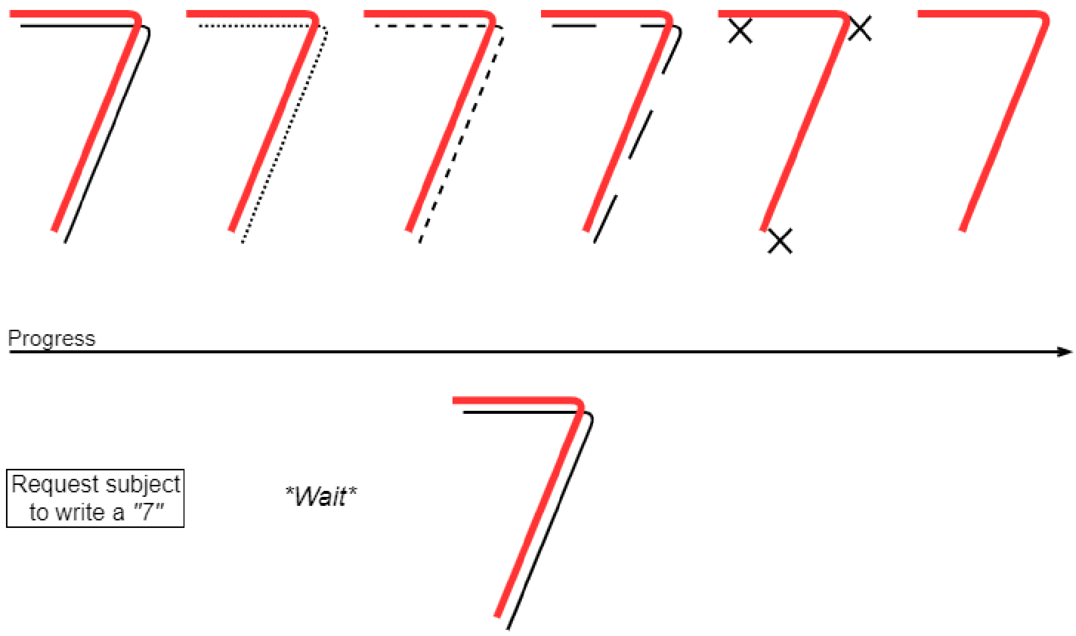

Figure 2.1: Above is the Vanishing Cue, the patient is asked to draw a seven overlapping (colour red) the already drawn seven (colour black) and after each try, the already drawn seven disappears a little bit. Bellow is the Spaced Retrieval, the patient is requested to draw a seven and only after a given interval of time is the answer given (colour black). However, if the patient answers (colour red) before the therapist gives the answer then the waiting time is increased until the exercise is unnecessary.

The therapy process involves creating a safe environment where the patient can repeat the instructions until they learn the behaviour. When the behaviour has reached a satisfyingly level of reliance the patient is taken to a non-safe environment to test the learned behaviour, this is called EV.

This is the process of validating that a knowledge acquired in an environment is capable of being transferred to another. To ensure EV it is required that the safe environment has the most, as possible, aspects of the real environment to guarantee more complete retention but it is also implied that the practice method chosen fits the needs of the behaviour being learnt.

To enforce the learning process, the number of times a person tests their knowledge on a subject directly affects the retention of long-term memory of the knowledge. Erica L. Middleton et al. [19] studied how the impact of different combinations of Study (S) and Test (T) sessions would impact the retention of the activity. Erica L. Middleton et al. compared two sequences that have the following structures: SSST (3 study sessions followed by 1 of test) and STST (a repeated sequence of 1 study and 1 test). When an approach STST happens the patient is bound to request long-term memory with a bigger frequency profiting with a better connecting between the studied subject when confronted with a test.

When testing these sequence combinations, Jeffrey D. Karpicke et al. [20] concluded that the patients that did STST presented and effectiveness of 68% at recalling the activity while the patients that did the SSST had 57%.

IADL focus heavily on Motor Learning implying that the behaviours will require a few sets of moves/steps.

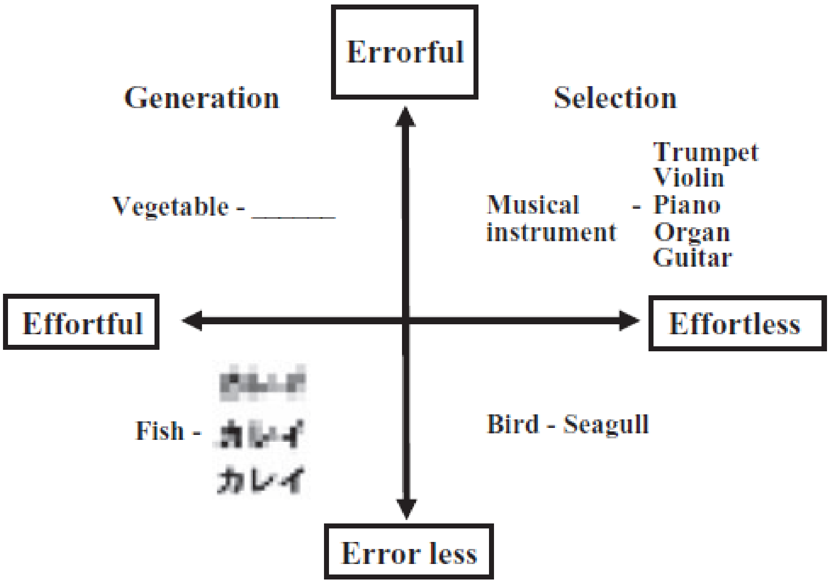

Figure 2.2: Correlation between Errorful and Errorless exercises and how it changes as the effort increases. An Errorless and Effortless exercise uses Spaced Retrieval. An exercise is Errorless and Effortful when Vanishing cues are used. The objective of an Errorful and Effortless exercise is to make the patient guess one of the answers. An Errorful and Effortful exercise is to give the question without any answer, making the patient guess or recall information. This image was presented by Masaru Mimura et al. [17]

Van et al focus on Serial Reaction-Time task and Pattern Learning Task to understand and correlate the capabilities between amnesiac [9]. This study leads to the conclusion that AD when facing Random Practice [1] the response time length increased while not affecting their overall capability of increasing their performance time. On the other hand, it also states a possible decrease in the attention of the AD patient on the task even though analysing demonstrates the use of IM, even if impaired.

When comparing AD and Parkinson Disease patients through their performance doing a Pattern Learning Task, AD patients have a decreased reaction and movement time when learning a pattern. However, over time AD patients can achieve lower error percentages than Parkinson Disease and healthy subjects in the same age group [9].

2.2 Serious Games

The Serious Game are video games directed for serious topics like education and health, instead of a ludic game where the objective is purely to entertain the end user. Being a small category in the fastest growing industry of entertainment media it has the advantage of being accessible, which also opens the possibility of a more controlled and structured treatment of patients [21]. Companies, like Nintendo, see this category of games as a method to entertain while provoking and stimulating on the subject topics like education, leading societal impact on specific topics, enhance individual user's aptitudes and, more recently, train cognitive faculties of older gamers. These games have the capability of keeping the patient in the flow state, or the feeling of complete and energized focus in an activity while maintaining a high level of enjoyment and fulfilment [21–23].

In more recent studies, it has been observed that physical games can improve balance, gait and voluntary motor control. Cognitive games showed progress on cognitive functions, like attention, memory and visuospatial abilities. When merging the two types a positive impact on social and emotional functions were reported [23].

The possibilities of SG go beyond the traditional therapy and laboratory testing since they have the capability of simulating real-life environments and activities, enhancing the EV of the results. SG can be used to analyse the decisions and reactions to either save, them for further analysis, or to adapt the activity of the player [23].

Even with only recent beginning of the research and the few games, some guidelines can already be considered [21, 24–26]. These focus on the need for simple yet intuitive interfaces, directed for a comforting yet calming space where the user feels at ease to relax, without ever forgetting that the interface and environment should always enforce the EV of the exercise/task being done by the user. Besides, the SG require extra attention to who and how the users will be playing the game, implying that the user is central to the design and development choices.

A solution dedicated to cognitive training for AD patients was proposed by Frédérick Imbeault et al. [22] where the objective was to present straightforward and easy challenges addressing the IADL, more properly the activity of cooking a meal. Pointing out a set of practices necessary to create an environment familiar to the user. Such as, the feedback should be adequate to the help required, the capability to estimate the cognitive abilities of the user, customised experience and structure the activity in well-defined steps.

An important characteristic of SG is the ability to evaluate the actions of the player and present challenges adequate to his performance by dynamically adjusting the complexity of the game [22, 23] or by presenting different levels of difficulty [24].

Frédérick Imbeault et al. [22] uses the ELO system to dynamically adjust the difficulty by comparing the performance of the player in the previous game sessions and using these to decide how the difficulty should be increased or decreased. Every game session, the player receives a performance rank, R. By calculating the difference between the performance ranks the necessary difficulty adjustment is found. In Frédérick Imbeault et al. case, this adjustment is achieved by calculating the normal distribution of the skills difference FN(R2 - R1), i.e. the normal function of the difference between the score obtained the first and the second time the user does a specific task.

This ability takes a very important role when dealing with AD patients [22, 23] since it is expected that many errors would naturally happen it is required that these are being actively mitigated during the session. Since SG uses these errors to create a performance rank to be later compared with a newer rank [22]. Considering these errors can be learned by AD patients then an EL approach is more advisable [26].

Filipe Duarte [27] proposes a SG where the goal is to stimulate the patient cognitively to delay the advance of the AD. The proposed solution includes six distinct games to stimulate the patient, which are:

- **Temporal Orientation Game** - The player is prompt to select the current date;
- **Memory Game** - Remember the cued positions in a matrix(4x4);
- **Attention Game** - Click on the picture when the cued object appears on the screen;
- **Inhibition Game** - Select the cues words, i.e. select from a matrix of words those that correspond to intention. For example, pick all the words written with lower-case letters;
- **Processing Speed Game** - Tests the ability of the patient to select the numbers in the cued order;
- **Mental Calculus Game** - Choose the solution of the shown math exercise;

The solution had a database containing the statistics of the actions of the patients during exercise, allowing for later analysis by the therapists.

In another study, Hélio Neto [28] implemented a set of games to compare the effectiveness of SG by evaluating the performance of the patient when playing and their cognitive evaluating, Montreal Cognitive Assessment - MoCA was used to evaluate the patient.

The games were:

- **Separate the Sheeps Game** - The player must separate the sheep ensuring that the black sheep are on one side of the fence and the white sheep on the other;
- **Count the Sheeps Game** - The player is cued to count the sheep, ignoring the wolfs;
- **Milking Game** - Click on the cows following the order they should be milked;

Even though the tests weren't with random users it allowed speculating the potential of such a game. During the testing of the games, some players noticeable suffered from time distortion of playtime, looping during the process of counting sheep. Was observed that the players maintained motivated due to medical recommendation and the low level of complexity of the challenges. Overall, the games required some design review to normalise the challenge, fix bad behaviour implementation and the timing of some instructions.

2.3 Virtual Reality

The concept of VR appeared over half a century ago. In the past was necessary supercomputers to calculate the processing needs of a Virtual Environment. Until in 1993, Sega proposed a hardware solution accessible to every common user. When tested, conclusions stated that when used for long periods, users were either affected by symptoms of motion sickness or headaches, feeling sick for days.

The ability to create an environment requires a high hardware fidelity to ensure enough feedback, to ensure that all senses can produce the proper sensation and perceptions. When the hardware is not capable of following the head movements or to provide the correct stimuli to the eyes to properly interpret the environment, it is not possible to take people to an embodiment state, i.e. when people feel present in the virtual environment. Furthermore, motion sickness is caused by either a low image frame rate or the inability of following all of the user movements, e.g. lack of gyroscopes or not enough position tracking.

As hardware reached a high enough level of reliability motion sickness and headaches can be avoided. However, the older population still have a higher possibility of feeling these symptoms, caused by the deterioration of the body which debilitates their senses.

The VR has been used to communicate what is AD to educate the people to detect it and how to help people that suffer from it, for example, the project *"A walk through dementia"* presented by Alzheimer's Research UK. Other studies used this technology to create environments that allow for a faster and accurate diagnosis by testing the capabilities of comparing memories, navigation and spatial memory. Opening up the capability of recognising if a Mild Cognitive Impairment patient has progressed to AD by checking their performance on the tests, allowing for early treatment.

Teresa Paulino et al. [29] developed Reh@City, a VR simulator that lets the AD patients practice Activities of Daily Life by simulating multiple environments to let them go to the cloth store, kiosk, park and home. This simulator used a dynamic difficulty adaptation module, which adapted the experience based on MOCA [30] cognitive assessment score and performance in the simulator. However, this simulator definition of VR aims to display the created environment through a monitor and not an Head Mounted Display, which does not allow the user to reach embodiment state.

Déborah A. Foloppe et al. [31] presented a VR software called Virtual Kitchen Software with the use of a Head Mounted Display and controllers, making available a solution with multiple kitchen-related activities that implemented multiple levels of difficulty and EL methodologies. With this in mind, Déborah A. Foloppe et al. propose an intervention of multiple sessions of learning kitchen-related activities, that would interlayer real-world training with virtual world training to understand the pros and cons of each method of training.

The intervention was structured with:

1. **Pre-therapeutic assessment** - Neuropsychological and cooking tasks assessment;
2. **Therapeutic intervention** - Learning of the multiple choosen tasks for the patient;
   (a) *Coffee task* - Real World Training - 2 to 5 sessions;
   (b) *Cake task* - Virtual World Training - 2 to 5 sessions;
   (c) *Breakfast task* - Real World Training - 2 to 5 sessions;
   (d) *Soup task* - Virtual World Training - 2 to 5 sessions;
3. **Post-therapeutic outcomes** - Neuropsychological and cooking tasks assessment;
   (a) *After therapeutic intervention*;
   (b) *One-month after the intervention*;
   (c) *Six-months after the intervention*;

Having concluded the intervention Déborah A. Foloppe et al. [31] concluded a notable difference between the result of real and virtual world training. The patient showed significant improvements in autonomous performance when real-world training. Meanwhile, virtual world training allowed for a reduced need for written instructions and visuospatial indications of the target objects. After six-months assessment showed that the patients maintained their autonomy in both the real and virtual world trained tasks.

In this study, Déborah A. Foloppe et al. developed a very complete training environment with multiple exercises, that allow the patients to train more than one activity. However, the layout of the kitchen has two parallel balconies, provoking the player to turn completely when doing an exercise. Meaning that the patient has to use the Curiosity Zone [32] to do the exercise. Also, their solution does not consider any adaptation meaning the exercises had the same difficulty from start to end.

Rebeca I. García-Betances et al. [33] compared and categorised the use of VR technology for AD. The select works were categorised as:

- **Intended Purpose**:
  - *Assessment and diagnosis*;
  - *Cognitive training or therapy*;
  - *Caregivers' training*;
- **Impairment feature it is focused on**:
  - *Attention*;
  - *Executive Function*;

  - *Memory* - non-verbal episodic memory, allocentric and egocentric spatial memory, temporal order memory, prospective memory, short-term, and working memory, etc;

- **Methodology employed**: *Tasks, Games or IADL*;
- **Kind of virtual experience**: *Full immersion, Semi immersion or Non immersive*;
- **Type of interaction technique**: *Active, Passive, With or without AR*;

Having this in mind a subset of these projects were selected based on their similarities to the subject of this study, which implied: Cognitive Training or Therapy as Intended Purpose; Focused on Executive Function; IADL and/or Games Methodology; Full Immersion; And With AR;

The selected articles presented in this study were: Hofmann et al. [34]; Bartolomé et al. [35]; Shamsuddin et al. [36]; Yeh et al. [37]; Optale et al. [38]; Allain et al. [39];

Hofmann et al. [34] presented a study which compared the performance of three groups: AD patients; Major Depressive Episode patients; a control group. The groups played a non-immersive VR game to train a IADL task, comprised of finding a predefined shopping route, to buy three items, and to answer correctly to 10 multiple-choice questions related to the virtual tasks.

At the first stage of the study, the patients did a pre-intervention cognitive assessment with Clinical Dementia Rating (CDR) [40] and the Mini-Mental State Examination (MMSE) [41]. At the second stage, the patients did four training weeks which included 12 sessions. Three weeks after finishing the intervention, the patients repeated the cognitive assessment. When questioned the patients answered positively to the intervention, which incentivises that a virtual environment can bring positive emotional results from the intervention.

From the results of the intervention, it was clear that the AD patients presented larger improvements than the other groups. Presenting a distinct amount of mistakes, bigger latencies when answering, difficulties answering the multiple-choice questions and repeating the instructions more times than the other groups. By mid intervention, the AD were already having a performance closer to the other groups (see Fig. 2.3).

Bartolomé et al. [35] study delivers a non-immersive solution directed for memory, understanding and social skills training of patients of AD. This solution is divided into two functionalities, the training of the patients and the report of patients' performance.

In this solution the patients have 3 levels of difficulty:

- **Basic Level** - Three exercises with a question each. The exercise ends when the patient gives an acceptable answer;
- **Intermediate Level** - Two exercises with multiple questions. The patient advances to the next question when he gives an acceptable answer, until no more questions;

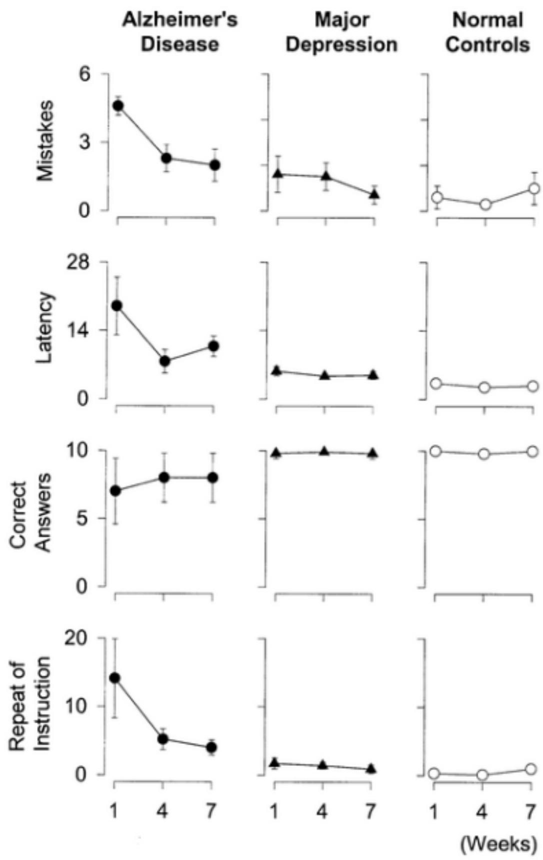

Figure 2.3: Results of the performance of the different groups. This image was presented by Hoffman et. al [34].

- **Advanced Level** - Three exercises with multiple questions, the patient advances to the next question, until there are no more questions;

Shamsuddin et al. [36] solution intend to reach MCI patients for early detection of AD on elderly subjects. This work proposed a non-immersive virtual environment of multiple common destinations, e.g. playground, art gallery, garden and others. The interaction was done through a keyboard. The SG had 5 levels, with each level becoming progressively harder.

On this study the, during the game session the player has to follow a red line through roads. As the game gets harder the player will find more complex roads and junctions.

Yeh et al. [37] developed one software for diagnosis and evaluation of AD. This software uses an Head Mounted Display to immerse the patient in a 120 degrees virtual environment. Containing tasks such as memorizing a shopping list, looking for certain goods, and checking out.

With this software, Yeh et al. propose an intervention with a total of 90 senior subjects, 60 senile dementia and 30 control subjects. The subjects must not have poor eyesight or any motion disability which prevented them from using the controller. Also requiring the subjects to sign an informed consent.

Afterwards, the subject would be guided through the experiment. This intervention was tested with only two subjects.

Optale et al. [38] implemented a VR training intervention to lessen cognitive decline and improve memory functions through a weekly:

- **Auditory session** - The participant would listen to a story told by two voices while listening to background music, created with the objective of music therapy;
- **VR session** - The participant was asked to follow a path in a virtual environment to test the ability to recall the path taken and his/her orientation;

For the intervention, the selection had the following exclusion criteria: serious sensorimotor deficits; psychiatric disorders; participation in previous cognitive training; serious medical conditions;

The intervention included 36 participants and went for 3 months, participants would alternate between 3 sequential auditory sessions and 3 sequential VR sessions every 2 weeks. This was followed by 3 months of 1 auditory and VR session. Also, the Mini Mental State Examination (MMSE) and Mental Status in Neurology (MS) were used to assess the participants' cognitive abilities pre, post-intervention and post booster phase.

With the intervention, Optale et al. [38] concluded that in general participants cognitive functioning and verbal memory improved after the initial training phase. It was also observed that the experimental group improved while the control group declined between every intervention phase (see Fig. 2.4) but this might have been caused by forming the groups blindly. Also, Optale et al. argued that having an extra intervention of 3 months helped the participants to consolidate the effects of the training even if little results were achieved.

The use of a full-immersive virtual environment helped free the participants from external distractions, which improved their focus in concluding the session. Having a clear goal promotes the learning and development of cognitive and perceptual-motor skills.

Allain et al. [39] approach was to develop a non-immersive virtual environment where the patient would have to prepare a cup of coffee, with the main objective of evaluating the EV and the ability to transfer the knowledge from the virtual to the real environment. Having a set of 24 patients neuropsychological assessment was made with Mini Mental State Examination (MMSE) and an executive function assessment with Frontal Assessment Battery (FAB).

The participants were divided into two groups, i.e. a patient's group and a control group. The participants went through two sessions training in the virtual environment and a third to try doing the task in the real world. The results show that both groups were able to transfer the behaviour, also showing a performance improvement when doing it. For example, the AD group halved their time when doing in the real-word, doing the behaviour with fewer errors, forgetting fewer steps and fewer anticipations.

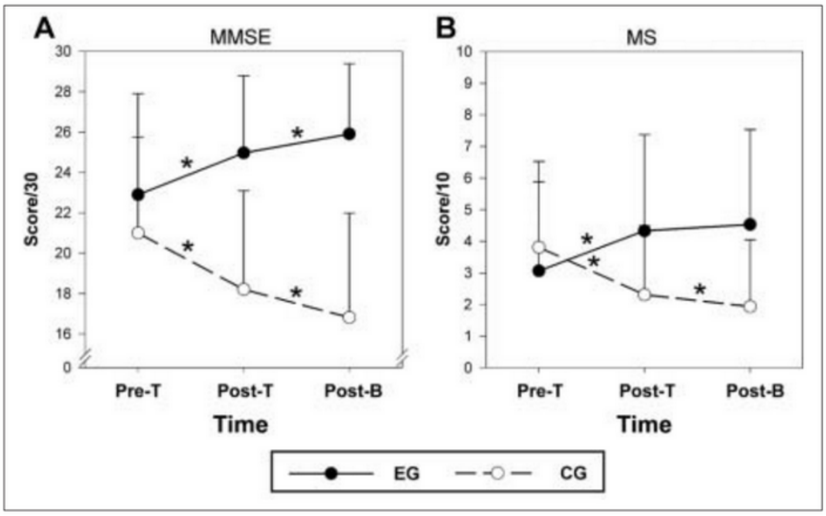

Figure 2.4: Results of the cognitive tests, i.e. MMSE and MS, between phases. This image was presented by Optale et al. [38].

3

Proposal

Contents

This chapter makes use of the analysis over the IM learning methodologies for AD to present an alternative therapy with VR technology.

The first section will explain the purposed solution. The second section proposes an intervention to test the solution developed in this study with the target audience. Due to Covid-19, the third section will explain the tests to the solution through an online questionnaire.

3.1 Solution

This study proposes a SG with the use of VR technology to create a controlled environment where patients that suffer from neurodegenerative diseases can go through exercises learning new behaviours, with emphasis on AD patients with low or moderate advanced stages of the disease.

As mentioned before, the AD EM is damaged, allowing the patients to forget some of their knowledge, cause this population to become dependent on other people daily. This solution proposes a methodology of training where the patient repeats the exercise multiple times, causing him to remember the activity by using Procedural Memory.

The learning method used will be EL, since it has been proven that it guarantees good retention of knowledge. The EL techniques being used are Spaced Retrieval, to test the ability to anticipate the therapist, and Vanishing Cues, to test the knowledge of the activity. These two techniques will allow for a better retention of the knowledge by making the experience effortful.

As a method to increase the ability of retention the game includes two types of practice, Block and Random.

Also, to ensure that the experience is properly adapted to the player the game considers adaptions depending on two different data sets. Initially, the game adapt based on neuropsychological score and as the game progresses the data generated from the performance of the player improve the adaptations and cause a controlled evolution of the difficulty, cueing and expected effort of the game session.

The environment is simple, i.e. the kitchen must not have complex features, and direct, i.e. have only the objects necessary for the exercise, to avoid distracting the user from the activity.

In other words, this SG contains an exercise that has the objective of teaching one activity to the player divided into multiple steps, where each of the steps will require the player to do one action.

The objective of the SG is to function as a simulator to teach the patient how to bake a cake (see Fig. 3.1). This activity can be easily divided into a set of sequential steps and allow for a clear understanding of the effects of the study on the AD patient. Also, this activity only require upper members movement, avoiding difficult or dangerous movements, and allowing the patient to be in a stationary position while doing the exercise.

The environment is a kitchen with only the equipment needed to accomplish the recipe, which is to

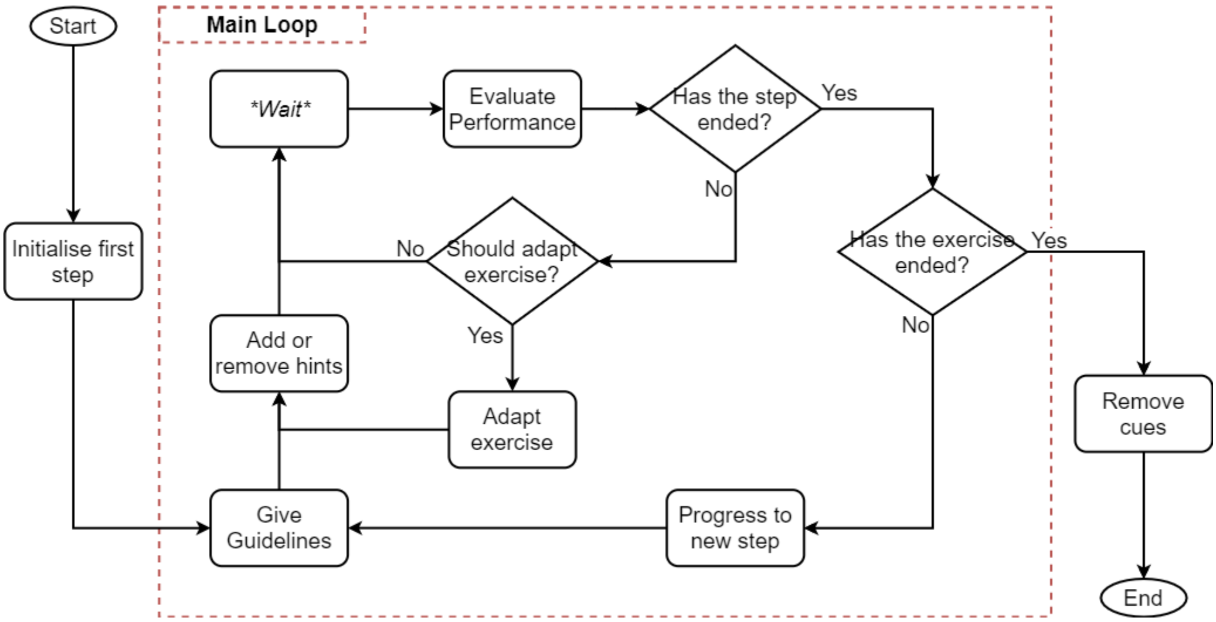

Figure 3.1: Core game loop shows how the player progresses through all the tasks, i.e. each step of the exercise. For each loop, the game will wait an interval of time, after which will evaluate the environment state. If the exercise step has not ended the game will check if any enforcement is necessary, i.e. any adaptation should happen so that the player can better understand the exercise step. When the player ends the current step he/she progresses to the next step if the exercise has more steps, removing the hints from the previous step and adding the hints from the new step.

bake a “Yoghurt Cake” (See Appendix A). The activity was chosen based on motivational factors for the patients, presenting them with the opportunity of creating something to share with their family.

Following these specifications of the solution a Concept Document (See Appendix C) was defined following the document structure by Carlos Martinho et. al. (2014) at *Design e Desenvolvimento de Jogos* [42].

For the VR, the hardware used is HTC Vive Head Mounted Display and LeapMotion to track the users’ hands since the movements of the hands and the interactions directly affects intervention EV.

This solution was developed in Unity game engine, version 2018.4.11f1, following game development and VR design paradigms, such as those presented by Mike Alger [32].

To ensure a viable solution, the development and the design decisions were discussed and evaluated by therapists to ensure:

- Proper interaction with the objects;
- The patient’s knowledge of the exercise’s objective;
- Intuitiveness of each hint;
- Patient’s physical and psychological state;
- Other missing details, necessary to apply an effective session;

3.1.1 Environments

The proposed solution is composed of two environments, the first one is an introductory environment and the second the exercise environment where the patient learns the activity.

The objective of the first environment is to give the patient some time to get used to the VR environment, by giving free movement and nothing to interact with. This environment contains relaxing elements, e.g. take place in a forest while hearing animal sounds and/or relaxing music. Meanwhile, in the computer screen the therapist is prompted to an interface where he can create or delete the patient profile and configure the available cues and hints. As the therapist starts the session, the therapist interface disappears while the patient fades out from the environment and fades in on the exercise environment.

When creating a new profile the therapist is be able to insert the cognitive assessment results so the solution can adapt to the disease stage.

The second environment takes place in a kitchen and has the objective to teach the patient how to cook/bake a simple cake. It has an "L" physical layout to ensure the patient can reach all the objects needed for the exercise, i.e. the equipment and ingredients, without effortful movements. The concept of the environment is to present an architecture close to where the real world session will take place. It also should be simple with only the needed equipment and ingredients needed for the recipe. While in this environment, the therapist is able to observe what the patient is doing through their computer screen and will only be able to do simple interactions, such as reset step, reset exercise or end the session. When the patient finishes the exercise the session ends and is sent back to the first environment through fade out and fade in.

3.1.2 Gameplay

This simulator implements EL techniques as the main mechanic, but it should also be capable of using the cognitive assessment score and performance to improve the experience.

In EL, attention and errors are very important since they require a prompt reaction. So a player is examined as **attentive** on the exercise when:

- Looking at the exercise objects;
- Grabbing the exercise objects of the current step;
- Reaching only to exercise objects of the current step;

An **error** happens when the player:

- Grabs and/or interacts with exercise objects from a different step;

- Releases the current step exercise object;
- Exceeds the duration of the step;

These assessments are done over-time rate, except those that require a prompt reaction, by evaluating if the exercise objects are in the field of view, LeapMotion hands are trying to reach objects and completing, or not, the steps.

The SG adapts reactively, allowing the player to initially interact with any object but tending to limit the interactions and redirect the focus of the player on the exercise by using hints. To fix situations where the game is in an inconsistent state the simulator proactively saves the progress to allow for recovery of the step before the step started.

The intention of this SG is to be used in an intervention divided into multiple sessions.

3.1.3 Comparison

To understand the features this study delivers and how distinct they are from other previous projects we compared the features (See Appendix D). With this in mind we compared by defining six categories:

- **Immersion** - How immersive is the experience, depending on the hardware used;
  - Full-Immersion;
  - Semi-Immersion;
  - Non-Immersion;
- **Interaction** - How the player interacts with the environment;
  - Hand Tracking;
  - Controller;
  - Other;
- **Method** - Methodologies used to define the experience and/or the intent of the game;
  - Errorless Learning;
  - Instrumental Activities of Daily Living;
  - Multiple Exercises;
- **Intended Purpose** - What skills are trained by playing the game;
  - Cognitive Skills;
  - Motor Skills;

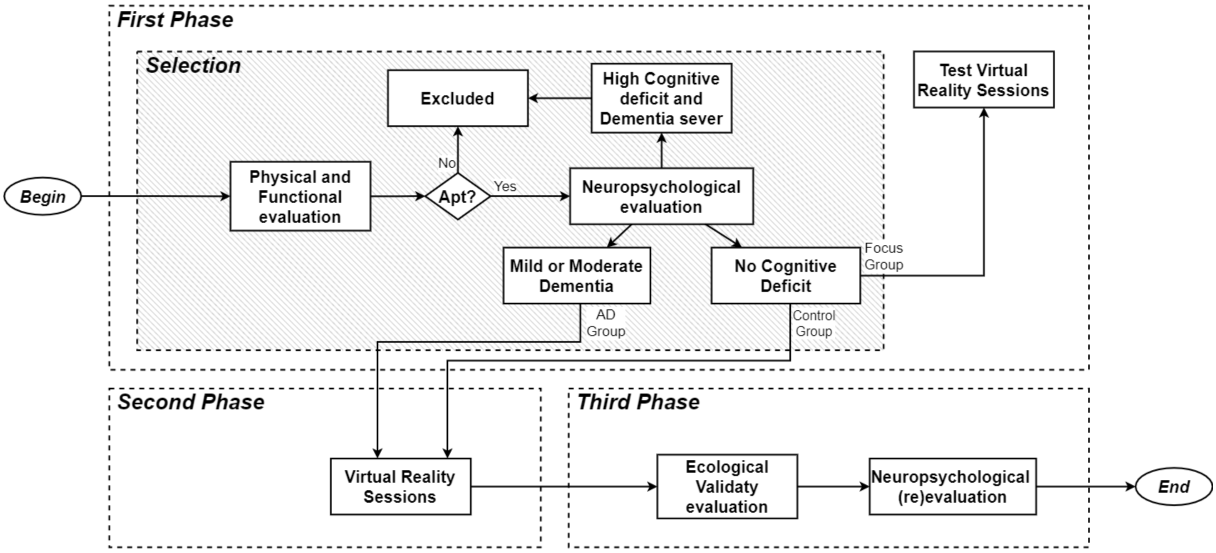

Figure 3.2: Intervention steps. The first phase where the participants are recruited. On the second phase, the intervention is applied. In the third phase, the participants are reevaluated and EV is tested.

- **Adaptation** - If the has some kind of adaptation and/or adaptation based on cognitive assessment score;
  - Input Psychological Score;
  - Dynamic Adaptation;
- **Analitics** - If the game saves any kind of data for the use of therapists
  - Treated Statistics

3.2 Intervention

This study also purposes an intervention, as a method to prove the purposed treatment concept. Due to Covid-19, it was unfeasible to apply this intervention. Still, we present the preparations done and the objectives set. An alternative approach was done to evaluate the player experience.

This intervention is planned to take up to three months following the usual steps of an intervention (see Fig. 3.2). Includes the recruitment process, pre-intervention cognitive assessment, physical assessment, post-intervention cognitive assessment and test EV of the solution.

3.2.1 Recruitment

It is expected that the selection takes into consideration the cognitive and physical health of the participants. This selection should follow a set of exclusion criteria that ensures that the participants are capable of being seated for 10-20 minutes focused on a given task, which can be challenging for some people. Also must not suffer from *Vertiginous Syndrome*, have good mobility on upper limbs and no serious eye problems, e.g. *cataracts*, *glaucoma*. From cognitive terms, a participant must not suffer from any type of psychosis or severe dementia.

The AD group must be composed of more than 10 participants that suffer from mild to moderate dementia. As a method of comparison, a Control group should be formed with the same amount of participants from the same age group, participants must be physically and cognitively healthy.

Additionally, if possible before the intervention to overcome the technological illiteracy, a Focus group should be formed with at least 3 participants selected with the same exclusion criteria as the Control Group. This group has the objective of testing that the expected experience is achieved, ensuring that the interactions feel natural. The former and the latter concepts are known as User eXperience (UX) and User Interface (UI), respectively.

3.2.2 Procedure

The intervention requires a space where the participants can do ample movements, i.e. at least 2 square meters. To allow the participant to turn and move the arms freely.

This intervention should be divided into three distinct phases. During the first phase, the group is defined, this includes doing a cognitive assessment to all participants for the creation their game's player profile and further comparison after the EV, in the third phase.

If a Focus group is set, the UX/UI tests should be performed accompanied by a therapist. A series of sessions should be defined, after which both the Focus group and therapists go through a closed interview.

To accommodate most of the therapists' view, an open interview should be done with the goal of understanding:

- The patient's performance;
- The patient's state after the session;
- Critical required changes;

The second phase of the intervention plans to go for 9 weeks with 2 weekly sessions of a duration of a maximum of 20 minutes for each participant. These sessions are composed by both Control and AD groups, supervised by the therapists. In these sessions, external interaction with the participants must be kept to a minimum, unless necessary cases, to understand the limitations of the game, helping to detect missing and necessary components.

During this iteration, the therapist configure the settings for the patient by choosing the profile, changing any configuration if necessary and starting the sessions.

The expected experience for the patient is that in the first sessions he finds only the necessary hints to go through all the steps to end the exercise as sessions progress the intensity of the hints reduce to approximately zero.

The last and third phase, examines the results of the study by testing the EV of the solution, this requires a free kitchen with a free balcony and an oven to let the participants try and cook the recipe independently, ideally with the same disposition as in the SG's Exercise Environment. The patient has access to the required ingredients and materials to cook the recipe.

3.2.3 Evaluation

Participants evaluation should occur pre- and post-study, these assessments contain physical and cognitive tests.

The pre-study evaluation is used to guarantee that the participants are apt for the study, excluding any that has a severe level of dementia or cognitive deficit, and to initialise the program to allow for a customised experience.

Serving the post-study evaluation to validate the EV of the solution and assess the impact of the study on the participants.

3.3 Questionnaire

Due to Covid-19, it has become difficult to do any presential activities. To overcome this limitation, a questionnaire is used to obtain feedback on the implementation of the proposed solution.

The participants of this questionnaire are anyone used to the use of computer and online services. This approach might be hard to participate by the target audience, i.e. senior population with AD, that has a low level of technological literacy.

This questionnaire is done online, following a simple set of questions where the participants are be directed to play the game and answer about their experience. The questionnaire must not take more than 30 minutes and has 3 parts:

- **About You** - Demographic questions and knowledge of the activity taught by the game;
- **The Game** - The participant is requested to play the game;
- **About the Game** - Questions to evaluate the participant experience by using a Post-Study System Usability Questionnaire (PSSUQ) Version 3 [43];

The objective of this questionnaire is to obtain metrics on how well the message was delivered, the user experience, improvements for the solution and limitations of this teaching approach.

However, it must be understood that this evaluation method is not fully appropriate for testing the solution that this study purposes. It requires testing with the target audience and with the VR version of the SG, which has more functionalities.

The structure and questions of the questionnaire (See Appendix E) are further explained in Chapter 5.2.

3.3.1 Solution

To make the questionnaire easily available to anyone, the VR solution was adapted to a Point-and-Click solution that could be played on any computer, without an Head Mounted Display.

The solution must be simple and direct the user right to the exercise. After completing the exercise it should close the game. With this in mind, the therapist interfaces was removed, since it requires knowledge of the methodologies used, the intended purpose and of the target audience.

The player interaction is made through the mouse, instead of LeapMotion hand tracking. However, this version will keep the design decisions done for the VR version, keeping the game experience as close as possible to the VR experience.

Some of the limitations of this version are:

- **There is no immersion** - The player is playing on their personal computer and not using the Head Mounted Display;
- **The interaction is different from the intended** - The player interacts with the environment through the mouse instead of LeapMotion:
- **Some adaptations won't be triggered** - The adaptation manager still works in this version, however, since the screen won't move and the virtualized hands won't exist, then the game won't trigger adaptations related to those.

These changes, must not compromise the learning experience, i.e. use the EL method.

4

Methodology

Contents

This chapter will explain present the design and architectural decisions.

The Design section is composed of five sections, each responsible for presenting the design requirements. These are: Exercise; Interaction; Exercise Environment; Preparation Environment; Therapist UI;

The Architecture section contains four sections. Each of these sections define one of the architectural domains, explaining the responsibility and capabilities of the contained components.

4.1 Design

4.1.1 Exercise Design

As stated the chosen exercise is ”Bake a cake” since it is an activity that players can share with their loved ones.

This exercise is divided into two phases (see Fig. 4.1). The first phase, i.e. the introduction phase, is intended to introduce the exercise and the second phase, i.e. the exercise phase is where the player will learn the activity.

Before the exercise starts an introduction to the exercise is given, explaining what player is supposed to do. The player receives an audio and visual prompt saying “Let’s Bake a Cake”, this first instruction is essential to create the stimulus that leads to all the consequent stimuli of the activity. This is followed by a presentation of the ingredients, utensils and appliances necessary for the exercise. The exercise environment shouldn’t contain more than the strictly necessary objects. This phase is intended to create a familiarity with the exercise environment and the activity the player will be doing.

The study uses EL methodology as the main method of teaching the activity since it has already been successfully used in multiple studies showing good performance results and allowing for long retention of the obtained knowledge.

The EL focuses on decreasing the chances of the user doing a mistake by ensuring the user does not have to guess when executing the exercise. In a real-world application of EL, the exercise is divided

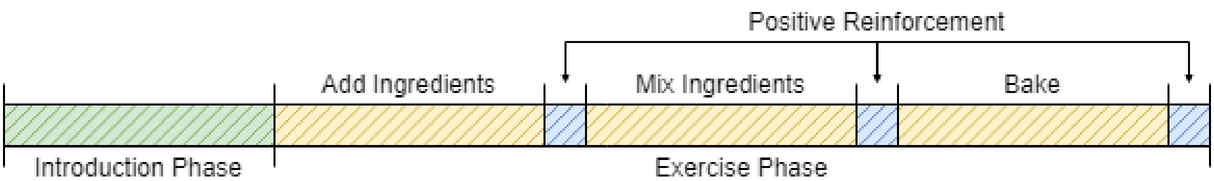

Figure 4.1: The exercise is divided into two phases. The Introduction Phase where the ingredients, utensils and appliance are introduced to create some familiarity with the activity. The Exercise Phase, divided into three distinct parts: Add Ingredients; Mix Ingredients; Bake. Between each part Positive Reinforcement happens, where the player is congratulated for finishing the part and giving some time for him/her to rest before starting the next part.

Figure 4.2: At the start of each step, a text box will appear in front of the player requesting an action. While an audio is played reading the content of the text box.

into steps, which are divided into three distinct phases:

1. **The action** - The therapist directly states the action to be done in this step;
2. **Exemplifies the action** - The therapist shows how the step can be completed;
3. **Execution of the action** - The patient tries to repeat the action. If the patient successfully repeats the action, the therapist gives a positive reinforcement. Otherwise, if the patient can't repeat, the therapist maintains or reinforces the intensity of the exemplification in next session;

Each step having an action associated with it. This action is asked through a textual and audio prompt. This prompt is a phrase explaining the action directly and explicitly. Since the target audience can have a hearing or visual deficit, both the prompts must be present at all steps to ensure the maximum reception possible of the message (see Fig. 4.2).

After this introduction to the step, the action is exemplified. The exemplification happens through hints. These are small changes to the environment and objects to enforce the action of the step. Further explained at Section 4.1.2.

The method of exemplification of the action can change depending on the Spaced Retrieval and Vanishing Cue.

As explained, Spaced Retrieval adds an interval of time between the first phase, i.e. ”The action”, and the second phase, i.e. ”Exemplification of action”. The use of Spaced Retrieval tests the ability of the subject to anticipate exemplification.

In the game, it happens between the step introduction and the exemplification. After the text box is shown the Spaced Retrieval controls when the hint will appear.

Figure 4.3: At the start the hint appears without any change. As the player performance increases the hint starts fading until it is almost unnoticeable.

Level	Intensity	Vanishing Cue	Spaced Retrieval
0	4/4	7	0 sec
1	3/4	7	5 sec
2	2/4	7	10 sec
3	1/4	7	30 sec

Figure 4.4: At the level zero the hint intensity is maxed, meaning that Vanishing Cue and Spaced Retrieval will not happen. As the player progresses, the intensity of the hints decrease until a minimum of one fourth, at level 3.

The Vanishing Cue is used to test the knowledge the player has of the step. As player performance increases, the exemplifications become more faded, since the therapist progressively hide the exemplifications. This technique affects the hints, by fading them depending on the performance of the previous session (see Fig. 4.3).

Both these techniques are structured to increase the required effort the player has to do as his/her performance increases. To ensure a balanced experience as the effort required increases, the game has 4 levels. The player starts at level 0 in every step, and the performance levels are evaluated per step.

Each of the steps define a time interval, for Spaced Retrieval, and a fade ratio, for Vanishing Cue (see Fig. 4.4).

The performance level increases when the player has a good performance, i.e. does not cause a single adaptation for three consecutive runs of the step. The level stops increasing when the player reaches level 3. If the player has a single run with a bad performance the level decreases to the level exactly below, the minimum level is 0.

Even if the performance level increases the player should never have to guess, this means that if he

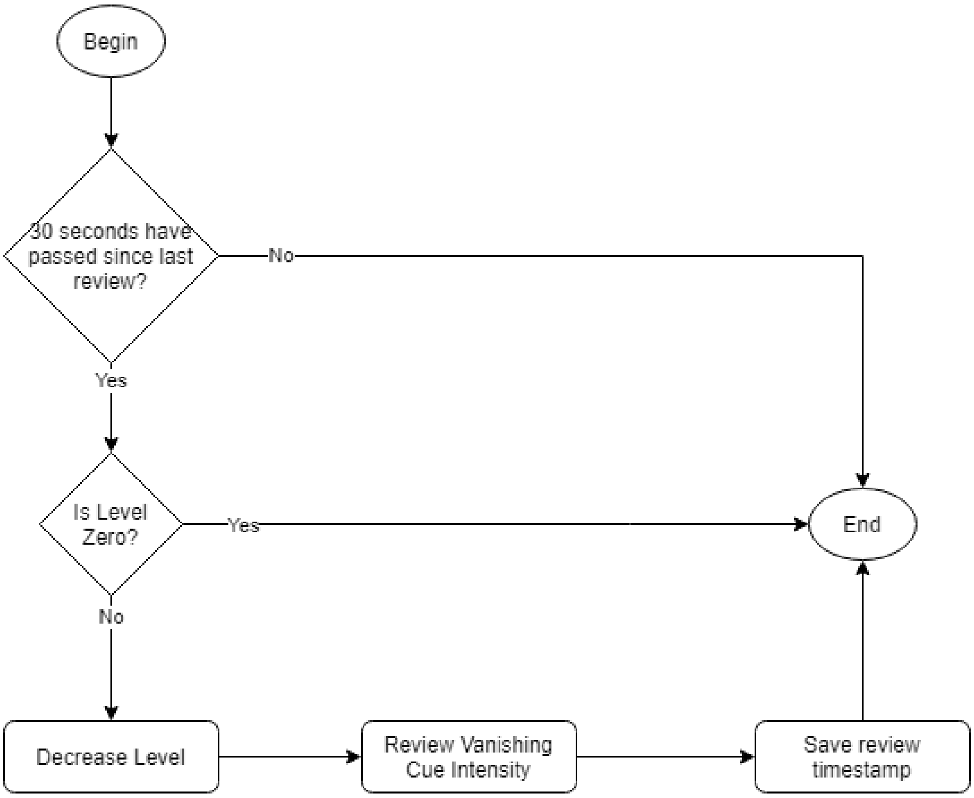

Figure 4.5: Every thirty seconds the game checks if the player is at a level above Zero. If so, the hint level is decreased to the level exactly below. Impacting the intensity of the hint and changing the Vanishing Cue.

forgets or is unable to anticipate the action then the game should still allow him to learn how to do the step. At level 0 the hints are very explicit, but if the player is on a very advanced level, e.g. level 2 or 3, then the hint reviews its intensity decreasing the level every 30 seconds (see Fig. 4.5).

In EL methodology real-world application, the execution phase happens after the therapist has finished exemplifying, if not using Spaced Retrieval, due to physical matters. In the game, this no longer is an obstacle so the player can do the action at the moment the step starts.

Positive reinforcement will happen at the end of each part of the exercise (see Fig. 4.1), which are:

1. **Add Ingredients** - Teaches the player to add all the ingredients with the right amounts, to the big bowl;

2. **Mix Ingredients** - This part instructs the player trough the process of mixing the ingredients;

3. **Bake** - The player is guided through the steps of putting the cake mould in the oven and see the final results;

Additionally to the EL, to strengthen the *in vitro* knowledge the patient must learn how to properly apply it. To reach this level of confidence the three steps of applying knowledge must be exercised.

Figure 4.6: In Block practice the exercise objects always appear in the presented positions. When doing the Random practice the exercise objects will be randomly placed on the balcony, considering the objects already placed.

These steps are:

- **Read** - Where the subject observes the actual state of the environment;
- **Plan** - The subject considers how the environment can be changed;
- **Do** - The subject takes action into the environment;

These three steps can be practised in two different manners, Block and Random practice [1, 5, 6].

Block practice is the aspect of practising the same behaviour, under the same conditions, over and over again, e.g. throwing a basketball to the basket from the same spot. Allowing for great improvements in the ability of "Doing", consequently causing few changes in "Read" and "Plan" since the behaviour is expected and known.

In Random practice the same behaviour is practised over and over again, while always changing the conditions, e.g. throwing a basketball to the basket and then throw the basketball from the spot where the ball falls. This forces the subject to "Read" and "Plan" their new action before the "Do" step allowing for the more complete exercise causing better retention of the newly acquired behaviour.

The exercise can be configured to Block and Random practice. When doing the exercise in Block practice, the starting position of the objects should not change between sessions. While doing Random practice, the starting positions of the objects should always change, given an exercise area (see Fig. 4.6).

Even though EL Methodology is being used errors can still happen, the game must be prepared to adapt upon an error or a clue of an eventual error.

The exercise shouldn't change further than an adaptation to ensure the exercise is clear. For this reason, an adaptation can add hints to make the exercise more explicit or at most reset the step.

4.1.2 Interaction Design

The player interaction with the game is guided by two different types of prompts: guidelines and hints.

A guideline is a simple, clear and direct phrase presented in a text box. This phrase is presented as a visual and audio prompts to state the actions the player must do to complete the step. The guidelines are intended to ensure that the player does not feel lost during the exercise and to create a certain level of human empathy.

The visual prompt is a text box that appears in the middle of the screen, this is intended to ensure the player receives the guidelines and creates an interval of breathing time between steps (see Fig. 4.2).

The audio prompt reads the phrase that is written on the visual prompt. The audio prompt is enforces the visual prompt since it is normal for the target audience to have some hearing impairment.

After the guidelines are presented the exercise enters the exemplification phase which means a set of hints will be added representing the action needed in the current step.

These hints are modifications to the game objects and behaviours, which are simple, intuitive and not intrusive. Their responsibility is to guide the player through the activity. With this in mind, a group of hints have been implemented (see Fig. 4.7):

- **Arrow Point** - An object which points to the objective position. For example, an arrow pointing towards the oven;
- **Audio** - An audio indication that can vary from a simple sound released from an object. For example, a bell sound coming from the oven;
- **Fade** - This hint causes the object to fade out when the player tries to reach it. For example, the selected object fades if the player hands try to reach it;
- **Fixed** - A translucid replica of the object expressing a destination or position. For example, a replica of the cake mould inside the oven to express the need to move the cake mould into the oven;
- **Light** - Turn off the ceiling light except on the desired object. For example, add a light to a bowl;
- **Moving** - A translucid replica of the object expressing a movement. For example, a replica of the oven door doing the opening movement expressing the movement that the door should do to be opened;
- **Outcome** - The use of a talk balloon with an image hovering on an object, representing the expected result, action or contents. For example, a talk balloon above the flour bag with a flour icon enforcing that the flour bag contains flour;

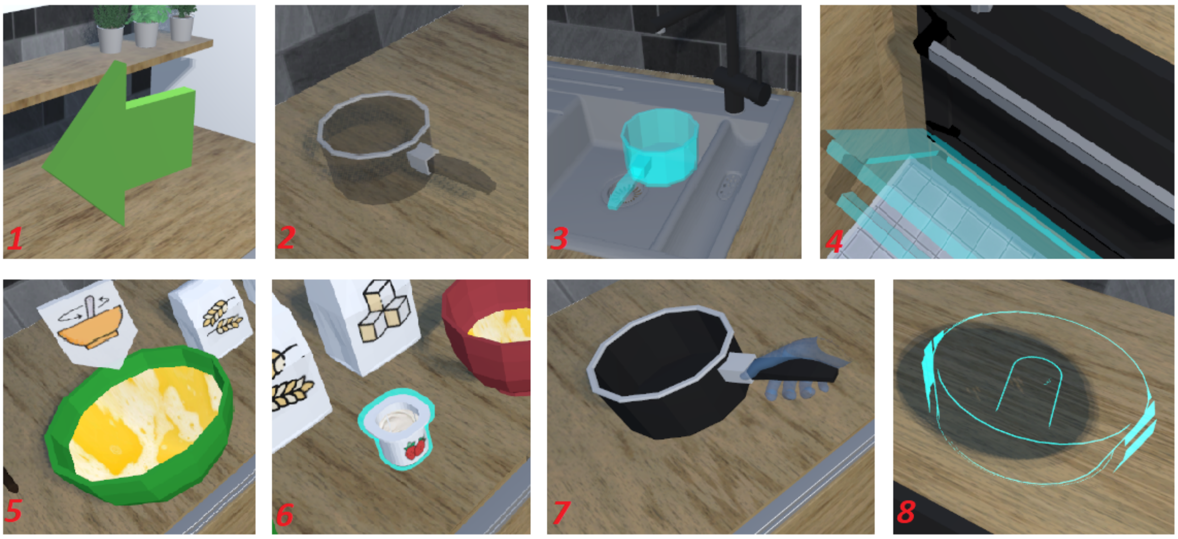

Figure 4.7: The visually perceptible hints, are: (1)Arrow Point Hint; (2) Fade Hint; (3) Fixed Hint; (4) Moving Hint; (5) Outcome Hint; (6) Outline Hint; (7) Shadow Hand Hint; (8) Silhouette Hint;

- **Outline** - The object with this hint is highlighted to suggest that it is expected to be grabbed. For example, an outline in the yoghurt cup to signal it must be grabbed;
- **Shadow Hand** - Shadow hand which does a set of movements to teach the player what behaviour is expected. For example, a shadow hand demonstrating were and how to grab the pan;
- **Silhouette** - Same as Fixed Hint. However, it only contains the wireframe of the object. For example, the silhouette of the mould on the balcony expressing the need to move the mould outside the oven;

When the player shows signs of not being attentive to the exercise or does an error, the game adapts by inserting hints in the game. An example of a necessary adaptation is when the player is not grabbing the exercise object in the current step so the game must enforce this action. The game must insert a hint that clearly shows the player what he needs to do. For example, have an outcome hint with the icon of a hand in grabbing form (see Fig. 4.8).

Since this project is directed to a specific target audience, then the interaction should take into consideration the challenges they have. For example, motor challenges, visual and technological illiteracy.

The adaptations can also be caused by any of these impairments. For example, in case the user is not interacting for a big interval of time then a hint is added, this is considered an adaptation caused by lack of attention.

The interval of time for an adaptation to be triggered changes depending on the player performance and cognitive assessment, going from instant to 30 seconds.

Figure 4.8: At this step, the player is required to grab the yoghurt cup. At the start of the step the object was highlighted by using the **Outline Hint**. Since the player never grabbed the yoghurt cup, then the game adapted the step and added an **Outcome Hint** with the image of a grabbing hand to enforce the action.

It is expected that on the first uses of this SG the AD players will cause many adaptations due to technological illiteracy.

It is also important that the environment is never full of hints at the same time to avoid dividing the attention of the player, so a maximum of 5 hints can be added during a step.

In VR the interaction involves any kind of movement, especially in this case since we track the user hands. To help the user do the movements at ease, it's considered a:

- Small balcony depth - to avoid the player to have to raise his hands;
- Items at a comfortable view angle;

Also, it is expected that the target audience to have any kind of visual impairment so, colours with big contrast are used to ensure the exercise objects are easily distinguishable.

The final version of the game must avoid showing an interface to the patients to maximise the EV, it is expected that the interaction of the user with the objects follows as much as possible the real-world interaction.

4.1.3 Exercise Environment Design

The exercise environment is where the player trains the activity. In this case, since the activity is to bake a "Yoghurt Cake" then the environment is a kitchen.

The player is transferred to this environment when doing the exercise and leave it as soon as the session ends or, if necessary when the therapist ends its.

Figure 4.9: Image of the exercise environment where the “Yoghurt Cake” activity is taught.

The architecture of the space was decided on two different factors, the target audience and space where the EV was planned to be tested. The real-world environment was already “L” shaped and allowed for a setup where items were at hand reach.

The objective of this environment is a space where the players feel at ease to do the exercise, this means that they should recognise that this space represents a kitchen. Since the players during the intervention spend some time in this virtual space then this space must have lots of illumination to maintain a bright environment to give them a sense of comfort.

Also, the orange and yellow colours are used to transpire feelings of happiness, energy and warmth.

No windows were added in front of the balcony where the player will be doing the activity to avoid deviating the attention of the player (see Fig. 4.9).

Enforce a calming training environment by using ambience sound with relaxing components. For example, the sound of a stream, birds or wind.

4.1.4 Preparation Environment Design

This environment has multiple purposes. It is to be used as an environment not related to the exercise environment where the player can be introduced and get used to the VR experience without having the pressure of doing the exercise. It should allow the opportunity of testing the Head Mounted Display and ensure all the components are working properly for the player. This first environment also allows for the therapist to prepare the session for the player.

This environment is intended to be the first and the last he sees when doing a session. It should be used as the environment to transition between real reality and virtual reality. With this in mind, it must

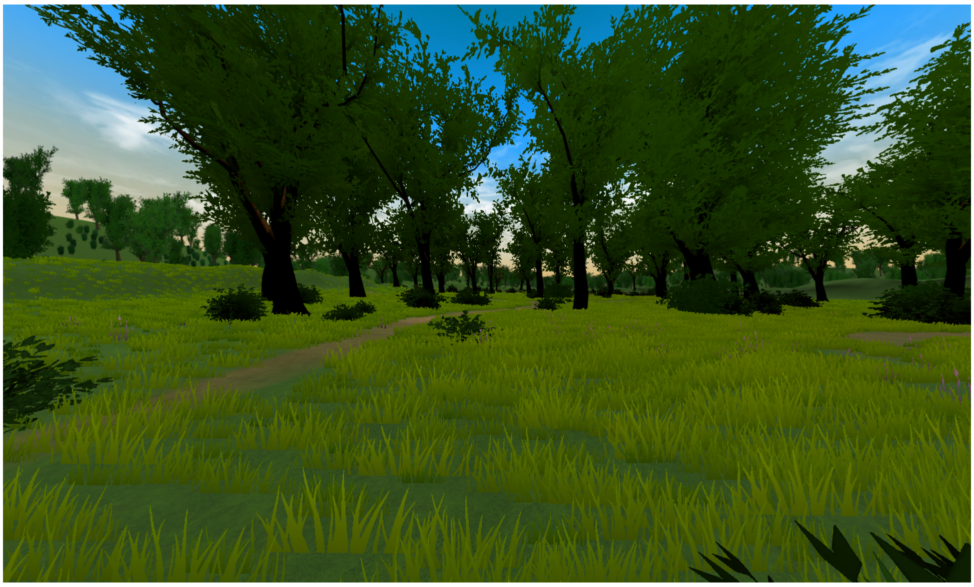

Figure 4.10: Forest environment from the user point of view.

allow the player to feel safe and peaceful when on it so that it can ease the process of removing the player from the immersion caused by the Head Mounted Display.

The preparation environment proposed is a forest or park, in hope that this environment will bring peaceful and calming feelings. So during his stay in this environment, he will see an ample space with some trees and hear nature sounds (see Fig. 4.10).

An ambience sound corresponding to the environment is used. For example, the sound of a stream, birds or wind.

4.1.5 Therapist Interface Design

This game is to be played by multiple players in an intervention managed by therapists. Meaning this game must be able to allow multiple player profiles and deliver an experience customised to the selected player.

As a method to supervise the VR experience the therapist is able to accompany what the player is doing, through the computer screen.

When the game first starts while the player is in the Preparation Environment, the therapist sees an interface allowing him to Create/Manage/Delete players and Start sessions. These interfaces are semi-transparent to allow the therapist to see what the player is doing at all moments (see Fig. 4.11 and Fig. 4.12).

When creating the player profile the therapist is asked an Addenbrooke cognitive assessment score, which represent the cognitive capabilities of the patient for the following five categories:

Figure 4.11: Interface of the therapist sees when creating a player. (1) Button to open the create new player profile menu. (2) Form requesting the player age and Addenbrooke cognitive assessment scores.

- **Attention** - The ability to focus on a given subject. Tested by asking the current date and season, repeat three words and subtractions;
- **Memory** - Ability to recall information. Tested by checking if the patient can recall words from a previous question and retain an address;
- **Fluency** - Ability to give information. Tested by requesting words started by a given letter and to name as many animals as he can;
- **Language** - Dominance of the language. Tested through asking to repeat a set of commands, ability to repeat phrases, name pictures, point to picture depending on description and read words;
- **Visuospatial Memory** - Ability to identify visual and spatial information. Tested by requesting drawings, count dots and recognise partially obscured letters;

The Addenbrooke score goes from 0 to 100. A score of fewer than 83 means abnormal cognitive state. A score between 83 and 87 is inconclusive and requires more testing. And a score greater than 87 means the subject is cognitively healthy.

While in session, i.e. on the exercise environment, the therapist is able to:

- **Reset the step** - If the player got in a situation the game can not recover from;
- **Reset Session** - If the therapist considers necessary;
- **End Session** - If the therapist considers necessary;

These three actions are meant to give some control of the session to the therapist Fig. 4.13.

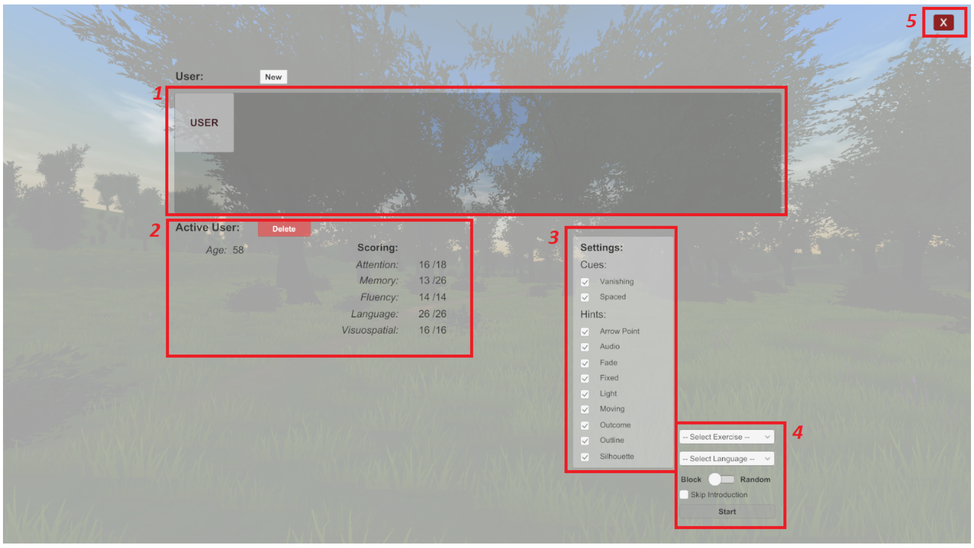

Figure 4.12: Interface that therapists see when managing/deleting and starting a session. (1) Player profile selection. (2) Player profile, button to delete the player. (3) Settings menu, allows the therapist to disable and enable cues and hints of the player. (4) Configure Session Menu and Start Session Button. (5) Button to exit the game.

Figure 4.13: Interface that therapists see while in session, (1) Buttons to Reset Step, Reset Session and End Session.

4.2 Architecture

The architecture of the project is based on previously presented solutions in other SG directed to the same target users as shown in Fig. 4.14.

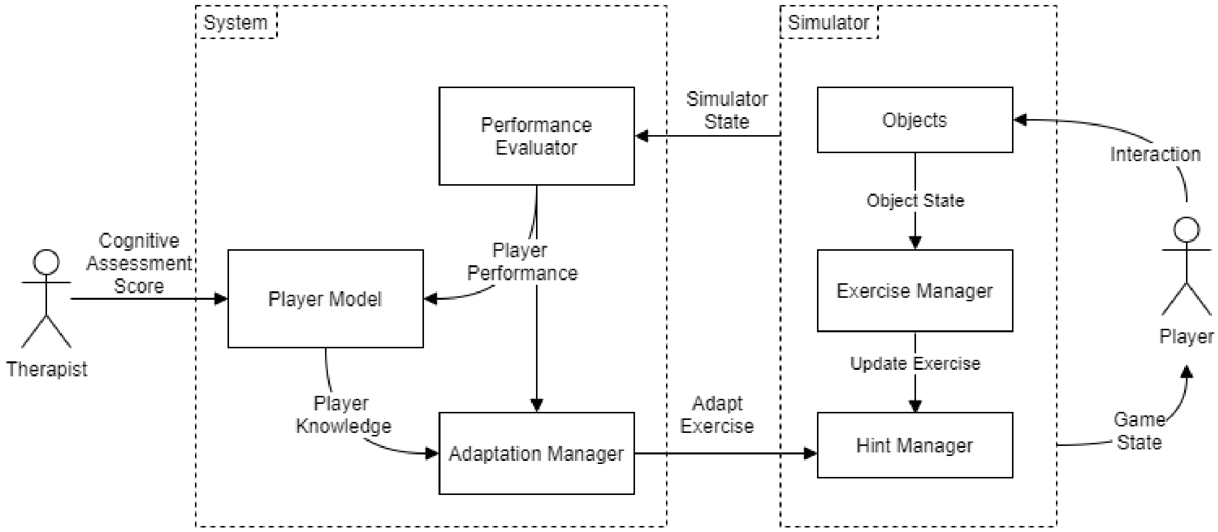

Figure 4.14: Architecture interaction and expected behaviours. The player interacts with the objects in the simulator causing the exercise to progress. Independently of the simulator, the system evaluates the state of the simulator environment and adapts the game, affecting how the player perceives the simulator environment.

The objective of following this methodology is to keep the modularity of the components while guaranteeing that the collected data is used not only to improve the future sessions of the player but also to allow the therapists to have a more in-depth evaluation of the patient capabilities.

The solution is divided into four domains (see Fig. 4.15). The **Simulator**, responsible for the game experience. This simulates the kitchen and the cooking activity. The **System** which is responsible for evaluating the player and generating adaptations to ensure the training experience is adapted to the player capabilities. The **Session**, responsible for managing the sessions and the Player Model data. Finally, the **UI**, responsible for managing the therapist interface.

4.2.1 Simulator Domain

The simulator is composed of two components: Exercise Manager and the Hint Manager. They work together to offer a simple and direct gaming experience.

The simulator uses the guidelines and hints to guide the player through the experience. The player is able of freely interacting with any object in the game. If the player properly follows the hints then the simulator will determine that the step has finished proceeding to a new step which triggers new hints.

When the step starts, the simulator initialises the step which implies requesting the Hint Manager to

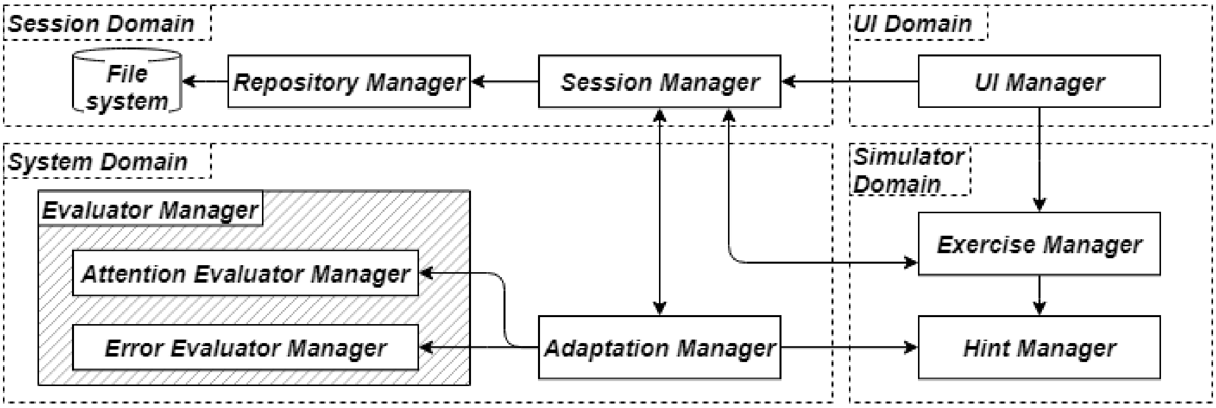

Figure 4.15: Decomposition and Uses architecture model. Defining the four architectural domains of the solution. Additionally, defines the main components of the solution and their allowed interaction.

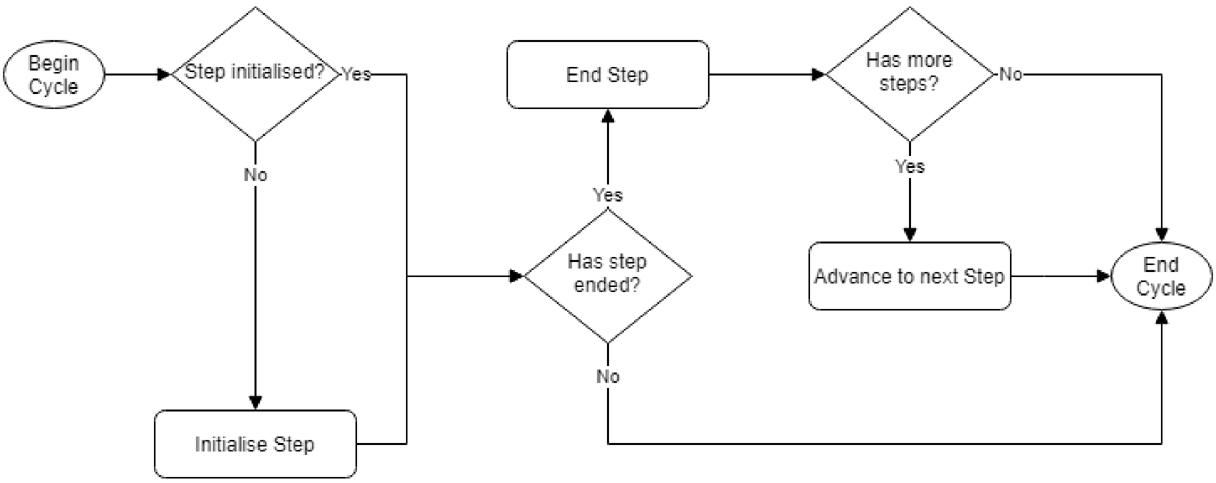

Figure 4.16: At every cycle the Exercise Manager will check if the step has initialised, if not then the initialisation happens. After this, checks if the player has finished the step, the cycle ends if not finished otherwise the step if properly ended and the exercise progresses for the next step if existing.

add the configured hints to the step exercise objects. At every cycle, the simulator asks the step if the player has finished it, upon positive response the hints are cleaned and the current step updated.

When in session, the simulator is responsible for notifying the Session Domain of the end and beginning of each step and the session itself. It is assumed that this component works independently of any other domain.

The Exercise Manager takes initiative in requesting the Hint Manager to add and clean the hints.

4.2.2 System Domain

The system is composed of two components: Evaluator Managers and Adaptation Manager. These components work together to ensure that the player has an experience adapted to the level of his capabilities.

The Evaluator Managers evaluate the changes of states of the simulator to determine the performance score of the player, recognising if he needs hint reinforcement. This evaluation is added to the Player Model and used by the Adaptation Manager to customise the exercise.

The performance is determined by a ratio(R), where $0 \leq R(t, o) \leq 1$ (see Eq. 4.1)

$$R(t, o) = \frac{S(t, o)}{\#o} \tag{4.1}$$

Where t is the fault type being evaluated and o is the set of exercise objects that can be evaluated for t. Finally, the score function(S) returns the number of exercise objects in the set that are affected, i.e. $0 \leq S(t, o) \leq \#o$, by the specified fault type.

This ratio intends to represent how much the player is being affected by a given fault. However, the performance score of the player (see Eq. 4.2) is measured by the ratio, which represents how much the player is causing faults.

$$P(e, t, o) = W(e, t) \cdot R(e, t, o) \tag{4.2}$$

Where W represents the weight value for the given evaluation and fault type. And where e is the type of mistake, this is $error$ or $attention$.

The objective of Evaluator Managers is to collect a set of values from the performance of the player to understand how the experience can be improved.

These are meant to allow the system to know the kind of failures the player is having and what kind of instruction it needs to improve the training sessions. In the case of this study, it allows the ability to apply the EL technique, which requires a prompt adaptation of the exercise upon the presence of a specific failure.

To collect this information the Evaluator Managers will look for attentional mistakes as well as errors by analysing the hands, camera and other information of the environment. Upon the change of the Evaluator Managers, the Adaptation Manager uses this information to request more hints, if necessary.

The saved metrics are discriminated by step and session. Having for each type the maximum weight reached, the weight at the end of the step, the maximum weight attainable and the number of adaptation tries. The metrics evaluated are:

- Line of sight with exercise objects;
- Trying to Reach non-exercise objects;
- Grab wrong exercise objects;
- Release exercise objects that are the focus of the step;
- The duration of the player in the step;

The Adaptation Manager has the duty of adapting the session by assessing the Player's Performance to decide the level of the player on each step.

Cue enforcement is decided based on the number of adaptations that happened in the past three completions of the given step of the exercise. This means that if the player was able to avoid adaptations for three sequential sessions then his level increases which lead to less intensive cueing.

4.2.3 Session Domain

The Session domain contains 2 Managers such as the Session Manager and the Repository Manager.

The Session Manager is responsible for managing the sessions, the Player Model and the player settings, i.e. active and inactive cues and hints. Also, creating an interface for other managers to access and manage the player.

The Repository Manager responsibility is to work as a communicator between the File System and the Session Manager. Being used to obtain/save/delete any game data that requires consistency between game sessions.

The Player Model is created by the Therapist, with the Addenbrooke cognitive assessment scores of the player, and further complemented by the player's experience, i.e. decisions, mistakes, accomplishments and performance scores. This data will affect the cueing of the hints by changing their behaviour and/or look. These behavioural changes of the hint are meant to enforce the learning mechanism, by using a Vanishing Cue and Spaced Retrieval.

The Addenbrooke cognitive assessment scores is used by Evaluator Managers to set the weights for the session. Helping define how much each type of failure should weight for different players and at different sessions.

4.2.4 UI Domain

The UI Domain only contains one manager called UI Manager.

This manager is responsible for managing all the interfaces the therapist sees. For example, when the therapist requests to restart the step, the button calls the UI Manager which then requests the restart step method from the Exercise Manager.

5

Implementation

Contents

In this chapter, we will approach the actual implementation of the solution, by explaining the integration of the managers.

Lastly, we will explain how the questionnaire was prepared. This is, the decisions made for the questionnaire and the changes made to the solution to allow a better experience when answering a questionnaire.

5.1 Solution

5.1.1 Managers

This section of the document describes the responsibilities of each manager. Also gives an overview of the integration, explaining some of the most important decisions.

5.1.1.A Adaptation Manager

The Adaptation Manager is responsible to ensure that the experience of the game is adapted to the player. These adaptations are done by using multiple metrics, such as previous player performance and current performance.

Since the game gets more challenging session by session, the objective of this Manager is to help the player complete the activity, through hints that enforce the action needed to complete the current step.

To do so two different types of adaptations were implemented: Active and Step.

Active adaptation happens by requesting new hints to Hint Manager to ensure the player can finish the exercise. To know when to request these hints the Adaptation Manager uses the metrics at the Error Evaluator Manager and Attention Evaluator Manager.

These adaptations are tested every cycle and happen when, for a given category, the Evaluator Manager has a *CurrentWeight* greater or equal to *TriggerWeight*. When the Adaptation Manager notices this threshold has been reached one or more hints are requested to the Hint Manager. This Manager also requests the Hint Manager to remove the hint when the Evaluator Manager marks the hint to be removed and the *CurrentWeight* is less than *TriggerWeight* (see Fig. 5.1).

For each case a set of hints have been defined as a reaction to any of the evaluated cases, this means that a set of generic hints have been implemented so that they can be used in any situation. The existing generic hints are:

- **Audio hint** - Configured with a bell sound;
- **Fade Hint** - The object fades if the hands get close to the exercise object;

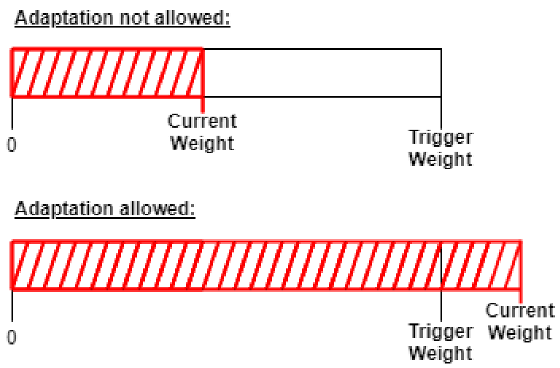

Figure 5.1: Active Adaptation. When *CurrentWeight* is bigger than *TriggerWeight* then the Adaptation Manager requests a new hint to the Hint Manager.

- **Grab Hint** - This is a *Outcome Hint* configured with the image of a hand grabbing;
- **Light Hint** - The specified object starts shining;
- **Outline Hint** - An outline is created around all the object;
- **Arrow Point Hint** - An arrow is created in front of the player. This arrow points to a destination or object;

For the Error adaptations, when:

- The player releases the current step exercise object - **Grab Hint** requested on the exercise object;
- The player is still holding an exercise object from a different step - **Outline Hint** requested on the exercise objects of the current step;
- The player has exceeded the duration of the step - **Light Hint** requested on the exercise objects of the current step;

For the Attention adaptation, when:

- The player is not grabbing the current step exercise object - **Grab Hint** requested on the exercise object;
- The exercise objects of the current step are not in the line of sight - **Audio Hint** and **Point Hint** requested on the exercise object;
- The player is trying to reach an exercise object from a different step - **Fade Hint** requested on every exercise object that is not used in the current step. This hint is only removed when the step ends;

Step Adaptation sets the cueing level (see chapter 5.1.1.D) of the Hint Manager for the current step of the exercise;

This adaptation happens by request of the Exercise manager if this manager is active.

After three completions of a specific step, the Adaptation Manager tests if the cue level can be increased. The level increases, until a maximum of three, if the player has completed the step three times in a row without causing any adaptation. However, if the player causes at least one adaptation the level decreases, until a minimum of zero.

These adaptations are discriminated by step, this means that a player must complete a given step at least three times, before the Adaptation Manager validates it. Consequently, the player might be on different levels at different steps. The expected result is to have more explicit hints at steps with lower levels and less explicit as the player increases level.

5.1.1.B Evaluator Managers

The Evaluator Managers are responsible to evaluate the environment to understand the player behaviours that represent mistakes.

Their objective is to translate their observations into measurements that allow the Adaptation Manager to make decisions.

The evaluators defines two weights for each category:

- ***CurrentWeight*** - This weight has a minimum of zero, and increases when the evaluator observes a mistake. This Weight stops increasing when it reaches the double of the *TriggerWeight*;

- ***TriggerWeight*** - This weight represents the required *Current Weight* for an adaptation to occur. This is, the greater this weight the harder is for the adaptation to happen;

The *TriggerWeight* is decided when the session starts. This weight is the result of the sum of two weights: *ScoreWeight* and *BaseWeight*.

ScoreWeight results from the AddenBrooke cognitive assessment score. For each evaluated category different cognitive processes are used (see Fig. 5.2). This is, for each category only a subset of cognitive assessment score should be considered. This results in having greater *ScoreWeight* when the player has good cognitive scores,i.e. the healthier the player the greater the *ScoreWeight*.

This final *ScoreWeight*, $W_{score}(\gamma)$, results from the multiplication of the base *ScoreWeight* with sum the of the scores divided by the maximum allowed scores that apply to that category (see Eq. 5.1).

$$W_{score}(\gamma) = ScoreWeight \cdot \frac{\sum_t^{\gamma} S(t)}{\sum_t^{\gamma} max(t)} \tag{5.1}$$

Where γ is the set of AddenBrooke scores that apply to the Weight being calculated.

BaseWeight is the weight resulting from the performance of the player in the previous sessions. The *BaseWeight* is static for the first 3 sessions.

After the first 3 sessions, if the median weight of all the completions of the given step is above the sum of the *BaseWeight* with the *Score Weight* then the *BaseWeight* is doubled. By doubling the *BaseWeight* the *Active Adaptations* happen less resulting in less help to the player.

If less then the *BaseWeight* is halved. Resulting in more *Active Adaptations*, since hints are given quicker.

The *TriggerWeight*, $W_{Trigger}(\gamma)$, is defined by the following equation:

$$\begin{cases} W_{Trigger}(\gamma) = 2 \cdot BaseWeight + W_{score}(\gamma) & \text{if } x < BaseWeight + W_{score}(\gamma) \\ W_{Trigger}(\gamma) = \frac{BaseWeight}{2} + W_{score}(\gamma) & \text{if } x > BaseWeight + W_{score}(\gamma) \\ W_{Trigger}(\gamma) = BaseWeight + W_{score}(\gamma) & \text{if } x = BaseWeight + W_{score}(\gamma) \end{cases} \quad (5.2)$$

The *TriggerWeight* can have a value between 50 and 300. This minimum *TriggerWeight* is obtained if the player makes bad performances, and his cognitive assessment score is zero. The maximum weight happens when the player is doing good performances, and his cognitive assessment scores are the maximum. The increments and decrements are 10. This is intended to have a controlled increase and decrease of the *CurrentWeight* (see Fig. 5.3) [44, 45].

The Evaluator Manager over time evaluates the environment for every category. Obtaining the resulting score and increasing or decreasing the *CurrentWeight* (see Fig. 5.4).

When a step ends the data is saved in the Player Model and all the weights are reset to zero.

5.1.1.C Exercise Manager

The Exercise Manager is responsible for managing the game loop. It is responsible to check if the player has finished the step and advance to the new one, iterating the steps until there are no more steps to be done.

When initialising the exercise environment, the manager puts on the balcony the needed exercise objects for the exercise based on the practise method. To do so the exercise manager gets all the

		Addenbrooke Scoring				
		Attention(18)	Memory(26)	Fluency(14)	Language(26)	Visuospatial(16)
Attention	Not Grab Exercise Object	x	x			x
	Reach Wrong Object	x				x
	Line of Sight with exercise objects	x				x
Error	Grab Wrong Object	x				
	Release Exercise Object	x				
	Step Duration		x		x	

Figure 5.2: How the trigger weight is decided. For example, for the Attention "Not Grab Exercise Object" category the game uses the Attention, Memory and Visuospatial scores to calculate the score.

distinct exercise objects used by every step and activates them for the exercise.

The manager places the exercise objects based on the practice method, this is:

- **Block** - The objects are displayed as configured by the developer.
- **Random** - The objects' positions are randomly placed inside a configured area. This causes the objects to have different positions every time the exercise is initialised.

After initializing the exercise environment the manager starts the exercise from the first step associated with the exercise.

A Step is an entity stating one of the actions of the exercise. To do so it defines:

- **Skippable** - Mark the step as skippable. A step only skips if the Therapist chooses the setting when starting the session;
- **Repeatable** - Mark the step as repeatable. If this flag is not active the exercise manager won't repeat the step;
- **Previous Step** - The step that precedes the current step. This property is null if it is the first step;
- **Next Step** - The step that succeeds the current step. This property is null if it is the last step;
- **Exercise Objects** - The list of exercise objects used in the current step.
  - **Hints** - For each exercise object the hints that should be attributed during this step;
  - **Focus** - If the exercise object is the focus during the step. This property is used by the Evaluator Managers;
  - **Grab** - If the exercise object must be grabbed during this step. This property is used by the Evaluator Managers;
- **Exercise Objects State** - Contains the Position, Rotation and contained liquid amount at the start of the step. This allows the exercise manager to reset the step;

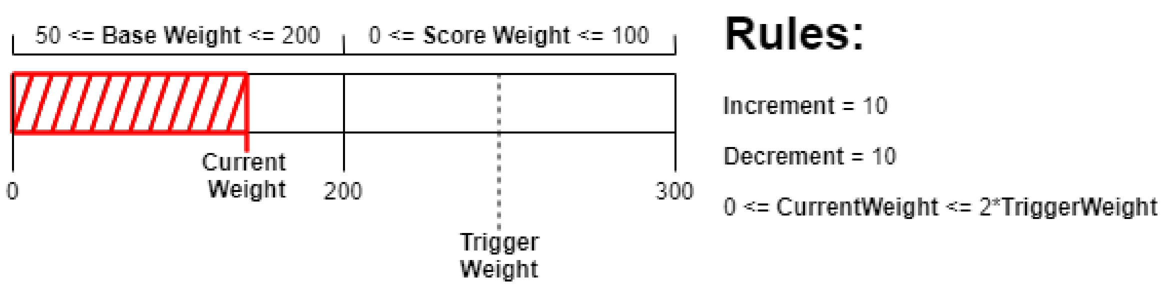

Figure 5.3: The weights ranges. The *TriggerWeight* is the sum of the *BaseWeight* with *ScoreWeight*. Base Weight varies from 50 to 200. The Score Weight varies from 0 to 100. The *CurrentWeight* has increases and decreases of 10. The *CurrentWeight* has a minimum of 0 and a maximum of the double of the *TriggerWeight*

		Trigger Method	Duration	Causes Step to Restart?
Attention	Not Grab Exercise Object	Overtime	Until Corrected	No
	Reach Wrong Object	Instant	Until Step Completion	No
	Line of Sight with exercise objects	Overtime	Until Corrected	No
Error	Grab Wrong Object	Overtime	Until Corrected	Yes
	Release Exercise Object	Overtime	Until Corrected	Yes
	Step Duration	Overtime	Until Step Completion	Yes

Figure 5.4: The trigger method, duration and which cause a restart of the step discriminated by category. For example, for Error ”Grab Wrong Object” category the adaptation is triggered based on the time the player is grabbing the wrong object. The adaptation hint is removed when the player corrects the behaviour. If the player triggers this adaptation then the step is restarted, unless the player already restarted the step too many times.

- **Guideline** - The audio and text content of the guideline. This info can be translated into English or Portuguese;
- **Initialised** - How the step is initialised; The Exercise Objects State is saved at this moment;
- **HasFinished** - The rule that validates that the player has finished the step;
- **End** - How the step should be ended.

For the implemented exercise seven different steps have been implemented:

- **Add** - This step defines the action of transferring a liquid from one container to another;
- **Grab** - This step defines the action of grabbing an object;
- **Mix Ingredients** - This step defines the action of mixing the ingredients;
- **Move** - This step defines the action of moving an object to a specific rotation or position;
- **Wait** - This step defines an interval of time. The step automatically ends after the defined interval of time passes;
  - **Change** - This step defines a **Wait Step** that also requires a change to happen in the environment/object;
  - **Visual** - This step defines a **Wait Step** that also makes an object follow a path. For example, show the player the wooden spoon mixing the ingredients;

When the exercise manager has a *CurrentStep*, the manager iterates until it completes the last step. With this in mind the manager cycles and applies the following steps:

1. **Initialise step** - Initialise the step;
2. **Show Guidelines** - Show the guideline to the player;

3. **Clean Guidelines** - Clean the guidelines when the player instructions end; The hints are only added right after this point;
4. **Finish the Step** - When the player has done the action of the step he progresses to the next step, unless Adaptation Manager states he should repeat the step;

The Exercise Manager only has a mandatory dependency, the Hint Manager. The Session Manager and Adaptation Manager are optional, meaning the game can be played without these two managers.

5.1.1.D Hint Manager

The Hint Manager is responsible to attribute to a specified object a specified hint.

When requested a hint on an object the manager tries to add the hint. The Hint Manager only adds a hint if the maximum number of hints have not been reached, this is to ensure the exercise environment is not full of hints triggering the attention of the player, and if the hint is allowed by the therapist, by ensuring the hint is enabled in the Player Model. All hints are allowed by default.

If available, the Adaptation Manager configures in the Hint Manager the Cue Level, which every hint is configured with. This effects can vary depending on the hint type.

As levels increase, the intensity lowers, meaning that at level three the player does not see clearly or hear any hints, causing the effect of Vanishing Cue. For example, when attributed the Cue Level One the Outline hint has it's outline fade to 3/4 of the maximum transparency while the Audio Hint has its audio reduced to 3/4 of the defined volume.

However, as levels increase the wait interval, i.e. the interval of time between the moment hints are requested and initialised, increase, provoking the effect of Spaced Retrieval. On lower levels, the player has to wait for little to no time and on advanced levels to wait for bigger intervals provoking the player to anticipate the hint.

As the player progresses levels, there might be a moment where the player reaches a level where the Vanishing Cue caused the hint to not be explicit enough for him to know what to do. For example, at level 3 the intensity is 1/4 which might be practically invisible. To help the player not get stuck because he can't recall the action the hint reduces level every 30 seconds, this number is static and based on the maximum wait interval of the Spaced Retrieval.

An hint has the ability to:

- **Initialise** - This initialisation is done by the hint component itself;
- **Clean** - Used when releasing the hint from the object;
- **Configure Cue** - Configures the Vanishing Cue and Spaced Retrieval. The cues are only configured if active at the player settings. By default the Cue Level is kept at Zero;
- **Review** - Called by the hint itself. This method reviews the Cue Level, decreasing if necessary;

5.1.1.E Repository Manager

This manager creates a layer of abstraction for communications with the file system. It is responsible for saving/loading/deleting the game data.

It saves the information in JSON data files.

At the current moment, the only entity saved by the Repository Manager is the Player Model which is composed by:

- Alias;
- Color;
- Age;
- Settings - configurations of usable hints and cues during exercise;
- Scoring - Addenbrooke scoring to allow adaptation to user capabilities;
- Sessions - Recording of the sessions;

The Session information contains all the data of all the sessions the player has started. This is:

- Session Number;
- Exercise Type;
- Practice Type;
- Guidelines Language;
- If introduction was skipped;
- Maximum hints allowed during this session;
- Max Hints - Number hints usable during any step;
- Steps - Recording of the steps;
- Start and End Date;

The saved steps data include:

- Identifier;
- Name;
- Cue Level - Cue Level used during this execution of the step;
- Amount of adaptations;
- Attention Statistics - *CurrentWeight* and *TriggerWeight* at the end of the step;
- Error Statistics - *CurrentWeight* and *TriggerWeight* at the end of the step;

- Exercise Objects - The position, rotation and liquid amount of the objects to allow restarting the step;
- Start and End Date;

5.1.1.F Session Manager

The session manager is responsible for managing the game data as well as the execution of the session.

This manager makes available to every other manager the following data:

- Exercise;
- Practice Type;
- Language of the guidelines;
- The Player data, which includes the current session and current step data.

Also it gives access to the UI Manager the ability to:

- Add/Load/Delete player;
- Set/Load Player Settings;
- Start/End Session;
- Reload Step;

5.1.1.G UI Manager

This manager allows the therapist to interact with the system of the solution giving him an interface to manage the player and the sessions.

The therapist is able to add a new player through the interface which require the therapist to previously do Addenbrooke cognitive assessment [46] to the patient. The fields related to the cognitive assessment is:

- Attention - Value between 0 and 18;
- Memory - Value between 0 and 26;
- Fluency - Value between 0 and 14;
- Language - Value between 0 and 26;
- Visuospatial - Value between 0 and 16;

The therapist can manage the player settings defining which of the hints and cues can be available during sessions. These changes are limited to the therapist since they have an impact on the results of the intervention.

The interface allows the therapist to start a session by configuring:

- The player profile;
- Exercise;
- Language - Default language is English;
- Practice Type - Default method is Block;
- Skip Introduction - Default to false;

During the session the therapist is able to *Restart a step*, *Restart the session* and *End the session*.

5.2 Questionnaire

This questionnaire intends to understand the quality of the experience delivered. The questions are intended to understand how the participant perceives this kind of experience and allow us to comprehend the main points that require improvement or a new approach.

The questionnaire is divided into three sections (See Appendix E). The first section to obtain data about the participant, their ability to do tasks related to the exercise of the game. In the case of this study, it involves the player cooking abilities and their knowledge of the kitchen. The questions are:

- Age;
- Email - Optional;
- How often do you cook?
- How complex are the meals you cook?
- How do you characterise your cooking skills?
- How do you evaluate your ability to follow recipes while cooking?
- How comfortable do you feel using any kitchen utensil?
- How comfortable do you feel using the oven?

The second section is intended for the participant to download and play the game. After the participant completes the game he continues to the third section. Where the participant has to fill a Post-Study System Usability Questionnaire (PSSUQ) Version 3 [43] which is intended to perceive their satisfaction with the solution.

The PSSUQ was chosen based on the questions it integrates, the variety of studies that use it. Since this questionnaire was used in many studies there is a good fidelity over the results.

The questionnaire is composed of sixteen Likert scale questions, where the participant chooses from 1(Strongly Agree) to 7(Strongly Disagree) and NA(Not Applicable). The questions are:

- Overall, I am satisfied with how easy it is to use this system.
- It was simple to use this system.
- I was able to complete the tasks and scenarios quickly using this system.
- I felt comfortable using this system.
- It was easy to learn to use this system.
- I believe I could become productive quickly using this system.
- The system gave error messages that clearly told me how to fix problems.
- Whenever I made a mistake using the system, I could recover easily and quickly.
- The information (such as online help, on-screen messages, and other documentation) provided with this system was clear.
- It was easy to find the information I needed.
- The information was effective in helping me complete the tasks and scenarios.
- The organization of information on the system screens was clear.
- The interface of this system was pleasant.
- I liked using the interface of this system.
- This system has all the functions and capabilities I expect it to have.
- Overall, I am satisfied with this system.

This questionnaire evaluates four metrics, which are:

- **Overall** - The average scores of questions 1 to 16;
- **System Usefulness (SYSUSE)** - The perceived utility of the system - The average scores of questions 1 to 6;
- **Information Quality (INFOQUAL)** - The quality of the information and how it is delivered - The average scores of questions 7 to 12;
- **Interface Quality (INTERQUAL)** - The satisfaction of the participant when interacting with the interface - The average scores of questions 13 to 15;

5.2.1 Solution

Since the game is used to answer the questionnaire and be played on a computer with a mouse then the SG was adapted for this new interaction method.

To keep the focus of the player in completing the questionnaire, the experience should not put questions the player can't answer. With this, the access to the therapist interface was removed, with it the

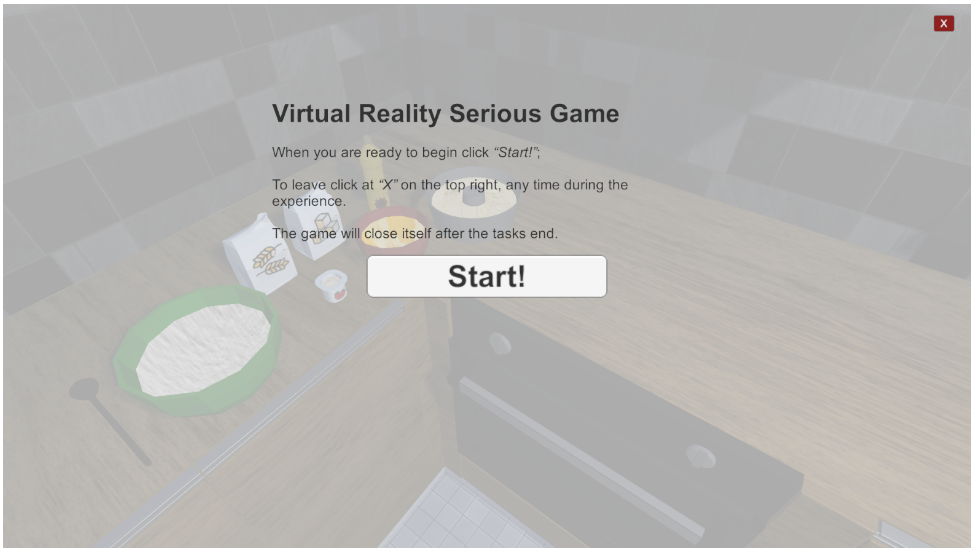

Figure 5.5: The interface of the game explaining how to start and close the solution. This interface exists only in the version used in the questionnaire.

ability to configure a new player profile which requires an Addenbrooke cognitive assessment score. The game is still able to adapt, but multiple game sessions won't cause the Cue Level to change or adaptation based on the player performance.

When the player starts the game he is already at the kitchen with an interface giving some basic instructions and waiting for the player to start the game session (see Fig. 5.5).

In this version of the solution, the player won't be using an Head Mounted Display, which means he won't be able to move his head to see the contents of the containers. The camera is static and above in an angle, that allows the player to see the whole exercise environment and the changes he is making to the environment.

The player won't be using the LeapMotion the interaction method has changed to a single click to do an action. Every step has, if necessary, a click behaviour that does the action of the step. The behaviours associated with each step are:

- **Add** - By clicking on the object the contents are transferred;
- **Grab** - The clicked object is grabbed;
- **Mix Ingredients** - The ingredients are mixed when the player clicks on the object that has all the ingredients;
- **Move** - When clicking on the object that must be moved or on the hint that is indicating the destination of the object;
- **Wait** - No click behaviour;
  - **Change** - No click behaviour;

Figure 5.6: Game showing the behavior of mixing the ingredients. By moving the wooden spoon inside the bowl that has all the ingredients.

– **Visual** - No click behaviour;

When the player clicks on an object that is not part of the step, or not the object of the action, the click action assumes the player is trying to grab. When grabbed, the objects rises above the balcony to visually show that the player is grabbing the object.

However, some behaviours won't be made by the player such as mixing the ingredients, so a step (Visual Step) has been created where the game shows to the player what the real action is (see Fig. 5.6).

The last step of the exercise, the Visual Step is used to put the cake in front of the screen so the player can properly see the result. This allows the player to contemplate his achievement.

After this, it's given an interval of time before the game quits, so the player can continue the questionnaire.

6

Evaluation

Contents

The study was evaluated using a questionnaire published shared online through Google Form. The participants fill this questionnaire on their personal computer, including playing the game.

6.1 Participant

This questionnaire was completed by 50 different participants, ranging from the ages of 17 to 33 (see Fig. 6.1).

The majority of participants age range from 25 and 27, representing more than 50% of the participants.

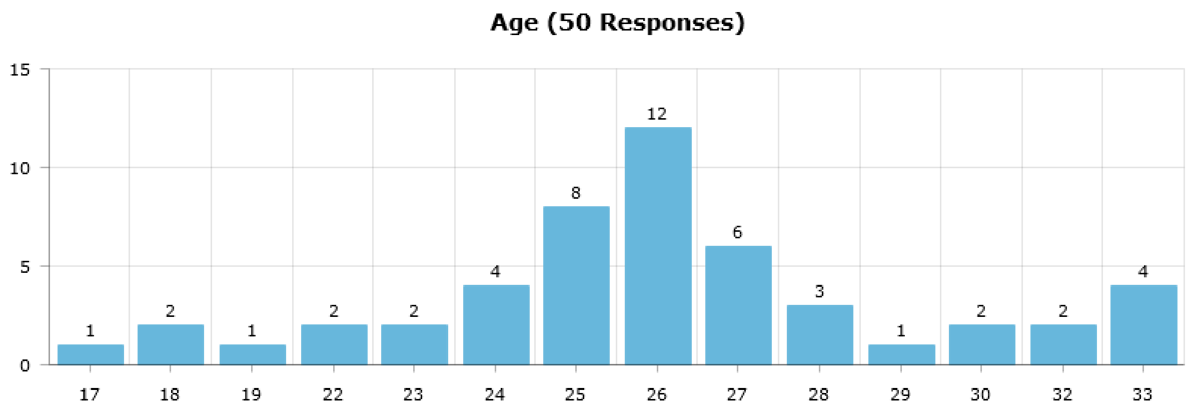

Figure 6.1: Range of ages of the participants

To understand their cooking skills the participants were questioned about their cooking habits, which showed that 62% of them cook daily (see Fig. 6.2). Even though some 14% of the participants don't cook very often, every participant was able to complete the exercise.

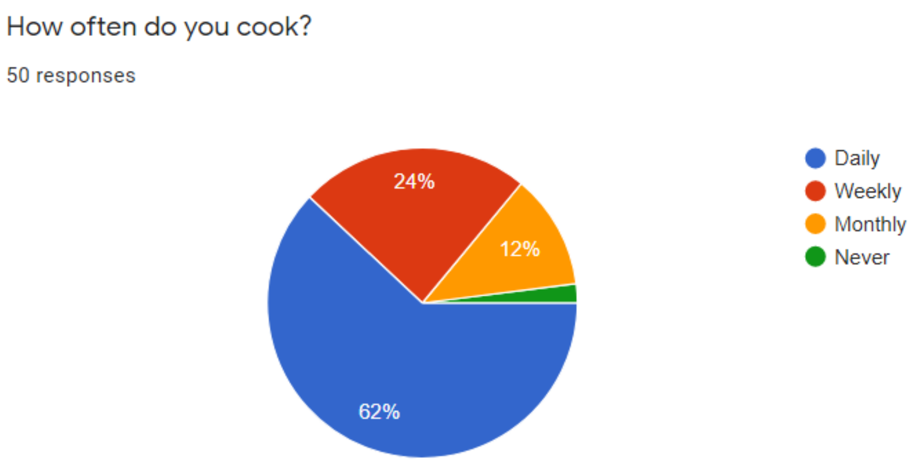

Figure 6.2: Cooking habits of the participants

Figure 6.3: Participants confidence in their cooking skills. Where 1 means ”Very Bad” and 7 ”Very Good”.

In general, the majority of the participants feel comfortable with their cooking skills (see Fig. 6.3).

On questions related to the skills and knowledge necessary to complete the exercise of the game, the majority of the participants showed confidence in their skills (see Fig. 6.4, Fig. 6.5 and Fig. 6.6).

Figure 6.4: Participants ability to follow recipes. Where 1 means ”Very Bad” and 7 ”Very Good”.

6.2 PSSUQ

In general the scores of the PSSUQ questionnaire were positive but demonstrate that more work is still necessary to create an experience that is intuitive and simple (see Fig. 6.7). The achieved scores were:

- **Overall** - Average is 1.90 out of 7;
- **SYSUSE** - Average is 1.64 out of 7;
- **INFOQUAL** - Average is 1.94 out of 7;
- **INTERQUAL** - Average is 2.33 out of 7;

The SYSUSE score is 1.64 out of 7, meaning that healthy population finds the system useful (see Fig. 6.8).

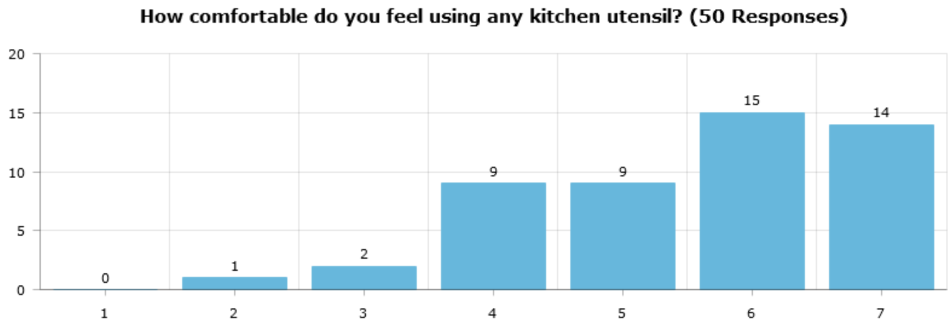

Figure 6.5: Participants comfort with the kitchen utensils. Where 1 means ”Strongly Discomfortable” and 7 ”Strongly Comfortable”.

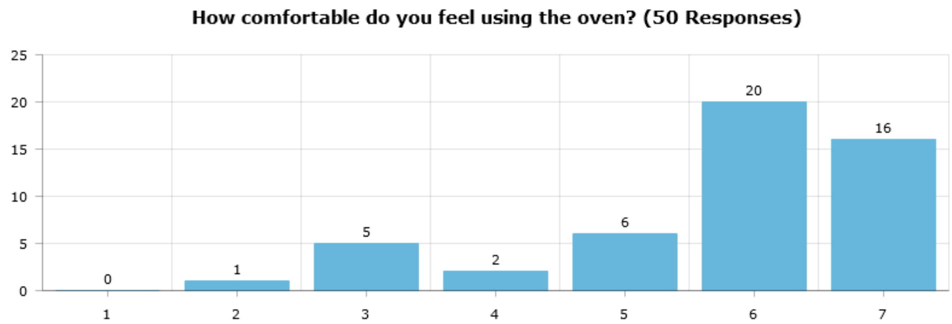

Figure 6.6: Participants comfort using the oven. Where 1 means ”Strongly Discomfortable” and 7 ”Strongly Comfortable”.

In the case of the sixth question,the participants are asked if they could be productive with this solution. The participants were divided resulting in an average score of 2.08 out of 7. This result might be due to the participants' age and cognitive health which might feel the game develops slowly due to having to wait for the guidelines every step.

The INFOQUAL score demonstrates that the solution has some problems delivering the information to the player (see Fig. 6.9).

On the seventh question, the participants are asked if the system gave them an error stating how to properly fix it. This score, 3.34 out of 7, can have multiple reasons, such as the interpretation of the question was not explicit in the context or the adaptation wasn't explicit enough for the player to know how to fix the action. Having 18 participants answer NA is positive since it is not intended for the game to explicitly point any error. Making the errors explicit can make the experience stressful for the target audience and make them give up or feel demotivated to continue the exercise. However, since the obtained score in this category is so high it means this subject requires further investigation.

Looking at the eighth question, where the score was 1.87 out of 7, the participants were asked if when they made a mistake they could recover quickly. The majority of the cases felt they could recover with ease except for some few participants. Also, 12 of the 50 participants voted NA meaning that they

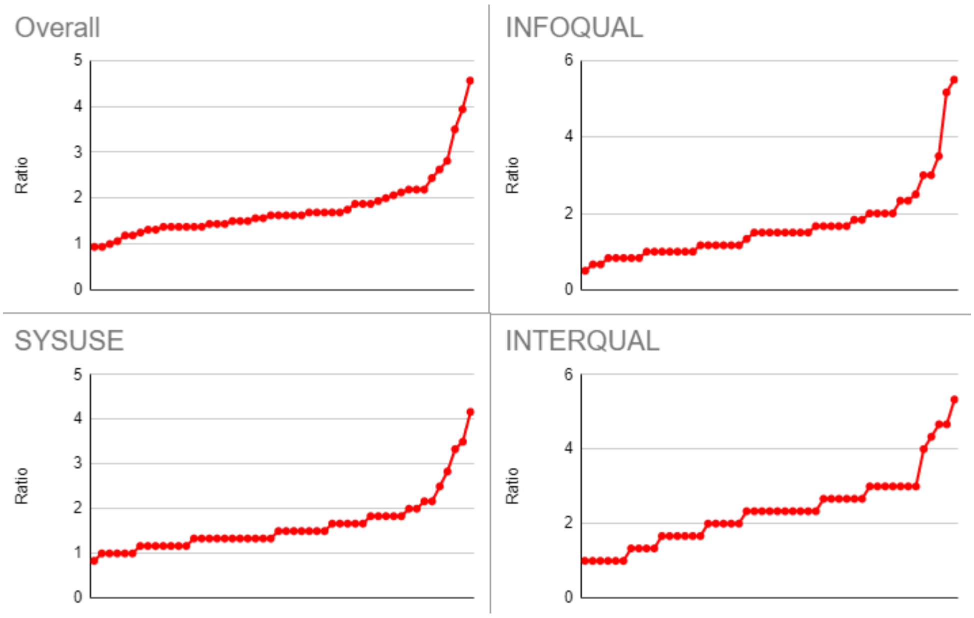

Figure 6.7: Scores of the participants.

didn't do or perceive any mistake.

The obtained INTERQUAL score means that the solution interface should suffer improvements. However, this score is comprehensible since the game was adapted from VR to computer-based while the mechanics were kept as close as possible to the original (see Fig. 6.10). This resulted in mechanics that are not very intuitive for a computer game.

The thirteenth question with a score of 2.52 out of 7 where the participants were questioned if the interface was pleasant.

At question fourteen where the participants are asked if they liked using the interface, the score is 2.22 out of 7.

On the fifteenth question, the question is intended to understand if the participants felt the solution had all the functions and capabilities they expected. The achieved score was 2.24 out of 7.

Even though the three scores of the INTERQUAL category were positive and close to the minimum, it is notable that the number of participants that voted higher scores increased. Since it is expected that the target audience has a lower technology literacy, then they have more difficulties understanding the interface of the game. However, the intended VR solution uses LeapMotion to virtualise the hands and offer a more natural interaction. Also, the use of the Head Mounted Display impacts the perspective the player has of the environment.

Lastly, when asked their overall satisfaction with the solution the participants gave a positive score of 2 out of 7 (see Fig. 6.11).

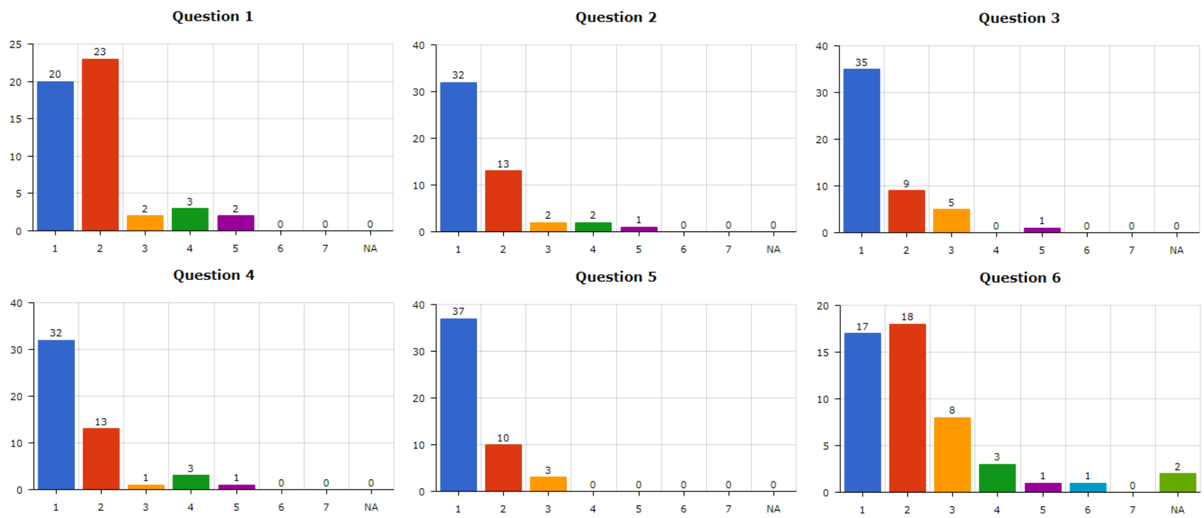

Figure 6.8: SYSUSE scores of the participants from Question 1 to Question 6.

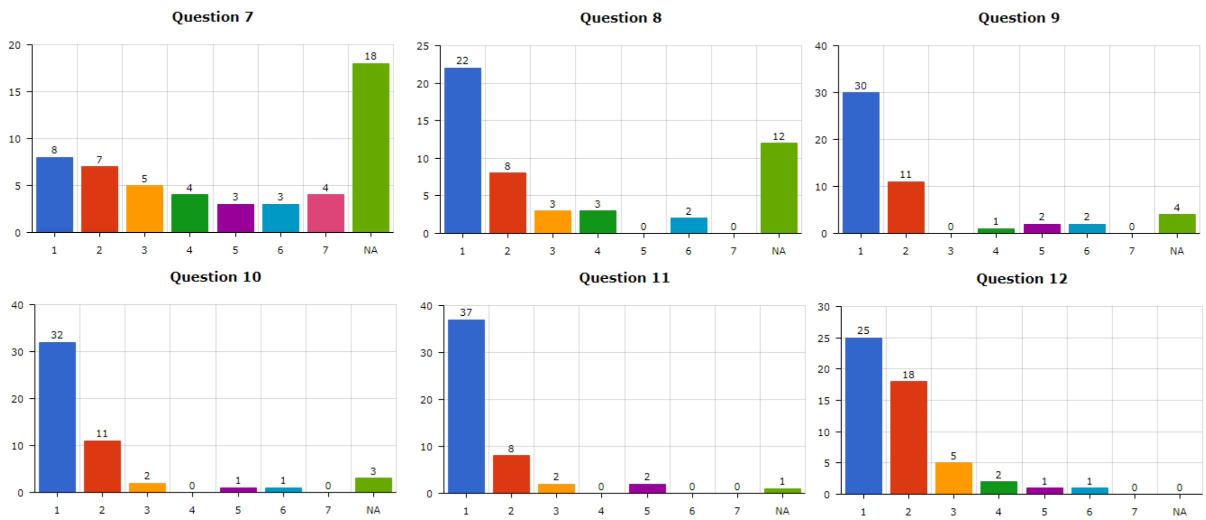

Figure 6.9: INFOQUAL scores of the participants from Question 7 to Question 12.

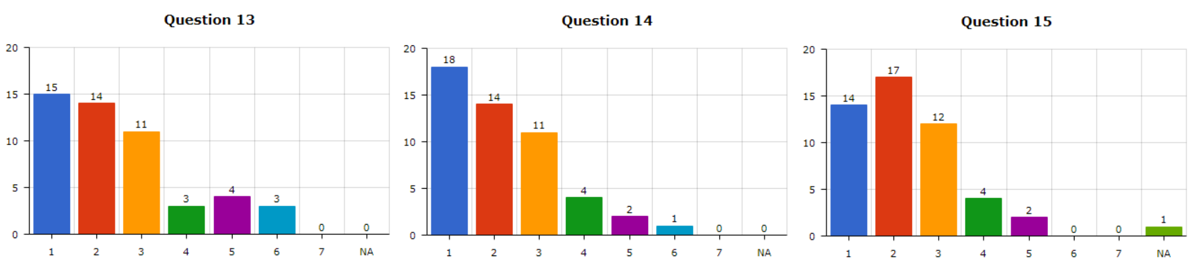

Figure 6.10: INTERQUAL scores of the participants from Question 13 to Question 15.

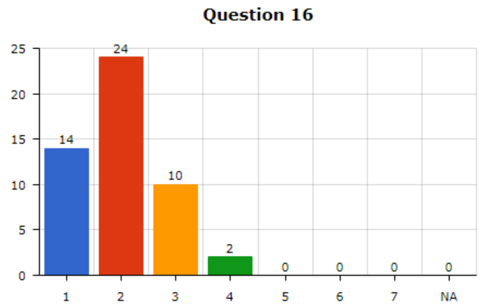

Figure 6.11: PSSUQ score of the participants for Question 16.

7

Conclusion & Future Work

The existing work state the ability to teach AD patients new habits and behaviours by using IM learning methodologies, like EL techniques. Studies argue that even though the AD patients lack some memories capabilities due to EM, they can compensate for the missing cognitive abilities by using Procedural Memory abilities to do IADL. To take the most of Procedural Memory, it is proven that an errorless approach is more beneficial than and errorful. Which by guaranteeing that the subject can't make mistakes the therapy is made simpler and straightforward since the probability of learning a wrong behaviour is mitigated by reactive correction from the therapist.

EL offers an effective (re-)learning of behaviours where people that suffer from minimal to moderate dementia have a diminished frustration caused by errors which then helps the subject to better consolidate the information by associating the intervention with a positive memory. Causing retention of knowledge for weeks and even months. A reinforcement of the technique can happen by adjusting the method to create moments to test the subject ensuring the long-term memory by stimulating the knowledge.

From necessity to make the therapy process much more regulated, counterbalancing therapist flaws during the intervention, and more accessible results the need to create a solution which allows the subjects to go through intervention with no or minimal arbitration from the therapist. This solution can also be used as a working asset analysing the actions of the patients during the sessions.

This study purposes a SG to ensure a bigger return is obtained from the sessions, as well as an improvement in the EV of the intervention, which improves with the familiarity and realism of the environment, by guaranteeing that the objects follow the same rules as the real environment. It is believed that taking the user to a VR environment allows for a reinforcement of the EV of the exercise. Also, it guarantees that the movements, actions and reactions of the user are as organic as possible, this can be accomplished by avoiding the use of controllers by tracking the hands to manipulate the VR environment.

The SG implemented present a proof of concept of a literal implementation of the EL methodology, during which the player is guided through every step of the exercise, in this case baking a cake. One of the major changes, relative to the conventional therapy, is that the phases of exemplification and execution of the action overlap since the patient is no longer physically obstructed by the therapist. This can be used to better understand the ability of the patient to anticipate the exemplification.

As the player increases in Cue Level, the use of Spaced Retrieval pushes the exemplification phase further from the moment the execution phase starts, while the Vanishing Cue tests the ability of the player to recall the action connected with the guide. This means that the patient starts from an effortless exercise and eventually end in an effortful exercise.

By using adaptation through the cognitive assessment and performance we are creating an experience that ensures that the player can always finish the exercise. At the same time, we are saving data and metrics that can be analised by the therapist and lead to a better evaluation of the cognitive state of the patient.

Unfortunately, it was not possible to test the solution with the target group due to Covid-19 but the questionnaire done with healthy population demonstrates a positive acceptance of the solution, an overall score of 1.90 out of 7. The solution still requires further investigation and review of the methods applied. From the participants' evaluation, some topics that require further study, are:

- The ability to be productive with the solution;
- How to solve the errors they make following the steps;
- The interface. This topic is relative to the interface of the solution used by the questionnaire participants;

The population that tested the solution does not serve as the ideal model to represent the target population, implying other topics not tested in this questionnaire might need review.

More direct work with the AD patients is necessary. This presents the limitations of the study and show if the implementation can present real benefits for AD patients.

With this in mind, an intervention was prepared, even if not executed. However, from these preparations, a single session was done with the healthy older population which resulted in optimizations. Such as the position of the objects, the depth and height of the balcony and others.

The use of LeapMotion helped create some comfort when interacting with the virtual-world objects. On the other hand, LeapMotion requires a very specific setup for accurate virtualisation of the hands. The incorrect virtualisation of the hands resulted in strange hand behaviours, impacting their confidence.

The people that tested the solution during this session seemed to enjoy the experience. Since some commented on how much the virtual-world seemed real and showed eagerness in repeating the experience.

The use of a proper intervention with multiple sessions might allow us to understand the retention of the knowledge of the exercise as well as more implementation requirements necessary to deliver the message, while contributing to understanding the impact of the use of VR in the population that suffers from dementia.

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A

Recipe

Yoghurt Cake

Ingredients:

- 4x Eggs;
- 1x Yogurt;
- 2x Sugar measures;
- 3x Flour measures;
- 1/2x Oil measure;
- Margarine;

Material:

- 1x Bowl;
- 1x Wooden Spoon;
- 1x Cake Mould;
- 1x Measure (Yogurt Cup);
- Oven

Assumptions:

- The Eggs have already been broken and put in a bowl;
- The Mould has already been greased with Margarine;
- The Oven has been preheated to 180ºC;

Steps:

1. Add the Yogurt;
2. Add the 3 cups of flour;
3. Add the 2 cups of sugar;
4. Add the oil;
5. Mix the ingredients with the wooden spoon;
6. Add the mix to the cake mould;
7. Put the cake mould in the oven;
8. Wait 40 minutes;
9. Remove the cake mould from the oven;

B

Exercise Guidelines

Script for “Bake a cake” exercise

(This script is directed to Portuguese population)

Give some step for the user to look around

Step 0 - Introduce the exercise

EN: “Hello! Let’s bake a yoghurt cake!”
PT: “Olá! Vamos cozinhar um bolo de iogurte!”

Step 0.1 - Introduce the ingredients and utensils

EN: “We will need:”
PT: “Vamos precisar de:”

Step 0.2 - Introduce the Yogurt

EN: “Yogurt”
PT: “Iogurte”

Step 0.3 - Introduce the Flour

EN: “Flour”
PT: “Farinha”

Step 0.4 - Introduce the Sugar

EN: “Sugar”
PT: “Açúcar”

Step 0.5 - Introduce the Oil

EN: “Oil”
PT: “Óleo”

Step 0.6 - Introduce the Eggs

EN: “Eggs”
PT: “Ovos”

Step 0.7 - Introduce the Bowl

EN: “A bowl”
PT: “Uma taça”

Step 0.8 - Introduce the Wooden Spoon

EN: “A Wooden Spoon”
PT: “Uma Colher de Pau”

Step 0.9 - Introduce the Cake Mould

EN: “A Cake Mould”
PT: “Uma Forma”

Step 0.10 - Introduce the Oven

EN: “And the Oven”
PT: “E o Forno”

Step 0.11 - Wait

Give some step for the user to look around

Step 0.12 - Start

EN: “Let’s start!”
PT: “Vamos começar!”

Step 1 - Yogurt

Step 1.1 - Grab Yogurt

EN: “Grab the yoghurt.”
PT: “Agarre o iogurte.”

Step 1.2 - Add Yogurt to the bowl

EN: “Add the yoghurt to the bowl.”
PT: “Adicione o iogurte à taça.”

Step 2 - Flour

EN: “Let’s add 3 cups of flour.”
PT: “Vamos adicionar 3 copos de farinha.”

Step 2.1 - Grab flour

EN: “Grab the flour.”
PT: “Agarre a farinha.”

Step 2.2 - Add flour to cup

EN: “Add flour to the yoghurt cup.”
PT: “Adicione farinha ao copo do iogurte.”

Step 2.3 - Grab flour

EN: “Grab the yogurt cup.”
PT: “Agarre o copo de iogurte.”

Step 2.4 - Add flour to the bowl

EN: “Add the flour to the bowl.”
PT: “Adicione a farinha à taça.”

Step 2.5 - *Repeat*

Repeat from step 2.1. two more times

Step 3 - Sugar

EN: “Let’s add 2 cups of sugar.”
PT: “Vamos adicionar 2 copos de açúcar.”

Step 3.1 - Grab Sugar

EN: “Grab the sugar.”
PT: “Agarre a açúcar.”

Step 3.2 - Add sugar to the cup

EN: “Add sugar to the yoghurt cup.”
PT: “Adicione açúcar ao copo do iogurte.”

Step 3.3 - Grab Sugar

EN: “Grab the yoghurt cup.”
PT: “Agarre o copo de iogurte.”

Step 3.4 - Add sugar to the bowl

EN: “Add the sugar to the bowl.”
PT: “Adicione o açúcar à taça.”

Step 3.5 - *Repeat*

Repeat from step 3.1. one more time

Step 4 - Oil

EN: “Let’s add 1 cup of oil.”
PT: “Vamos adicionar 1 copo de óleo.”

Step 4.1 - Grab Oil

EN: “Grab the oil.”
PT: “Agarre o óleo.”

Step 4.2 - Add Oil to cup

EN: “Add oil to the yoghurt cup.”
PT: “Adicione óleo ao copo do iogurte.”

Step 4.3 - Grab Oil

EN: “Grab the yoghurt cup.”
PT: “Agarre o copo de iogurte.”

Step 4.4 - Add Oil to bowl

EN: “Add the oil to the bowl.”
PT: “Adicione a óleo à taça.”

Step 5 - Eggs

Step 5.1 - Grab Eggs

EN: “Grab the eggs.”
PT: “Agarre os ovos.”

Step 5.2 - Add Eggs to bowl

EN: “Add the eggs to the bowl.”
PT: “Adicione os ovos à taça.”

Step 6 - Congratulate

EN: “Good Job! We added all the ingredients!”
PT: “Bom trabalho! Adicionamos todos os ingredients!”

Step 7 - Mix Step

Step 7.1 - Grab Wooden Spoon

EN: “Grab the wooden spoon.”
PT: “Agarre a colher de pau.”

Step 7.2 - Mix content of the bowl

EN: “Mix the ingredients.”
PT: “Mexa os ingredientes.”

Step 7.3 - Grab bowl

EN: “Grab the bowl.”
PT: “Agarre na taça.”

Step 7.4 - Add bowl content to the cake mould

EN: “Add the dough to the cake mould.”
PT: “Adicione a massa à forma.”

Step 8 - Congratulate

EN: “Well Done! We are ready to bake the cake!”
PT: “Boa! Estamos prontos para levar ao forno!”

Step 9 - Put in Oven

Step 9.1 - Open oven door

EN: “Open the oven door.”
PT: “Abra a porta do forno.”

Step 9.2 - Grab the cake mould

EN: “Grab the cake mould.”
PT: “Agarre a forma.”

Step 9.3 - Put the mould in the oven

EN: “Put the mould inside the oven.”
PT: “Ponha a forma dentro do forno.”

Step 9.4 - Close oven door

EN: “Close the oven door!”
PT: “Feche a porta do forno!”

Step 10 - Remove from Oven

Step 10.1 - Wait Step

EN: “Let’s wait.”
PT: “Vamos esperar.”

Step 10.2 - Open oven door

EN: “Open the oven door.”
PT: “Abra a porta do forno.”

Step 10.3 - Grab the cake mould

EN: “Grab the cake mould.”
PT: “Agarre a forma.”

Step 10.4 - Put the mould in the oven

EN: “Put the mould outside the oven.”
PT: “Ponha a forma fora do forno.”

Step 10.5 - Close oven door

EN: “Close the oven door!”

PT: “Feche a porta do forno!”

Step 11 - Congratulate

EN: “Congratulations! We finished the cake!”
PT: “Parabéns! Terminamos o bolo!”

C

Concept Document

Description

With the increase in **Average Life Expectancy** a larger percentage of the population reaches higher ages, this new societal paradigm is accompanied by an increase of age-related neurodegenerative diseases like **Alzheimer Disease**. The game objective is to approach this situation with a new approach to training for the people that suffer from Alzheimer Disease, by using already know and effective techniques by using **Virtual Reality** technology.
In this game the player is prompt to follow a set of steps, defining a **Instrumental Activity of Daily Life**.

Features

- Learn or relearn day-to-day activities by following hints and cues in a virtual environment;
- Have an experience dynamically adapted to the cognitive capabilities of the player;
  - Early **adaptation based on neuropsychologic assessment** based on **ACE-III**(Adden-Brooke cognitive assessment);
  - **Adaptation based on the player performance** of previous runs of the exercise;
- Change the training methodology based on player performance and intervention stage;
  - **Block training** - Environment has always the same starting arrangement of the exercise;
  - **Random training** - Arrangement of the exercise is randomised to ensure the player has to "$Read \rightarrow Plan \rightarrow Do$";
- **Errorless Learning** - a technique used to minimise the amount of error made by the player when doing a task/exercise. This learning methodology ensures the player always knows what he has to do before doing having the opportunity of doing;
  - **Spaced Retrieval** - Test the player knowledge of the exercise by setting a time interval between every step description and step answer;
  - **Vanishing Cues** - Progressively vanish/hide the step answer, has the player performance increases;

Player Motivation

The player plays to learn new **Daily Life Activities**. His objective as a player is to be able to repeatedly do the exercise in the highest possible difficulty. The player is prompt to properly follow the cues and hints to improve his performance. Resulting in game sessions with increased difficulty, this is fewer cues and hints.

Game Genre

This is a **Serious Game** categorised as a **Simulator**.

Target Audience

The target audience is the older population that suffers from mild to moderate Alzheimer Disease. This game is also a solution to remote treatment, to the part of this population that cannot be closely accompanied by a therapist.

Competition

- Déborah A. Foloppe, Paul Richard, Takehiko Yamaguchi, Frédéerique Etcharry-Bouyx and PhilippeAllain, “The potential of virtual reality-based training to enhance the functional autonomy ofAlzheimer’s disease patients in cooking activities: A single case study,” 2015;
- Shih-Ching Yeh, Chai-Fen Tsai, Yu-Chin Chen, Albert Rizzo, “An Innovative Virtual Reality Systemfor Mild Cognitive Impairment: Diagnosis and Evaluation,” 2012;
- Teresa Paulino, Ana Lúcia Faria, Sergi Bermúdez i Badia, “Reh@City v2.0: a comprehensive virtualreality cognitive training system based on personalized and adaptive simulations of activities of dailyliving,” 2019;

Unique Sale Points

- Use of **Block** and **Random** training;
- Use of Hand tracking, allowing the user to train the executive memory as closely as possible to reality;
- Use of ACE-III to set the base player difficulty;

Platform

Virtual Reality. Requires the ability to run SteamVR libraries and Leapmotion.

Conception Objectives

The objective of this game is to provide a new approach to the treatment of Alzheimer Disease patients. Allowing for better assessment of the patient progress and bigger control of the session, leading to an experience adapted to the player needs and cognitive capabilities.
It is also the objective to ensure a healthy and joyous gaming experience

D

Comparison

	Immersion			Interaction			Method			Intended Purpose		Adaptation		Analitics
	Full	Semi	Non	Hand Tracking	Controller	Other	Errorless Learning	Instrumental Activities of Daily Living	Multiple Exercises	Cognitive skills	Motor skills	Input Psychological Score	Dynamic Adaptation	Treated Statistics
This Study	✓		✓	✓		✓	✓	✓		✓	✓	**ACE-III**	✓	✓
"Delaying Alzheimer" *by Filipe Duarte (2015)*			✓			✓	✓		✓	✓				✓
"Jogo do Separar as Ovelhas" *by Helio Neto (2017)*			✓			✓				✓			✓	✓
"Jogo do Conta Ovelha" *by Helio Neto (2017)*			✓			✓				✓			✓	✓
"Jogo da Ordenha" *by Helio Neto (2017)*			✓			✓				✓			✓	✓
"Reh@City v2.0" *by Teresa Paulino et al. (2019)*			✓			✓	✓	✓	✓	✓		MoCA	✓	
"Virtual Kitchen Software" *by Déborah A. Foloppe et al. (2015)*	✓				✓		✓	✓	✓	✓	✓			
by Marc Hofmann et al. (2003)			✓			✓		✓	✓	✓				
by Nuria Aresti Bartolomé et al. (2012)			✓						✓	✓			✓	✓
by Syadiah Nor Wan Shamsuddin et al. (2012)			✓			✓			✓	✓				✓
by Shih-ChingYeh et al. (2012)	✓	✓			✓			✓	✓	✓			✓	✓
by Gabriele Optale et al. (2010)	✓					✓			✓	✓				
by Philippe Allain et al. (2014)			✓			✓		✓		✓	✓			
by Paul Van Schair et al. (2008)		✓				✓		✓		✓	✓			

E

Questionnaire

Virtual Reality Serious Game

This serious game was developed as part of my Master's subject. It has the objective of helping the elderly population, that suffer from Alzheimer Disease, to learn tasks, such as learn how to bake a cake.

Unfortunately, due to COVID-19, it is impossible to either test the Virtual Reality or with the target audience. So, a Point-and-Click version has been developed to test the usability of the game.

The full experiment should last around 30 minutes and will involve playing a game and answering a questionnaire before and after playing the game.

To participate in this questionnaire you require Windows Operative system.

By fully participating in this questionnaire you will receive the option of entering a draw of three FNAC digital gift card of 10€ each. To participate in the draw you will have to fill the email field so that we can contact you. The draw will happen at 20/11/2020.

The participation in this questionnaire is voluntary and can be given up at any moment. The participants will not be identified at any point of the study and the individual data will not be shared outside of the context of this study. Finally, participation in this questionnaire does not involve any physical or psychological risks.

By proceeding you agree with all mentioned above.

Student: Marcelo Nunes
For questions or more info: marcelojcnunes@ist.utl.pt
*Required

About you (1/2)

1. Age *

____

2. Email

   Fill this field if you wish to participate in the prize draw

____

About you (2/2)

3. How often do you cook? *

Mark only one oval.

- Daily
- Weekly
- Monthly
- Never

4. How complex are the meals you cook?

Mark only one oval.

	1	2	3	4	5	6	7	
Very Simple								Very Complex

5. How do you characterise your cooking skills? *

Mark only one oval.

	1	2	3	4	5	6	7	
Very Bad								Very Good

6. How do you evaluate your ability to follow recipes while cooking? *

Mark only one oval.

	1	2	3	4	5	6	7	
Very Bad								Very Good

7. How comfortable do you feel using any kitchen utensil? *

Mark only one oval.

	1	2	3	4	5	6	7	
Strongly Discomfortable	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Strongly Comfortable

8. How comfortable do you feel using the oven? *

Mark only one oval.

	1	2	3	4	5	6	7	
Strongly Discomfortable	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Strongly Comfortable

The game

As mentioned this is not the intended experience of the game. Some mechanics of the game were adapted, maintaining the original intent. It serves only the purpose of testing some of the usability aspects of the game.

Use the Left Mouse click to grab and do any of the actions.

Download the game from the link below.
https://drive.google.com/file/d/1Zpwns-pBEOHBrw0e2Pljz2jZCI7FO_fD/view?usp=sharing

How to start the game:
1 - Download the file;
2 - Unzip the file;
3 - Execute "VirtualRealitySeriousGame";

After you have completed the task return to this questionnaire and continue to the next section.

About the game

9. On a scale between 1 (Strongly Agree) to 7 (Strongly Disagree), please rate the following statements regarding the game *

Mark only one oval per row.

	1	2	3	4	5	6	7	NA
Overall, I am satisfied with how easy it is to use this system.	◯	◯	◯	◯	◯	◯	◯	◯
It was simple to use this system.	◯	◯	◯	◯	◯	◯	◯	◯
I was able to complete the tasks and scenarios quickly using this system.	◯	◯	◯	◯	◯	◯	◯	◯
I felt comfortable using this system.	◯	◯	◯	◯	◯	◯	◯	◯
It was easy to learn to use this system.	◯	◯	◯	◯	◯	◯	◯	◯
I believe I could become productive quickly using this system.	◯	◯	◯	◯	◯	◯	◯	◯
The system gave error messages that clearly told me how to fix problems.	◯	◯	◯	◯	◯	◯	◯	◯
Whenever I made a mistake using the system, I could recover easily and quickly.	◯	◯	◯	◯	◯	◯	◯	◯

The information (such as online help, on-screen messages, and other documentation) provided with this system was clear.	◯	◯	◯	◯	◯	◯	◯	◯
It was easy to find the information I needed.	◯	◯	◯	◯	◯	◯	◯	◯
The information was effective in helping me complete the tasks and scenarios.	◯	◯	◯	◯	◯	◯	◯	◯
The organization of information on the system screens was clear.	◯	◯	◯	◯	◯	◯	◯	◯
The interface of this system was pleasant.	◯	◯	◯	◯	◯	◯	◯	◯
I liked using the interface of this system.	◯	◯	◯	◯	◯	◯	◯	◯
This system has all the functions and capabilities I expect it to have.	◯	◯	◯	◯	◯	◯	◯	◯
Overall, I am satisfied with this system.	◯	◯	◯	◯	◯	◯	◯	◯

Thanks for your participation