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Francisco Alexandre Correia Guerra

VIRTUAL REALITY SERIOUS GAME FOR SENSORY OVERRESPONSIVITY TRAINING

Dissertation in the context of the Master in Informatics Engineering, specialization in Intelligent Systems, advised by Professor Marco António Machado Simões and presented to the Department of Informatics Engineering of the Faculty of Sciences and Technology of the University of Coimbra.

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Abstract

Autism or Autistic Spectrum Disorder (ASD) is characterized by persistent difficulties in communication and social interaction, as well as restricted and repetitive patterns of behaviour, interests and activities. The goal of this dissertation is to create a serious game (SG) in virtual reality (VR) in order to help people with this problem to reduce the discomfort produced by being present in an environment with certain sounds that causes sensory overload. To find the sounds we used we used a questionnaire sent to the autism associations of Viseu and Coimbra and to people who were already in studies on autism at the Coimbra Institute for Biomedical Imaging and Translational Research (CIBIT) so that we could identify them. This game is composed of the main game that aims to decipher a maze, without the player's knowledge about it. After a while, the player is submitted to one of two minigames to try to gain a clue to finish the maze, and it is in these minigames that the player gets to interact with the various sound stimuli. At the end of this work, we evaluated the usability of the game with 4 people without autism and then with 3 people with autism. There were a few reasons why we only got this small number of people, and therefore it cannot be said for now that the game is ready for a clinical trial. However, we have gotten a lot of positive feedback about the game, which will make us say that we are not far from achieving this goal. None of these tests involved biosignal collection due to technical problems, and when this problem was solved, no volunteers could be found to conduct a pilot test with this configuration.

Keywords

Autism, Autism Spectrum Disorder, Sensory Overload, Virtual Reality, Serious Game

Resumo

Autismo ou Transtorno do Espectro Autista (TEA) é caracterizada por dificuldades persistentes na comunicação e interação social, bem como padrões restritos e repetitivos de comportamento, interesses e atividades. O objetivo desta dissertação é criar um `serious game` (SG) em realidade virtual (RV) de modo a ajudar pessoas com este problema a reduzir o desconforto produzido por estar presente num ambiente com certos sons que o faz ter um sobrecarga sensorial. Para encontrar os sons que utilizamos recorremos a um questionário enviado para as associações de autismo de Viseu e Coimbra e a pessoas que já se encontravam em estudos sobre o autismo no centro de investigação biomédica e investigação translacional (CIBIT), de modo que conseguíssemos identificá-los. Este jogo é composto por um jogo principal que tem como objetivo decifrar um labirinto, sem o conhecimento do mesmo. Após um tempo o jogador é submetido a um dos dois minijogos para tentar ganhar uma pista para acabar o maze, e é nestes minijogos que o jogador consegue interagir com os vários estímulos sonoros. No final deste trabalho avaliamos a usabilidade do jogo com 4 pessoas sem autismo e depois com 3 pessoas com autismo. Foram alguns os motivos para os quais só conseguimos este número pequeno de pessoas e, portanto, não se consegue afirmar, para já, que o jogo está pronto para um ensaio clínico. Contudo obtivemos muitos comentários positivos acerca do jogo, o que nos fará dizer que não estaremos longe de conseguir atingir esse objetivo. Nenhum destes testes envolveram recolha de biosinais devido a problemas técnicos, e quando se resolveu este problema não foi encontrado nenhum voluntário para a realização de um teste piloto com esta configuração.

Palavras-Chave

Autismo, Transtorno do Espectro do Autismo, Sobrecarga Sensorial, Realidade Virtual, Serious Game

Contents

Acronyms

ASD Autism Spectrum Disorders.

CIBIT Coimbra Institute for Biomedical Imaging and Translational Research.

DSM Diagnostic and Statistical Manual of Mental Disorders.

FOV Field of View.

FPS Frames per Second.

SG Serious Games.

SO Sensory Overload.

VR Virtual Reality.

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Chapter 1

Introduction

Autism or Autism Spectrum Disorders (ASD) is a lifelong developmental disability, and there is no known cure. Symptoms of this disorder include repetitive and restricted behaviours, difficulty interacting with others, verbal or nonverbal communication deficits and difficulties in establishing friendships appropriately for their age [Association, 2013]. Normally, parents notice this disorder's effects around the age of three years old [Gyawali and Patra, 2019].

Autism can also be characterized by hypersensitivity (over-responsiveness) and hyposensitivity (under-responsiveness) to a variety of stimuli, but most people experience both at the same time [AutismSpeaks, 2014]. An individual with hypersensitivity will often avoid these stimuli in a way intended to reduce their sensitivity to them, for example by covering their ears. People with hyposensitivity need to stimulate themselves to regain balance in their sensory systems, for example, by making repetitive movements [Leonard and Saripalli, 2021]. When they are unable to self-regulate, they may experience exhaustion, burnout, or Sensory Overload (SO). SO is characterized by distortions in the perception of sensory information, and studies suggest that more or less 90% of ASD individuals have unconventional sensory experiences in the 5 basic senses [Pavanatto et al., 2020].

To identify these disorders, psychiatrists use the Diagnostic and Statistical Manual of Mental Disorders (DSM) [AutismSpeaksDMS, 2014]. Psychotherapy or occupational therapy follow-up for ASD people is often recommended in order to help them understand themselves better and the world around them [Simões et al., 2014]. Serious Games (SG) are games that have another purpose besides entertainment. By utilizing the entertainment and engagement components provided by games, they solve problems in many areas, involving challenges and rewards. Gamification is a common technique used in therapy. By utilizing this concept, the person starts to become more competitive in order to earn the bigger rewards and to become more enthusiastic about what they are doing [Silva Mota et al., 2020].

The goal of this dissertation is to develop a game, with and without the possibility of virtual reality immersion, so that most people with autism can use it, and to help ASD individuals, gradually, get used to negative sensory situations. Virtual Reality (VR) is a computer-generated environment with scenes and objects that appear to be real, making the user feel immersed in their surroundings [Shaker et al., 2020]. This game will have at least four negative stimuli related to sounds: car and train engines, plane sounds and a lot of people talking at the same time. Using VR to recreate an authentic environment that has the negative sensory situation, and gamify that as they do in therapy, with the intention of having the same benefits. Both games will have the option to be played while the biosignal reading is being acquired so that it will be possible to analyze them with the activity they are doing. This product was developed in five stages. The first was the entire development of the game, followed by a phase of testing by normal people (pilot tests). With the results of these tests, the first iteration of changes to the game will be made in order to lose the bias of the game developer. After these changes, we will move on to testing with people with autism, and finally, an analysis of the responses obtained, documenting any changes that need to be made.

Both games will be used by people doing their PhD at Coimbra Institute for Biomedical Imaging and Translational Research (CIBIT). This piece of software, after the end of my dissertation, will be improved, as one more feature will be implemented. This feature will allow the game environment to be changed depending on the real-time analysis of the collected biosignals. To refer to these changes in the next chapters will be by the name S3RRA project.

There are seven chapters in the paper: It starts with an introduction to the theme, context and what will be done in the scope of this dissertation; afterwards, it will be presented the background chapter with the basic concepts to understand what will be spoken in the next chapters; then it will follow the chapter where an analysis of the state of the art in VR games used in the health field will be done; the next chapter will present the materials needed to achieve the intended goal, a brief analysis of the stakeholders and ends with the analysis of a preliminary questionnaire conducted to know what stimuli we would introduce in the game; the fifth chapter refers to the development of the game where it will be presented; in the next chapter the results of the various iterations of tests performed will be presented; finally ends with the conclusions of the work.

Chapter 2

Background

In this chapter, we will explain the relevant concepts to this thesis. The concepts are Autism Spectrum Disorders (ASD), Virtual Reality (VR), Serious Games (SG) and gamification.

2.1 Autism Spectrum Disorder

Autism is a spectrum disorder, meaning that a child's symptoms can appear in a variety of ways, ranging from mild to severe [Association, 2013]. A person with autism may find it challenging to speak and engage with others. It can also cause an individual to engage in repetitive activities and motions, become agitated when their daily pattern changes, and react in odd ways to particular situations [Lord et al., 2000]. Cognitive deficits are frequent comorbidity in autism but do not affect all of them. In the autism spectrum exist varying levels of cognitive impairment, which give this person a completely different way of seeing the world. As listed in [Gyawali and Patra, 2019], these people frequently suffer from intellectual disability, attention deficit hyperactivity disorder, anxiety, depression, opposition defiant disorder, tics, and epilepsy.

2.1.1 Evolution of the Autism Concept

Autism's behavioural characteristics have attracted people's interest ever since they were discovered. This fascination has spawned a slew of theories about the origins of the phenomenon. Early on the beginning of twenty century, Bleuler used the term autism to describe people with psychosis [Evans, 2013]. The term "early infantile autism" was used by American psychiatrist Leo Kanner in 1943 to describe children who showed little interest in other people [Silva Mota et al., 2020]. Hans Asperger, an Austrian doctor, identified another group of individuals with comparable characteristics but milder intensity and superior intellectual capacities in 1944 [Wolff, 2004]. Since then, his name has become synonymous with Asperger syndrome, a higher-functioning variant of autism. Bruno Bettelheim in the 1960s associated this disorder with parents wishing that their child should not exist, and another hypothesis associated autism with emotionally frigid mothers [Gyawali and Patra, 2019]. As time went on, autism was renamed to "infantile autism" in 1980, "autism disorder" in 1987, and, more recently, "autism" or the global term "Autism Spectrum Disorder" [Won et al., 2013].

Over time, the definitions and diagnoses of these disorders have been expanded to cover milder types of autism. Autistic disorder, Asperger disorder, and pervasive developmental disorder-not otherwise specified are three of the five pervasive developmental disorders listed in the DSM, Fourth Edition and the International Classification of Diseases, Tenth Edition as ASD [Gyawali and Patra, 2019]. In 2013, American Psychiatric Association publishes the fifth edition of the DSM. The DSM is updated by this association on a regular basis to reflect new knowledge about mental health problems and the best strategies to detect them.

2.1.2 Diagnosis

Since 2013, psychiatrists use the fifth edition of DSM to evaluate the symptoms. The change to this edition allows having more accuracy in the diagnosis, identification of symptoms that may warrant treatment or support services and Assessment of severity level [Association, 2013]. The main changes are represented in the following table .

Changes	**DSM Changes**	
	4th Edition	**5th Edition**
Consolidation of Categories: Autistic disorder, Asperger syndrome, Childhood disintegrative disorder, Pervasive developmental disorder-not otherwise specified.	They are in different categories.	They are together in the same category: " autism spectrum disorder".
Categories of autism symptoms.	- Social impairment; - Language/communication impairment; - Repetitive/restricted behaviours.	- Persistent deficits in social communication/interaction; - Restricted, repetitive patterns of behaviour.
Social communication disorder.	Do not exist this diagnosis.	A new diagnosis for disabilities in social communication without repetitive, restricted behaviours.
Sensory issues as a symptom under the restricted/repetitive behaviour category.	Do not included.	This includes hyper- or hypo-reactivity to stimuli (lights, sounds, tastes, touch, etc.) or unusual interests in stimuli (staring at lights, spinning objects, etc.)

Table 2.1: Some changes between the fourth and fifth edition of DSM.

To diagnose this disorder requires two stages [Kandola, 2021]:

1. **Developmental checkups:** As children get older, they should have a routine of developmental screenings, that is transmitted at each appointment. Between the ages of 18 and 24 months, a doctor will examine a kid for signs of autism. They'll also discuss with a parent or caregiver about the child's behaviour, development, and family medical history.

2. **Developmental checkups:** If a doctor suspects a kid is autistic, they will assemble a team of healthcare specialists to conduct more tests. Cognitive

and linguistic abilities will most likely be assessed by child psychiatrists and speech-language pathologists. Additional testing may be required to rule out other conditions.

After that, if the diagnose is positive the kid will be evaluated which one of the three levels of support he needs. An educator or healthcare professional can use the three level definition to determine the appropriate level of support for each individual [Kandola, 2021]:

Level 1: a person can live a relatively independent life with a minimum of assistance.

Level 2: Support is required to help the individual communicate and adapt to change effectively.

Level 3: As they cope with everyday life, the individual may need the support of others. However, medication and therapy can help manage some of their challenges.

2.1.3 Sensory Overload

When one or more of the body's five senses become overloaded [Pavanatto et al., 2020], this is known as Sensory Overload (SO). The brain receives too much information in these instances to effectively process them. SO causes a wide spectrum of unpleasant experiences, from moderate to severe [Leonard and Saripalli, 2021].

Specific phobias/fears can cause substantial discomfort and have a major impact on persons with ASD and their families, impeding the development of educational or daily life skills and leading to avoidance of everyday circumstances [Maskey et al., 2014].

At some time in their life, everyone feels SO. Everyday circumstances might be difficult for those with ASD. Going to school or shopping might cause SO for them. The noises of people chatting loudly, heavy food odours, and flashing fluorescent lights might all make them feel uneasy and overwhelmed.

2.2 Virtual Reality

VR is a fully immersive experience that may be enjoyed safely while simulating something real. You can enter specific simulations by wearing a VR headset or using appropriate software. These simulations are intended to be fully immersive experiences with which the user may engage and explore. The viewer has complete control over the environment, including the ability to look about and interact with the items in it.

Virtual Reality is most commonly used in computer-generated simulations in which a whole 3D environment is portrayed in the most realistic way possible

[Pan et al., 2006]. A user may then engage with the scene and manage the surroundings using a range of technological devices.

In general, VR refers to the creation of a technologically enabled simulation of a real-world experience that a person can join and exit at any moment. As VR technology advances, these simulations will only get more detailed and realistic. The main features of this are:

Immersion: Any VR system's purpose is to entirely immerse the user in a new simulated environment. This involves utilizing the visor to fill their peripheral vision, adding sound-cancelling surround sound headphones that immerse them in the environment, and allowing them to control the scene with their head movements.

Interaction: In VR, using a specialized controller can assist users in interacting with the scene and controlling items. The ability to pick up things in the scene or even interact with characters can enhance immersion and increase the value of VR simulations.

The main applications of this technology are gamming, workspace collaboration, training and learning, therapy and advertising.

2.2.1 The technical aspects of Virtual Reality

There exists four technical aspects that are improving nowadays and consequently evolving the VR technology. The VR technical aspects are Field of View (FOV), frame rate, sound effects and head and position tracking.

Field of View

The FOV has remained a source of worry for VR creators. VR must match human FOV in order to immerse us in a new environment. Unfortunately, humans have a considerably larger FOV in general than headsets can normally offer. The average person can view around 220 degrees of surrounding information while a VR headset only can achieve around 180 degrees.

The FOV in your headset determines what you see around you and how well it resembles your present surroundings. No headset can yet handle our entire natural FOV, yet technology is advancing, as are frame rate options [Carter, 2021].

Frame Rate

The other visual aspect that defines how VR works is frame rate. To imitate what we see in real life, frames must move at a faster rate within a VR headset screen. According to experts, the human eye can process up to 1000 Frames per Second (FPS). The human brain, on the other hand, is never exposed to such detail. Most developers have noticed that anything less than 60 FPS causes feelings of disorientation and nausea [Kovačević, 2021].

Sound Effects

Another critical technological feature of VR is the way designers incorporate sound effects to give the user a sense of three-dimensional space. Today's cutting-edge VR depends on a technology known as spatial audio to generate a simulated aural landscape that matches the sights provided by VR.

Anyone who has sat in a well-designed concert hall should be familiar with how the sounds we hear may vary depending on where we are in a place and even which way we turn our heads. Spatial audio is a technology used by VR designers to generate binaural (stereo) audio using a set of headphones that simulates that same feeling [Kovačević, 2021].

Head Orientation and Position Tracking

The ability to walk around in a virtual realm and have the environment change to your location is what makes VR extremely interesting. Head orientation and position tracking characteristics are quantified in degrees of freedom, so you may experiment with either 6 or 3 degrees of freedom.

Headsets with 6 degrees of freedom can detect your location in a room and display the direction your head is pointing. This implies that you can navigate about an area entirely on your own. Sensors outside of the VR headset can also assist you in remaining safe while moving around in a room.

Tracking technology for virtual reality is becoming increasingly remarkable. Eye-tracking technology can assist enhance attention in VR experiences and lessen the discomfort that some individuals feel when working within a headset. Haptic feedback sensors and other tracking technologies used to insert controller choices into VR may also make the environment feel more immersive [Carter, 2021].

2.2.2 Hardware and Software

VR hardware is used to generate stimuli that are then utilized to modify the sensors of the VR user. These can be worn on the body or utilized independently when the user is not present. VR hardware includes sensors to detect motions such as the user's button pushes and controller movements such as the hands, head, and eyes. The sensor has receptors that gather mechanical energy from the user's body. The sensors in the hardware transform the energy received from a hand movement or button push into an electrical signal and are sent to a computer or device for processing.

VR software controls the VR input/output devices, evaluates incoming data, and generates appropriate feedback. The VR software's inputs must be timely, and its output reaction must be fast [SoftwareTestingHelp, 2022].

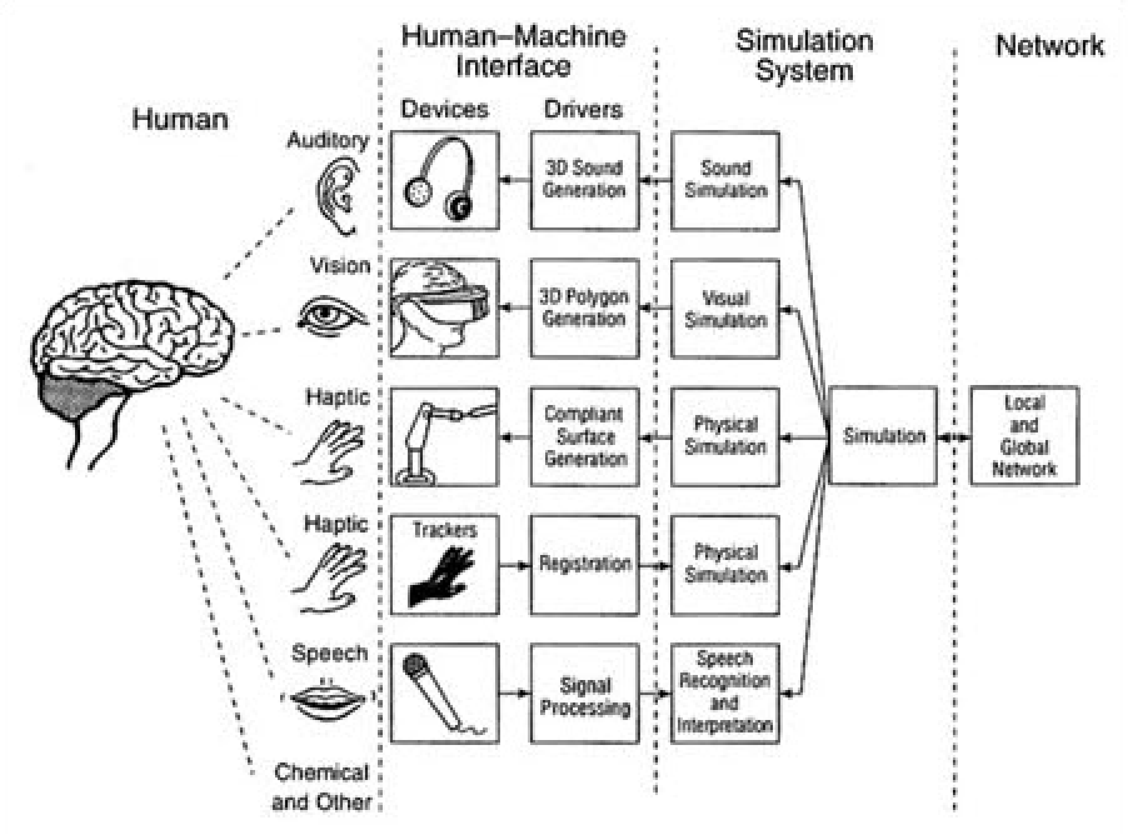


Figure 2.1: Organization of the VR technology.

(Picture adapt from **softwaretestinghelp**)

2.3 Serious Games and Gamification

The concept of playing games extends back to ancient times and is regarded as an essential feature of all communities [Laamarti et al., 2014], and is a popular pastime for adults [von der Heiden et al., 2019]. Firstly, a game is defined as a physical and/or mental contest organized by pre-defined rules with the express purpose of educating and/or entertaining the player(s) [Laamarti et al., 2014]. Another important concept is video games, that the author of [Esposito, 2005] defined as "a game which we play thanks to an audiovisual apparatus and which can be based on a story".

SG are games that are specially designed to achieve a specific change, such as changing knowledge, attitudes, physical abilities, cognitive abilities, health or mental well-being in the person [Mccallum, 2012]. There is evidence that video games enhance concentration, multitasking, and working memory, but they may also have adverse consequences when used excessively [von der Heiden et al., 2019]. Aside from that, the best advantage is that users can experience controlled situations not easily attainable in the real world due to reasons like time, money, and safety [Susi et al., 2015]. Nowadays, video game players spend many hours per week on their computers [Drummond et al., 2017]. Video games were thought to be an interesting educational method because they allowed for the incorporation of educational content, keeping the game interesting and causing the player to continue playing it for several hours and these become more productive because they are learning something [Prensky, 2002].

It is the ability of SG to balance entertainment, interaction, and replayability of typical games with the learning objectives of a given educational objective, such as cultural heritage, health, classroom instruction, cultural training, or social awareness, that determines the potential of SG as an educational tool [Pereira et al., 2012].

Figure 2.2: Relationship between SG, games,learning and simulations.

(Picture adapt from Frederick Joseph F. on LEADERSHIP&FLOW)

There are some sub-categories for the areas of SG, some are [Susi et al., 2015]:

- **Military area** - Simulations for tanks, helicopters, group training, and other military equipment have evolved from simple games, which allow officers to plan for battles more effectively;
- **Government Games** - Various levels of simulation and training are conducted by government agencies at all levels, from local to national. As an example, government games can involve a variety of different kinds of

crises, including terrorist attacks, disease outbreaks, biohazards, health care policy issues, city planning, traffic control, firefighting, budget balancing, ethics training, and defensive driving;

- **Educational Games** - games that are used for example in schools in order to help teach something during classes;

- **Healthcare Games** - games that will be used to help with physical or mental health, for example, physical fitness, distraction therapy, recovery and rehabilitation, surgical training, diagnosis and treatment of mental illness/mental conditions, cognitive functioning and games with biofeedback equipment.

According to the list above, we include the game developed in the healthcare category.

The term "gamification" is associated with the gaming industry. This is a strategy for improving systems, services, organizations, and activities in order to generate experiences similar to those found in video games in order to encourage and engage users [Blohm and Leimeister, 2013]. This concept has been adopted by the field of education, allowing for the creation of teaching and learning environments capable of engaging teachers and students in a fun way, so contributing to a rethinking of the formal educational context [Kiryakova et al., 2014].

Gamification is the use of game components, mechanics, dynamics, and strategies outside of the game, in the context of an individual's daily life. As enumerated in [Silva Mota et al., 2020], scores, levels, ranking tables, badges, challenges/missions, initial engagement, and other engagement cycles are the seven primary elements of gamification. The primary principle behind a gamified system is that the "player" can carry out the intended activities using both intrinsic (such as competition and collaboration) and extrinsic (such as points, levels, missions, and ranking) stimuli [Morschheuser et al., 2019].

Figure 2.3: Gamification concept.

(Picture adapt from **digital.hec.ca**)

Chapter 3

Related Work

Virtual Reality (VR) has had a significant impact on rehabilitation research and clinical practice in recent years, which cannot be overestimated [Alexandrovsky et al., 2020]. The advantage offered for this technology, as said in section 2.2, helps the integration and the necessity of using this kind of system during therapy.

The first approach to this technology needs the intervention of a therapist or a psychologist to configure the system according to the patient's needs and adjustable time to time depending on the performance of the individual. VR may complement the role a therapist traditionally performs as a motivator for patients [Levac and Galvin, 2013].

This technology allows researchers to describe the sensory cues that convey information about the virtual world explicitly and comprehensively. With VR, you can add or remove sensory cues, something we can't do in real life, to examine the influence of certain stimuli to elicit a specific response [Minderer et al., 2016].

VR is used in many fields of therapy such as fears and phobias, teaching, body and balance recovery, among others. The next list shows some examples of applications used in therapy:

- Morag Maskey and coworkers conduct a study with nine kids, each one with a different phobia, like crossing a bridge and enter in an almost full bus. They use VR to recreate the different scenarios, and after the fourth session, their parents report a decrease in the level of anxiety that stimulus provokes in them [Maskey et al., 2014].

- Margot Ferrand and co-researchers design a virtual environment to try to reduce the fear of flight. The experiment, according to the statistics reported was a success after a day of simulations in the virtual environment [Ferrand et al., 2015].

- Costa Anton and co-researchers have developed a system to combat the fear of heights, and read galvanic skin response and heart rate [Anton et al., 2020]. They were unable to draw conclusions since they had a very small sample due to the pandemic.

- Associate words to images is a simple way to teach new words to children, and its a method used in schools and in therapy. AssociAR [Silva Mota et al., 2020] is a virtual game that reproduces this method to a virtual environment where the user associates words to 3D images.

- The authors of [Ma and Bechkoum, 2008], have developed a series of minigames to aid movement recovery after a stroke. The games were based on simple environments that allowed the user to make various kinds of moves, such as picking oranges and putting them in a basket, or using a hammer to smash a mouse that might appear anywhere on the table. This study showed improvements in the participants.

- K I Ustinova studied in [Ustinova et al., 2013], a form of VR in people with traumatic brain injuries. Nine people completed fifteen sessions and in most participants, there was an improvement in their postural stability, gait, and upper extremity movements.

- Margarida Pereira used a virtual reality environment to improve hand rehabilitation. In this study, the players had to pick vegetables from a vegetable garden [Pereira et al., 2020]. This study was conducted with a hand tracker which allowed the players to make various movements with their hands and thus improve the condition of their hands.

- Get the job! [Pavanatto et al., 2020] is a game that provides normal people to experience a day as an autistic person. The objective of the game is to arrive at a job interview in time facing adversities, for example the brightness outside.

The altered sensory processing associated with autism can manifest as sensory over-reactivity, an overreaction to stimuli that causes discomfort for the person, or sensory under-reactivity, a low reaction to a stimulus. While the two types of sensory reactivity are distinct, both can be present in the same Autism Spectrum Disorders (ASD) individual depending on the stimulus [AutismSpeaks, 2014]. Sensory over-reactivity can be directly linked with stress manifestations. The effects of sensory over-reactivity do not just affect executive functioning, but also interpersonal relationships. One of the most important findings is the association between hypersensitivity and the development of specific phobias, common comorbidity associated with ASD [Muskett et al., 2019].

In particular groups, such as young children with ASD, short attention spans, a lack of incentive to comply with others demands, and communication issues might limit the length of an experiment. The time changes depending on the age or the task that is performed [Kylliäinen et al., 2014]. After this time, the kid should be stimulated in order to perform more tests. This stimulation can be achieved by giving something to eat or drink, in a small break so that person does not lose focus on the goal of the game. The next list is about works done to help ASD people during therapy.

- With the objective to help ASD people improve their autonomy in simple daily activities like laying a table for lunch or learning how to do recycling, HoloLearn [Garzotto et al., 2018] was created. With the same objective, Neurohab [Simões et al., 2014] is an application developed on Coimbra Institute for Biomedical Imaging and Translational Research (CIBIT) to help with activities like catching a bus or going to a supermarket buying stuff. In this context, the players are subjected to various sound stimuli such as people talking and the bus engine, which will put the players under stress.

- Changing the normal life can be too stressful for an autistic person since they will be able to face more negative sensory situations. [Miller et al., 2020] made a game that recreates all the steps to catch a plane since arriving at the airport.

- A virtual reality game called SoundFields was designed to treat children and adolescents with VR. With binaural-based spatial audio, the system is able to present the player with naturalistic representations of feared auditory stimuli. A realistic simulation of dynamic movements of an adverse stimulus, as well as the acoustic environment that typically accompanies them. They use sounds like sirens and a baby crying. They report a decrease in the level of anxiety that stimulus provokes in them [Johnston et al., 2020].

Similar to the final goal of the S3RRA project, we found a system called DUST that evolves its environment according to the response given by the biosignals [Michela et al., 2022]. This system allows police officers to train themselves to remain calm during tense periods. The breathing and heart rate of the person causes him to have more or less vision within the game. That is if the breathing is normal, the player has full vision, and the more inconsistent the breathing, the more the visible area is lost, forcing the policeman to calm down in order to regain his vision.

VR is being developed to improve the real-life adaptability of people suffering from psychiatric disorders. Patients, like computer gaming addicts, may become obsessed or addicted to the VR environment.

Many research and clinical trials have adopted VR as a simulation, interaction, and diversion method for individuals suffering from mental diseases. By successfully exposing people to causes of fear, providing interactive virtual environments of cognitive-behavioural techniques, and contributing to other rehabilitation applications, VR environments demonstrate the promise of improving their anxiety, cognition, and social functions. Modern VR systems can provide an excellent setting in which to tackle the problem that must be overcome, not only via conversations with physicians but also through virtual surroundings with well-controlled sensory inputs. Patients with mental problems may have cognitive and behavioural changes as a result of this. VR, on the other hand, must overcome technological challenges such as motion sickness and dry eyes, as well as user challenges such as obsession and addiction.

Chapter 4

Experimental Design

This dissertation's goal is to develop a serious game, with and without Virtual Reality (VR), to assist individuals with autism in gradually adapting to negative sensory situations. Both games will be connected to two systems that will record different biosignals. One of them is the `BIOPAC` which will record an electrocardiogram and will be placed on the wrist of the player. The other one is the `g.Nautilus` which will record an electroencephalogram and will be placed in the head.

The final goal of the S3RRA project, where this dissertation is integrated, is to have a game, with and without VR, that has a big list available of negative sensory situations in order to help Autism Spectrum Disorders (ASD) people gradually adapt to these situations. The game will have a module, inside him, that will analyze biosignals in real-time in order to understand the relationship between the biosignals and the reaction of the person. Another functionality of this module is to change the environment present by adding/removing sound sources depending on the analyzed biosignal.

There are three sections in this chapter: a materials section that will enumerate all the resources that will be used to work with this project; a stakeholders section that will be describing all users for whom this game is intended, and a survey section that will present the results of the survey that I made to autistic people from the autism associations that will be one of the end users of the game, in order to understand what are the sounds that they do not like from the daily lives.

4.1 Materials

To build a virtual reality game, we have several engines that we can choose between `Unity`, `Amazon Sumerian`, `Google VR for everyone`, or `Unreal Engine 4`. I choose to use `Unity` because I already have experience using this engine and the existence of a lot of free assets that can be used to facilitate the creation of the environments. To accomplish the VR, I used the library `Steam VR`, so for that is needed a `Steam` account and the `Steam VR` installed in order to use the VR.

To gather information about what stimulus we need to add to the game, we used the `Google Form` in order to make a survey to ASD people. To record the biosignals we use two technology one developed by `BIOPAC`, the `BioNomadix wireless` and the other is the `g.Nautilus`. This wireless technologies, as shown in the Figure **4.1** and the Figure **4.2**, allows us to reduce the number of cables connecting the patient and the computer thus ensuring that the user will be free to walk around while is playing the game. To play the VR game we will use the headset HTC VIVE PRO with eye tracking, as shown in the Figure **4.3**.

Figure 4.1: `BioNomadix wireless` system.

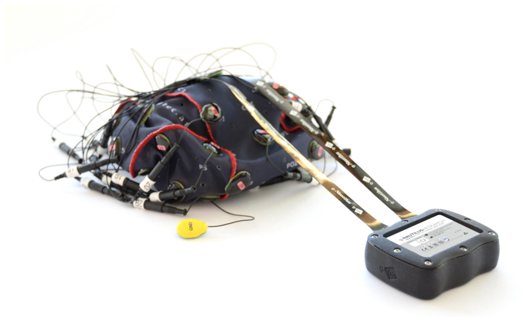


Figure 4.2: `g.Nautilus` system.

Figure 4.3: HTC VIVE PRO with eye tracking.

4.2 Stakeholders

Our stakeholders for the project S3RRA are autistic people and the healthcare worker in charge of them. The application should handle both sides: the autistic people that will play to gradually adapt to negative sensory situations; and the healthcare worker that can monitor the progress and can make the right setup for each patient. Personas are fictional characters, which you create based upon your research in order to represent the different user types that might use your service or product in a similar way. Personas will define users' needs, experiences, behaviours and goals. We defined five personas, with the help of psychologist Tânia from the Associação Portuguesa para as Perturbações do Desenvolvimento e Autismo in Coimbra, in order to portray our stakeholders. These can be seen at appendix **A**.

4.3 Survey

With the goal of trying to identify the most negative sensory situations that affect the daily life of an autistic person, we made a survey. This survey is available https://neurohab.pt/s3rra/, and we sent them to people that are working on other projects about ASD, on Coimbra Institute for Biomedical Imaging and Translational Research (CIBIT), that want to receive information about other projects in the same area and to Associação Portuguesa para as Perturbações do Desenvolvimento e Autismo of Coimbra and Viseu.

This survey has five sections: the first one to gather personal information, the second to know how well the persons are familiar with the gaming world, the third to obtain information about sensory response to touch, in the fourth section we present eight videos and in each one will show one sound that possible cause a negative sensory situation and in the final section will show four images for the same room but this room is illuminated with different fluorescent coloured lamps.

4.3.1 Results

We obtain thirty eight answers in total. The ages are between three and forty-five and follow the distribution of the Figure **4.4**.

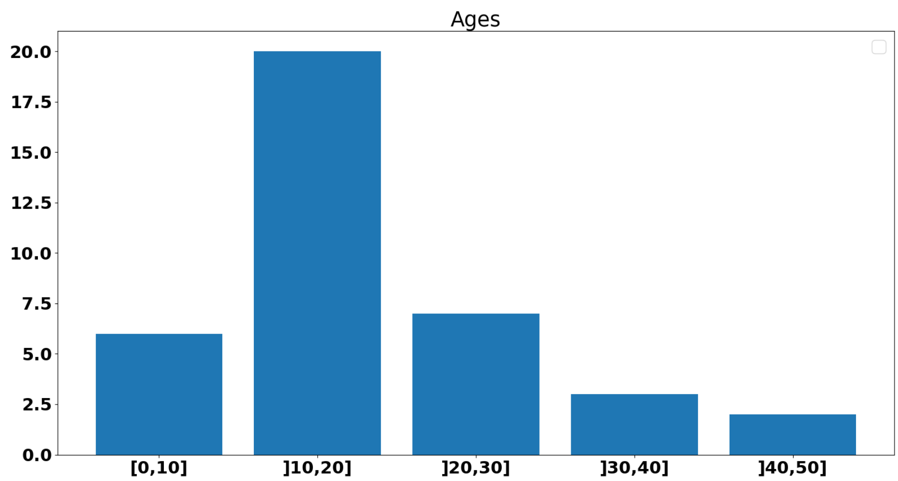


Figure 4.4: Group of ages of the people who responded to the survey.

Through the Figure **4.6**, we can see 36.8% do not interact with video games in daily life and through the Figure **4.5**, more than three-quarters of the people that answer the survey never had an experience using VR, so this means that is needed a tutorial to help people interact with the virtual world.

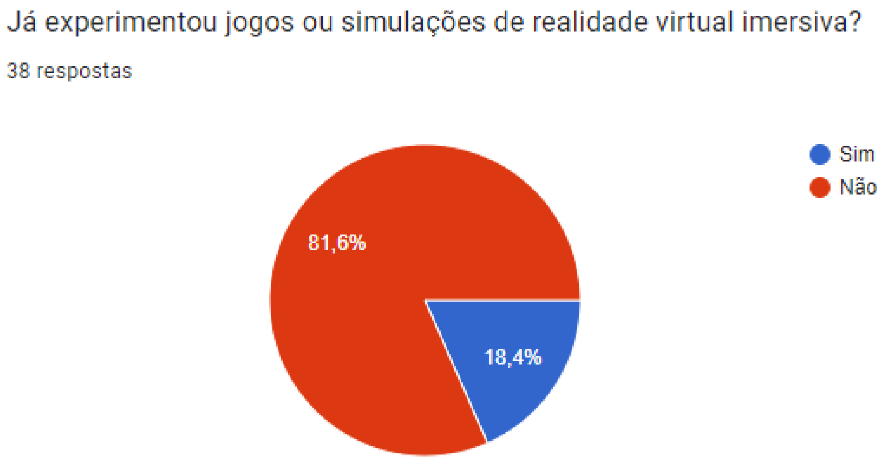


Figure 4.5: Already tried VR.

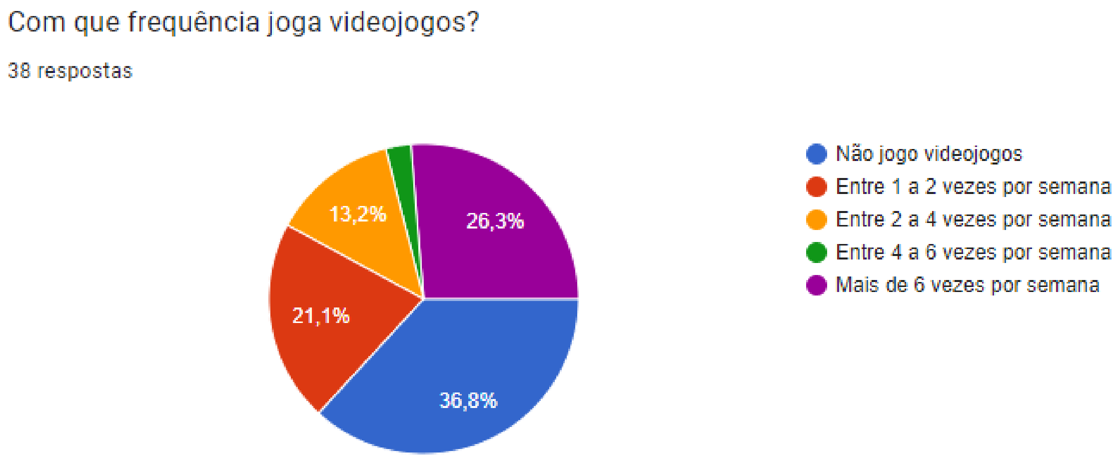


Figure 4.6: Frequency playing video games.

We question about the sensory response to touch in order to know if the people can handle all the objects during the session, the velcro around the fingers and the watch to measure the biosignals and the VR headset and the elastic tape that hold the VR headset in order to perform the immersive simulation. These results are not totally reliable since people were asked only by seeing the object and not touching it in real life to give an accurate answer . With these results, Figure **4.7**, we know that the game needs to be played with and without the measure of the biosignals and the immersive simulation, since the results do not show the values concentrated on the lowest values of the scale.

We made two types of questions about the sounds that were possible to provoke a negative sensory situation. first one, mandatory, shows eight sounds with a duration of thirty seconds each. We asked to assign a rating from zero to ten, the results are shown in Figure **4.8**. In the second, we asked them to write five sounds that they like and five they dislike. This one was not mandatory. So we choose

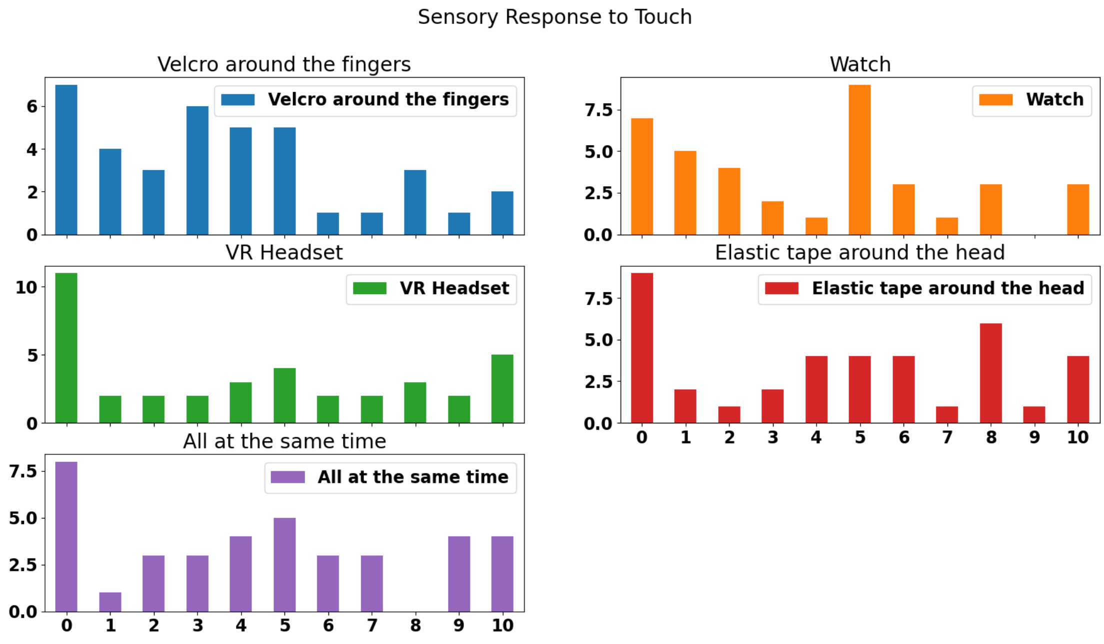


Figure 4.7: Sensory response to touch.

to integrate the first version of the game with the two stimuli that were a higher rank of disturb, people talking at the same time and the sound of the train engine, and for the written answers we choose two more: planes e the car engine. These last two do not show their importance through the graph, but they often appear in the written answers.

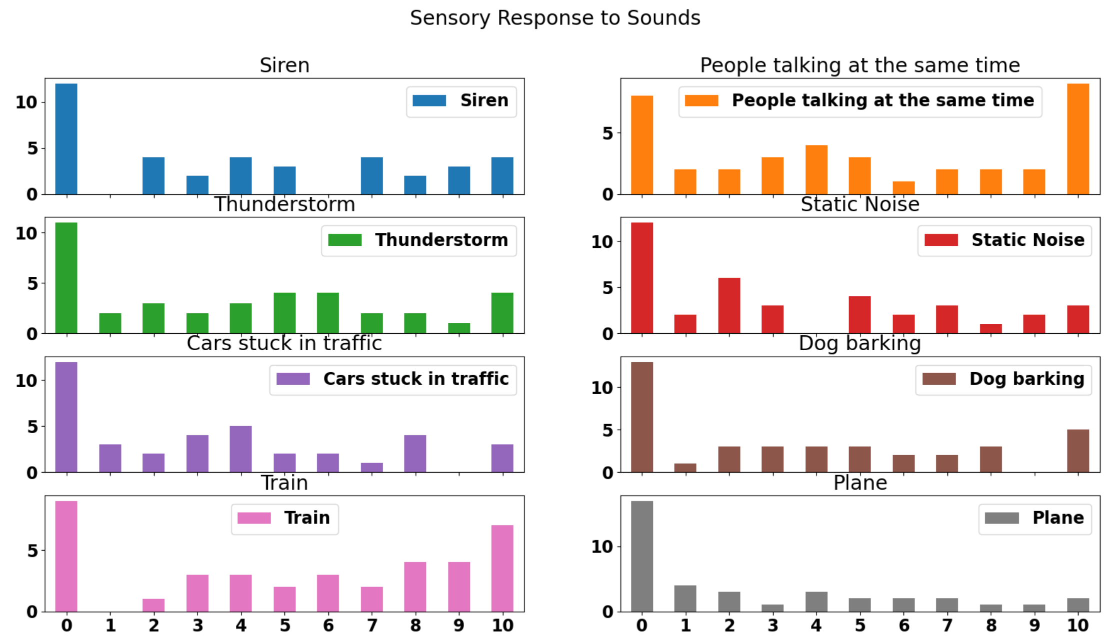


Figure 4.8: Sensory response to sounds.

To know the influence of fluorescent coloured environments using coloured lamps, we use four equal setups and change the colour of the lamp. After the intermediate defense, in a project meeting, we decided not to explore the influence of lights for now. But if we did, according to the results of Figure **4.9**, we will chose to include the environment with red light.

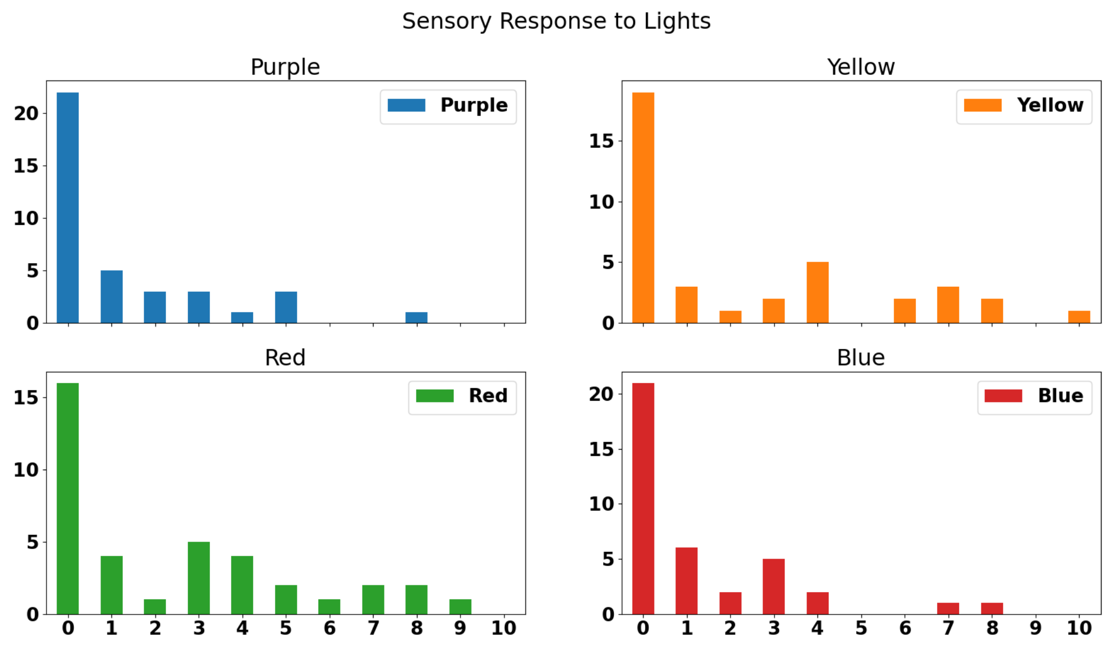


Figure 4.9: Sensory response to lights.

The results of Figures **4.10** and Figure **4.11** allow understanding of whether the people in any part of their life had sensory integration training. These results show us that will be necessary, before playing the game, to explain the purpose of the game and the advantages that we are trying to produce. The results of Figure **4.12** show us that this project can be promising and the people want to be part of the project.

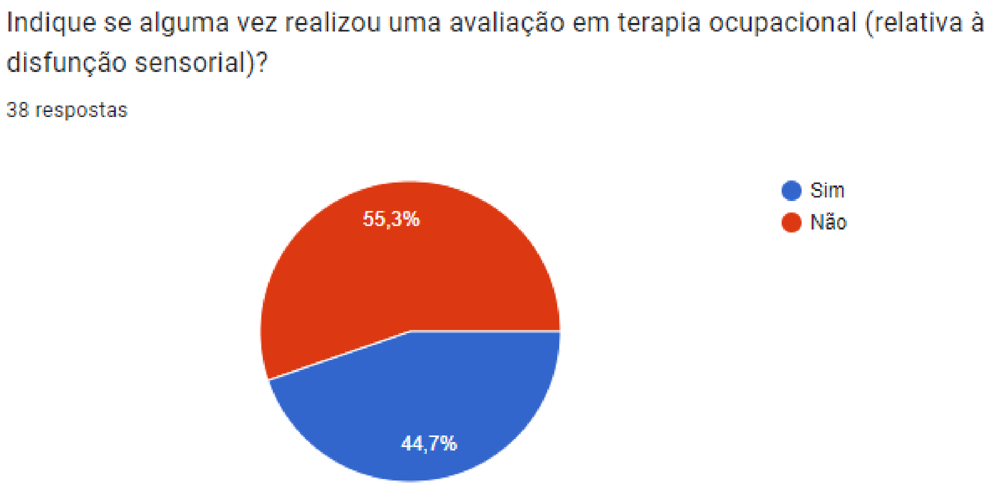


Figure 4.10: Realization of occupational therapy.

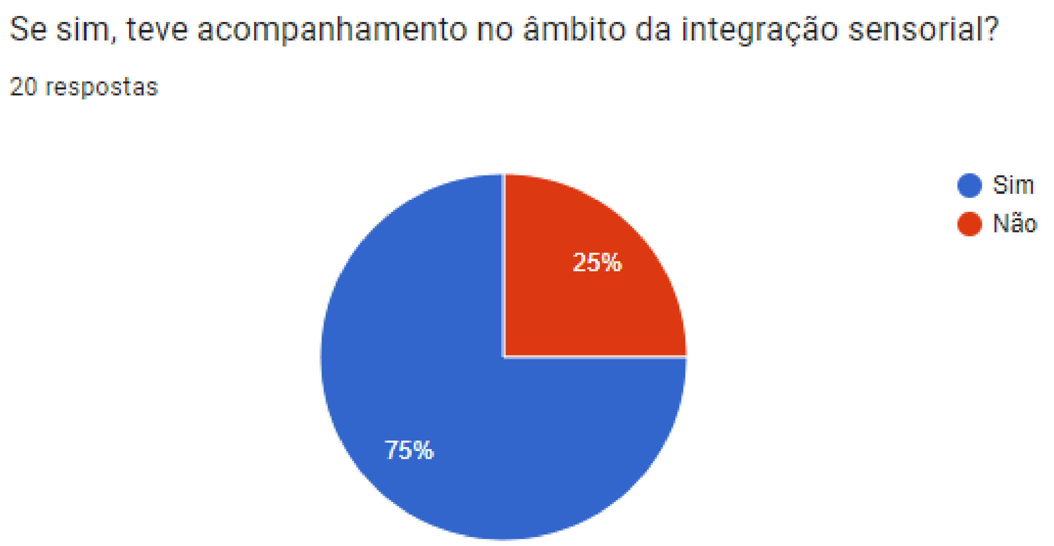


Figure 4.11: Sensory integration follow up.

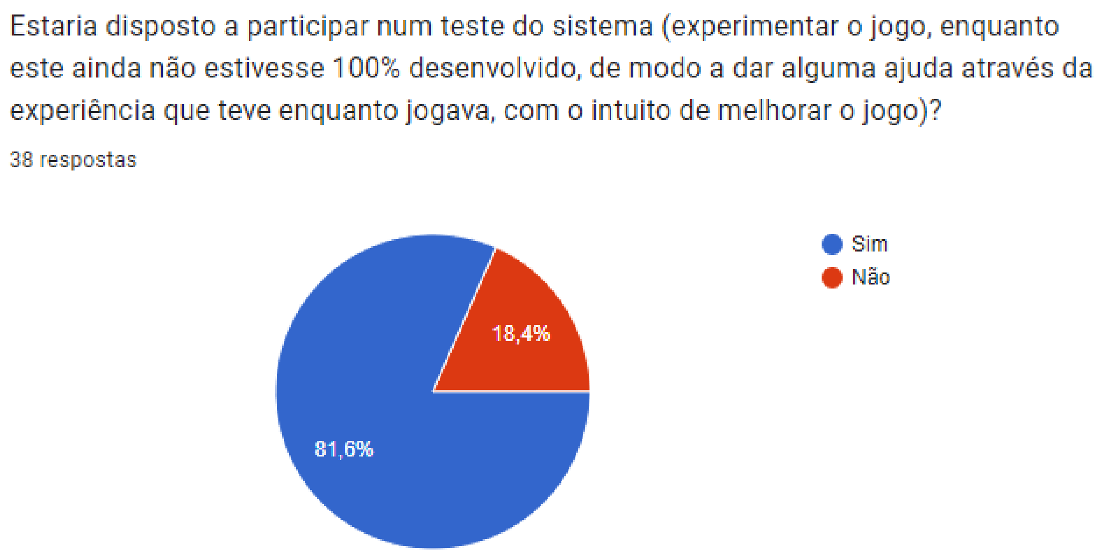


Figure 4.12: Interested in testing the game

Chapter 5

Game Development

This chapter serves to demonstrate the game creation process from the idea to the final product. First, the concept of the game will be discussed, followed by the requirements and architecture of the game. After that, the final product will be presented and the differences between the two possible ways of playing the game. Finally, the development plan for the both semesters will be presented.

5.1 Game concept

The game is in the first person, this means the player will see the game through the character's eyes and interact with the world with the character's hands. The main game will consist in solving a maze. Once inside them and without a map it is hard to find a way out. To win some help to find the exit, the player will be submitted to minigames with their selected negative sensory situations in order to achieve that advantage and to win more points.

For the sounds of car and trains engines and airplanes, the user will distribute cardboard boxes around a virtual city, as if he were a mailman from that city. The reward will depend on whether you manage to deliver the pre-defined number of boxes within the time limit. For the people talking at the same time, the game is in a supermarket and the objective is to buy all the groceries on the list within the time limit. It is not necessary to completely finish the minigames to get the help to find the exit to the maze, but this feature will be explained later in this chapter.

5.2 Requirements

Like any piece of software, to build is necessary to define the software requirements. These are the functional requirements:

1. Allow to select various number of stimuli to play and its intensity;

2. Stop the game at any time;
3. Have a tutorial;
4. Keep the rules with simple statements;
5. Make a reward system;
6. Grab objects;
7. Find the delivery destination;
8. Make the delivery;
9. Accomplish the groceries list.
10. Generate always different mazes inside the same difficulty;
11. Change the size of the maze accordingly the difficulty;
12. Connect via parallel port to the `BIOPAC` system;
13. Connect via UDP to the `g.Nautilus` system;
14. The environment must have more sound sources the higher the level;
15. Log system;
16. Send to biosignals system the time where the negative sensory situations start and end;

5.3 Software architecture

In this section, it will be explained both architectures used to build for this dissertation. The first one, can be seen in Figure **5.1**, and in the Figure **5.2** can be seen the architecture for the S3RRA project.

For this dissertation, the architecture is divided into two parts, while the whole project is divided into three parts. The middle part of the figure represents the core of the project the game, and it is common to both architectures. The game can be played using the Virtual Reality (VR) headset or the mouse + keyboard in order to give all people the chance of playing the game independent of its physical or sensorial situation. Going for the right side of the Figure **5.1** represents the connections for both biosignals recording systems. On the other hand, in Figure **5.2** is represented the connection of the game to the biosignals data processing, a piece of software that is being developed in Coimbra Institute for Biomedical Imaging and Translational Research (CIBIT), that will process the biosignals in real time and will influence the environment of the game. For these two parts, in both architectures, we have two types of users: user 1 represents all of the people that will play the game using at least one of the biosignal receptors; user 2 represents the people who can not handle the biosignal receptors or just do not want to measure. The third part in the Figure **5.2**, the left side of the figure, represents the webserver that will be responsible to make the login for the people, storing the progress of each player and allowing healthcare workers to access only the data of their patients.

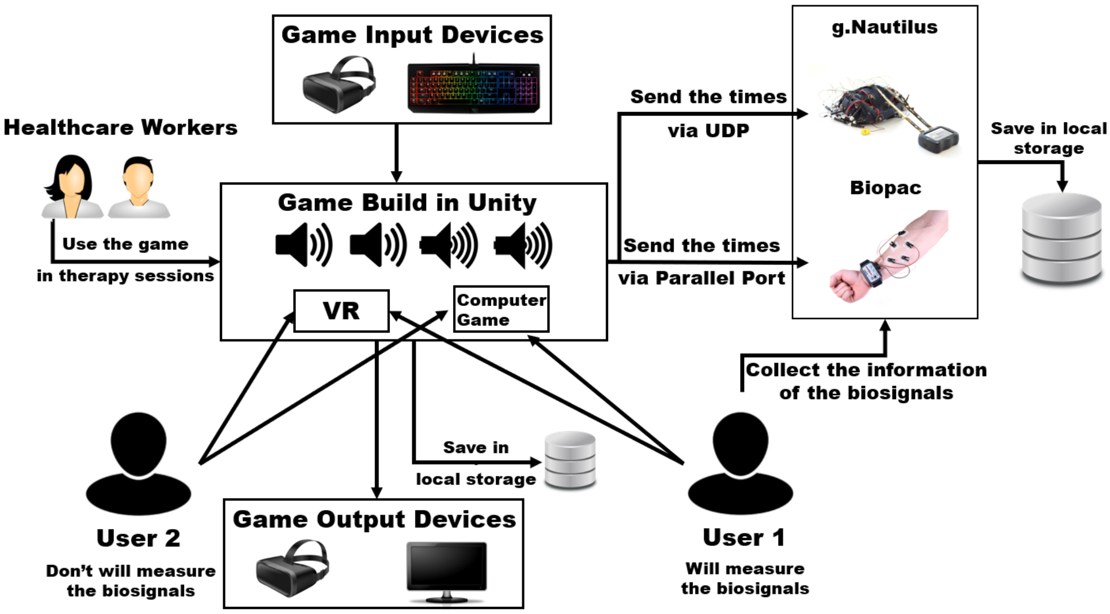


Figure 5.1: Architecture used for this dissertation.

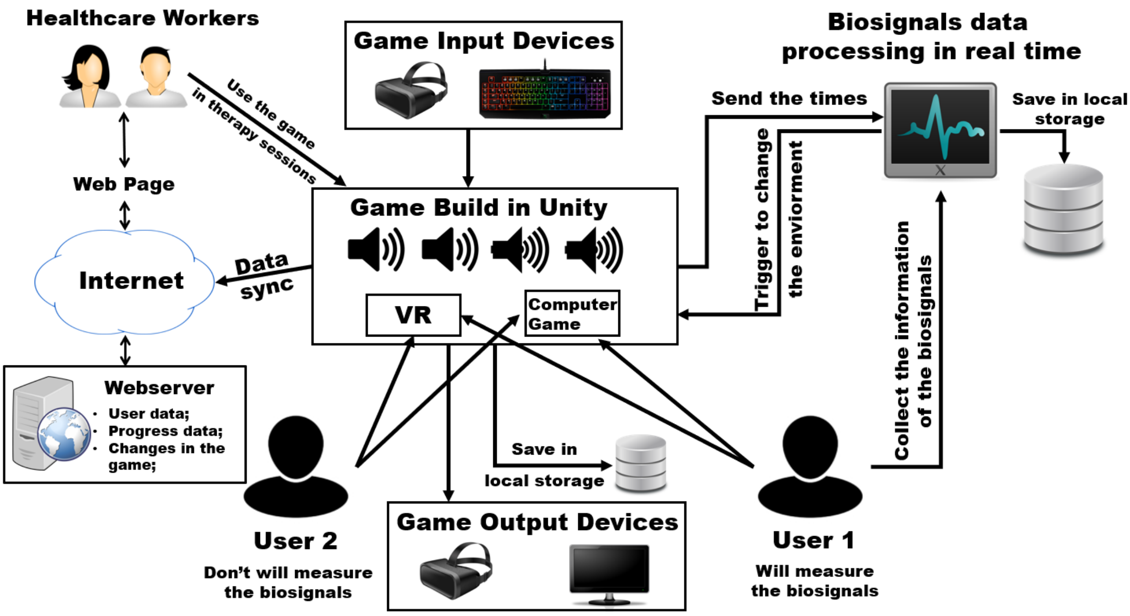


Figure 5.2: Architecture defined for the S3RRA project.

5.4 Design and implementation of the game

Through my undergraduate and master's degrees, I was able to learn how to use Unity, the tool used to develop the games for this dissertation. This experience allowed me not to need to learn how to use it during this dissertation, in order to develop computer games (played with a keyboard and mouse). In the case of virtual reality, however, it was necessary to learn through tutorials found on the internet. It was necessary to use the `Steam VR` library in order to achieve immersion and assign functionalities to the buttons of the controllers.

The next subsections refer to each part of the game in order to give an overview of the development process of each part of the game.

5.4.1 Menus

There are five menus in order to allow users to give the necessary setup until they start the game and they can be seen in order in Figure 5.3. The first is the main menu that allows the user to choose whether they want to play the game normally, do the tutorial, or close it. The second menu is for the biosignals that will be in use while playing the game. To select them, use the checkboxes in front of the name of each acquisition system. The next menu is about which sounds you want to interact with, and for that, you use the checkboxes to select them. Next is the menu where you select the difficulty you want for the game, being the difficulty selected is the one that is greyed out. The last menu serves to indicate the maximum volume that can support the sounds. In this menu, you can make it sound to sound or mix sounds as it is possible to interact in the city game. To do this just select the checkbox to activate the sound and move the slider of the sound to the maximum volume that can support it.

5.4.2 Tutorial

For the tutorial, a track was created where all the steps needed to overcome both the maze and any minigame are recreated. The tutorial starts with an explanation of how to move in the game and asks the user to move to a cardboard box that is a few meters in front of him. When you get close to it, it explains how to grab objects and asks you to move to the place indicated in green. After this delivery, a shopping cart will appear and the player is asked to take the cart to the supermarket shelf at the end of the track. To finish the tutorial it is necessary to place one product from the six shown in the cart. This final task allows the user to realize that they may have to stretch or stoop in real life to be able to grab the objects.

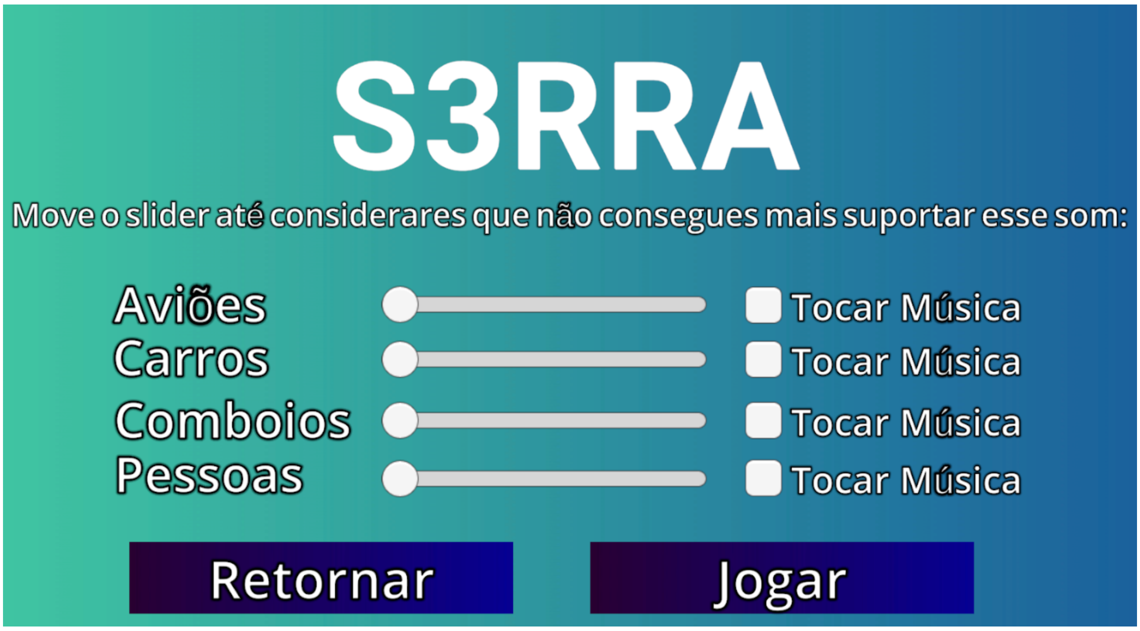
The images referring to the tutorial will be presented in the appendix B.

(a) Main Menu.

(b) Biofeedback Menu.

(c) Sounds selector Menu.

(d) Difficulty Menu.



(e) Menu that allows to select the volume.

Figure 5.3: The five menus.

5.4.3 Maze

The maze is always randomly generated using the Hunt and Kill algorithm. This algorithm has four phases:

1. Choose a starting location, A image from the Figure 5.4, in our case is the cell where the player will be found.

2. Make a random walk, carving a passage to unvisited neighbours, until the current cell is free of unvisited neighbours, B,D and F images from Figure 5.4.

3. Enter "hunt" mode, and scan the grid looking for an unvisited cell adjacent to the one you have already visited. In such a case, carve a passage between both cells and make the formerly unvisited cell your new starting point, C and E images from Figure 5.4.

4. Steps 2 and 3 should be repeated until the hunt mode has scanned the entire grid and has come up with no unvisited cells.

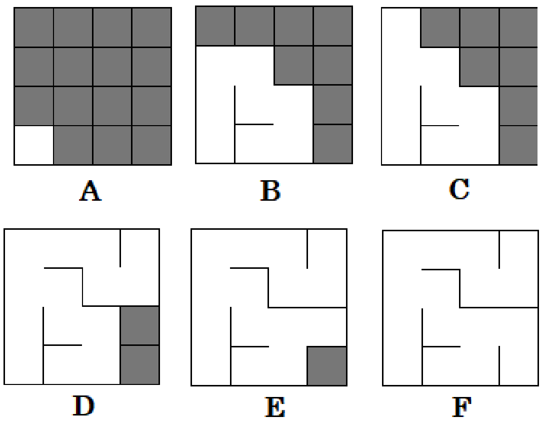


Figure 5.4: Example of the Hunt and Kill in 4x4 grid.

(Picture adapt from **Buckblog**)

According to the level in question the maze increases in size. On the easy level it is a 12x18 grid, on the medium level it is a 18x27 grid, and on the hard level it is a 24x36 grid. On the Figure 5.5, we can see a example of the maze in a easy difficulty. The most top left cell is where the player start the maze, and need to reach the blue cube on the most bottom right cell. The player is marked with a light blue.

To find the exit from the maze, I used the Depth-first search algorithm. To do that I converted the labyrinth to a graph in order to be able to apply this algorithm. The DFS algorithm works as follows:

1. Start by putting the graph's vertice corresponding to the player's location on top of a stack.

2. Take the top item of the stack and add it to the visited list.

3. Create a list of that vertex's adjacent nodes. Add the ones which are not in the visited list to the top of the stack.

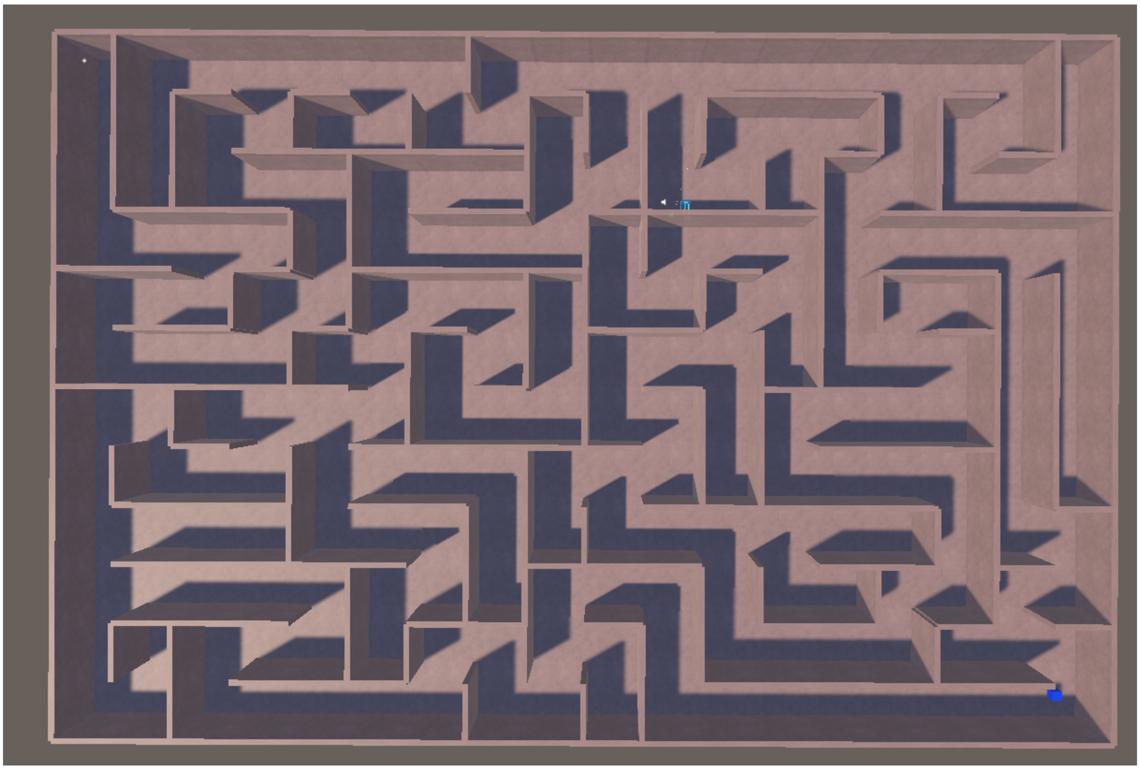


Figure 5.5: Example of a maze in a easy level.

4. Keep repeating steps 2 and 3 until finding the solution to solve the maze.
5. Return the solution.

In the Figure 5.6 its possible to see the solution path marked and in the Figure 5.7 is represented the way that is seen in VR. More images are available in the appendix **??**.

In the Table 5.1, you can see the relationship with the number of attempts of the minigames and the points you get when you finish the maze.

Number of tries	Points
0 or 1	2000
2	1250
3	800
4	400
5 or +	150

Table 5.1: Points you earn when you finish the maze.

5.4.4 Delivery game

This minigame takes place in a virtual city, where six possible delivery locations are marked in green "rocket ships", as shown in Figure 5.8. These locations are

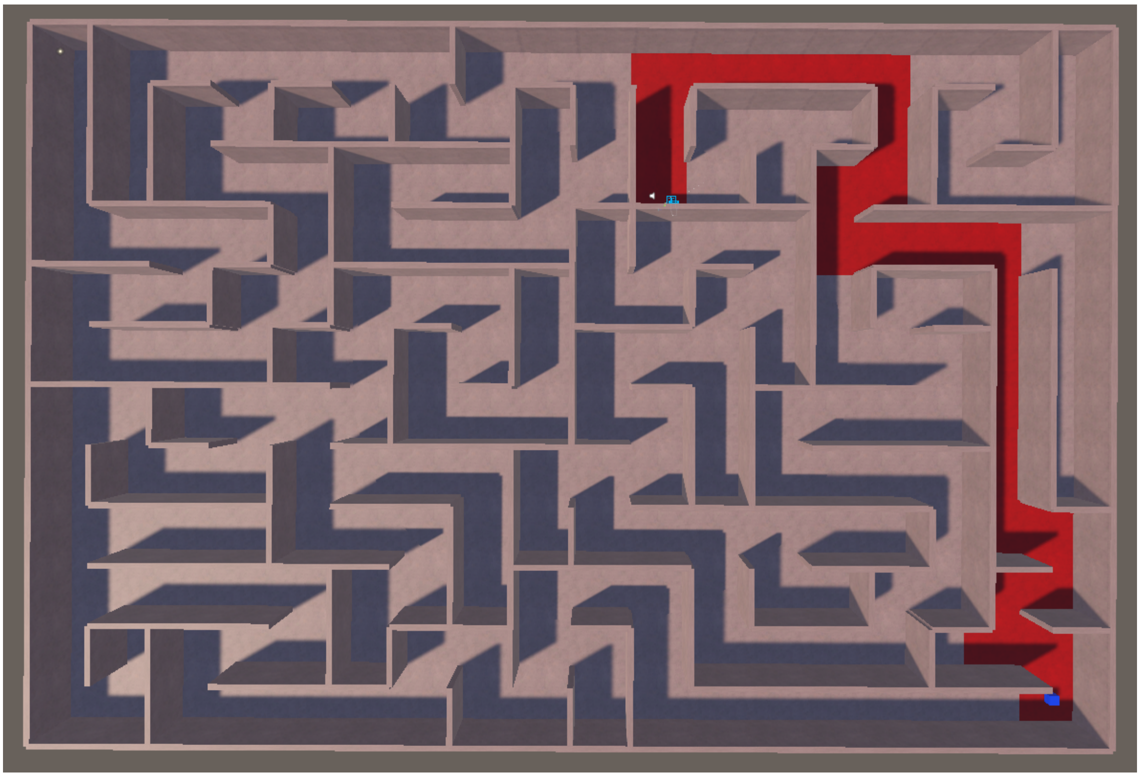


Figure 5.6: Solution of maze presented above.

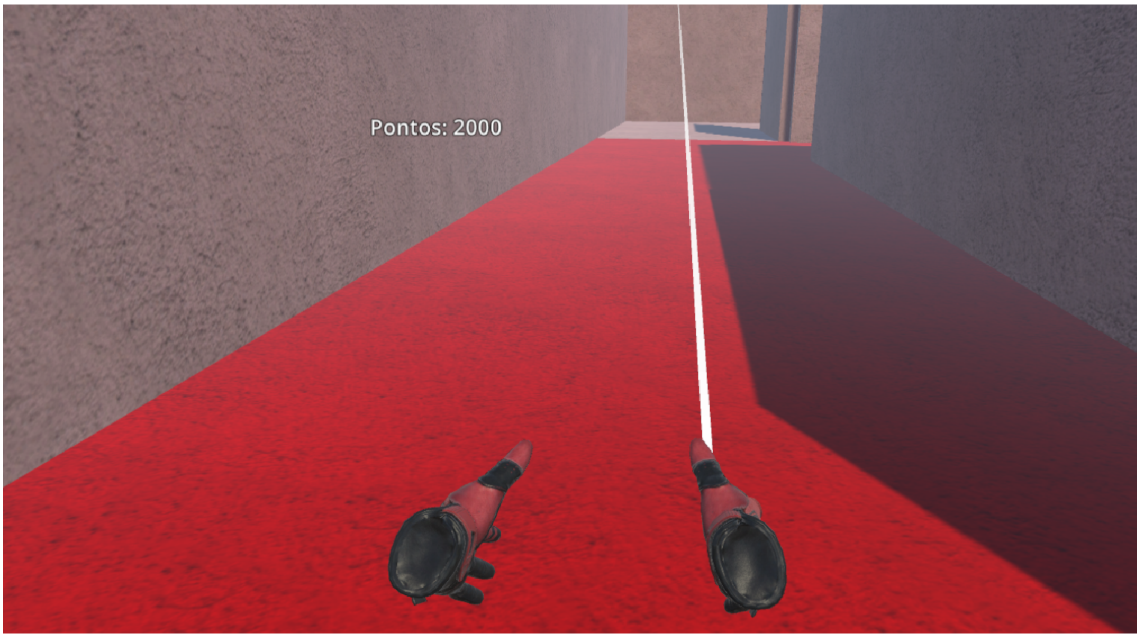


Figure 5.7: Visualization of the solution in VR.

always chosen randomly, and the level setup follows the configuration in Table 5.2, according to the difficulty of the game.

In Figure 5.8 you can see the complete map in an aerial view. The red ellipse marks where the player starts and the green lines represent the routes of the vehicles. More pictures to show this game mode can be seen in appendix D.

Difficulty	Time Available	Number of boxes to delivery	Number of Planes	Number of Trains	Number of Cars
Easy	2 min and 30 s	2	1	4	28
Medium	3 min and 30 s	4	2	6	56
Hard	4 min and 30 s	6	3	8	80

Table 5.2: Configuration of the delivery game.

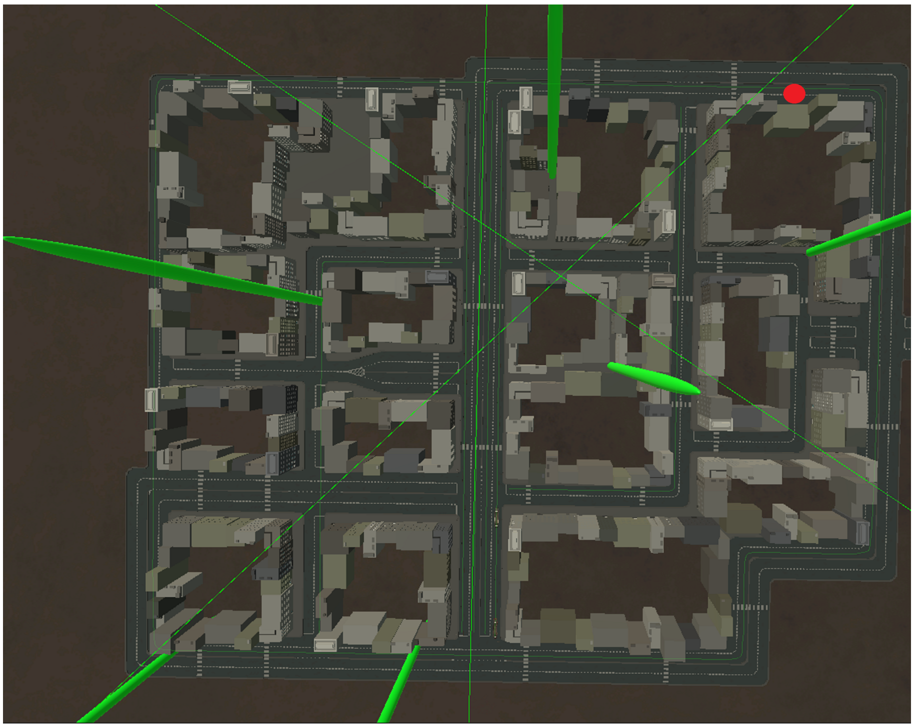


Figure 5.8: Aerial view of the city.

The following assets from the unit store were used to create this minigame:

- **City Voxel Pack** to create the City;
- **Cardboard Boxes Pack** to create the box to transport to the selected destinations;
- **Realistic Car 7-V5** to put cars in the virtual world. This asset is no longer in the Unity store;
- **Tram 1** to put trains and the train tracks on the city;
- **Planes & Choppers - PolyPack** to put planes on the city;
- **8K Skybox Pack Free** to select the skybox presented on the scene;
- **Bézier Path Creator** to make the routes for every vehicle.

In the Table 5.3, you can see the scores and rewards referring to this minigame.

Points and Reward Distribution									
Points	500 points for each box delivered.								
Difficulty	Easy			Medium			Hard		
Description	Make 1/3 of the deliveries	Make half of the deliveries	Make all deliveries	Make 1/3 of the deliveries	Make half of the deliveries	Make all deliveries	Make 1/3 of the deliveries	Make half of the deliveries	Make all deliveries
Reward	0 seconds of the maze solution	4 seconds of the maze solution	5 seconds of the maze solution	5 seconds of the maze solution	7 seconds of the maze solution	10 seconds of the maze solution	7 seconds of the maze solution	10 seconds of the maze solution	15 seconds of the maze solution

Table 5.3: Points and rewards when return to the maze.

5.4.5 Shopping game

This minigame takes place in a virtual supermarket, where the player needs to finish the shopping list than appears on the screen, as shown in Figure 5.9. Exist more props that the ones that can appear in the shopping list. This list is always chosen randomly, and the level setup follows the configuration in Table 5.4, according to the difficulty of the game.

Figure 5.9: Beginning of the suppermarket game in easy.

Difficulty	Time Available	Items to buy	Number of Persons
Easy	2 min and 30 s	5	5
Medium	3 min and 30 s	8	8
Hard	4 min and 30 s	12	11

Table 5.4: Configuration of the supermarket game.

The following assets from the unit store were used to create this minigame:

- **Modern Supermarket** to build the entire supermarket including props;
- The **people** in the supermarket it is made with prefabs that are included in order projects of CIBIT;
- **Bézier Path Creator** to make the routes for the persons that have static routes;
- **NavMesh** is an artificial intelligence asset that allow the developer to make agents find the fastest way to reach an endpoint. This asset allow me to make some of the persons have a random behaviour in the supermarket.

More pictures to show this game mode can be seen in appendix E.

In the Table 5.5, you can see the scores and rewards referring to this minigame.

Points and Reward Distribution									
Points	100 points for each product inserted in the chart.								
Difficulty	Easy			Medium			Hard		
Description	Make 1/3 of the deliveries	Make half of the deliveries	Make all deliveries	Make 1/3 of the deliveries	Make half of the deliveries	Make all deliveries	Make 1/3 of the deliveries	Make half of the deliveries	Make all deliveries
Reward	2 seconds of the maze solution	4 seconds of the maze solution	5 seconds of the maze solution	5 seconds of the maze solution	7 seconds of the maze solution	10 seconds of the maze solution	7 seconds of the maze solution	10 seconds of the maze solution	15 seconds of the maze solution

Table 5.5: Points and rewards when return to the maze.

5.4.6 Biosignal connection

Through the setup allowed by the menu in Figure 5.3b, it is possible to connect to the biosignals.

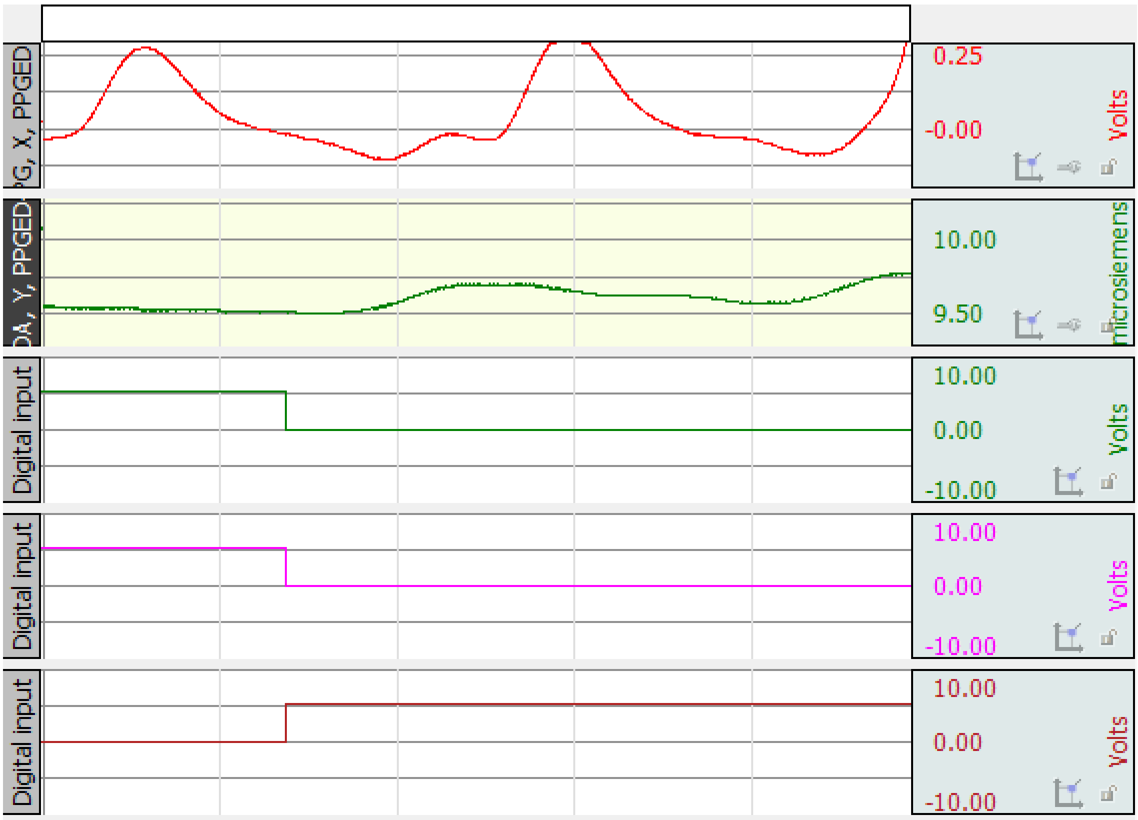
To connect to the `BIOPAC` system it was necessary to make a connection through a parallel port to the system. In the case of `g.Nautilus`, we made a connection to the system via UDP in order to send the information. For both systems, the messages are just an integer referring to the event that happened during the game. The following list represents the integer that is sent and the event that is associated with it.

1. Start of the game;
2. Started the City Minigame
3. Grabbed an Object
4. Delivered the Box
5. End of Delivery Minigame
6. Started the Supermarket Minigame
7. Put an object in the Cart
8. End of Supermarket Minigame
9. End of Maze

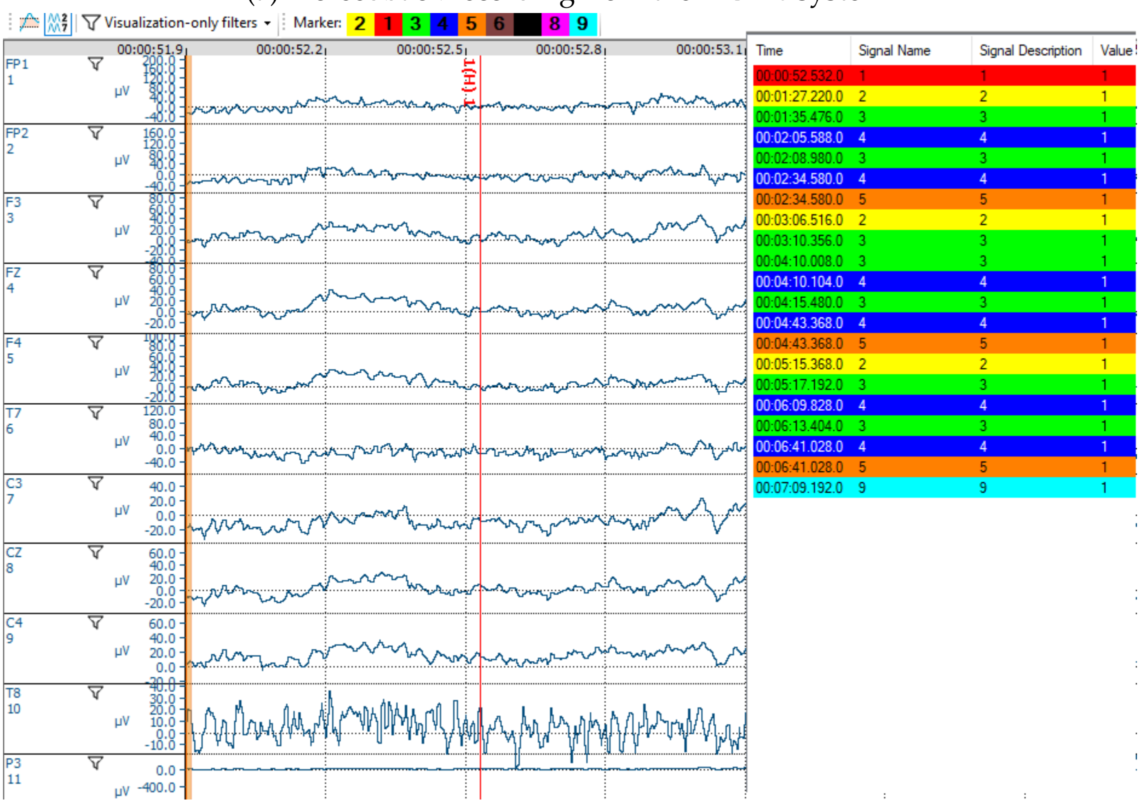
Figure 5.10 shows two biosignals collected while testing the game. In Figure 5.10a is a signal collected through the `BIOPAC` system in which it is possible to see that the trigger is marked with a four in the digital inputs. On figure 5.10b is a signal collected by the `g.Nautilus` system where it is possible to see the trigger with the number one marked on the signal by the red stripe and the list of all the events that happened on the right side of the image.

5.4.7 Logs

Due to the need to store the volume of the sound sources for later cross-referencing with the information that was collected on the biosignals, the need was seen to create a logging system. Throughout each minigame, the sound source and the volume of the sound produced are stored, and at the end of each minigame, a JSON with this information is stored. At the end of the maze, the JSON files are all compiled into a new one, Figure 5.11, with that information and the maximum volume of each type of sound chosen, the number of attempts and the seed to regenerate the maze.



(a) Biofeedback recording from the BIOPAC system.



(b) Biofeedback recording from the `g.Nautilus` system.

Figure 5.10: Two biosignals collected while testing the game.

```
{"level":1,
"volumePlanes":0.307140082,
"volumeCars":0.302169174,
"volumeTrains":0.3069539,
"volumePeople":0.0,
"points":500,
"minigamesTries":2,
"giveUp":true,
"key":"14233421144122211113134442433432211432414221444214414 2",
"listLogSound":[{"timeStamp":"12:21:20:524","sound":0.0917,"name":"Car 7 (2)(Clone)"},
{"timeStamp":"12:21:20:548","sound":0.0915,"name":"Car 7 (2)(Clone)"},
{"timeStamp":"12:21:20:570","sound":0.0913,"name":"Car 7 (2)(Clone)"},
{"timeStamp":"12:21:20:592","sound":0.0911,"name":"Car 7 (2)(Clone)"},
{"timeStamp":"12:21:20:615","sound":0.0909,"name":"Car 7 (2)(Clone)"},
{"timeStamp":"12:21:20:636","sound":0.0906,"name":"Car 7 (2)(Clone)"},
{"timeStamp":"12:21:20:659","sound":0.0904,"name":"Car 7 (2)(Clone)"},
{"timeStamp":"12:21:20:679","sound":0.0901,"name":"Car 7 (2)(Clone)"},
{"timeStamp":"12:21:20:702","sound":0.0897,"name":"Car 7 (2)(Clone)"},
{"timeStamp":"12:21:20:724","sound":0.0894,"name":"Car 7 (2)(Clone)"},
{"timeStamp":"12:21:20:746","sound":0.089,"name":"Car 7 (2)(Clone)"},
```


Figure 5.11: Example of the beginning of a log.

5.5 Differences between the two games

Both games have the same goal, but also have differences in the gameplay of each.

The first difference is that running is allowed by pressing the shift key on the left side in the computer game, which allows the speed to always be the same regardless of which part of the game you are in. In the VR setting, on the other hand, the speed is different in each part of the game in order to adapt more easily to what you have to do.

The next difference is that you are allowed to grab objects from a certain distance in the computer game, but you can only grab one item at a time. In the VR game you really have to be touching the object, but you can carry an object in each hand.

The third difference was necessary because of how the rendering of the environments in the VR glasses is done. It is only rendered up to a certain distance from the player's position, so one had to be very close to the delivery locations, in the delivery game, in order to be able to see where those locations were. Since the players do not know which one is active, it was necessary to put an arrow indicating the direction to the delivery location.

Another difference between the games is the UI within them. When the VR headset is not fully tightened, the corners of the observed image start to blur, and it is impossible to read the information in the corners. So for the VR game, the UI is centred while in the computer game it is near the edges of the screen.

Because of some changes described above, it was necessary to adapt some instructions in the tutorial and in each minigame.

5.6 Time plan

In the Figure 5.12a it is possible to see that the plan defined in the beginning of the first semester. This plan has five order tasks:

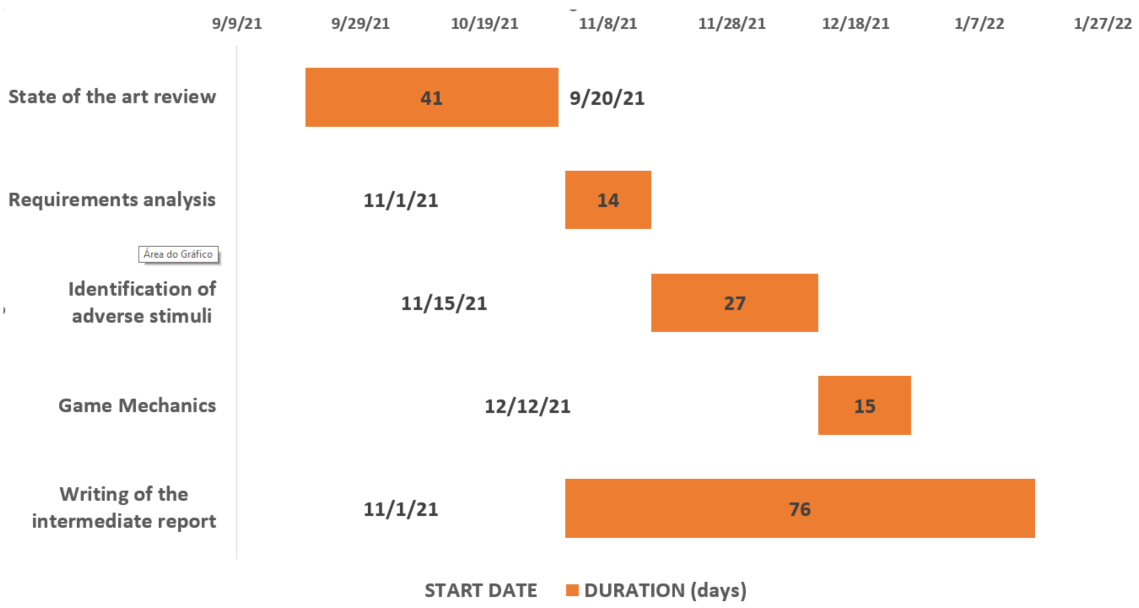
1. **State of the art** review that will originate chapter 3 of this document and that is what will give me the basis for this work;
2. **Analysis of the system requirements** and for that it was necessary to make a connection between the analysis made of the state of the art and what the psychologists and researchers wanted for this piece of software. This fusion of the information will generate the Section 5.2 and the Section 5.3;
3. **Identifying the adverse stimuli**, was a joint effort between me and psychologist Daniela in order to get the best possible results. This work is shown in the Chapter 4;
4. After analyzing the survey results it was possible to define the **game mechanics**, resulting in the Section 5.1;
5. **Writting of the intermediate report**;

Comparing the two graphs in Figure 5.12 it is possible to see that not everything went as expected, the first two tasks were faster than expected, but the third one was more time-consuming because it was difficult to get the results from the associations, which caused the time that was gained in the first two tasks to be lost. Another unforeseen thing was the work that the three disciplines that are in the first semester were doing, so I could only start writing the intermediate report when they were almost done.

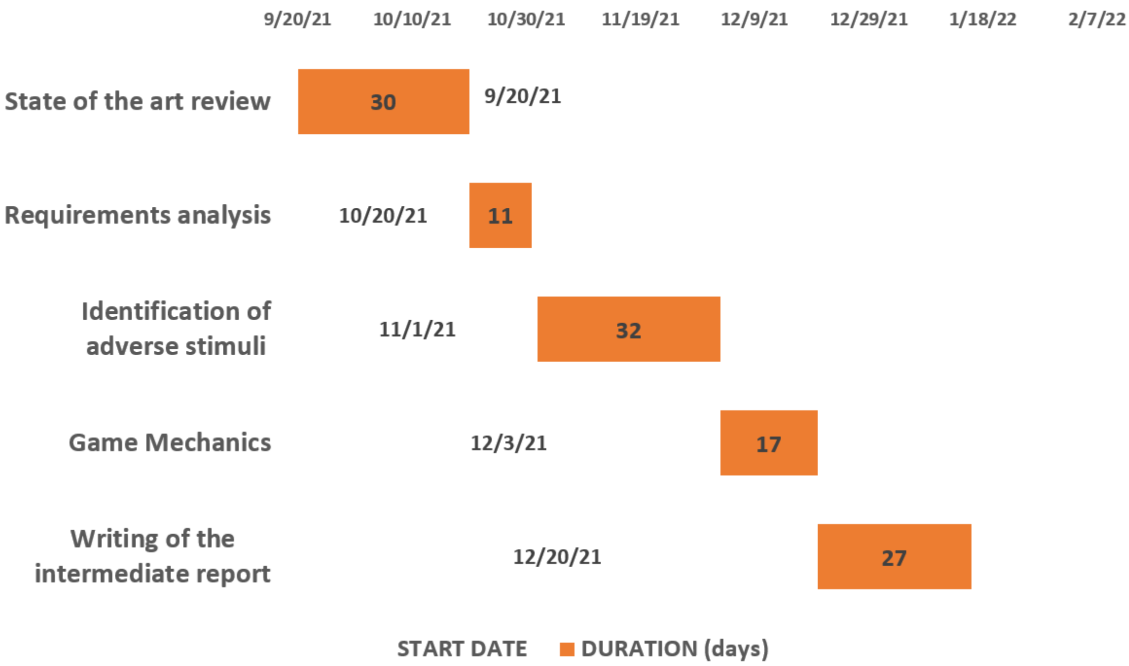
In the second semester, the work is divided into six tasks that were planned according to Figure 5.13a. The tasks are:

1. **VR tutorial** to give me knowledge how to work with VR;
2. Development of the **Maze**, that generate the Section 5.4.3;
3. Development of the **Delivery Game**, that generate the Section 5.4.4;
4. Development of the **Supermarket Game**, that generate the Section 5.4.5;
5. Connect to both the **biosignals systems**, that generate the Section 5.4.6;
6. **Write the dissertation**, that genereate this paper;

Regarding the validation of the game, no time frame was planned to carry it out, since it was necessary to fit into the schedules defined by them. The tests took place on August 18 for the pilot population and on August 25 for the population with autism. The delays were noticeable in the first activity since it took a long time to access the room with the VR equipment. A lot went on during this semester that delayed the work, so on May 14, we decided to postpone the delivery to the special season.

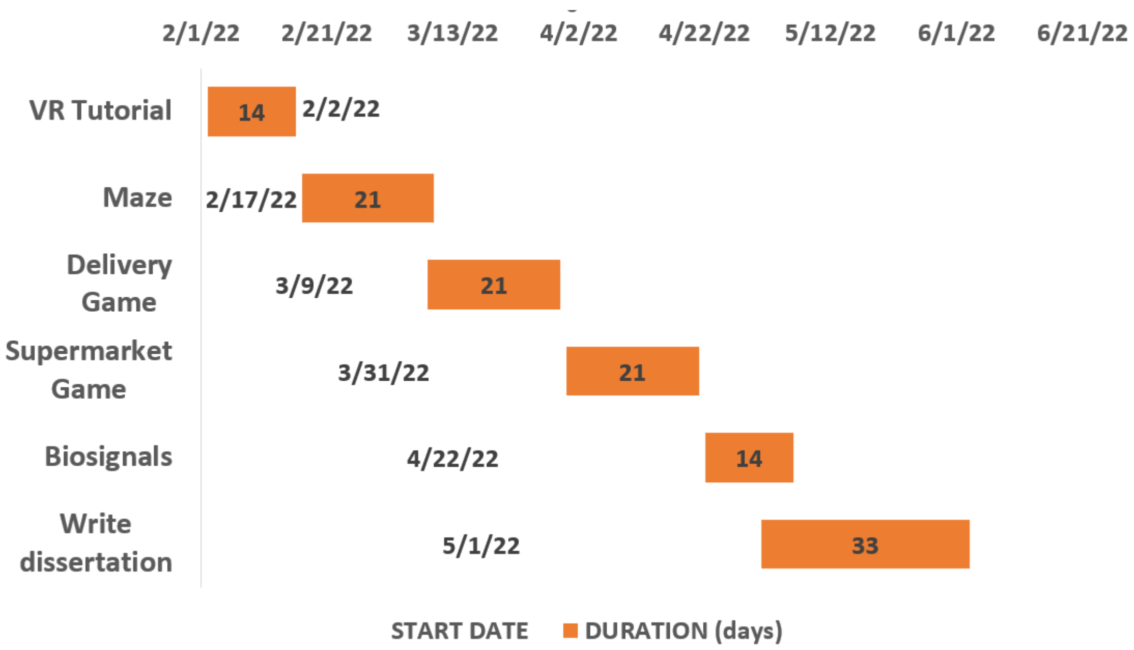


(a) Plan for the first semester.

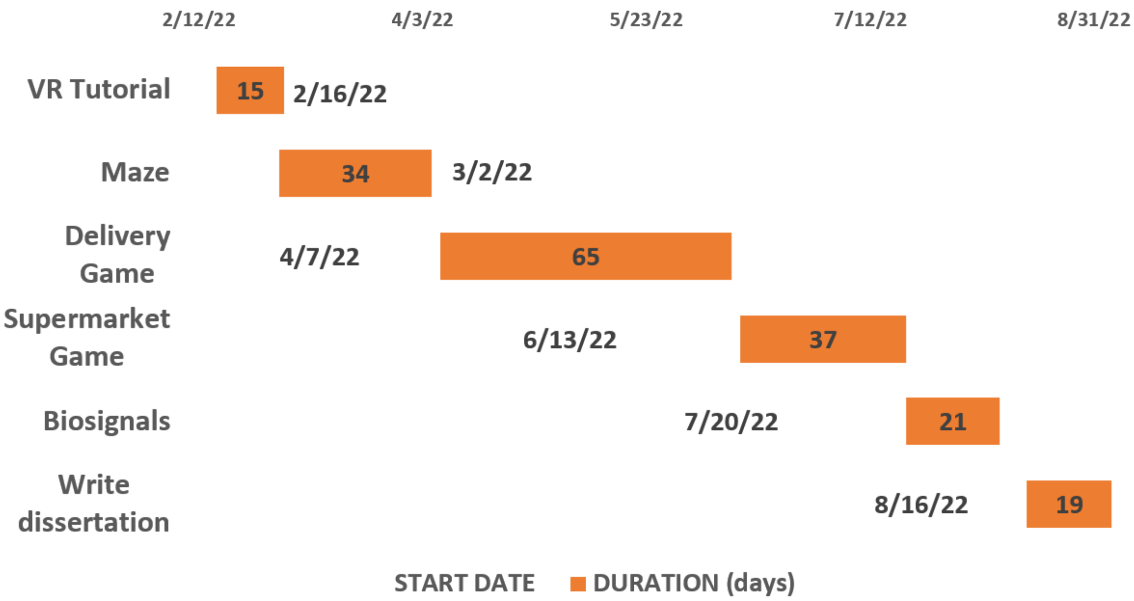


(b) Plan executed in the first semester.

Figure 5.12: Gantt charts for the first semester.



(a) Plan for the second semester.



(b) Plan executed in the second semester.

Figure 5.13: Gantt charts for the second semester.

Chapter 6

Evaluation of the game

Validation of the game was performed firstly with four pilot participants and after with three people with autism. First, was performed an oral interview in order to know more about familiarity with videogames, playing videogames, the participants' opinions about Virtual Reality (VR) and if they feel sick at that moment. After that, both groups performed a guided list when the last two are given in random order so that in the end they could give their opinion about the usability of the game. The plan always started with the tutorial and after that, some started with the delivery game and others with the supermarket game, but everyone played all the minigames. The tests ended with a usability and sensorial survey in order to get information to improve the game.This questionnaire followed a scale used by psycholgos in order to evaluate the person's sensory profile. This scale is composed of the following levels:

- **almost never** - up to 5% of the time;
- **rarely** - about 25% of the time;
- **occasionally** - about 50% of the time;
- **frequently** - about 75% of the time;
- **almost always** - about 95% or more of the time;

In none of the tests were the biosignals acquired due to material problems which led to the fact that in the time available in this dissertation they were not tested with any of the groups of people. The reduced number of participants for the pilots was due to few people being present during the month of August in Coimbra. Regarding the number of people with autism, it was always going to be small since there were not many in the association on the day of the tests, but they were even smaller since it was badly estimated the time of each experiment that each individual would need to complete the game, and then at the end of the third person the headsets ran out of battery and with the time available it would not be possible to charge the device and perform the test with someone else.

This chapter has three sections where the first section is related to the results of the pilot tests, then the one related to the results of the tests of the autistic population, and finally observations made during the tests and other information about the tests.

6.1 Results of the pilot population

Four participants (all males), ages between 22 and 23 and without any presenting illnesses or symptoms that could influence the experience. All of them have high experience in video games on computers and commercial consoles, but none of them has tried VR before.

Regarding the tutorial, all the people mentioned that the instructions are clear and easy to understand. Relatively the menus, the indications given were also easy to understand, but there was a suggestion to appear next to the volume slider the volume that is marked by him. This idea was discarded since this value could influence the player with autism not to overcome a certain barrier. Regarding the instructions given the first time, you try one of the games in all of them I received a suggestion. For the maze indicate in the text explaining the clue what colour the clue is. For the delivery game, the suggestion is to always make the arrow visible on the camera, something that unity's `lookat` function doesn't allow. For the supermarket game, the suggestion was to make an animation when you put the products in the cart.

Relatively the VR experience, only one needed to stop the simulation during the course of the experiences due to nausea and/or headaches, and another reported that he felt the need to stop for the same reasons but did not want to stop. After the immersion, 50% of the participants reported that they were feeling dizzy. Regarding the controls, 75% of the participants reported that the shaking of the controls would cause them to discomfort up to 25% of the time they were shaking while the rest did not bother them. Relatively the VR headsets, two of the participants reported that they caused discomfort, one up to 25% and the other up to 50% of the time they were with them, and both reported that they needed to use vision obstruction strategies (e.g. closing their eyes) during testing.

6.2 Results of the autistic population

Three participants (two males and one female) and none of them present any illnesses or symptoms that could influence the experience, except being autistic. All of them have experience with video games: one with computer games and the others with commercial consoles.

Regarding the buttons, instructions, and usability of the menus, only one person found the buttons on the controls too sensitive, which made it difficult for him to perform tasks such as grasping objects. Regarding the other parameters, everyone agreed that they were easy to understand and execute.

Relatively the VR experience, two of them needed to stop the simulation during

Figure 6.1: One of the pilot participants during the tests.

the course of the experiences due to nausea and/or headaches. After the immersion, 66% of the participants reported that they were feeling dizzy. Regarding the controls, only one of the participants reported that the shaking of the controls would cause them to discomfort up to 25% of the time they were shaking while the rest did not bother them. Relatively the VR headsets, one of the participants reported that they caused discomfort to 50% of the time they were with them. One of them reported that they needed to use vision obstruction strategies (e.g. closing their eyes) during testing.

6.3 Observations

The ten-second increase in the time it takes to walk the maze, which changed between the study of the two populations, did not make the people with autism finish faster, but it did make them able to move more calmly and adapt better to the existing movement within the maze.

Another fact observed was that in the normal population, after two or three attempts, they were able to complete the mini-games, while in the autistic population, even after the fifth attempt, they were still unable to finish the levels. Therefore, it will be necessary to increase the time of the minigames so that they

Figure 6.2: One of the participants with autism during the tests.

can complete them and take advantage of the maximum reward. Since they never managed to complete the level, it is hard to ascertain whether the way they are being shown the correct path is efficient as they got a bit lost in the transition from maze to minigames and back again and the time available was always too short. But in principle, from the feedback given even by the short time of interaction, it seemed that it is well executed.

The problem pointed out by one person in the pilot population is the difficulty in understanding that the item has already been placed in the shopping cart. The suggestion given was to have an animation when putting the item in the cart. This animation could not have many visual or sound effects so that there would be no distraction from what was being done. Another action observed in this minigame is that the autistic population never grabbed two items at the same time when it would be possible to do so.

In relation to the sensory profile, it was not possible to draw conclusions and comparisons between the two populations since the sample was small and very different between them. This profile contained questions such as whether they felt pleasure or discomfort from all the sounds included in the game, whether the sounds were helping or distracting from the task they were doing, and finally, a prolongation to understand the influence of other sounds in the person's life.

Regarding the biosignals, the faults were composed in early September and a pilot was attempted in order to obtain data for this dissertation. It was not possible to find anyone willing to participate, so we only tested the connections between the game and the two acquisition systems. Some of the results produced can be seen in Figure 5.10 and in Figure 6.3 it is possible to see what it looks like when the whole system is assembled.

Figure 6.3: The whole system assembled.

Chapter 7

Conclusion and Future Work

Due to the few tests that could be done consequently due to various factors such as time and people's availability to perform the tests, it is not possible to conclude whether the game is ready for a clinical trial, but the positive comments left at the end of the experiments referred to by both populations leads one to think that this goal is not far off. For the Autism Spectrum Disorders (ASD) people, they made a note of how much they enjoyed the experience they just had and when it would be done again, several times while they were taking the final quiz. For those who did not have the opportunity to experience it, they also let us know how quickly they hope to have another experience because they also wanted to experience something in Virtual Reality (VR).

Regarding the difficulties of doing all this work, the most difficult was writing this report, but the connection of the biosignals and transforming the game from computer to VR were able to give the headaches. This work also served to work with people from different backgrounds such as psychologists and biomedical engineers and learn from all of them.

For future work, we will need to do studies with biosignal acquisition, and do more tests with people with autism to figure out when we can move into a clinical trial. Regarding the changes that need to be made to the game that has already been detected: introduce something that allows the player to realize that he has already inserted something in the cart, such as a hand animation when he hands it in; make it clear that grabbing using both hands is allowed in the instructions for the supermarket game; adjust the times for the minigames.

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Appendices

Appendix A

Personas

Catarina, the Kind Psychologist
Catarina has been a psychologist for five years in an association of autistic individuals, and she is known for being kind to everyone. She is 29 years old and has a son diagnosed with autism, and she lives in a city that has many sounds that disturb him.
Catarina loves technology, especially those that can use during his work. The main objective of her work is to help autistic people improve their daily lives, but she didn't find a good method for maintaining the patient's focus during therapy, so she plans to introduce computer games as a method of motivating them.

(Picture adapt from **careergirls**)

(Picture adapt from **vistahealthcare**)

André, the Survivor Kid
André is 10 years old student that has been diagnosed with autism since his 2 years old. He needs a wheelchair since a car accident when he is visiting his grandparents.
He loves playing computer games and painting. André life goal is to become a landscape painter but he knows to achieve that we need to face sounds that makes him uncomfortable.

António, the Sensitive and Marcelo, the Restless
António and Marcelo are fake twins, both autistic with 4 years old. António is really sensitive, so he is very careful, for a person with is age, with everything that he touches, manly if is something made with velcro. Marcelo is restless and moves everything to find new stuff. They are very competitive with each other in any daily activity. They don't know about the computer games world yet, but their therapist will start using them during therapy.

(Picture adapt from **thehealthsite**)

Ana, the Dreamer
Ana is 59 years old and is a poetess with some books published. She likes to walk in the city to gain inspiration from what she sees. She wears gloves because of her high sensitivity to touch. She is the number one fan of Tony Carreira, but she has never seen a live concert of him because of her lack of mobility and his negative reactions to the light effects used during the concert.

(Picture adapt from **theneighborhoodadvocate**)

Appendix B

Tutorial Images

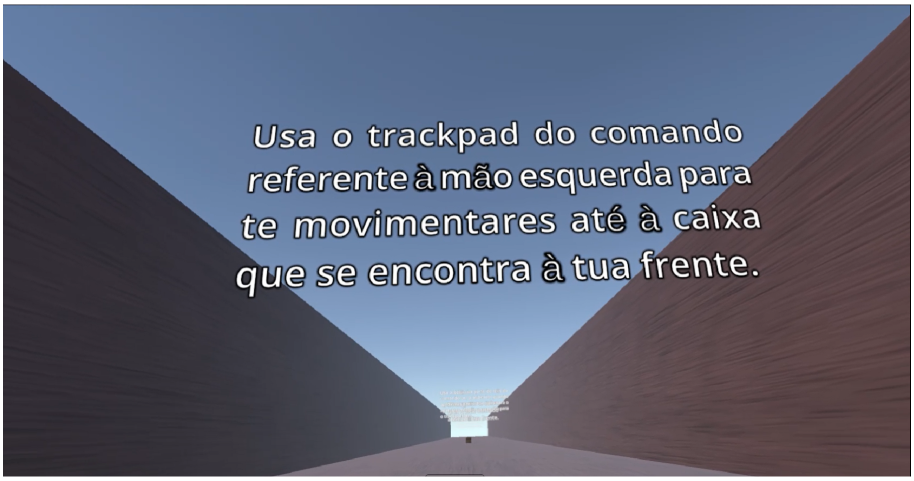

Figure B.1: First instruction.

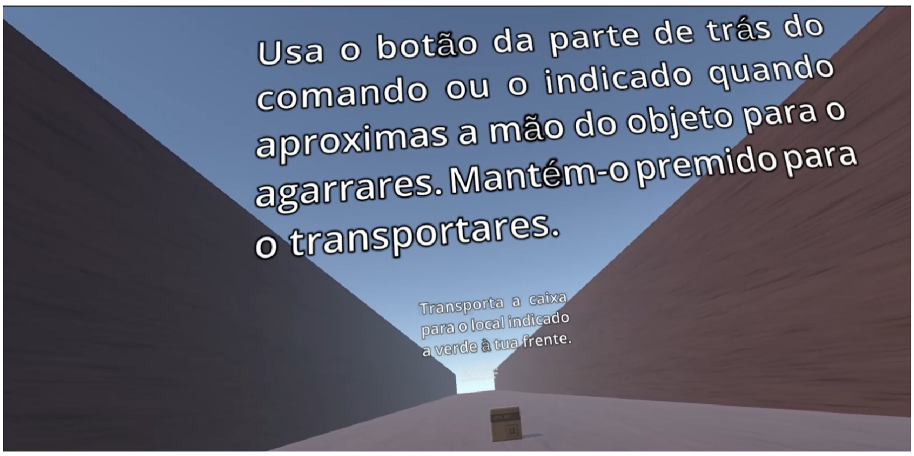

Figure B.2: Second instruction.

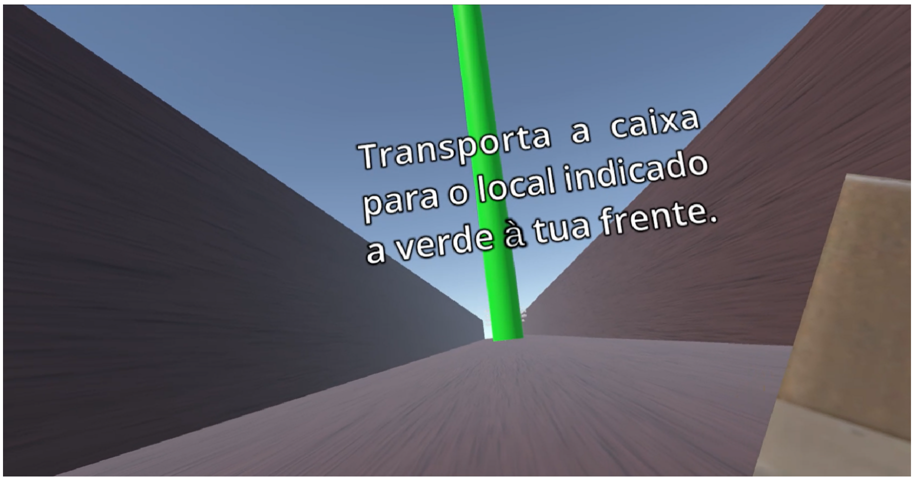

Figure B.3: Third instruction.

Figure B.4: Fourth instruction.

Figure B.5: Fifth instruction.

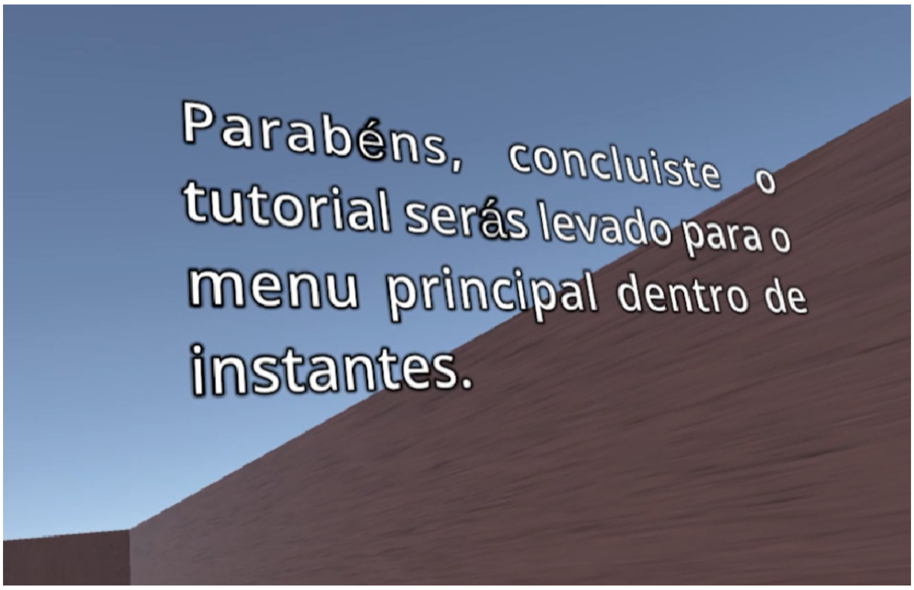

Figure B.6: Sixth instruction.

Figure B.7: First instruction in the computer version.

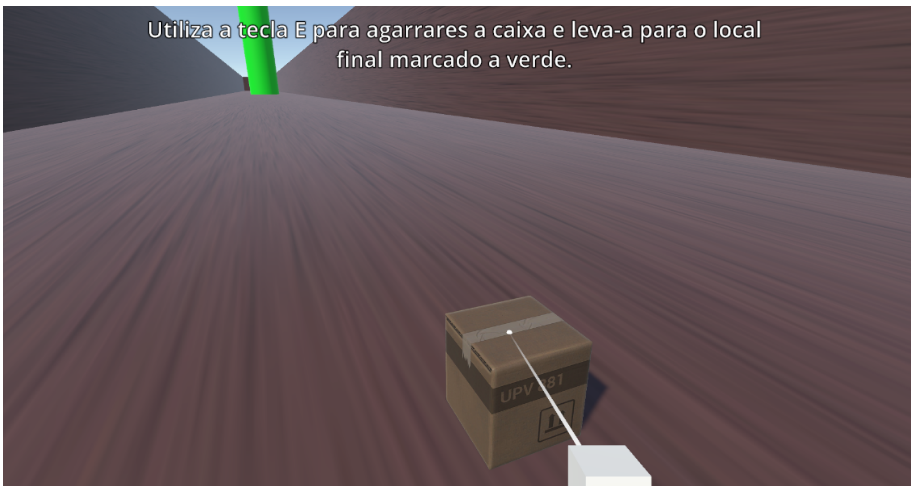

Figure B.8: Second instruction in the computer version.

Appendix C

Maze Images

Figure C.1: First instruction.

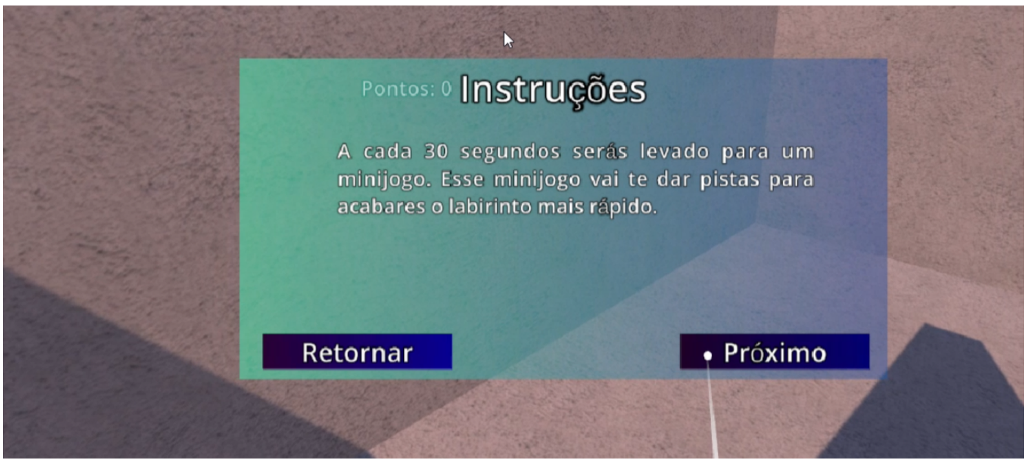

Figure C.2: Second instruction.

Figure C.3: Third instruction.

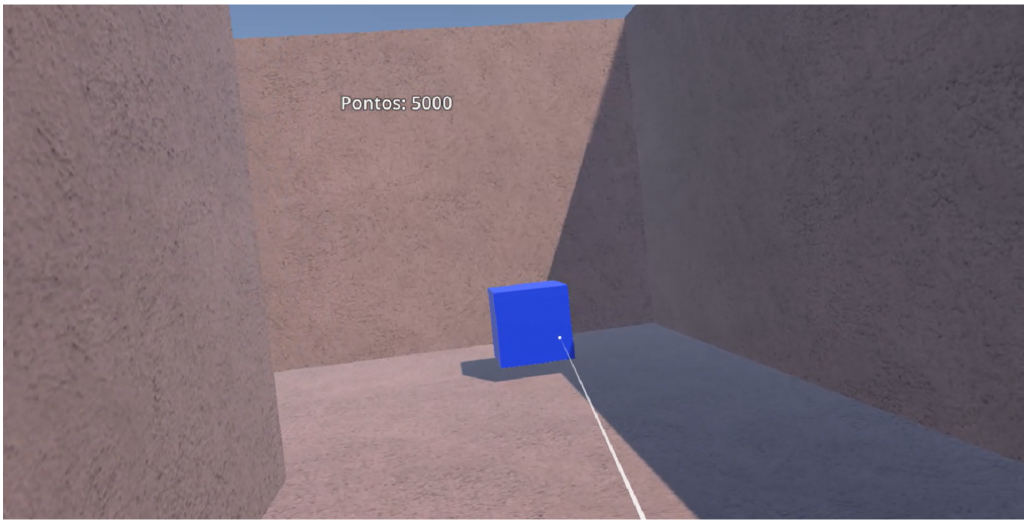

Figure C.4: Final place.

Appendix D

Delivery game images

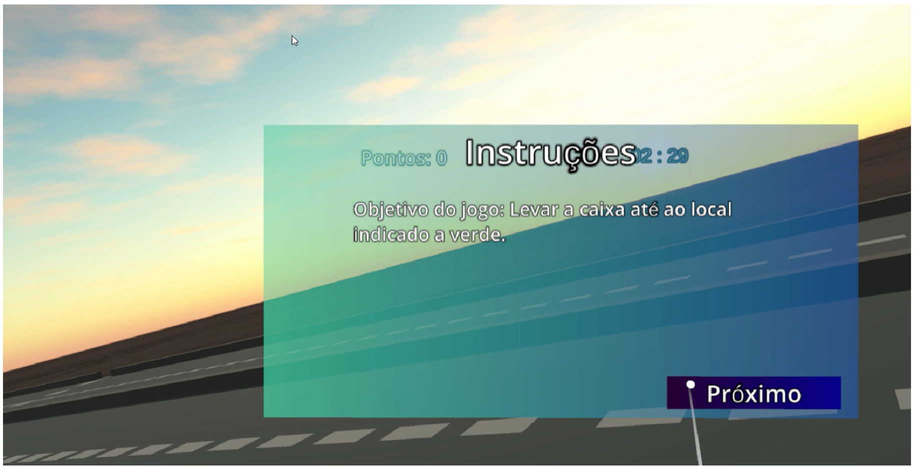

Figure D.1: First instruction.

Figure D.2: Second instruction.

Figure D.3: Third instruction.

Figure D.4: Fourth instruction.

Figure D.5: Fifth instruction.

Figure D.6: Sixth instruction.

Figure D.7: Delivery location.

Figure D.8: Main road in easy level.

Figure D.9: Beginning of the minigame in easy.

Figure D.10: Beginning of the minigame in medium.

Figure D.11: Beginning of the minigame in hard.

Figure D.12: Show the key that you have to press to grab the box.

Figure D.13: Second instruction in the computer version.

Figure D.14: Third instruction in the computer version.

Figure D.15: View in computer version.

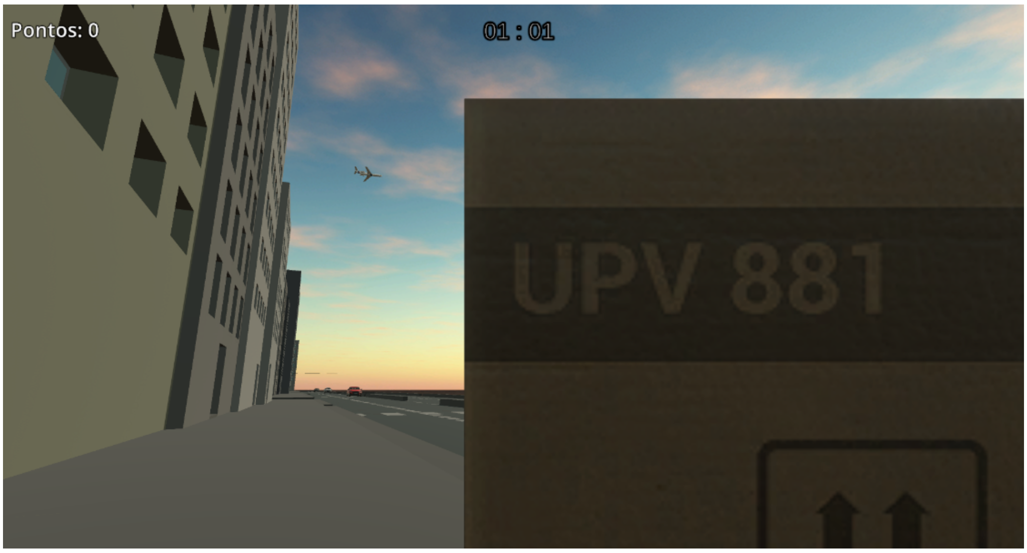

Figure D.16: Holding a box in computer version.

Appendix E

Supermarket game images

Figure E.1: First instruction.

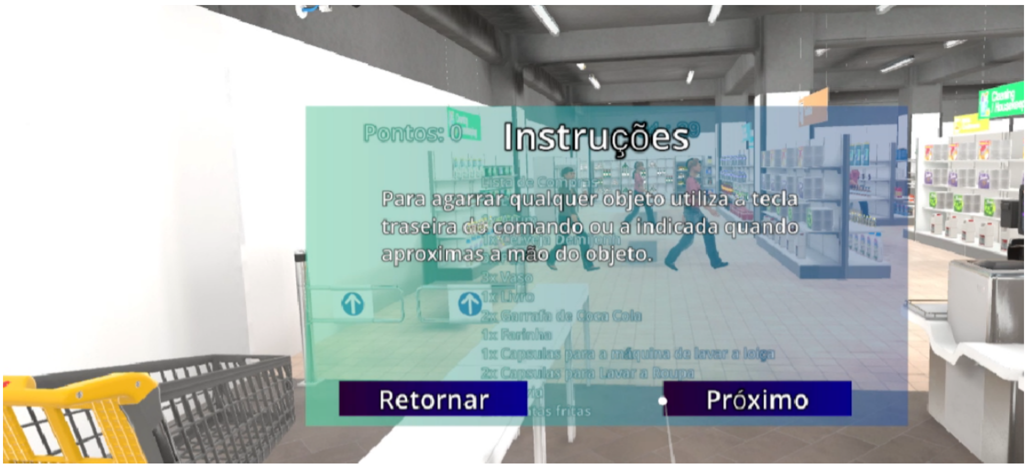

Figure E.2: Second instruction.

Figure E.3: Third instruction.

Figure E.4: Last supermarket aisles.

Figure E.5: Grabbing two items at the same time.

Figure E.6: Shopping list in medium level.

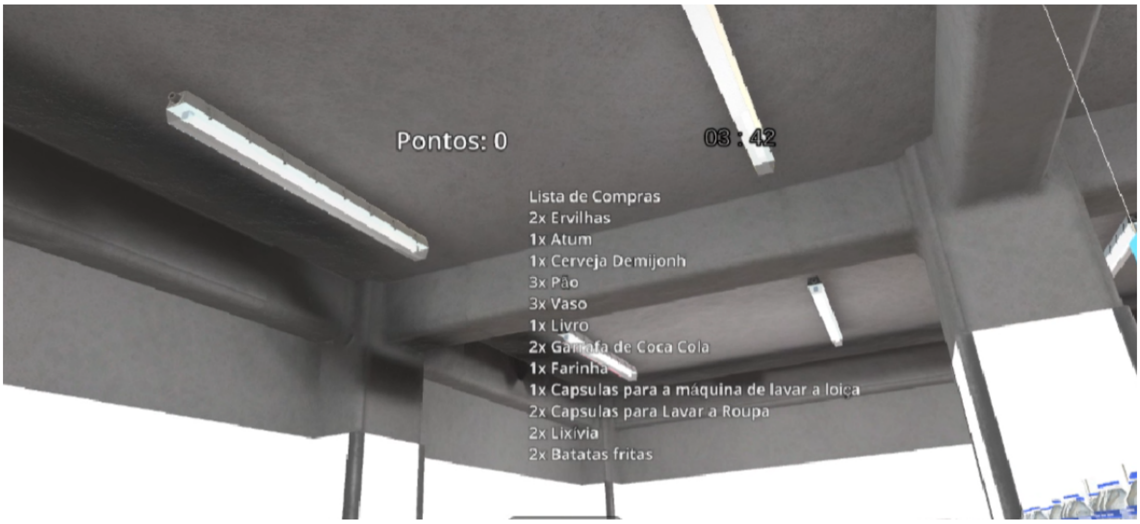

Figure E.7: Shopping list in hard level

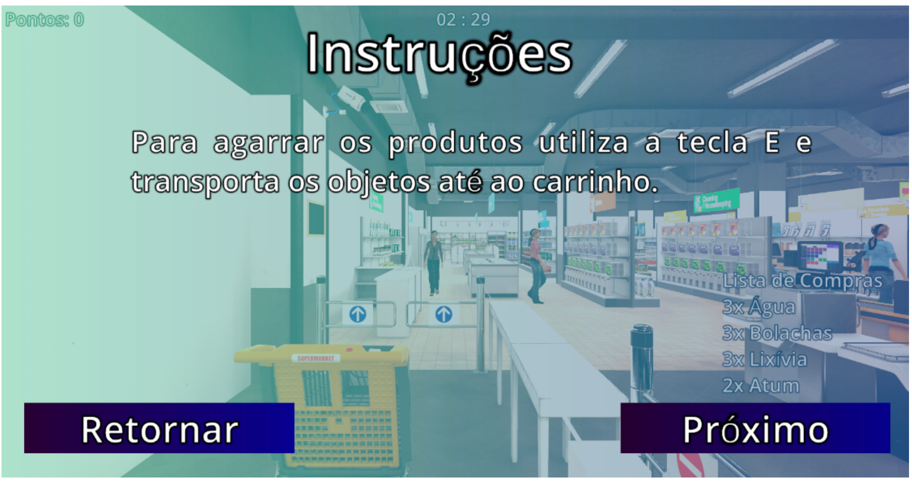

Figure E.8: First instruction in computer version.

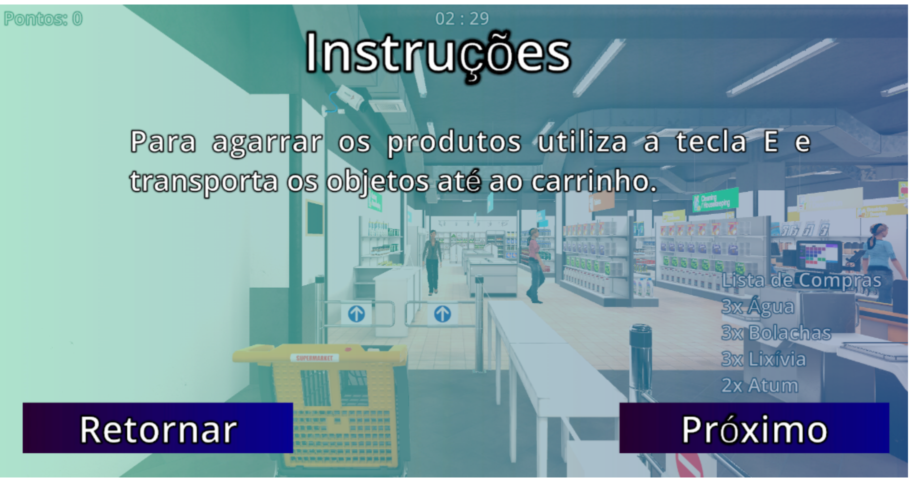

Figure E.9: View in computer version.