Diploma Project

VIRTUAL ENVIRONMENTS FOR THE IMPROVEMENT OF WELL-BEING FOR PEOPLE SUFFERING FROM DEMENTIA VALIDATED VIA EYE-TRACKING

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Abstract

Dementia is one of the major causes of disability and dependency among older people worldwide. It is a syndrome in which there is deterioration in cognitive function beyond what might be expected from normal ageing. There is no cure or treatment to slow the progression. Nonetheless, there are some drug treatments and therapies to improve the symptoms for a short period of time.

People suffering from dementia are forced to stay at home or in a hospital care environment. Most of the patients require support from a caregiver, while some who are suffering from a more severe type of dementia might be confined to bed. Consequently, they start to feel inferior and depressed since they are restricted in specific environments and are unable to complete simple tasks on their own.

This project aims to create virtual environments for the improvement of the emotional well-being of people suffering from dementia. The goal is to develop restful and jovial environments for our patients and deliver the experience of being outdoors or a place they want to visit like their home. To succeed we will utilize tools like eye tracking, link heart rate with gaze and various questionnaires gaining feedback about the interest of demented people and what environments they prefer. We conducted experiments to validate our environments and the usability of the whole system.

We expect that with the use of our Virtual Reality system, the patients' emotional state will be improved thus make them happy despite their disability and help the caregiver to provide the necessary care and treatment since the patient will be relaxed. Also, we anticipate a boost in cognizance triggered from the stimuli we will expose the patients in the Virtual Reality System.

For the optimization of this system, future research is expected, increasing the features and virtual environments for further improvement of the patients.

Content

Chapter 1

Introduction

1.1 Background

According to World Health Organization [1], dementia is one of the major causes of disability and dependency among older people worldwide with the estimated proportion of the general population aged 60 and over at a given time to be between 5-8%.

Dementia is a syndrome in which there is deterioration in cognitive function beyond what might be expected from normal ageing. Cognizance is the knowledge or awareness of something [2]. It affects memory, thinking, orientation, comprehension, calculation, learning capacity, language, and judgment. The impairment in cognitive function is commonly accompanied and occasionally preceded, by deterioration in emotional control, social behavior, or motivation [1].

According to a study, people with dementia were significantly associated with an increased risk of hospitalization rather than people without dementia [3]. Based on that fact, it is suggested to expand our knowledge on the therapeutics for dementia to improve the care of demented persons.

With the rapid growth of technology, various opportunities emerge for the creation of a new application that will lend a helping hand to healthcare. There are multiple examples where we utilize technologies like artificial intelligence, virtual reality, machine learning, blockchain and mobile apps [4-6]. Our goal is to capitalize on these new technologies to provide an improvement to the well-being of people suffering from dementia.

1.2 Problem Statement

People suffering from dementia are forced to stay at home or in a hospital care environment. Most of the patients require support from a caregiver, while some who are suffering from a more severe type of dementia might be confined to bed. Consequently, they start to feel inferior and depressed since they are restricted in specific environments (e.g., their own house, nursing home or a hospital, etc.) and are unable to complete simple tasks on their own. According to a study, dementia is highly associated with depression and nearly half of the patients live through both diseases [7]. Moreover, movement limitation leads to physical problems like obesity and overall weakness of the body which enhance their condition.

Another difficulty is the impact of dementia on family and friends, principally the caregivers. Many studies have found that caregivers of those with dementia have higher levels of burden than other caregivers [8]. In addition, they are forced to watch their loved ones slowly losing the ability to interact with the world and they cannot stop it.

The rapid growth of new technologies enables the improvement of well-being for these people. Nonetheless, the current research in the field of Technologies for dementia focuses mostly on the early diagnosis of the disease. It is vital to detect the problem as early as possible, so we can confine the progress of dementia, but what about the people who reached the mid or final stages and are unable to live a normal life.

1.3 Aim and Research Questions

My research aims to create virtual environments for the improvement of the emotional well-being of people suffering from dementia validated with eye-tracking and heart rate sensor. The goal is to develop restful and jovial environments for our patients which will help their user experience when interacting with our application. It will deliver the experience of being outdoors or even visit famous places from the leisure of their nursing home.

The application will make use of a Virtual Reality headset with eye-tracking support and a smartwatch to measure heart rate. Since our target group suffers from severe dementia, most of them are bedridden. Considering this we decided to place the player at stationary position with the ability to move his head to scan the virtual environment.

It is fundamental for the design of suitable environments to understand the possible reactions patients can have when interacting with virtual reality. The majority have never experienced virtual reality interaction. On this wise, we must consider how to make them feel comfortable wearing the headset, establish a smooth transition from the real to the virtual world and urged them to try again next time.

In the future, we can replace the eye-tracking VR headset with a standard VR headset or Google Cardboard since there will be no need for collecting the data anymore. The data we will use in this study will be used to understand how people with dementia respond to some stimuli and create suitable and personalized environments for them. Below we can see a table describing the differences between our VR headset options. Briefly, google cardboard is just a box where you place your smartphone and run VR programs on your phone, oculus quest is the standard VR headset and VIVE Pro Eye supports eye-tracking which gives us more information about the patient.

	Google Cardboard [9] 	Oculus Quest [10] 	VIVE Pro Eye [11] 
Weight (g)	96 + phone weight	571	555
Controllers	No	Yes	Yes
Eye Tracking	No	No	Yes
Resolution	depends on phone	1600 × 1440 Per eye	1440 x 1600 Per eye
Price (€)	12.24	325.68	1439

Table 1.1 Virtual Reality headsets comparison

1.4 Contribution

Based on the literature review, there is a lot of research where people with dementia make use of Virtual Reality equipment. Although they focus on diagnosing dementia before any of the symptoms and how likely dementia will be developed. The closer research to what we try to achieve in our research is one where they designed virtual environments tailored-made for people with dementia. They had a regular session where candidates followed a set of tasks and compared their performance throughout the study. Also, they considered the psychological impact on their patients where they noticed a boost in their behavior.

Our research will reinforce the lack of information in Literal Review regarding the improvement of well-being, for people suffering from dementia using virtual reality and appropriate environments. The research focuses on understanding how people with dementia process information by tracking their sight, where they fixate their attention and how they feel when they look at a certain item. Based on this information, we will adjust our program aiming for providing positive feelings to the patient but also try to help him improve his cognitive function.

Furthermore, we experiment with eye-tracking in Virtual environments for demented people, something a few have done before, if not none. Combined with biometrics like heart rate, we will have a better understanding of demented people and produce a variety of data we can analyze later to enforce the literal review of the subject.

1.5 Structure

The Structure of the diploma project is being analyzed in section 2 to 5 as follows:

Chapter 2:

In chapter two we have the Literature review for the subjects associated with our study. We understand what dementia is and get a deeper understanding of the links between dementia-exercise. Furthermore, we explain the technology of virtual reality and its enforcement in Healthcare. Afterwards, we present the eye-tracking technology, its utilization on the Health industry and its impact on people with dementia. Closing the chapter there is a synopsis of all the available information and how we will avail of them.

Chapter 3:

In this chapter exists all information about the implementation of the study. The VR system is presented, and all virtual environments are described. Then we list all the equipment that is essential for the research and provide some basic guidelines on how and what data should be collected. Lastly mentioned will be the most important part, the process of the collected data, to extract information which will be used to adapt our system to the user.

Chapter 4:

The fourth chapter will be exclusively about the results collected from the testing with real candidates suffering from dementia. There will be an analysis of observations during the testing, but also a collate of the behavior and cognizance function of our candidates, before, during and after the use of our system.

Chapter 5:

In the fifth and final chapter, we present our conclusions and future work that is needed for our application. The center of attention for our conclusions will be how the patients react when you put them in a known/unknown environment, what feelings are triggered and the effect on their cognizance.

Chapter 2

Literature Review

2.1 Dementia

Damage to brain cells is the main reason a person can suffer from Dementia. This damage interferes with the ability of brain cells to communicate with each other. When brain cells cannot communicate normally, thinking, behavior and feelings can be affected [12]. The most common causes of damage to brain cells are bad blood circulation in the brain, brain injuries and long-time alcohol or drug use. Furthermore, factors like age, gender, early-life mental health disorders such as anxiety depression and history of illnesses like diabetes the person at a higher risk of developing dementia [13].

Types of Dementia can vary, each one of them affects the patient disparately and the treatment depends on the specific type. The most notorious type is Alzheimer's disease and begins with memory problems. Experts think between 60% to 80% of people with dementia have this disease [14]. Alzheimer's disease is originated from mutations of three genes, specifically apolipoprotein E4 (APOE) [15]. APOE is responsible for some proteins to be carried to the brain and when its dysfunctions high levels of certain proteins inside and outside brain cells are formed, troubling the communication between each other [1].

Other types are vascular dementia, Dementia with Lewy Bodies, and frontotemporal dementia. Starting with vascular dementia, someone could get it if he had a major stroke or numerous smaller ‘silent’ strokes without realizing it. Unlike Alzheimer vascular begins with poor judgment or trouble planning, organizing, and making decisions [14]. Lewy bodies are microscopic deposits of a protein that form in some people's brains. They are named after the scientist who discovered them. The fourth type is a set of brain disorders that mainly affect the frontal and temporal lobes of the brain. Signs of these types are dramatic changes in personality and/or failure to communicate properly. Last but not least is mixed dementia, a combination of Alzheimer and vascular Dementia.

There are some initial signs which indicate that you might have Dementia. If you find it difficult to concentrate, struggling to find the right word, having a hard time completing familiar daily tasks or have memory loss, most probably you have ‘mild cognitive impairment’ (MCI) [16]. However, it can be challenging to be diagnosed with MCI, since we do not take these symptoms seriously and point our finger to ageing. Therefore, it is essential to seek medical advice if you notice problems with your memory. MCI is not considered dementia but if the symptoms get worse you will develop Dementia.

Due to all the problems Dementia causes, people who suffer from mid-stage and late-stage Dementia need a caregiver to assist them throughout their daily life. They usually must stay home and if they want to take a walk outside, it must be with the company of someone to ensure their safety and well-being. Besides cognitive problems, patients develop physical problems like muscle weakness and severe movement decline without assistance. In other words, they are sorely dependent on other people.

Woefully there is no cure or treatment to slow the progression. Nonetheless, there are some drug treatments to improve the symptoms for a short period of time. Fortunately, there is light at the end of the tunnel because over the last few years we increased research funding and clinical studies focusing on finding a cure and improve the well-being of people with Dementia.

2.1.2 People with Dementia and Emotional Health

It is a fact that dementia has a massive influence on the emotional health of the patient with dementia. Only by looking at some statistics, you understand that developing emotional problems while you are suffering from dementia is not a coincidence, but a phenomenon. The prevalence of depression in dementias has been reported to be between 9 and 68% [17]. Prevalence of anxiety is estimated between 8% to 71% for anxiety symptoms and 5% to 21% for anxiety disorders [18]. Also, apathy and Alzheimer disorder have prevalence ranging from 19% to 88%, with an overall mean prevalence of 49% [19].

Depression

Depression is a medical illness that negatively affects how you feel, the way you think and how you act. To diagnose depression two of the following must be true: depressed mood, loss of interest and enjoyment, or reduced energy for at least 2 weeks period [17]. It can also be a prodrome of dementia and not only a result of it. Depression will worsen the well-being of the patient since he is sad most of the time and as a result, they give up on fighting the disease.

Anxiety

Anxiety is a feeling of unease, such as worry or fear, that can be mild or severe. Due to their situation, patients with dementia face multiple challenges hence they are prone to anxiety. It can cause rapid heart rate and chest pain, digestive disfunction and insomnia, all added to the current problems they face with dementia.

Apathy

Apathy is defined as loss of or diminished motivation, sufficient to cause significant impairment in everyday life, in at least two out of three domains: goal-directed behavior, cognitive activity or emotion [19]. It is highly associated with depression and often they occur at the same time. Apathy appears to be associated with accelerated emotional decline and increased morbidity, while it is related to more severe cognitive and functional decline.

All the above disorders are very similar and sometimes overlap each other, making harder the life of demented people. They cause a feeling of hopelessness and aggravate symptoms of dementia.

2.1.2 Dementia and Psychotherapy

Clinical guidelines specify the use of non-pharmacological treatments for Dementia before pharmacological treatments are tried [20]. These psychotherapy treatments can be categorized into three groups: emotion-oriented therapies, brief psychotherapies, and sensory stimulation therapies.

Emotion-oriented therapy

It focuses on the emotional needs of the patients to improve their mental health which will have a positive impact on their symptoms. There are various methods such as reminiscence, reality, validation, and simulated presence therapy. Reminiscence resort to patient's memories and past, with the help of old photos and personal items. Reality orientation is based on the fact that the inability to orient themselves, leads to doing fewer efforts for activities. In this therapy, they repeatedly give orientation clues to help them have a better understanding of the environment. Some people suffering from dementia can create an inner reality to escape from their cognitive deterioration. Validation therapists acknowledge their reality and they do not try to convince them otherwise, allowing them to have meaningful conversations addressing their emotions. The last emotion-oriented therapy is a simulated presence that exposes the individual to audio or videos of their loved ones [21].

Brief psychotherapy

Brief psychotherapies can be split into behavior and cognitive-behavioral. Behavior is usually applied in the later stages of the disease. Such therapies do not consider depression as a result of dementia. They require a period of detailed assessment in which the triggers, behaviors and reinforcers are identified, and establish a connection between patient and therapist. After the analysis of the findings, they can intervene to help the patient change patterns in their behavior. Examples of such interventions are progressive muscle relaxation, imaging, and social skills training. Cognitive-behavioral shares the same philosophy with Behavior, however, they do not stop on behavioral patterns, they try to change the way of thinking and beliefs of patients. This type of treatment targets people with early-stage dementia since they still have almost all their cognitive functions. It often focuses on a person's current problems and how to solve them.

Sensory Stimulation therapy

Sensory stimulation therapies include art therapy, aromatherapy, pet therapy, activity therapies and massage therapies. These therapies improve the mood and memory of demented people. For example, in art therapy, they encourage people to create a painting or a song or interact with various completed exhibits. Clinical studies have shown an improvement on mood, although sometimes it can worsen depression because they cannot create a pleasing work of art. Aromatherapy or oil therapy makes use of natural plant extracts, each one with a different function such as relieving stress, calm nerves, boost energy, etc. Animal-assist therapy has been reported as a tool of improving the socializing skills of the patients and activity therapy boosts physical strength and confidence [21].

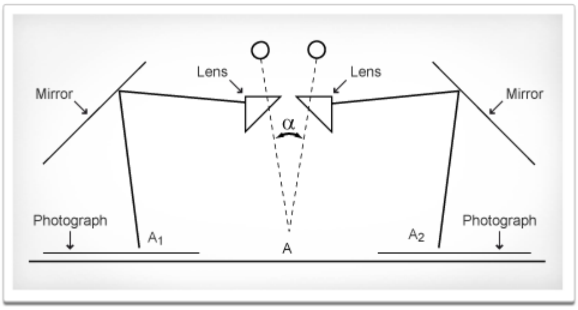
2.2 Virtual Reality

In simple manners, Virtual Reality (VR) is a simulation in which computer graphics is used to create a realistic-looking world. The synthetic world is dynamic and transmutes accordingly to the user's input, like gestures, verbal commands etc. [22]. The key feature of Virtual Reality is the real-time interactions that are essential to immerse the user in the virtual world. In this simulated artificial environment, the user can experience numerous situations without the need to be in the simulated place or have any equipment besides the VR equipment. The fundamental elements defining Virtual Reality are the Virtual environment, the Virtual presence, the sensory feedback, and interactivity.

Nowadays, Virtual Reality can be considered among the top emerging technologies for the years to come [23]. Nonetheless, it is built upon ideas that date back to the 1800s, 1838 to be exact when the first stereoscope was invented [24]. One milestone was Morton Heilig's Sensorama in 1956. The Sensorama experience simulated a real city environment, which you "rode" through on a motorcycle. Multisensory stimulation let you see the road, hear the engine, feel the vibration, and smell the motor's exhaust in the designed "world." [24]. Heilig also patented a head-mounted display device, called the Telesphere Mask, in 1960. Many inventors would build upon his foundational work [24]. Another inventor, Ivan Sutherland expanded on the idea of a head-mounted display device and used computer-generated scenes instead of analog images taken by the camera [23]. He described it as "the Ultimate Display" [23-24]. In the 1970s and 1980s, it drew the attention of the military and NASA due to the potential of minimizing the cost of training soldiers or astronauts. Those decades were important for the development of Virtual reality and introduced the VR gloves [23]. In conclusion, the past six decades contributed to reducing costs, developing high-quality equipment, and maximizing the performance of today's VR systems.

Figure 2.1 On the left we can see a stereoscope and on the right Google's Daydream VR. Here we can see the foundations of current-day technology.

Virtual Reality deceives a human, believing he is a 3D world although he sees from a 2D screen by tricking the eyes. We use a head-mounted headset which contains two monitors, one for each eye. The images create a stereoscopic effect, giving the illusion of depth [25]. In other words, the user does not see the image, he sees the reflection of the image from the lens. Another technique used to create a virtual environment is called Cave Automatic Virtual Environments (CAVE). CAVE is a room where they project images on the walls, floor, and ceiling [25]. They require special glasses to complete the illusion and give more freedom of movement to the user.



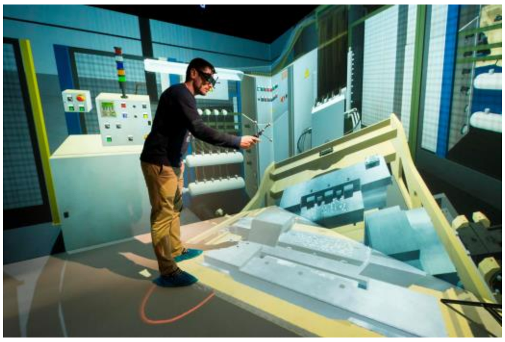


Figure 2.2 Stereoscopic effect

Figure 2.3 Heudiasyc laboratory's VR CAVE

Virtual reality technology can be used in a wide variety of fields. As I mentioned before, the military still makes use of the VR for the training of soldiers, using flight, vehicle, and battlefield simulations [26]. In the healthcare industry, we can see many utilizations of VR which we will describe in the next chapter. Another application is in education. It is an excellent learning tool both for professionals since we can visually represent the information, and children, due to the immersive experience [27-28]. Moreover, VR can be used for entertainment. From interactive exhibitions to gaming from the leisure of your home. Big companies, like SONY, have invested and developed their own VR system for PlayStation 4 and 5 consoles. Also, VR gives the ability to display realistically and accurately anything we can imagine. Industries like Automotive, Engineering, Architecture and Fashion capitalize on that to reduce costs and time before going to development [28-29].

In Virtual Reality applications, the most essential gadget is the Head Mounted Display (HMD). It is an output device, wearable on the head, from which we can see the virtual world through two monitors. HMDs devices can be categorized into two general categories. The first category is Mobile HMDs. In most cases, they make use of a common smartphone and they are essentially a simple case for the phone to keep it at a specified distance. Google and Samsung already launch their products, and more are in development. The advantages of Mobile HMDs are their low-cost and they are easy to use. The second category is Stationary HMDs. They need to be connected to a computer or console to operate. Most of the times they have better resolution, graphics and are more powerful than the Mobile HDMs. Their purpose is only to run VR programs, so they are optimized and use niche techniques ensuing the high price tag on them. Currently, the most established companies in the industry of Stationary HMDs are Oculus Rift, PlayStation VR and HTC Vive [30]. Many HMDs have sensors integrated inside, like accelerometers, magnetometers, gyroscopes, eye tracking, collecting data we process to provide a better user experience during sessions.

Another output device is headphones. Audio plays a major part in the immersion. Better headphones can help trick the user into believing he is in a real environment. Besides the quality of the sound, we make use of 3D sounds to give depth to our world and make it more realistic. Haptic feedback is an output engaging our sense of touch. Through the program, we sent signals to the controller to vibrate and enhance the experience physically and not only visually.

Likewise, we use numerous input devices to make the interaction more intuitive. First and foremost, there are VR controllers. They all differ in design; however, they all have similar components. The controllers consist of buttons, sensors like Gyroscope Accelerometer and Magnetic, touchpad or joystick and triggers. Sensors are used to detect the movement of the user’s hands. The rest give more freedom to the user to interact with the environment. An alternative to controllers is data cloves. Data gloves include the ability to perceive pressure, linear force, torque, temperature, and surface texture. Fine-motion control involves the use of sensors to detect the movements of the user's hand and fingers, and the translation of these motions into signals that can be used by a virtual hand. This allows the user to interact normally with objects in the virtual world [31]. Moreover, we can use a camera to detect user movement. Sony and Nintendo elaborated on the technology and moved forward to the commercialization of their product. Lastly, there are advanced input devices like Data suits and Platforms. Data suits are like data gloves, yet for the whole body. Platforms serve more as maximizing the experience because they allow the player to move freely in the virtual world, without moving in the real one. Basically, it is a 360º treadmill adjusting the speed based on user movement.

Figure 2.4 Virtual Reality Input Devices

2.2.1 Virtual Reality in Healthcare

Virtual Reality has lots of functional applications in the medical field. From training future doctors or simulating dangerous surgeries, to pain relief and giving a second “life” to the disabled.

One of the main applications of Virtual Reality in healthcare is staff training. College students’ lack of knowledge causes anxiety, stress and poor clinical judgment compromising patient safety. With the use of Virtual Reality, there is no need for a patient hence students are more relaxed and focus on learning instead of having fears of doing a fatal mistake. Moreover, they can practice anytime without waiting for an actual patient or having equipment. Experienced doctors can make use of Virtual Reality too to master their technique on high-risk surgeries. Studies have shown VR training significantly improves knowledge among nursing students [32]. HoloAnatomy is a growing trend studying the virtual representation of human anatomy. Effects can be easing the learning curve of students, and helping patients understand their medical condition better [33].

Exposure-based treatment is well established and has been proven highly efficacious for anxiety disorders. Researchers took advantage of Virtual Reality and contacted studies exposing patients to their fears and measure the effectiveness of the treatment, all under a safe virtual environment. One of those studies tried to find the most successful type of exposure in patients with arachnophobia. They divide the group into four smaller ones and used a different type of exposure for each one, all using Virtual Reality. They did not come up to a clear conclusion on their goal, however, from their results, it is obvious that in all the groups patients benefited from the exposure to virtual spiders [34]. An additional treatment, using Virtual Reality is with people suffering from Posttraumatic disorder (PTSD). Exposure therapies may not be effective if patients are unable to sufficiently recall the traumatic event and its associated effects. Nonetheless, VR can recreate the exact memory without depending on a patient’s imagination and make it possible to reproduce the traumatic stimuli in a controlled and realistic way [35].

Various studies have investigated the effects of applying VR during the perioperative period on relieving postoperative pain, but the results are still controversial. Some studies yielded positive results, but others got negative ones [36]. Nevertheless, on some occasions, Virtual Reality can be a non-pharmacological alternative for pain relief. They accomplish that by immersing the user to a virtual environment, distracting him from his attention to pain. Commonly it is used for situations where the patients are under severe stress, deteriorating their pain. One example of this application is the use of VR on postoperative patients with significant success over the usual care [36].

Last but not least, the area our research is into is Virtual Reality for the disabled. When we say disabled people, we mean individuals who have a physical or mental impairment that substantially limits one or more major life activity. Some are amputated, bedridden or cannot even move. Virtual Reality can offer to them a second chance. There are programs specially designed for socializing using VR. Having those means that even bedridden patients can put on a VR headset and communicate with others in an instant. Other programs stimulate activities that people cannot do in real life, however with clever design and interactions in a virtual world they can [37]. All the above can help dramatically to the psychology of the person, giving him back his freedom and his will to leave.

2.2.2 Virtual Reality and Dementia

As we explained above Virtual Reality is very useful in numerous fields of healthcare, so why not capitalize on Dementia too? Using Virtual Reality technology, we can provide people suffering from dementia a place to relax. Socialize with other people or take a virtual walk wherever and whenever they like. The benefits of virtual over physical would be a major cut to expenses, due to needing no specialized equipment for the walks outside. One more advantage would be preventing patients' and caregiver's inconvenience, from unnecessary outings. The patient might struggle to walk and be too weak for going outside to breathe fresh air. On the other hand, the caregiver could be very tired from taking care of the other needs of the patient and he has his personal life as well. Hence, he probably does not have the energy nor time for taking for a walk the patient with dementia. With Virtual Reality, the patient can take his walk from the leisure of his bed, since severe cases of dementia are bedridden, and the caregiver takes a break or continue with the other jobs he must do. Furthermore, patients can explore other areas or activities they are unable to do, giving them some freedom.

Unfortunately, research material is very limited for offering people, suffering from dementia, a Virtual Reality environment for their enjoyment. Even research evaluated the available literature for studies combining Virtual Reality and Dementia, and only five from 119 papers were identified as relevant. [38] Most of the studies, containing the use of Virtual Reality technology and Dementia, aim for the early detection of the disease or enhance empathy and awareness for caregivers. To detect early signs of dementia using VR we ask the user to complete some tasks and while he does, we try to spot navigational deficits [39]. Understanding and knowledge of dementia enable caregivers to deliver high-quality care. This could in turn reduce caregiver burden and improve relationship quality. This can be achieved by simulating the experience of having dementia and let caregivers use it [40].

Still, we manage to find five studies in which they investigated the benefits of Virtual Reality in the well-being of demented people. The first study [41], compared a real walk versus an identical virtual one. The walk consisted of three "phases", a quiet shopping route, a modern shopping precinct and a route along a busy road with bus stops. They assigned patients to complete tasks, like finding a specific building. Patients had to use signs and other information from their surroundings to succeed. Additionally, they slightly manipulate the virtual environment to compare results. For example, instead of only signs they accommodated them with a related word and replaced *You are Here* maps with directional landmarks. Their dedication was signage made a measurable difference in patients' navigation and cognitive awareness. Moreover, VR walks were as enjoyable as the real ones and patients were satisfied with the experience. The second study [42], focused thoroughly on personalizing the virtual environments for seven participants. They had a lot of sessions and interviews both with participants and their caregivers to develop tailor-made environments. By the end of the study, participants and caregivers were extremely satisfied and thrilled with the virtual environments and the positive influence on participants' mental health. One minor complication was the fear of participants to wear the VR headset because they believed they will look foolish or because the headset was too heavy for them. Third [43] and forth [44] study tried to get more metrics to analyze and come to conclusion. The data was collected from observation and interviews with the patients when they interacted with a virtual environment created for each study. In general, we have positive results of demented people interacting with a Virtual Reality world for their amusement. Nonetheless, all four studies had a small sample size.

The last study is very similar to the first part of ours [45]. They decided to use 360° video-based VEs recorded with omnidirectional cameras. First, they organized a gathering with the participants and brainstorm the types of environments. Based on the conversation, they created the VEs and tested them with the participants. To summarize their results, they confirmed their speculation that VR exposure can significantly increase pleasure and alertness. Moreover, they observed a reduction in challenging behaviors from the patients and that VR environments can be a private isolated space for patients to relax.

In our research, we will use Virtual Reality technology for the relaxation of the patient, in order to make easier the job of the caregiver. We will create a personalized and specially designed virtual environment for demented people. They will have the ability to traverse the environment and interact with it. Our target group is mostly bedridden patients with severe cognitive decline; however, we would like to encourage individuals and organization associated with dementia to make use of our application.

2.3 Eye Tracking

Eye-tracking is a sensor technology that enables a computer or any other machine to determine what the user is looking at. This sensor is very useful for feedback on what draws the attention of the user, at that moment, to observe a phenomenon or improve the interaction. Another feature is releasing your hands from the computer. You can control your computer screen by focusing and blinking to navigate across your computer. People without arms were benefited and the limitations are far less with the use of eye-tracking.

An emerging field using eye tracking is Usability Research. Websites increase sales and revenue streams, so companies invest thousands of dollars to create adaptive and personalized sites. In order to accomplish their goal, they must design the website and most importantly test it. Here eye-tracking comes. With eye-tracking, they observe what draws the attention of the user, how long they see something, where they usually put their gaze first. All this information is used later to create websites “manipulating” the user to see what they want or giving him a great user experience so we will visit their website again. Likewise, we have user testing in the marketing and design of products. Before mass production, they make research to measure attention to brands, products, and their key messages. Also, they test if it draws visual attention on the shelves, so it stands out from the competition. One more application can be gaming [46]. If the player looks to a specific location, and the game knows that he sees there, it might trigger an animation or rearrange the whole level. By doing that, they maximize the interaction and experience between the player and the game. Additionally, if the player is stuck, with eye-tracking we could detect that and hint the solution to him.

In 1879, Louis Javal noticed that people do not read smoothly across a page, but rather pause on some words while moving quickly through others. Edmund Huey later built a device that was used to track eye movement in reading [47]. After 22 years, since further development of technology, the first photographic eye-tracker was invented by Dodge and Cline. They used light that reflects from the surface of the cornea and falls through an optical system onto a moving photosensitive photographic plate, thus leaving a record of the eye movement on that plate [48]. A breakthrough in terms of comfort for subjects was achieved following the development of mobile eye tracker technology. The technology was perfected in the 1960s, by Shackeland Mackworth and Thomas, to make them even less burdensome for the test subjects [48]. During the 1970s-1980s eye-tracking technology started to flourish with more research on the subject, even so, the clutch moment was in 1990 when eye tracking met software engineering and developed to how we know it today.

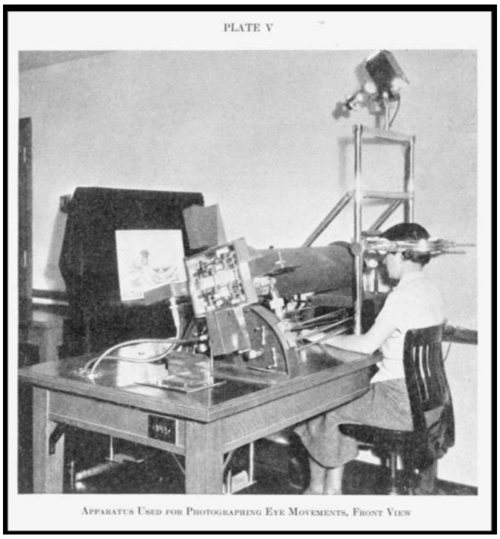


Figure 2.5 Photographic eye-tracking system

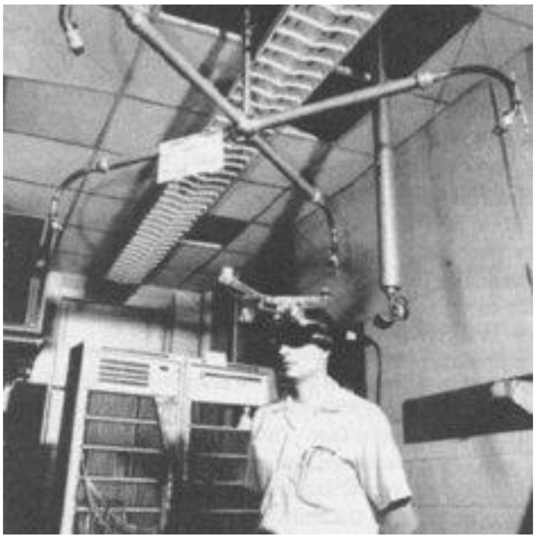


Figure 2.6 Early head-mounted eye-tracking system

There are two kinds of eye trackers. The first is a screen-based eye tracker usually used to track a user's navigation on a screen, and the second is a wearable eye-tracker used on goggles and headsets. Both work with the same logic, the only difference is their components are placed accordingly. Components are an infrared illuminator, a camera, and algorithms. First, an illuminator sends out near-infrared light to the eyes. The eyes reflect the light. Subsequently, the camera picks up those reflections. With the help of algorithms, we filter the data and extract information about where the user looks.

There are various eye-tracking algorithms, implementing different techniques. Some are easy to implement, others sacrifice convenience to achieve better accuracy. Before we describe the various algorithms, we must explain some terms. Essentially, these algorithms try to detect fixations and saccades. Fixation is when the user focuses on a particular object or area, while saccade is a rapid movement of the eye between fixation points.

Fixation and Saccades Identification Algorithms

Velocity-Threshold Identification (I-VT)

```
For each point {
        Get the next point;
        Find velocity between the two points;
        If velocity < threshold
                State[point] = fixation;
        Else
                State[point] = Saccade;
}

For each state {
        Get next state;
        if (fixation && nextFixation) Group fixations;
        if (fixation && nextSaccade) Close Fixation;
        if (saccade && nextFixation) Create fixation;
        if (saccade && nextSaccade) Do nothing;
}
```

Velocity-Threshold Identification is a Velocity based algorithm. To identify a fixation, we find all points with low velocity (i.e., <100 deg/sec). Saccades have high velocity (i.e., >300 deg/sec). After we make the calculations, we want to group the fixations into the real ones. So, if we have back-to-back fixations, it means it is the same fixation, while if we have a fixation and then saccade, then the user loses focus in that spot. The algorithm is very easy to implement, fast and decently accurate however it cannot tolerate a big workload [49].

HMM Identification (I-HMM)

Hidden Markov models (HMMs) Identification Algorithm is a Velocity-based algorithm too, like I-VT with the only difference on how they identify fixations and saccades. It uses probabilistic analysis to determine the most likely identifications with the help of probabilistic finite state machines. The advantage is accuracy and more robust identification using dynamic programming to find the optimal assignment efficiently. Also, the algorithm can learn parameter values, by himself, by giving him a training set. This can be used for any situation and setup. The drawbacks are a fall in speed and implementation ease [49].

```
For each point {
        Get the next point;
        Find velocity between the two points;
}

For each velocity {
                Identify stat of points as fixation or
        saccade points using two-state HMM
}

For each state {
        Get next state;
        if (fixation && nextFixation) Group fixations;
        if (fixation && nextSaccade) Close Fixation;
        if (saccade && nextFixation) Create fixation;
        if (saccade && nextSaccade) Do nothing;
}
```

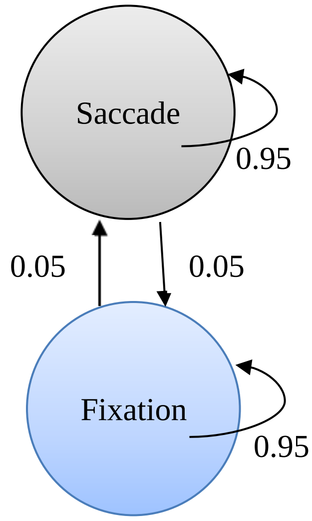


Figure 2.7 The HMM state machine (Percentages is the Probability of what is going to be the next stage)

Dispersion-Threshold Identification (I-DT)

```
While available points {
   Create window and put first point;
   Put all available points within duration threshold;
   If (dispersion of points < dispersion threshold) {
        Do {
                Put more points in window;
        } Until (dispersion > dispersion threshold)
        Find center of points;
        Mark fixation in center;
        Delete all points;
   }
  Else
        Remove first point;
}
Return fixations;
```

Fixation points tend to cluster closely together due to their low velocity. I-DT identifies fixations as groups of consecutive points within a particular dispersion and duration. It has two thresholds, duration is 100-200 ms since fixations typically have a duration of at least 100 ms and dispersion can be set to include 1/2° to 1° of visual angle if the distance from eye to screen is known or be estimated from an exploratory analysis of the data [49].

Area-of-Interest Identification (I-AOI)

```
For each point {
        Label as fixation in target area which lies;
        OR
        Label as saccade if none target area
}

Collapse consecutive fixation points on same target;
Remove saccade points;
Remove fixation groups that do not span the
minimum duration threshold;
Combine fixation groups to a fixations at center of
points;
Return fixations;
```

The four previous identification methods can identify fixations at any location in the visual field. In contrast, area-of-interest fixation identification identifies only fixations that occur within specified target areas. It is extremely useful when we need to observe specific objects, reducing unnecessary data [49].

Gaze-To-Object Mapping Methods

After finding fixations, further information we can extract is what object the user looks at, hence gaze. Again, there are various methods, and we can separate them into two categories, passive (P) and active (A). In passive methods, we assume that gaze determines what the user sees. In active use, we assume that when attention targets are selected, the gaze is directed there [50]. Below there is a description of the various methods:

Ray Casting (P)

The simplest approach is, at fixation cast a ray. The first object it hits is where the gaze looks.

Closest Feature Mapping - CFM (P)

In this option, we try to find the closest object to the gaze/fixation. To find it we find the closest feature of all objects, weight the Euclidean distance with a Gaussian with a standard deviation of θ_s [50]. The minimum value is our object with gaze into him.

Fovea Splatting – FS (P)

A second alternative is to assume that a user attends to multiple features at the same time and to infer the attention probability by accumulating all features by a Gaussian splat of the size of the fovea. It is very similar to CFM though instead of comparing distances while searching the closest pixel of each object we compute the Gaussian energy at each pixel and accumulate these values [50].

Center of Gravity Mapping – CM (A)

This method exploits the strong tendency of users to focus on the center of an object. So, we calculate all objects' center of gravity and place them on the average position of the object. By doing that we only have one point for each object. Gaze can be determined to the closest center of gravity. We do not have accurate visibility information; however, it finds application in situations where an item buffer is difficult to obtain [50].

Normalized Closest Feature Mapping/Fovea Splatting - nCFM / nFS (A)

Identical to CFM and FS logic, but we also consider the center of an object theory. After finding the distances, we normalize the data and use a function that sums up to 1.0 for all possible gaze positions. In simple words, we do not define which object we have our gaze, but the probability of what objects the gaze is [50].

2.3.1 Eye Tracking in Healthcare

The Healthcare Industry exploits the power of eye tracking, implementing it in various applications. For example, medical researchers have shown that eye movement can be a predictor for many diseases. Neurological diseases like Alzheimer, Parkinson and stroke, Visual like Glaucoma or even Behavioral such as Autism and Schizophrenia, can be detected from patterns created from eye movement. Early detection of the diseases has a higher probability of successful treatment. Eye-tracking observations can spot these patterns in early stages, even before symptoms emerge and later contribute to the therapy stages. Another important feature of eye-tracking, considering the previous, is the convenience of equipment. Patients like infants and mentally ill will not show resistance to using eye-tracking, because they might not even realize they are being tested. The test can be made using video games or pleasant videos (i.e., NovaSight CureSight) [51].

Eye-tracking can help in the training of medical students too. Using illuminating behavior, i.e., instead of just watching the experts operating to learn, we can use eye-tracking and a screen. As a consequence, medical students can see from the expert's point of view while executing some tasks and what he looks at. It is vital for surgeries to be precise, and this eye-tracking technology provides more detail rather than the conventional observation there is today [51]. Using Virtual Reality and eye tracking is a great synergy. When we know where the user looks there is no need to provide high-definition display for the whole environment. Hence, we focus the high resolution where the user's gaze is and reduce the peripheral resolution, optimizing computing efficiency [51].

Literature expands a lot to how eye movement indicates the likelihood of disease. Thus, we have a lot of information about detecting dementia in early stages too. However, few studies combined Virtual Reality technology and eye-tracking for observing how the environment affects the well-being of the patient. In our research, we will try to investigate this, in order to create the appropriate environments. We will come to conclusions based on our data, if the user looks at a specific object, what emotions will surface.

2.4 Summary and Conclusion

To conclude, Dementia is causing cognitive decline resulting in deterioration of their well-being and mental health. Luckily, we can help demented people have a decent life, without depriving them of the joy of life. Virtual Reality is a very powerful technology, transforming our imagination into reality. It has many applications in healthcare. It cannot be used for the treatment of dementia, nevertheless, it can diminish the negative side-effects of dementia which are depression and physical deterioration. Finally, eye tracking can provide useful data we can process. This information can lead to a breakthrough, in understanding demented people and how we will make the best environments for them.

Chapter 3

Methodology

3.1 Ethics

Participants were engaged from the «Archangelos Michael» Nursing Home for People with Dementia (AMEN). The nursing home provides ministration and restoration to patients suffering from mild to severe dementia Furthermore, we used the 'Mental Capacity Act (MCA) 2005 Assessment Checklist' [52] to ensure an individual's capacity to consent on their participation. In circumstance where individuals were unable to consent, a caregiver responsible for him was asked for consent on their behalf.

3.2 Study Design and Procedure

The study design was a result of thorough talks with experts, specialized in dementia, HCI research in the health industry and a systematic review of the effect on individuals, suffering from mild to severe dementia, using VR [53]. The collection of data took around a month and included interviews and VR sessions with observation. We contacted a VR session and afterwards an interview with the patient. First of all, before the VR session, we recorded the patient's behavior for 15 minutes and heart rate using a pulse oximeter provided by the nursing home. They were accompanied by their caregiver and we reassured them they will be next to them during the whole procedure. The caregiver and clinical researcher could observe what the patient was looking at through a screen. We stated that they had the choice to stop the session whenever they wanted or not participate at all. The maximum duration was set to 15 minutes to prevent side-effects if using VR like dizziness and motion sickness. Finished with the session we once again measured the heart rate using the oximeter. To clarify during the session, we collected more quantitative measures using the VIVE Pro Eye for eye-tracking and Galaxy watch for heart rate. The use of oximeter before and after the session was more for verification and accurate comparison pre-and post-exposure. Afterwards, a semi-structured interview followed and when they returned to their usual care, a clinical researcher observed the patient for 15 minutes to identify changes in behavior. Finally, caregivers who accompanied the patient had a semi-structured interview too. After analyzing the data and modifying the environments based on the analysis, we ran another session using the same procedure. On average, the duration of each session was approximately an hour to one and a half hours.

3.3 Virtual Environments Research

Before proceeding to the primary research, we had to create virtual environments. The virtual environments were based on secondary research asking participants through questionnaires, about their preferences.

3.3.1 First phase of Procedure

Participants

Within the group of eligible participants (n = 34), 11 where patients with dementia (4 = male, 7 = female). The mean age was 85.09 years (range = 76-93) and standard deviation equal to 6.04. Diagnostic stage included: mild stage (n=1), moderate stage (n=4), severe stage (n=6) and other stage (n=0). Mean score for the stage was 2.45 with standard deviation = 0.69. The other 23 participants were caregivers whose professions included Physical Trainer (n=2), psychiatrist (n=1), clinical psychologist (n=1), psychologist (n=2), social worker (n=1), speech therapist (n=1), nursing staff (n=9), physiotherapist (n = 4) and other (n=2). The mean age of caregivers was 31.74 years (range = 19-51) and standard deviation = 6.04.

First, two of our researchers explained Healthcare Technologies and the potential of VR against dementia, in a 20-minute presentation during the 36th annual conference of AMEN. Due to Covid-19 pandemic, the conference was a virtual one and attendees were specialists such as physical trainers (n=2), psychiatrist (n=1), clinical psychologist (n=1), psychologists (n=2), social worker (n=1), speech therapist (n=1), nursing staff (n=9), physiotherapists (n = 4) and other (n=2). Afterwards, attendants were promptly asked to brainstorm and answer a questionnaire regarding suggested virtual environments. The context of the questions was general information about them and their proficiency and what they believed a suitable virtual environment for demented people would be. Participants proposed the following categories:

1) Nature (Mountains, Lakes, sea, Forests) {CG = 9, PwD = 11}
2) Home (Garden, Living room) {CG = 8, PwD = 11}
3) Village (Hometowns or in occupied territories in Cyprus) {CG = 6, PwD = 8}
4) Pets{CG = 5, PwD = 8 }
5) Familiar places or people (Kids, Friends) {CG = 10, PwD = 11}
6) Church{CG = 1, PwD = 1 }
7) Social (Traditional coffeehouse, pub, with other people) {CG = 0, PwD = 10}
8) Celebrating event{CG = 2, PwD = 2 }
9) Art experience (Music, theater, museum) {CG = 14, PwD = 10}
10) Park{CG = 7, PwD = 0 }
11) Hobbies and Sports (football, fishing, golf, bowling {CG = 6, PwD = 5}
12) Travel (google maps, cities around the world, cruise) {CG = 8, PwD = 8}
13) Sights (Historical) {CG = 1, PwD = 0 }
14) Town Square {CG = 5, PwD = 0 }

Based on the technical experience of the researchers in the HCI combined with the knowledge of a specialist, we created a guideline for the creation of potential VEs:

- Resolution over 2K to avoid the bad quality of content.

- Smooth transitions between scenes to not confused patients.
- Fixed camera position so reduces motion sickness.
- Animals or people that might feel intimidating be far from the camera.
- Avoid content that may be perceived as scary or confusing.
- Audio content consistent with the environment (e.g., birds - birdsongs)
- Audio content is soft and calm.

First phase Results

According to the results of the questionnaire environment categories, we identified the following environments as candidates: (CG is out of 23 – all participants, PwD is out of 11 – people with dementia)

1) Familiar places or people (CG = 14, PwD = 11)
2) Nature (CG = 12, PwD = 11)
3) Art (CG = 14, PwD = 10)
4) Home (CG = 9, PwD = 11)
5) Pets (CG = 14, PwD = 8)
6) Social (CG = 2, PwD = 10)
7) Village (CG = 5, PwD = 8)
8) Travel (CG = 5, PwD = 8)
9) Hobby (CG = 9, PwD = 5)

The highest-rated categories were familiar places and people, nature, art, and home. Additionally, pets, social, village and travel were chosen from the majority of demented people, so we included them in the study. Further information and snapshots of the environments follow in the next section.

Phase 1: Detailed identification of all Virtual Environments

We used the exact search terms aiming to cover any type of relevant Virtual Environments:

- Christmas
- Office
- Nature
- Celebration
- School
- Park
- Infant
- Birthday
- Forest

- Trees
- Orchard
- Ocean
- Exhibits
- Home
- Living Room
- Furniture
- Animals
- Restaurant
- Pub
- England
- Italy
- Travel
- Village
- Ship
- Sports
- Mountains
- Sea
- Cinema
- Temple
- House
- Garden
- Apartment
- Dogs
- Café
- Bowling
- London
- France
- Greece
- Gym
- Space
- Hobbies
- Flowers
- Beach
- Museums
- Sculptures
- Kitchen
- Bedroom
- Pets
- Cats
- Club
- Sights
- Spain
- Wild West
- City
- Sailing
- Earth
- Pool

Overall, we identified 150 relevant Virtual environments.

<u>Phase 2: Virtual Environments retrieved for detailed evaluation.</u>

All search results from phase 1 imported into a folder. Then, we exclude manually any content which was not consistent to the following inclusion criteria which were agreed by the research team. Inclusion criteria that were used to identify the potential Virtual Environments were: 1) Resolution more than 2K to avoid bad quality of content; 2) Smooth transitions between scenes to avoid PwD being startled or confused; 3) Fixed camera position to avoid dizziness and motion sickness; 4) Audio content relevant to the visual content (e.g., viewing birds and listening to bird tweets) to avoid inconsistency to audial-visual feedback; and 5) Elements and content that is not possible to be perceived as intimidating, startling or scary from the PwD.

Based on these criteria, we identified the following number of Virtual Environments within each category: 1) Travel (n=9), 2) Nature (n=10), 3) Arts Experience (n=5), 4) Hobbies and Sports (n=4), 5) Social Experience (n=4), 6) Home Experience (n=5), 7) Pets (n=8), 8) Familiar (n=7), 9) Village (n=3).

3.3.2 Second phase of Procedure

Participants

Within the group of eligible participants (n = 30), 13 where patients with dementia (8 = male, 5 = female). The mean age was 82.61 years (range = 62-92) and SD = 7.8.

Diagnostic stage included: mild stage (n=1), moderate stage (n=9) and severe stage (n=3). Mean score for the stage was 2.45 with standard deviation = 0.55 The other 17 participants were caregivers whose professions included Physical Trainer (n=2), psychiatrist (n=1), clinical psychologist (n=1), psychologist (n=2), social worker (n=1), speech therapist (n=1), nursing staff (n=4), physiotherapist (n = 4) and other (n=1). The mean age of caregivers was 28.41 years (range = 19-41) and SD = 4.87.

In the second phase, we created a questionnaire presenting various samples of environments for each popular category from the first phase and asked caregivers and patients to choose the ones they like. For each category, the sample environments were listed:

<u>Familiar</u>

Figure 3.1 Christmas

Figure 3.2 Wedding

Figure 3.3 Office 1

Figure 3.4 Office 2

Figure 3.5 Birthday

Figure 3.6 Infant

Figure 3.7 School

Nature

Figure 3.8 Park 1

Figure 3.9 Park 2

Figure 3.10 Snowy Mountains

Figure 3.11 Orchard

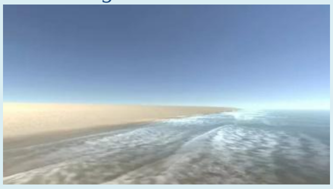


Figure 3.12 Sea 1

Figure 3.13 Sea 2

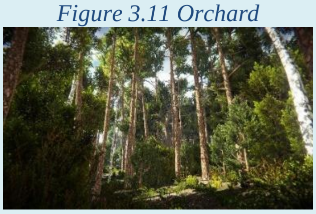


Figure 3.14 Forest 1

Figure 3.15 Forest 2

Figure 3.16 Forest 3

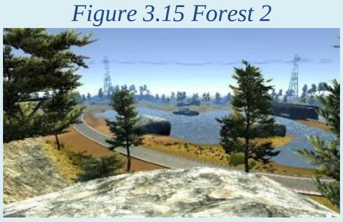


Figure 3.17 Lake

Arts

Figure 3.18 Outdoor Cinema

Figure 3.19 Cinema

Figure 3.20 Museum 1

Figure 3.21 Museum 2

Figure 3.22 Temple

Home


Figure 3.23 Living Room 1


Figure 3.24 Living Room 2


Figure 3.25 Bedroom


Figure 3.26 Kitchen


Figure 3.27 Garden

Animals


Figure 3.28 Dog


Figure 3.29 Cat


Figure 3.20 Cow


Figure 3.31 Elephant


Figure 3.32 Gorilla


Figure 3.33 Penguin

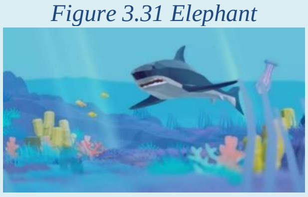


Figure 3.34 Shark


Figure 3.35 Bear

Social


Figure 3.36 Cafeteria


Figure 3.37 Pub


Figure 3.38 Pizzaria


Figure 3.39 Bowling

Villages

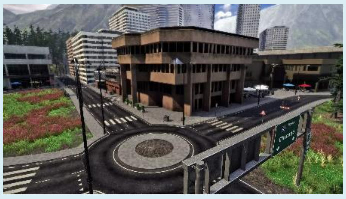


Figure 3.40 Village 1


Figure 3.41 Village 2


Figure 3.42 Village 3

Travel


Figure 3.43 Sights


Figure 3.44 Venice


Figure 3.45 London


Figure 3.46 Nauplio


Figure 3.47 Wild West

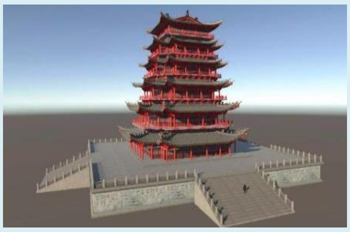


Figure 3.48 Japan


Figure 3.49 Egypt

Hobby


Figure 3.50 Space


Figure 3.52 Sailing


Figure 3.53 Gym

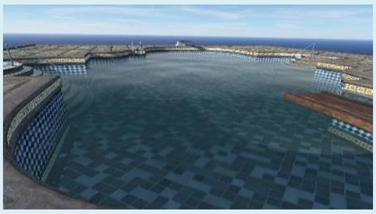


Figure 3.54 Swimming

Second Phase Results

Below you can see the results for all the categories as follows:

Familiar places or people

- Christmas (CG = 12, PwD = 13)
- Wedding (CG = 6, PwD = 12)
- Office 1 (CG = 3, PwD = 6)
- Office 2 (CG = 5, PwD = 5)
- Birthday (CG = 12, PwD = 12)
- Infant (CG = 7, PwD = 13)
- School (CG = 3, PwD = 12)

Nature

- Park 1 (CG = 14, PwD = 13)
- Park 2 (CG = 2, PwD = 3)
- Snowy Mountains (CG = 7, PwD = 12)
- Orchard (CG = 7, PwD = 12)
- Sea 1 (CG = 6, PwD = 7)
- Sea 2 (CG = 9, PwD = 11)
- Forest 1 (CG = 7, PwD = 12)
- Forest 2 (CG = 1, PwD = 0)
- Forest 3 (CG = 9, PwD = 11)
- Lake (CG = 8, PwD = 9)

Art

- Outdoor Cinema (CG = 5, PwD = 9)
- Cinema (CG = 5, PwD = 9)
- Museum 1 (CG = 9, PwD = 10)
- Museum 2 (CG = 3, PwD = 9)
- Temple (CG = 6, PwD = 12)

Home

- Living room 1 (CG = 9, PwD = 6)
- Living room 2 (CG = 8, PwD = 11)
- Bedroom (CG = 9, PwD = 12)
- Kitchen (CG = 12, PwD = 10)
- Garden (CG = 11, PwD = 10)

Pets

- Dogs (CG = 13, PwD = 11)
- Cat (CG = 12, PwD = 10)
- Cow (CG = 7, PwD = 7)
- Elephant (CG = 5, PwD = 6)
- Gorilla (CG = 4, PwD = 3)
- Penguin (CG = 5, PwD = 8)
- Shark (CG = 4, PwD = 2)
- Bear (CG = 4, PwD = 6)

Social

- Retro Cafe (CG = 8, PwD = 8)
- Pub (CG = 4, PwD = 9)
- Pizzaria (CG = 7, PwD = 9)
- Bowling (CG = 5, PwD = 2)

Village

- Village 1 (CG = 7, PwD = 5)
- Village 2 (CG = 6, PwD = 6)
- Village 3 (CG = 8, PwD = 11)

Travel

- Sights (CG = 9, PwD = 12)
- Venice (CG = 8, PwD = 12)
- London (CG = 6, PwD = 10)
- Wild West (CG = 3, PwD = 7)
- Nauplio (CG = 9, PwD = 11)
- Japan (CG = 9, PwD = 3)
- Egypt (CG = 3, PwD = 10)

Hobby

- Space (CG = 5, PwD = 7)
- Gym (CG = 9, PwD = 11)
- Sailing (CG = 5, PwD = 4)
- Swimming Pool (CG = 7, PwD = 8)

From the results, we can see the most popular environment is Park 1 with 27 from the 30 votings it, including all demented people. The Christmas scene follows with 25 votes, again with all demented people showing interest and the Birthday scene has 24 votes, 12 of those from patients.

Park 1 (40)	Christmas (38)	Birthday (36)
Dogs (35)	Bedroom (33)	Infant (33)
Sights (33)	Kitchen (32)	Cats (32)
Venice (32)	Park 3 (31)	Orchard (31)
Gym (31)	Garden (31)	Forest 1(31)
Sea 2 (31)	Forest 3(31)	Nauplio (31)
Village 3 (30)	Temple (30)	Wedding (30)
Living Room 2 (30)		* score is CG + PwD (demented people votes is worth twice)

Table 3.1 Most popular scenes based on results.

3.3.3 Selected Virtual Environments

Having all the information we needed, it was time to choose our environments. For the selection, we relied heavily on questionnaires' results and the cost for the assets from the Unity Asset store. Below we will describe our environments and what areas of interests we have chosen.

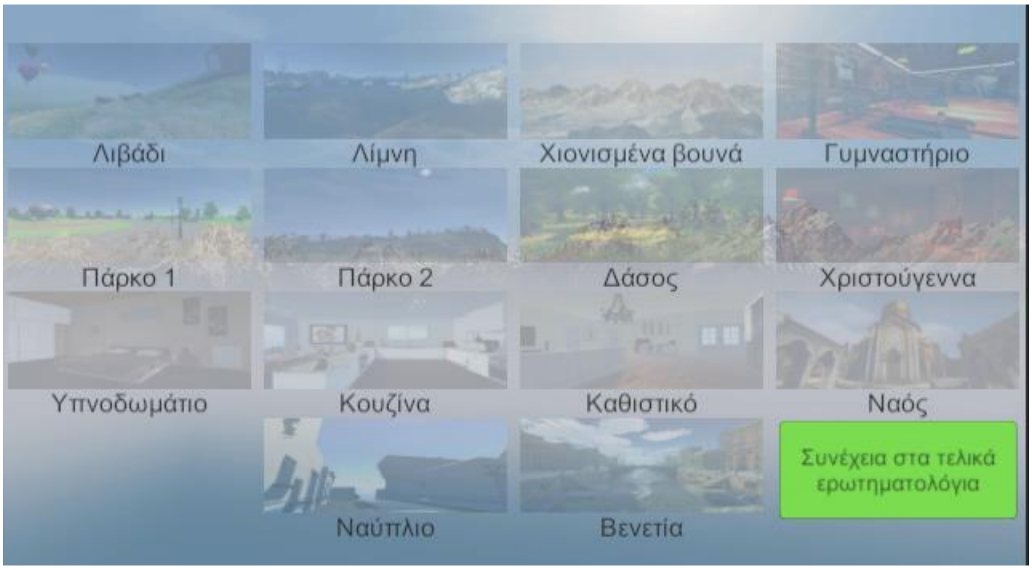
First, we created two characters representing the user. One is male and the other one is female. They both sit in an armchair which is also an area of interest since we want to know if the patient tries to look at himself.

Figure 3.55 Female (left) and male (right) Characters

Figure 3.56 *Player's Point of View*

Character models do not have a head because there is the position of the camera and as in real life, the user will be unable to see his head.

Main Menu



This screen is for the caregiver. He can see the available environments and choose whichever the patient indicated. To select an environment, he clicks on the image. Also, when u hover over an image it becomes colorful and very visible.

Christmas (Free)

The second most popular choice from the Virtual Environments Research and a free asset. It has a festive atmosphere with Christmas music and lots of decorations, such as lights, paintings, and socks. The patient can celebrate and feel the Christmas Joy. We also combined it with a free cat asset since Cats were a popular choice too. Areas of interests are:

- Giant Cookie
- Cat
- Present
- Table
- Fireplace
- Christmas Tree
- Wall Decorations
- Walls

Orchard (Free)

The second environment is a calm orchard. It is an ideal environment in nature design to be peaceful and relaxing. It consists of cows grazing, air balloons floating in the air and a wooden cabin. Additionally, the grass is full of colorful flowers. Areas of interest:

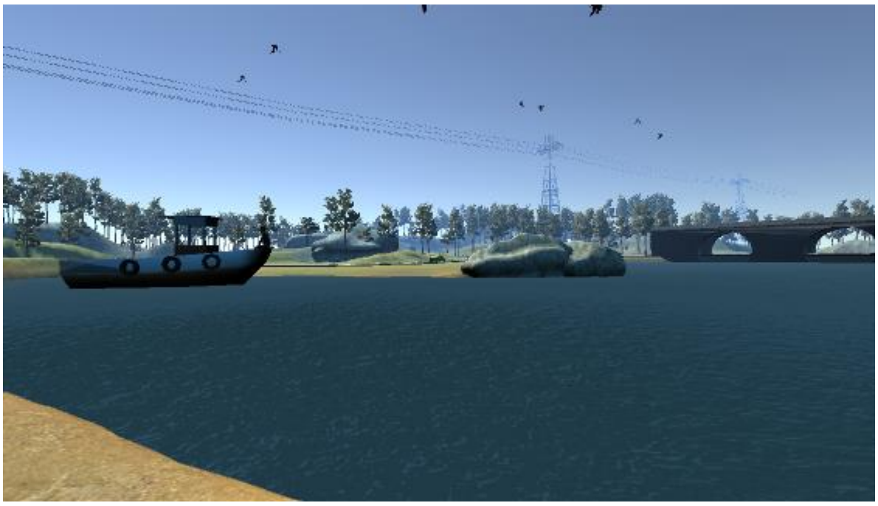
- Air balloons
- Cows
- Cabinet
- Sky
- Sun
- Grass

Snow Mountain (Free)

For a small adventure, we offered the snow mountains environment. It has a particle system simulating snow and we used sounds from wind at high altitude to enhance the experience. Area of interests are:

- All mountain peaks
- Snowy ground
- Sun
- Sky

Lake (Free)



The lake environment is another natural environment. The user is on the edge of a lake surrounded by a forest. Inside the lake, there is a fishing boat and around the lake, a yellow car is making circles. Furthermore, we added birds hovering over the skies and fishes swimming in the lake. Areas of interests:

- Birds
- Forest
- Sun
- Sky
- Fishes
- Fisherman
- Fishing Boat
- Car
- Lake
- Electricity Towers
- Rocks

Temple (Free)

A religious environment where the patient can relax spiritually. It is not based on a specific religion and you can hear choral psalmodies. Ares of Interest:

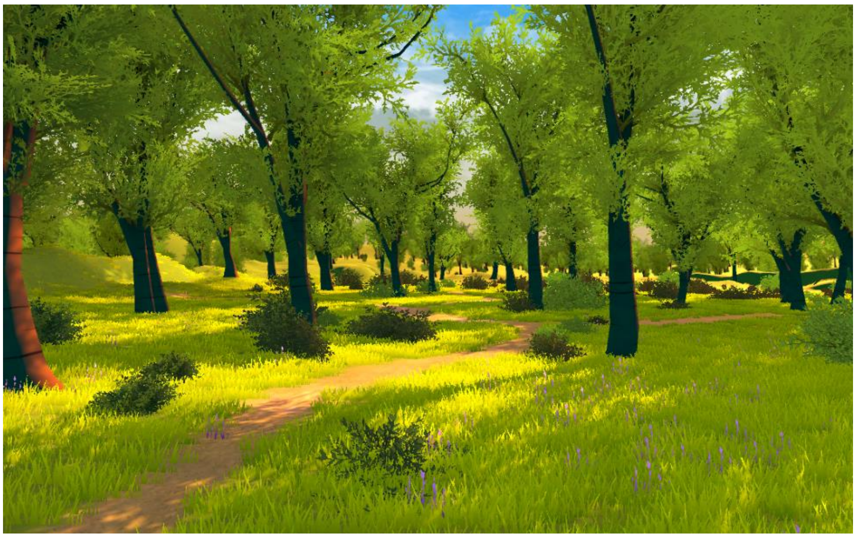
- Ground
- Trees
- Houses
- Clouds
- Sun
- Temple
- Towers
- Walls
- Cement builds

Gym (Free)

The gym environment consists of various gym equipment and posters on the walls. The music is energetic kai motivates the user to exercise. Area of interests:

- Gym equipment
- Posters
- Walls
- Ground
- Ring
- Lights
- Lockers
- Matts
- Cement builds

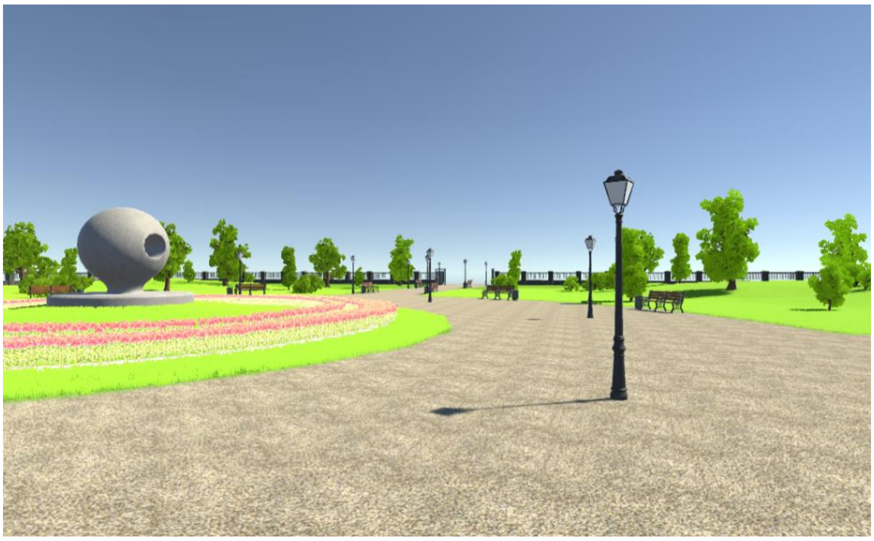
Forest (Free)



A peaceful environment close to nature. The forest is full of green and offers the patient a place to rest. Areas of interests are:

- Trees
- Sun
- Sky
- Grass
- Bushes

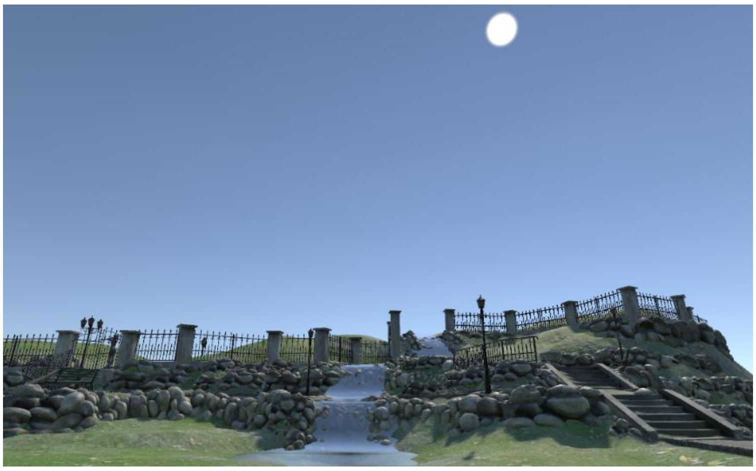
Park 1 (Paid)



The most popular environment from our research study with all demented people interested in visiting it. It is a simple park with trees, benches, and a sculpture in the middle. Areas of interests:

- Ground
- Sun
- Sky
- Sculptures
- Lanterns
- Flowers
- Benches
- Fence
- Trash Cans
- Trees
- Birds

Park 2 (Paid)



One more realistic park environment since we had very positive feedback about parks. The assets from this pack are photorealistic models of real objects in a park.

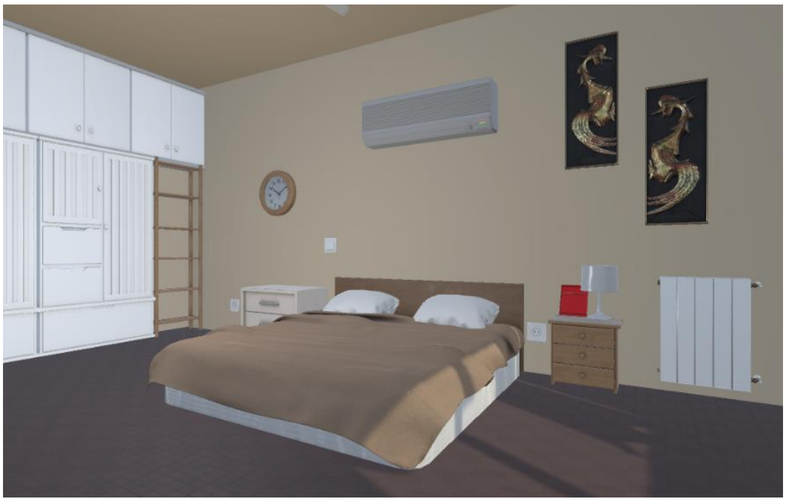
• Ground	• Sun	• Sky	• Sculptures
• Lanterns	• Flowers	• Benches	• Fence
• Trash Cans	• Fountains	• Rock walls	• Trees

Kitchen (Paid)

One of the three house environments we have chosen. The kitchen consist of a kitchen stall and a table for the family to eat. It is a bright environment and reminds you of a Sunday lunch with the family. Areas of interest:

• Ground	• Windows	• Stall	• Phone
• Flowers	• Kitchen gadgets	• Image	• Table
• Silverplated	•Door	• Walls	

Bedroom (Paid)



The second house environment is a modern bedroom with a big window. It has big storage on the one side of the room and various items on the walls. Areas of interest:

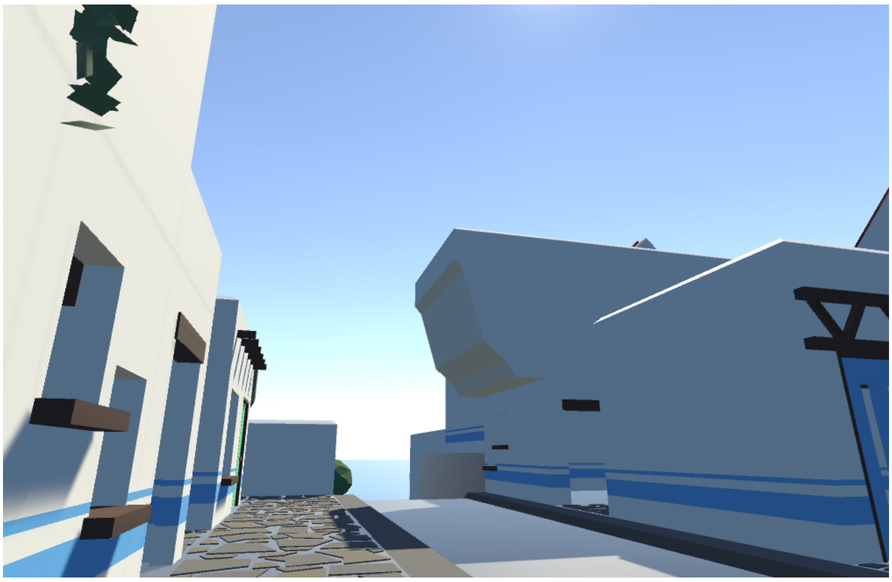
- Bed
- Window
- Clock
- A/C
- Painting
- Lamp
- Book
- Calorifier
- Ground
- Walls
- Door
- Storage furniture

Living room (Paid)

The last house environment is a living room. On the right, we have a big piece of furniture, in front of a desk for work and on the left a TV with sofas. On the tv, we play traditional Cypriot dances. Areas of interest:

- Sofas
- Window
- TV
- Desk
- Painting
- Ceiling Lamp
- Furniture
- Doors
- Ground
- Walls

Nauplio (Paid)



A Greek island with a graphical landscape and quiet streets. Areas of interest:

- Buildings
- Sea
- Sky
- Road
- Sun

Venice (Paid)

Our last environment is Venice. We choose this because it has a lot of similarities with Cyprus' old villages. Areas of interest:

- Buildings
- River
- Sky
- Pavement
- Boats
- Stairs
- Wheels
- Trees
- Benches
- Lanterns
- Electricity towers

3.4 Apparatus

VIVE Pro Eye Virtual Headset

VIVE Pro Eye Virtual Headset is a piece of very powerful machinery. Its greatest features are Precision Eye Tracking, optimize graphic fidelity in users' line of sight and reduce rendering workloads on GPUs, and provide deep immersion and comfort [54]. We decided to go with this VR headset because of the precise eye-tracking embedded which is essential for our study. Moreover, we can deliver realistic graphics and immerse demented people in the virtual world. It is compatible with the Unity engine and the minimum requirements are 4 GB Ram, Windows 7+, graphics card equivalent or better than AMD Radeon™ R9 290 equivalent or better and processor as powerful or more than AMD FX™ 8350 [55].

Figure 3.57 Vive Pro eye Virtual Headset

VIVE Pro Eye Specifications [55]	
Screen	Dual OLED 3.5" diagonal
Resolution	1440 x 1600 pixels per eye
Refresh Rate	90 Hz
Sensors:	G-sensor, Gyroscope, Proximity, Eye-tracking
Eye Tracking Specs	
Gaze data output frequency	120 Hz
Accuracy	0.5°–1.1°

Calibration	5-point
Data output	• Timestamp (device and system) • Gaze origin • Gaze direction • Pupil position • Pupil size • Eye openness

Table 3.2 Vive Pro eye Specifications

Galaxy Watch Active 2

Watch Active 2 is a smartwatch developed by Samsung Electronics. It was announced on 5 August 2019 and released on 23 September 2019. This smartwatch can be a useful health companion tracking your movements and vitals while working out. For us, the interesting feature is taking an electrocardiogram (ECG) from the wrist. It is more convenient to measure the heart rate from the wrist of demented people instead of strapping a heart rate monitor on their chest [56].

Figure 3.58 Samsung's Galaxy Watch Active 2

3.4.1 Virtual Reality System

Requirements analysis and design definition

For the requirements analysis and design definition, we communicated with healthcare workers and «Archangelos Michael» Nursing Home for People with Dementia (AMEN) who provided us with the requirements of such a system. Moreover, we followed well-known guidelines for the system's usability and user experience so the caregivers can operate our system with ease. The system must make the patient comfortable and be enjoyable for them on every session. They can choose as many environments as they want and stay on them for 10 minutes max.

Functional analysis

Based on the requirements we defined the functions of our system. The most important function is to ensure the proper transition to scenes and player placement. The patient must not see a black screen while on VR because he might get frightened and anxious. One more function is to collect data to monitor the health of the patient. Heart rate will be always displayed through the screen of the caregiver and a green line will follow the gaze of the patient. Every environment will be relaxing and pleasant, with no loud noise or sudden movements either from objects in the scene or the player. Patient and caregiver can have the ability to connect to the VR environment at any time. Lastly, the system must have quick responses, low storage needs and function properly both on affordable and high-end devices.

Virtual Reality Description – Design Synthesis

The patient has to wear the Virtual Reality headset and the smartwatch to collect the data. If he is unable to do it alone, the caregiver will help him. The caregiver is advised to be present during the whole session to monitor his health and calm him if something he sees makes the patient nervous or afraid. When the patient is ready, we connect Visual Studio to monitor the heart rate and we start the Unity application. From a secondary screen, we can see what the user sees, and the interaction can start. Firstly, the patient will see the Main Menu. The Main Menu is nine pictures representing the available screens. With his gaze, he can look at the picture and by doing that the name of the screen will be displayed in the center of the Menu. To select a scene, the patient has to focus on a picture for five seconds. Moreover, there is a smaller picture with a cross, which is the exit from the game. When a scene is selected, the patient is transferred to that virtual environment. In the environment, we added some areas of interests for which we collect data for. The patient will be unable to move, however, he can explore the whole environment by tilting his head. If he wants to select a new scene, he presses a button on the controller and goes back to the main screen. After the session ends, we can collect all the data from the eye tracker and heart monitor.

3.4.2 Equipment

In our research, we mainly used the Unity Game engine where we connected the VIVE Pro Eye VR headset which supported eye tracking. For the heart rate monitoring, we collected the data with Samsung Galaxy Active 2 smartwatch. Finally, to combine everything our code was written on Unity, Tizen Studio and Eclipse.

Unity game engine

Unity is a cross-platform game engine developed by Unity Technologies, in 2005. It supports over 25 different platforms from desktop, mobile, consoles and VR including iOS, Android, PlayStation, Xbox, Windows, Mac, Steam VR (this is what VIVE Pro Eye uses) and many more [57]. For the development of the application, you must use the Unity Editor which is provided on Windows, MacOS and Linux Systems. You can create two-dimensional (2D), three-dimensional (3D), Virtual Reality or Augmented reality games as well as simulators. Additionally, it is considered among the best free game engines, competing toe-to-toe with Unreal Engine, with each one being superior in different aspects and situations.

Unity is a complete system providing you with all the tools to create whatever you want. Programmers, artists, and designers can all work even without having programming knowledge (however to utilize the engine it is essential to learn). It provides the ability to create high-quality graphical environments and preview how the game will run. During testing you can give your input, modify parameters etc., giving you the ability to experiment easily and make debugging easier. Another feature is the ability to edit sound files like MP3 and WAV within the Unity editor. We decided to use Unity for the reasons listed above, but also for the Main characteristics described below.

Main characteristics

Free: Unity is free for anyone, making it easier for people who cannot afford to buy a gaming engine to start developing. Of course, they do not give full access to all the features of Unity if you do not pay. However, if you are a student and provide your intuitional email you unlock some of those features.

Learning Unity: Even if you decide to learn by yourself Unity without the help of a teacher, Unity technologies provides a tremendous amount of tutorial videos guiding you in understanding the engine and learning new features.

Community: The community is very big and friendly. Creators have their websites that can share their projects and assets, while others make YouTube tutorials for almost everything. Most probably, whatever your problem is, you will find a tutorial or a forum reply solving it, within a short time.

SDKs: You can use Software Development Kits in your Unity project for developing the application for various devices and only have few changes in your code. For example, the same application can run on mobile and desktop.

Coding ease: Unity editor mainly uses C# and less frequently JavaScript. Luckily, they give you the freedom to use any IDE you want to use for the development of the code and then add it to the project. Moreover, you can connect Visual Studio with Unity to detect errors easier and autocompletion of the code.

Documentation: They provide documentation for all their functions with examples.

Asset store: It provides you with various assets like buildings, animations, characters and many more created from others or Unity Technologies. Some of them are free and others you must pay to use them. This can be a time saver for developers since we do not want to “discover the wheel every time” and instead we can buy the asset using it right away.

Open Broadcaster Software (OBS)

OBS is a free and open-source cross-platform streaming and recording program built with Qt and maintained by the OBS Project. Written in C, C++, and Qt, OBS provides real-time source and device capture, scene composition, encoding, recording, and broadcasting.

HeartRateOBS

HeartRateOBS is a smartwatch and computer application used to display the heart rate from the watch to our screen in OBS. In order to operate it, you need a smartwatch, a phone, and a computer. Smartwatch and computer must have the appropriate application installed to communicate between them. It is an open-source program shared on GitHub (https://github.com/loic2665/HeartRateToWeb).

Code

<u>Unity</u>

Behavior of objects in Unity is controlled by the Components connected to them. A component has Scripts, properties, and variables. Actions an object does are activated from Scripts that interact with the inner functions of Unity, considering Components' properties and user Input. For the creation of Scripts, we will use the object-oriented programming language C# and Visual Studio to edit them.

<u>Eclipse</u>

Eclipse is an integrated development environment. We will use it for a minor process we want to complete which is processing two text files with data to create one text file showing us his heart rate and where the user was looking at a specific time. The programming language we used it Java.

3.5 Data Collection

Eye Tracking

To collect the eye-tracking data we used the embedded VIVE Pro Eye VR headset eye tracker. First, we initialize the eye-tracking source. To do that we created a script searching for available sources. The first eye-tracking source it finds, activates it and stops the search for other sources. After we have our tracking source, through its data we create a ray cast using a point and a direction. The point is the origin of the gaze, i.e., our camera and the direction of the ray is defined from the direction of the gaze. The first object the ray collides with is the object with the focus.

Heart Rate Monitoring

For the heart rate data, we used the Galaxy Watch Active 2 and HeartRateOBS. First, we connect the smartwatch with a phone via Bluetooth. The phone and computer must be connected in the same network. On the computer, we execute the python program which will display the network and the port we will need. This python program creates a fake server in the laptop where the smartwatch will send the data to that port, and the computer will collect the data. On smartwatch we run the HeartRateOBS. It will ask for a network and a port which are those we had on the computer. When we insert the information and press continue the data extraction will start. To display the data in OBS we create a text source and set the output file from the HeartRateOBS to the source.

Quantitative measures

To evaluate our system on various sections we used some quantitative measures which we describe below. All measures were embedded in our system and the user using the computer was taking the questionnaires during the session during each scene, after the end of a scene and after the end of a session. For each measure, we present them below with the relevant screenshot of our system.

Slater–Usoh-Steed [58]

A simplified version of the SUS assessed the level of presence and immersion for each iterative design session on a 7-point Likert scale (1 = being somewhere else and 7 = being in the Virtual Environment).

Visual Analog Scale (VAS) [59]

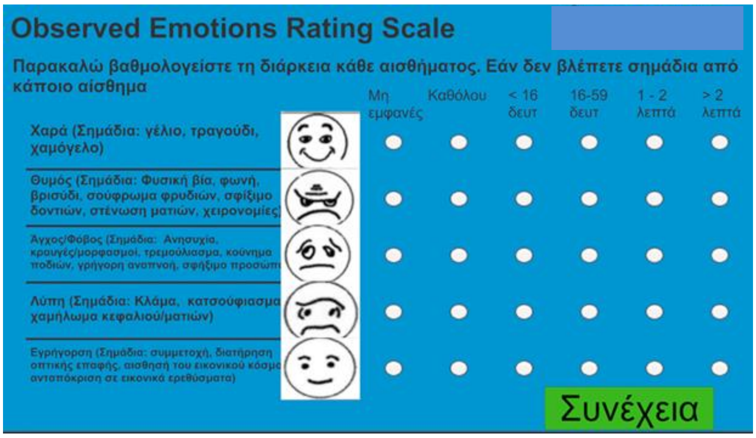
VAS was used as a psychometric response scale of depicted emoji to measure emotions (0 = happy and 5 = sad). The scale was used to allow patients to express their emotions towards each method of interaction. We asked patients to point to the specific emoji which matched their emotional state before and after each task execution.

The Single Ease Question (SEQ) [60]

SEQ assessed the level of difficulty for each interaction on a 7-point Likert scale (1 = very difficult and 7 = very easy)

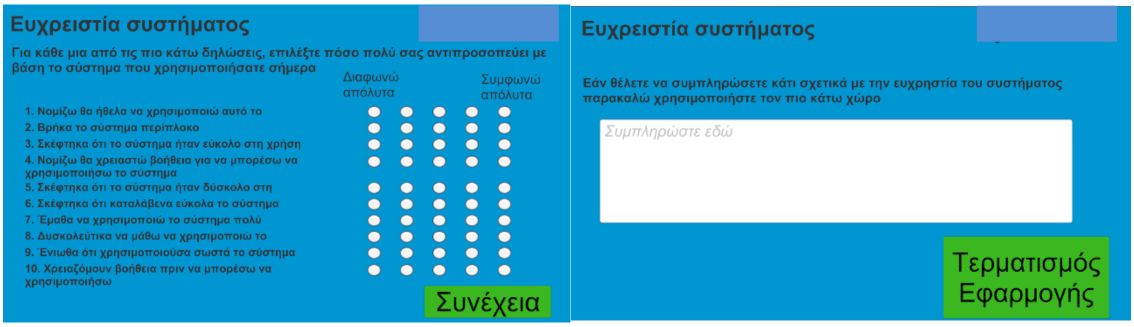
Observed Emotion Rating Scale (OERS) [61]

OERS was used to assess the patient's interactions with the VR. The OERS is used routinely in the care setting since the scale offers direct observation of the time spent expressing five affect types: pleasure; anger; anxiety; sadness; and general alertness. Ratings are measured on a Likert scale (1= never; 2= <16 seconds; 3= 16- 59 seconds; 4= 1-5 minutes; 5= >5 minutes; and 7= not in view). The tool was held by the researcher for the pre- during and post- of the VR exposure. This was to maximize the richness of the data.



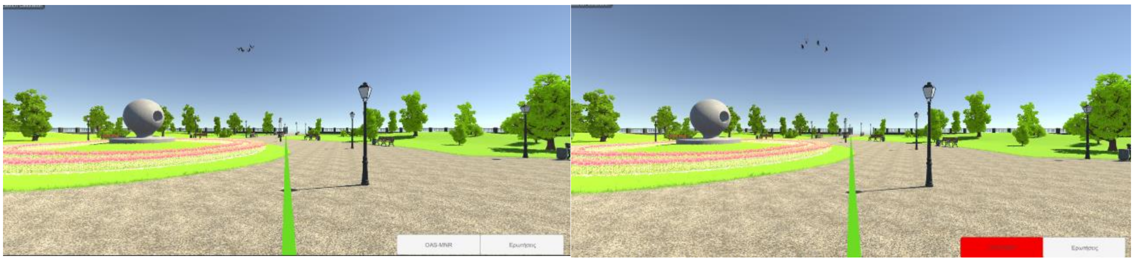
System Usability Scale (SUS) [62]

A simplified version of the SUS assessed usability for each iterative design session on a 5-point Likert scale (1 = strongly disagree and 5 = strongly agree). Note that the analysis is performed at 0 to 100 rates. To do so SUS required to subtract 1 from the user responses to positive statements and subtract corresponding values from 5 in the negative statements. All responses are added and multiply by 2.5.

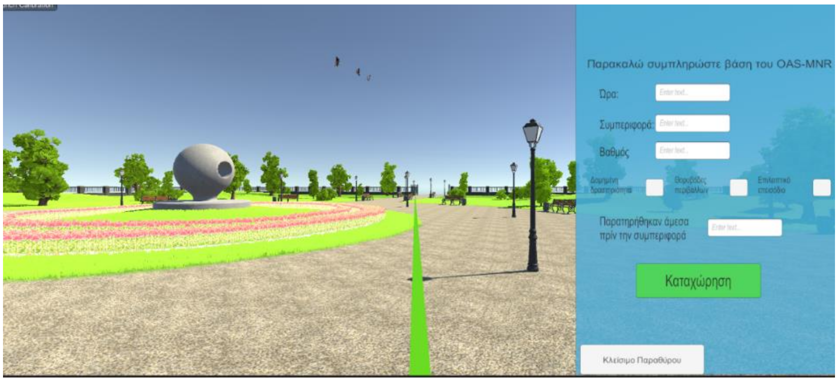


Overt Aggression Scale-Modified for Neurorehabilitation (OAS-MNR) [63]

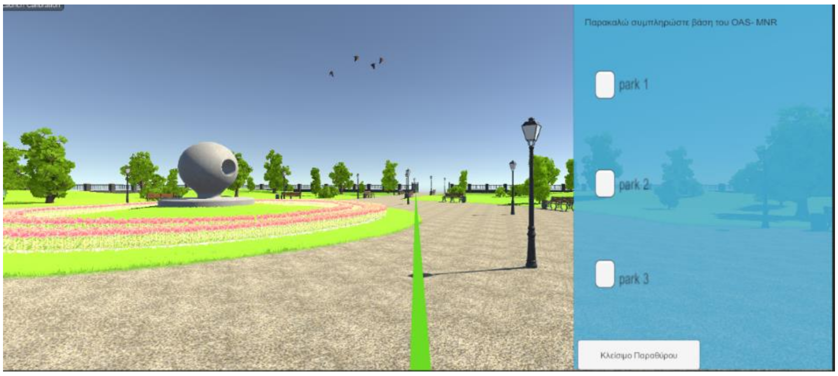
Used to offers continuous direct observation and assessment of antecedents, contexts, behaviors, and interventions. It records the type and severity of aggression from four categories: verbal aggression, physical aggression against objects; physical aggression against self; physical aggression against others. The tool was held by the researcher for the pre- during and post- of the VR exposure. Below you can see the user's screen during a scene. The green line is the patient's gaze. There are two buttons on the bottom-right corner. The first is the OAS-MNR questionnaire. Every minute the user must in fill the observations from the behavior of the patient. To remind him when a minute passed without an entry, that button turns red to warn the user.



Based on the OAS-MNR guidelines which we explained in advance to the user, he must fill in all the necessary information and submit the entry. By pressing the window on the bottom, he can minimize the window.



The second window provides the user with some demonstrative questions to start a conversation with the patient and get more feedback from his experience with the virtual environment. When the question is made, he can check the box and that question will be replaced with a new one. If no more questions are available, the checkbox will be disabled, and the label will be “No more questions”.



3.6 Data Processing

<u>Eye Tracking Data</u>

For processing further data, we created two components, eyeTarget and AreaOfInterest. EyeTarget component indicates if the object is important to our observation or not. So, if the ray hits an object without the eyeTarget component nothing will happen. On the other hand, if we observe the object, the object will update its corresponding Area of Interest (AOI) with information we keep about eye tracking. AreaOfInterest can be one or more objects. For example, a table consists of four legs and the top. The table is the area of interest while the legs and top are eye targets. The changes are updated dynamically.

The algorithm we used for detecting fixations is a velocity-based with minimum threshold 100ms. The velocity-Threshold Identification algorithm was not suitable for the system because it applies only to static objects. Nevertheless, we implemented a variation of this algorithm and manage to track gaze to dynamic objects too. The factor we considered was the velocity of the object and the only step we added was subtracting the object's velocity from the velocity of the eye.

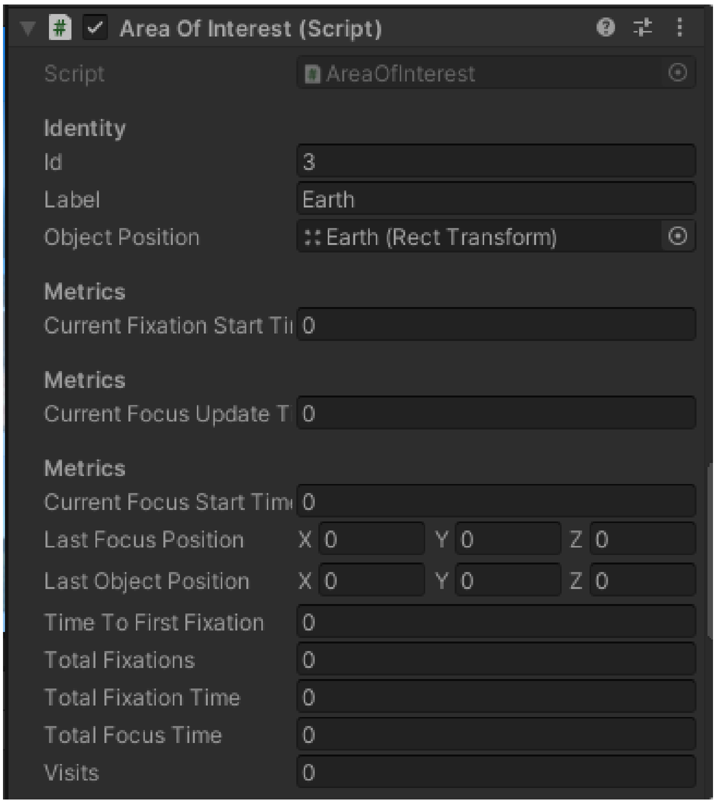


Figure 3.59 Area of Interest Component

Above we see what information we gain during run-time and we can extract all area of interest's information at the end of the session. In this example, we got the Earth select screen from the Main Menu. Every AOI has an identity with a unique id, a label, and its position. There are lots of metrics we keep track of, most notable total fixations, how long they looked at the AOI, when was the first and last time they fixated on it and visits to AOI. The difference between fixations and visits is that visits increase even when their velocity is below the threshold.

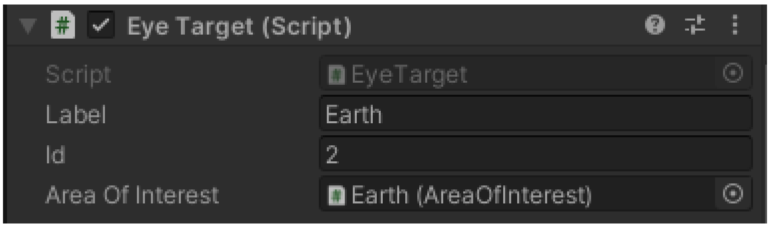


Figure 3.60 Eye Target Component

Eye Target is simpler than the AOI component. It only has an id, label and the assigned AOI to him. Afterwards, we imported all eye-tracking data into excel to visualize our results.

Heart Rate Data

Our goal is to link the two log files created, the one from the console of HeartRateOBS and the other from Unity's log file, into one. The final file will have multiple entries and each entry includes the heart rate, the object which the user was looking at and the time. To process the two text files, we used Eclipse.

Because it is unnecessary to keep track of the heart rate every 100ms, we decided to keep one heart rate measure for every five seconds. Moreover, because we primarily want to monitor the heart rate and what the user sees is supplementary, final data was based on Heart rates' log file's times.

First, we needed to convert Time to seconds. With simple calculations, we created one additional file, for the unity log. After that, we could start processing our data. For each entry of the Heart Rate log, we checked if we already had an entry in the final file for the same second. If we had, then we did nothing. Else we continued and accessed the additional file we created from the unity log. There we tried to find one entry from the unity log file, which had less than 17ms difference from that specific heart rate entry. When we found such an entry, we returned the object and updated the final file with the heart rate, object, and time. If we did not manage to find one entry less than 17ms, that meant the user was not looking in an Area of interest and we returned Void. We repeated the process for all Heart Rate entries, and we got our data.

For better observation, we created an Excel Spreadsheet and used the final document to create a Graph, making it clear when Heart Rate increases or decreases and where the user looks just by hovering at that point.

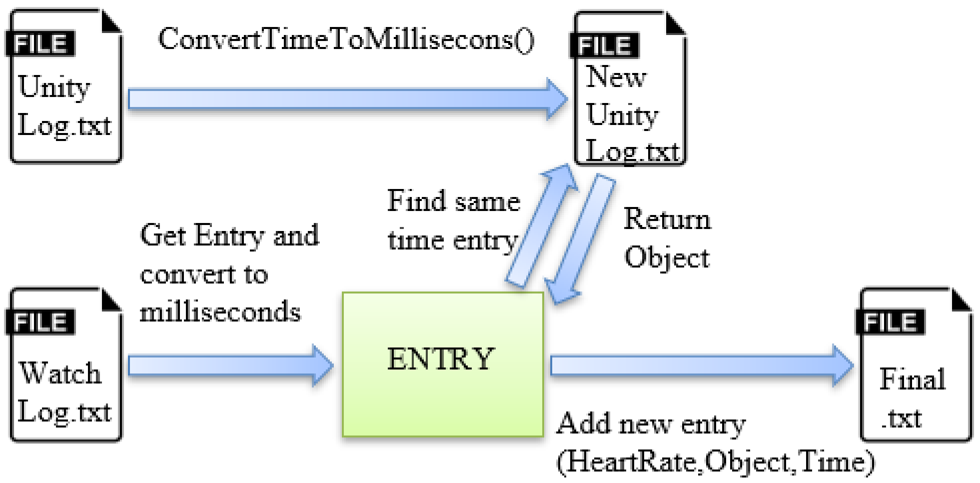


Figure 3.61 Iteration for an Entry of Final Log

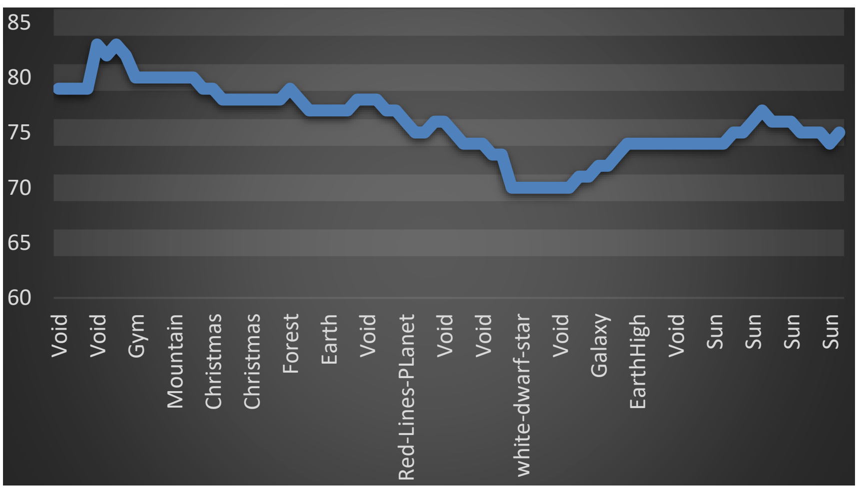


Figure 3.62 An example from a short session, where we track his Heart Rate.

Quantitative measures

For the quantitative measures, we collected them and used the statistical software platform “SPSS”.

Chapter 4

Results

Unfortunately, due to the Covid-19 pandemic, we were unable to test our system with people with dementia. We decided to validate our system with healthy population of all ages. Hence for this chapter of our study, we had 18 healthy participants and all Covid-19 protective measures were implemented.

4.1 Quantitative Measures

Participants

Eleven males (n = 11) and females (n = 7), aged between 15 to 83 years, participated in this study. The mean age was 38.78 years old with standard deviation 23.59 years.

Observed Emotion Rating Scale (OERS)

OERS was used to assess the participants' emotions before, during, and after the exposure. A Friedman test indicated that ratings of pleasure significantly differed before (M = 2.56, SD = 1.72), compared to during (M = 4.94, SD = 1.11) and after (M = 4.28, SD = 1.41) VR exposure, $\chi^2 (2) = 21.97$, p = .000.

As can be seen in Table 4.1, the Friedman test indicated no significant differences for the ratings of anger, anxiety/fear, sadness, and general alertness before, during, and after the VR exposure.

Emotion	Pre- Exposure	During Exposure	Post- Exposure	*p*
	M/SD	M/SD	M/SD	
Anger	.00/.00	.00/.00	.00/.00	-
Anxiety/fear	2.39/104	2.33/0.97	1.94/0.24	.175
Sadness	.00/.00	.00/.00	.00/.00	-
General alertness	6.00/.00	5.94/.24	6.00/.00	.368

Table 4.1 Means and Standard deviations for the component of OERS, before, during and after the exposure.

Visual Analog Scale (VAS)

In line with the above findings, we found a significant difference in the scores before (M = 3.00, SD = .77) and after (M = 1.89, SD = .76) exposure t(17) = 1.11, p = .000.

Presence and System Usability

As expected, results indicated that presence was high during the VR exposure (M = 5.02, SD = 1.37). Results showed that the system was also rated high in terms of usability (M = 61.94, SD = 9.09).

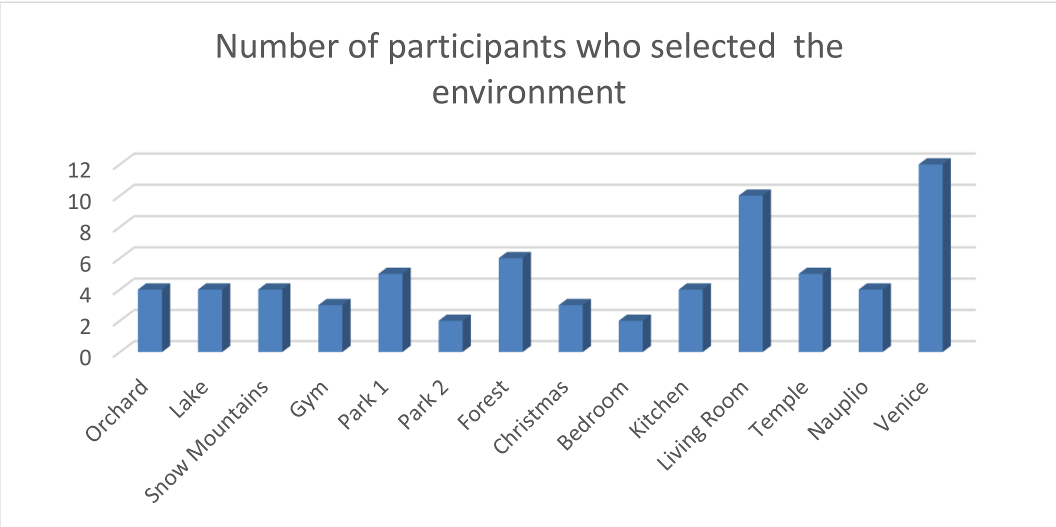


Figure 4.1 Number of participants who selected the environment

As we can see from the graph, the most popular environment was Venice with 12 out of 18 participants selecting it. The second and third environment were the Living room and Park 1. Park 2 and bedroom were the least preferable by the participants.

4.2 Eye Tracking

For the eye tracking analysis, we divided our data based on each environment. We created three graphs for each one. The first one shows the average fixation time of all participants who entered the environment, as a percentage of the time fixating on the object, divided by the total time spend on the environment. We applied this because we did not control exposure time. If someone spent 30 seconds and the other person spent 2 minutes, their eye movements will be different, as well as the actual amount of time spent looking at each element.

Second graph is the average number of fixations and visits on each object. The difference between the fixation and visit is that during a fixation the participant focuses on the object while on a visit he just passes right through it. Comparing them we can see where the user actually and subconsciously focuses on. Last graph is the hit radio. Hit radio is the number of people that saw the object, divided by the people who visited the environment.

<u>Orchard</u>

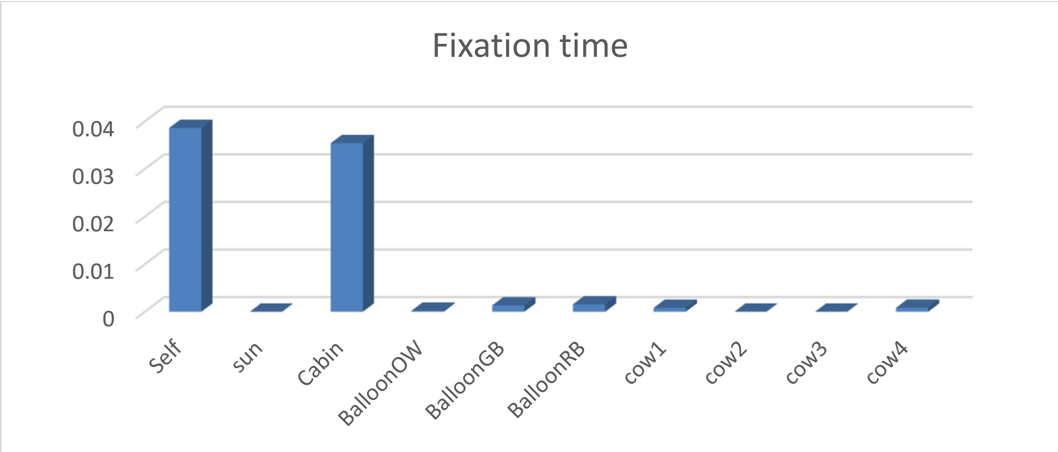


Figure 4.1 Fixation time for orchard environment

It is obvious that the participants paid a lot of attention to their self and the cabin in this scene. The orchard environment was usually the first environment of all the participants who selected it and that explains the high focus on themselves. The air balloons followed, with the Red and black colored having more focus that the other two.

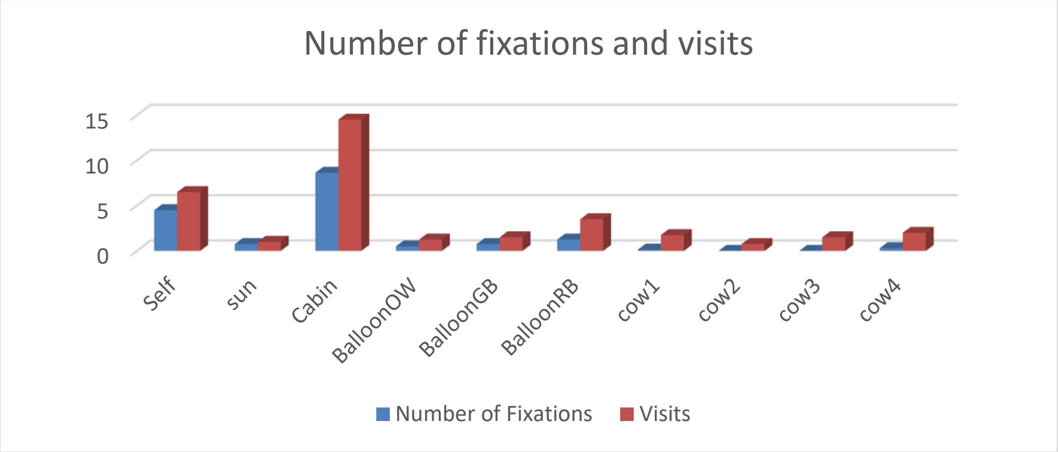


Figure 4.3 Number of fixations and visits for orchard environment

From the graph we can conclude that they were looking at themselves fewer but longer durations and at the cabin multiple but short times. Moreover, unconsciously they saw the cows, but never paid attention to them.

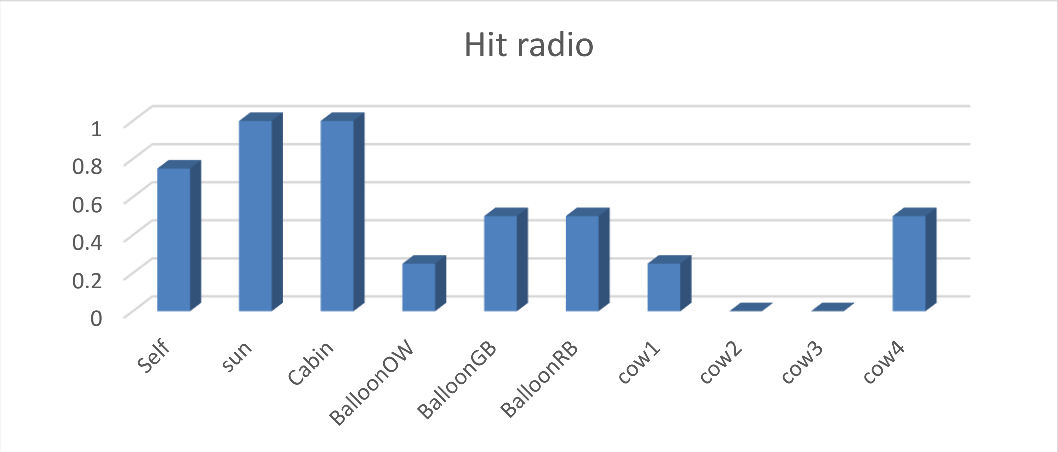


Figure 4.4 Hit radio for orchard environment

Everyone saw the cabin and the sun, although, the fixation time of the sun was almost zero. This means that all got a glimpse of the sun and then ignored him. Besides cows being the closest object to the participant, only half of them focused on just one of the four cows and two of the cows were not seen at all from no one.

Lake

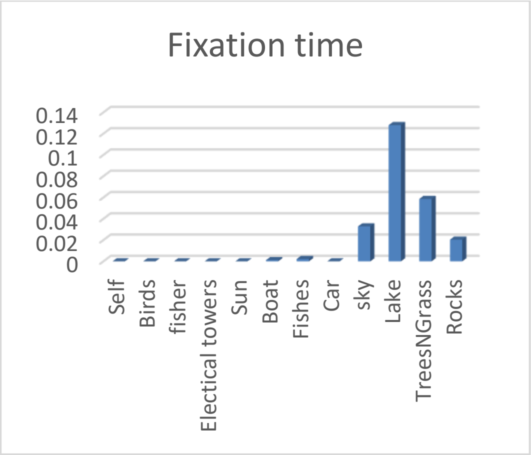


Figure 4.5 Fixation time for Lake

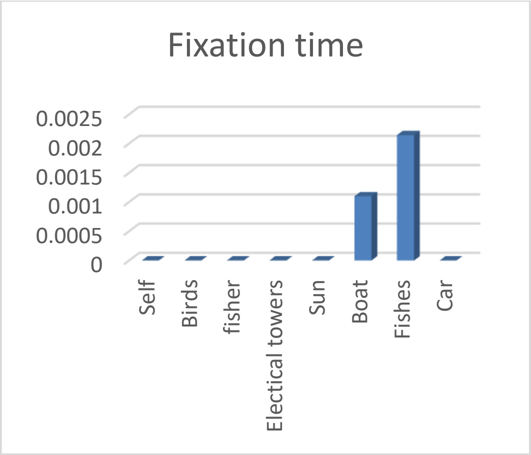


Figure 4.6 Zoomed in Fixation time for Lake

On our second environment we observe that the fixation time of the terrain and especially the lake was enormously high in comparison to the other objects in the environment. This can indicate that they focused on the whole environment rather in the details we added, like the car doing circles around the lake and birds flying on top. If we zoom in our lower value data, we can see they fixated on the fishes and boat, which were inside the lake.

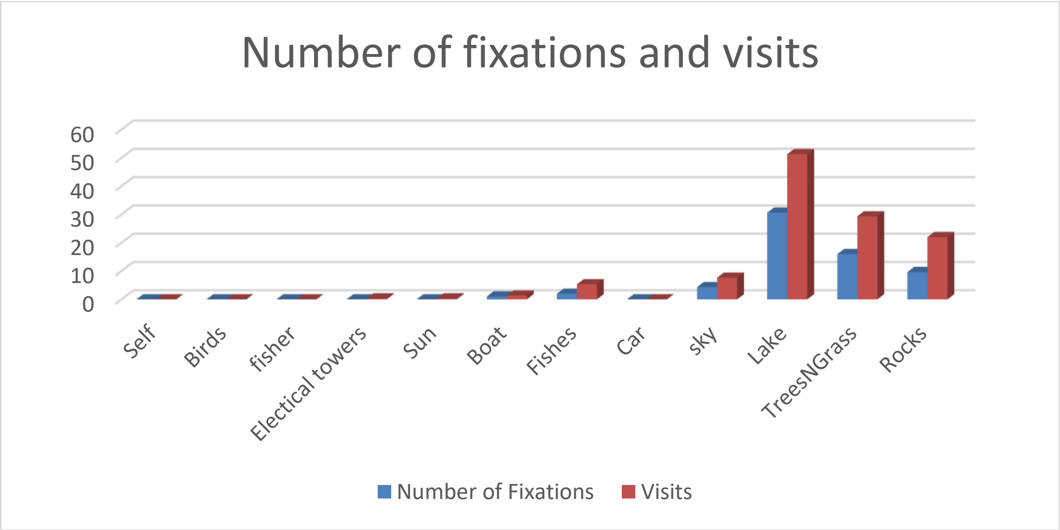


Figure 4.7 Number of fixations and visits for Lake

Based on visits we can confirm that participants noticed the fishes and boat and the reason is since they focused the most in the lake, they scanned the whole area of the lake. On the contrary, they might not noticed the birds and sun because they looked at the sky for less duration.

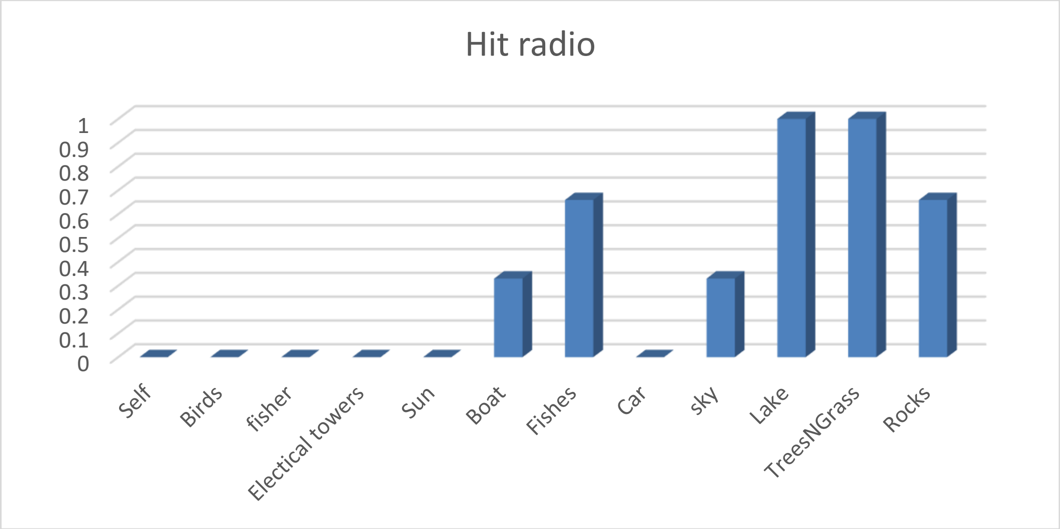


Figure 4.8 Hit radio for Lake

As we can observe everyone saw the lake and 66% of the participants saw the fishes and rocks. They saw the fishes once or few more times and did not actually focus on them.

<u>Snow Mountains</u>

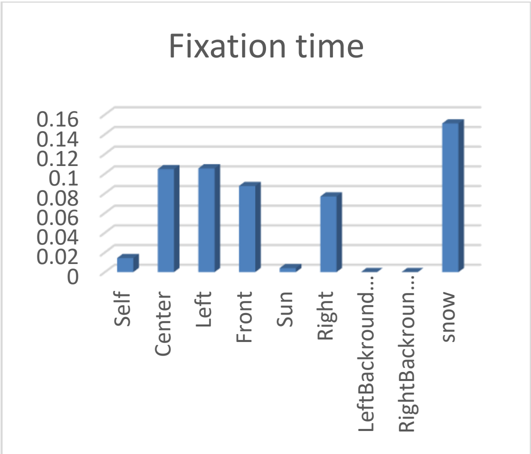


Figure 4.9 Fixation time for Snow mountains

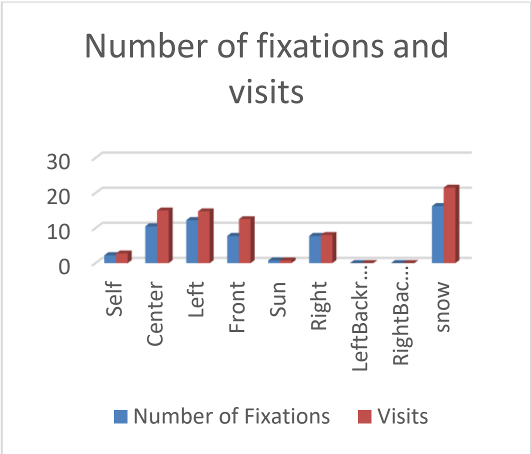


Figure 4.10 Number of fixations and visits for snow mountains

Here, we observe that most of the fixation time is looking at the snow under the mountains. The participants focused mostly on the mountain peaks in front of them while no one saw the mountains behind them. On the second graph there is nothing different from what we concluded based on the first one.

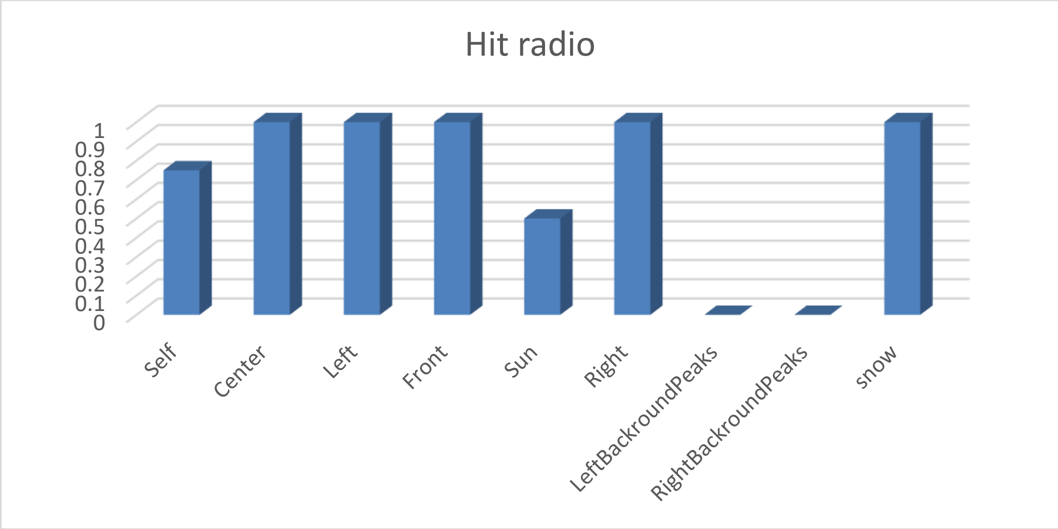


Figure 4.11 Hit radio for Snow mountains

In this environment every participant almost looked at everything except the background mountains. Having few large areas of interest urges might be the simple explanation for this observation.

<u>Gym</u>

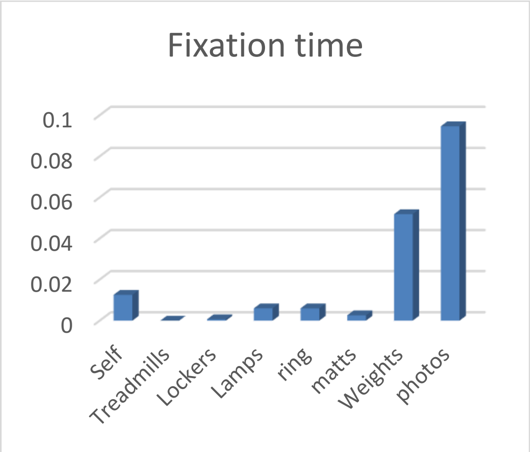


Figure 4.12 Fixation time for Gym

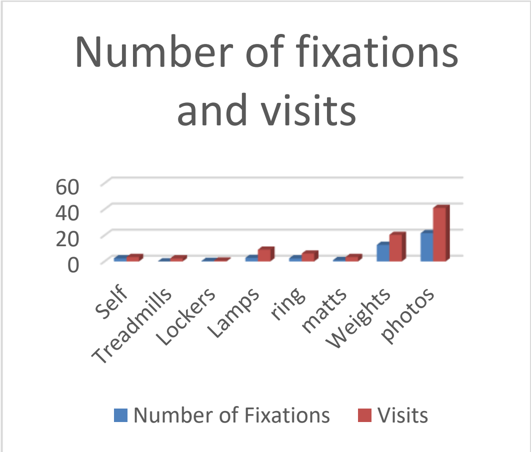


Figure 4.13 Number of fixations and visits for Gym

On the gym environment participants mostly focused on the posters in the walls. The posters had a motivational quote or a sporty human. The next more popular area of interest was the weights since they picked the gym environment they anticipated to search for the weights. The ring came fourth, despite being in front of the user. Based on the number of fixation and visits graphs, they saw the lamps in the ceiling but did not focus on them so much.

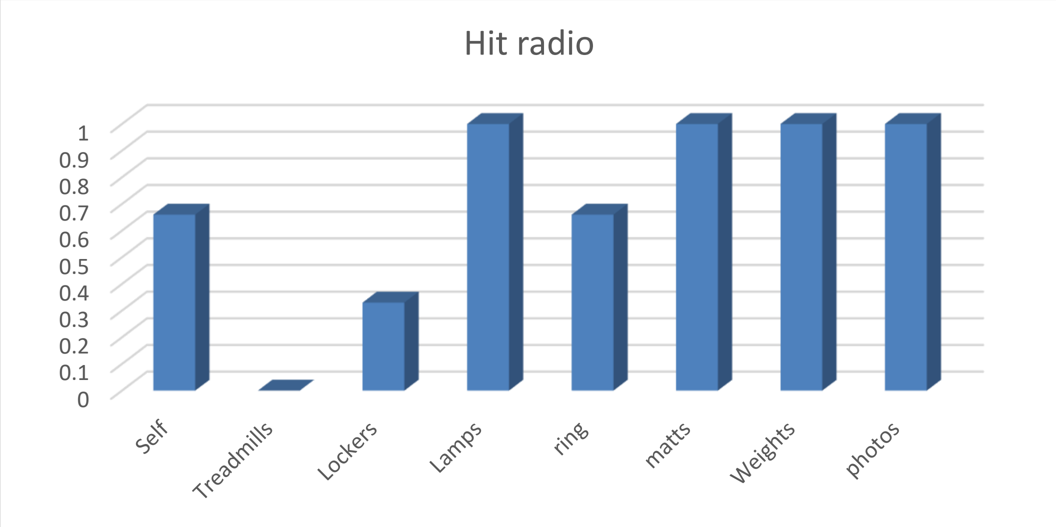


Figure 4.14 Hit radio for Gym

Although their low fixation time, everyone saw the lamps and gym matts and as expected everyone saw the weights and photos. Two thirds of the participants focused on the ring and themselves, while no one saw the treadmills, despite having multiple ones across the whole room.

<u>Park 1</u>

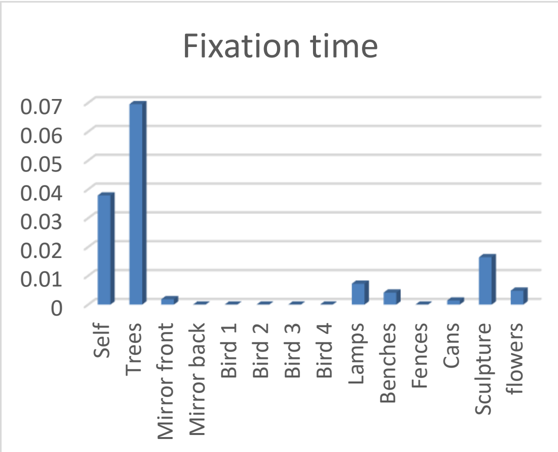


Figure 4.15 Fixation time for Park 1

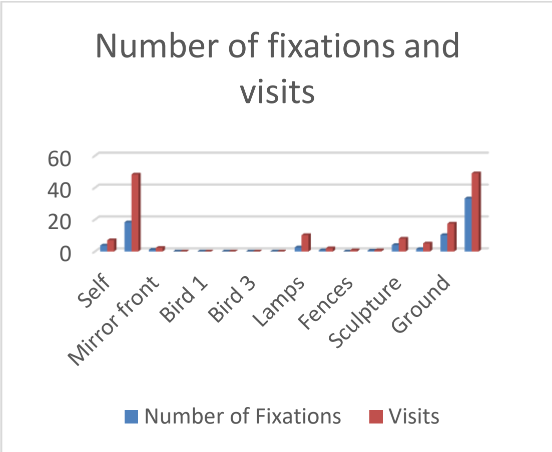


Figure 4.16 Number of fixations and visits for Park 1

Next environment was the first park. We have a big gap between the trees and all other areas of interest. Maybe nature draws the attention of the participants more than man-made objects. The sculpture was the third most seen object, and we can explain it due to its position of our scene (it was the center of it) and the interesting design. Nothing noteworthy was observed in the second graph except the high number of fixations in the sky but almost none to all four birds.

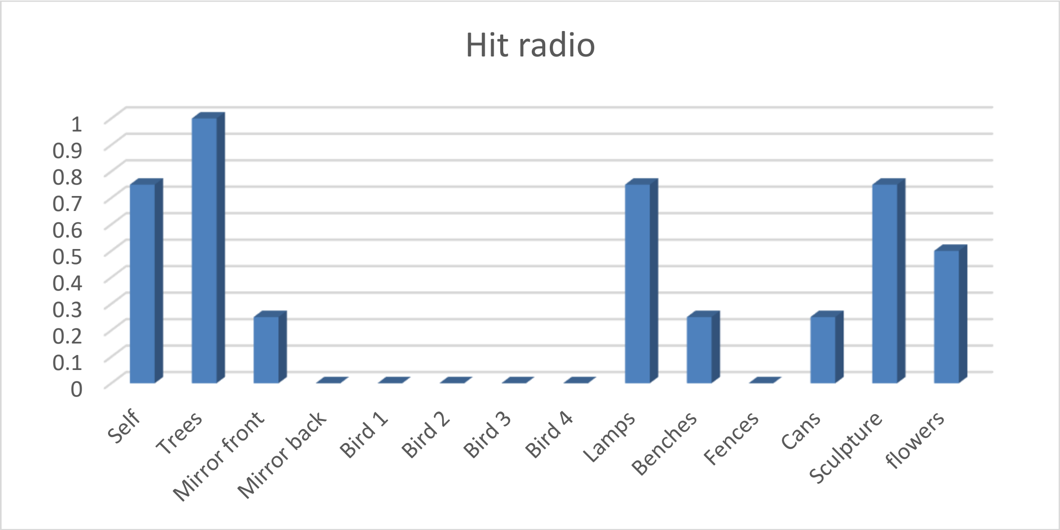


Figure 4.17 Hit radio for Park 1

In this graph we notice everyone saw the trees and no one the birds, fence, and the back mirror art. The birds and fence might be far from the position of the participant while they did not realize that behind them, they had the back mirror art. Like we saw in the gym environment, 75% saw the lamps but did not actually fixate on them.

<u>Park 2</u>

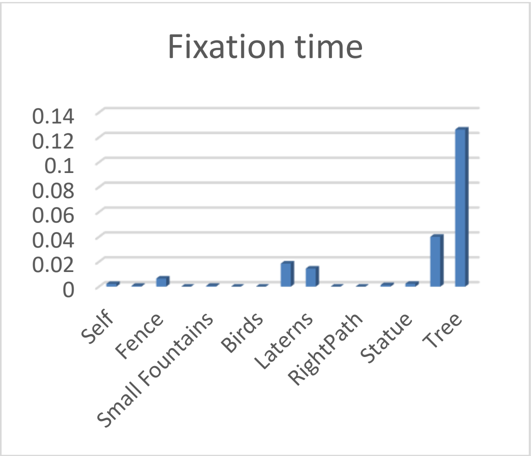


Figure 4.18 Fixation time for Park 2

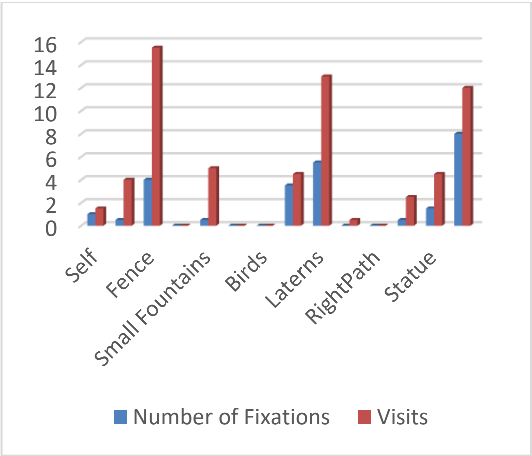


Figure 4.19 Number of fixations and visits for Park 2

The second park follows a similar pattern with the first one. We have high attention to the trees followed by the main area of interest, the fountain. In the second graph, we ignored the trees to see clearly what happens with the other areas of interests. Unconsciously people saw the fence surrounding the whole park and the lanterns scatter around the area.

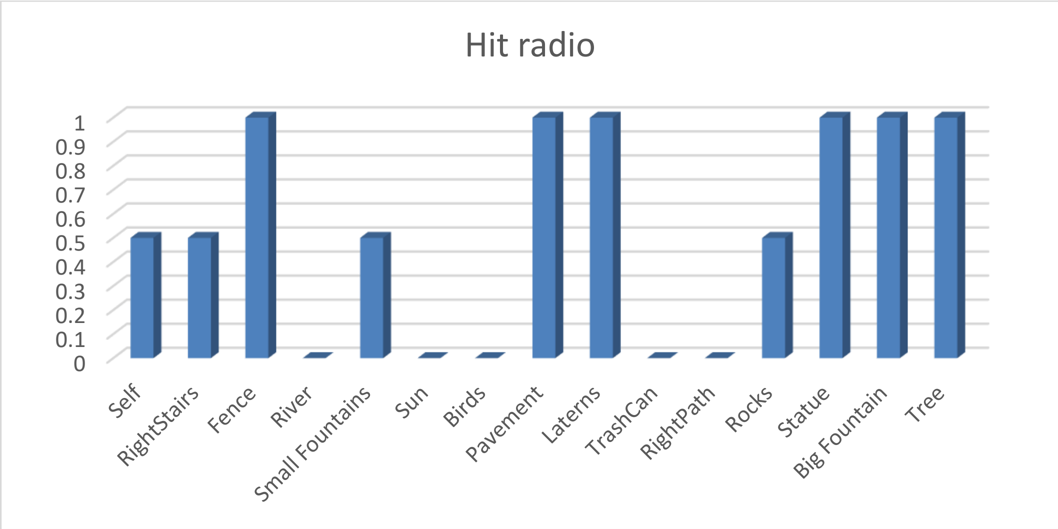


Figure 4.20 Hit radio for Park 2

Here we have 5 objects everyone saw and 5 no one saw. In the first category, the trees, fence, fountain and statues are objects that are unique and add something special to the environment, except the trees of course which are common. The other category is more of a filler objects like the trash cans and side paths. The only odd thing was that they did not see the river which is a nature element and usually draws the eye of the participants.

<u>Forest</u>

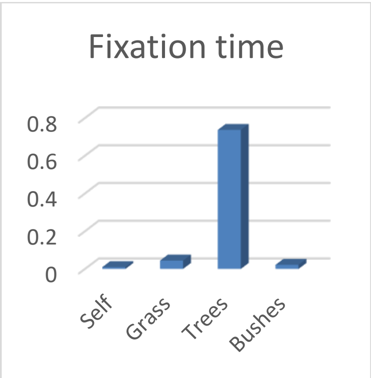


Figure 4.21 Fixation time for forest

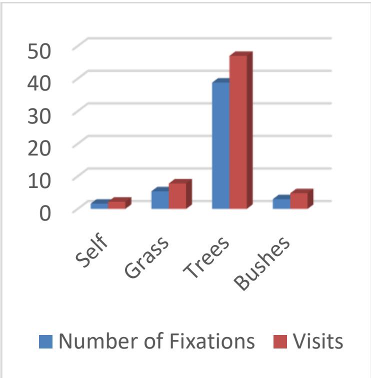


Figure 4.22 Number of fixations and visits for forest

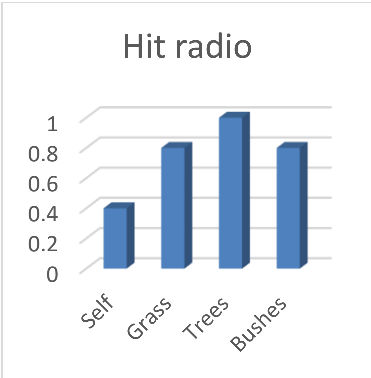


Figure 4.23 Hit radio for forest

The forest was a simple environment with few areas of interest. As we can see, almost for 80% of their time in the environment, participants were looking at the trees while the grasses and bushes, which were equally visible as trees, had significantly lower results. Nonetheless, almost every participant saw the grass and bushes too.

Christmas

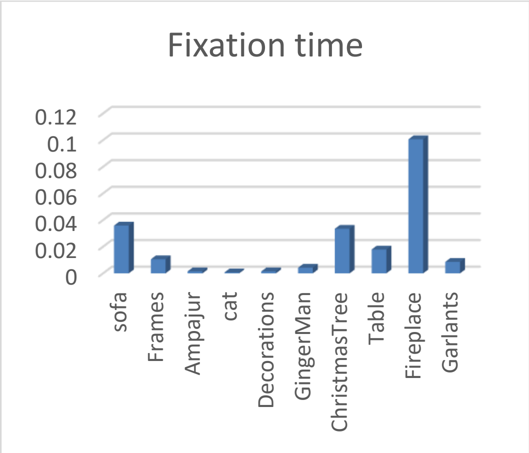


Figure 4.24 Fixation time for Christmas

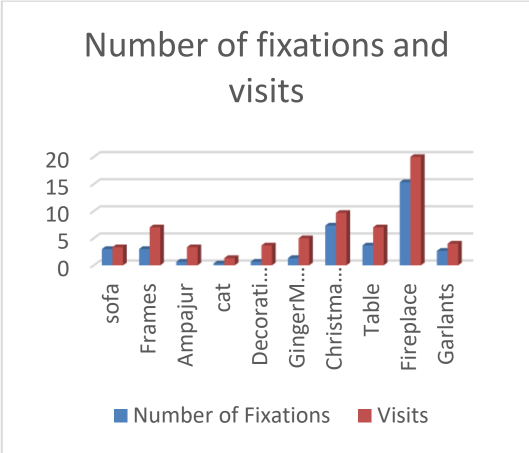


Figure 4.25 Number of fixations and visits for Christmas

For the Christmas environment, the fireplace was the area of interest with the highest fixation time. The reason might be because it had movement from the fire, and you could hear it burning. Then, the Christmas tree followed with almost as many visits as fixations. This means that were purposefully looking at the tree and they did not hover it through their scanning of the room.

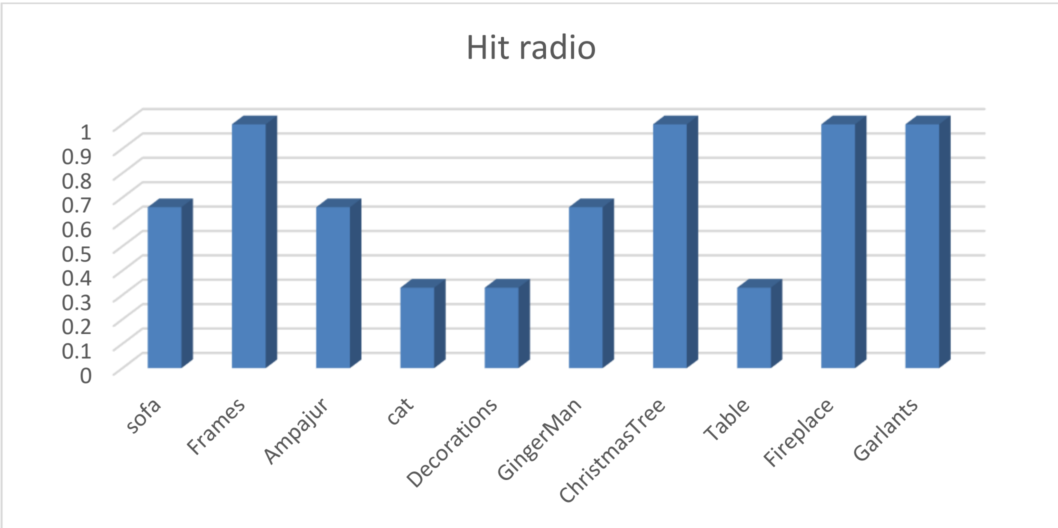


Figure 4.26 Hit radio for Christmas

This is the only environment where all participants fixated on all areas of interest. Everyone saw the wall decorations but very few saw the table, which was in the center of the room, in front of them.

Bedroom

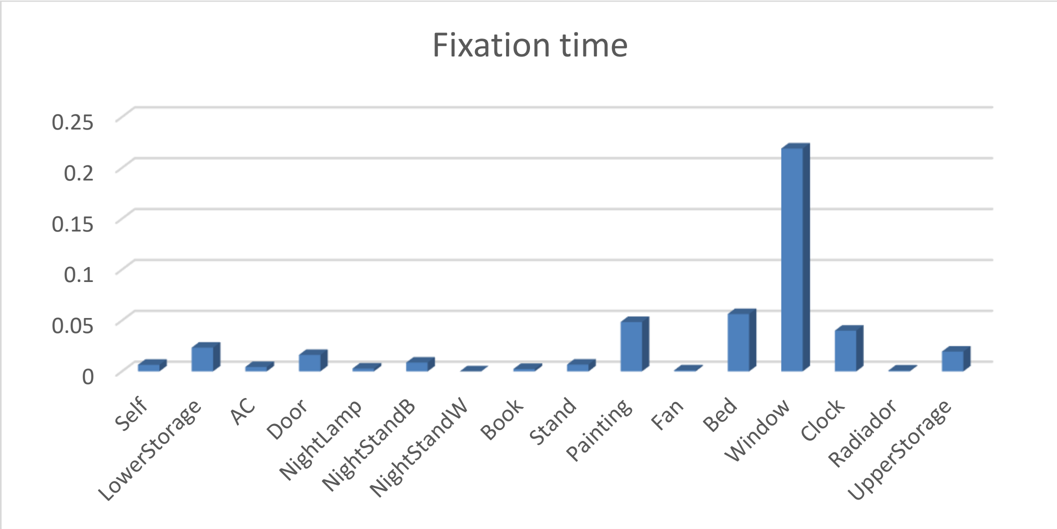


Figure 4.27 Fixation time for Bedroom

For our first home environment, we have the bedroom. Almost a quarter of their time in the room, they were looking at the window. The other popular areas of interest where the bed, the painting, and the clock. One of the participants also noticed that the clock was showing the wrong hour.

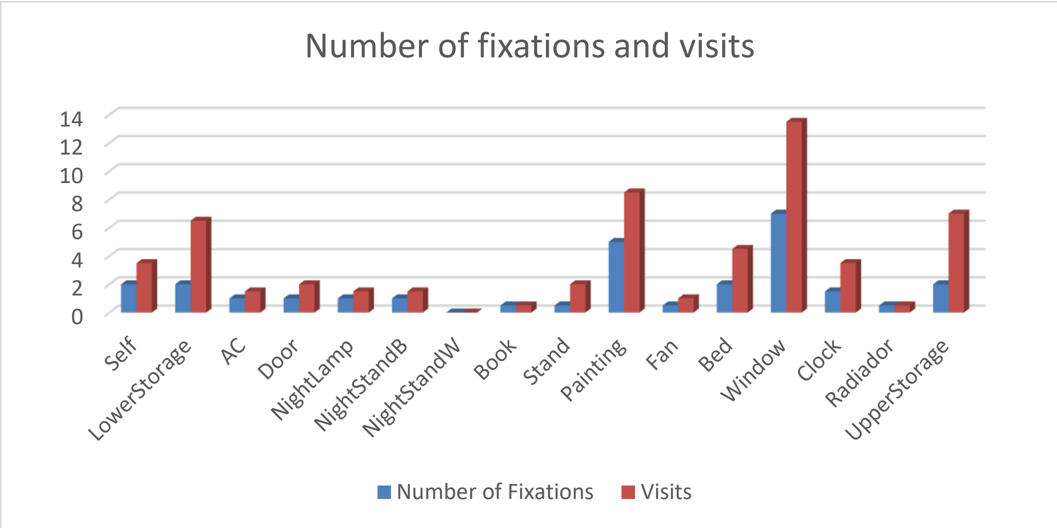


Figure 4.28 Number of fixations and visits for Bedroom

We do not spot anything different from what we observed in the previous graph. The only thing we can see is that the storage had a lot of visits, but the participants only focused on it only a third of the time.

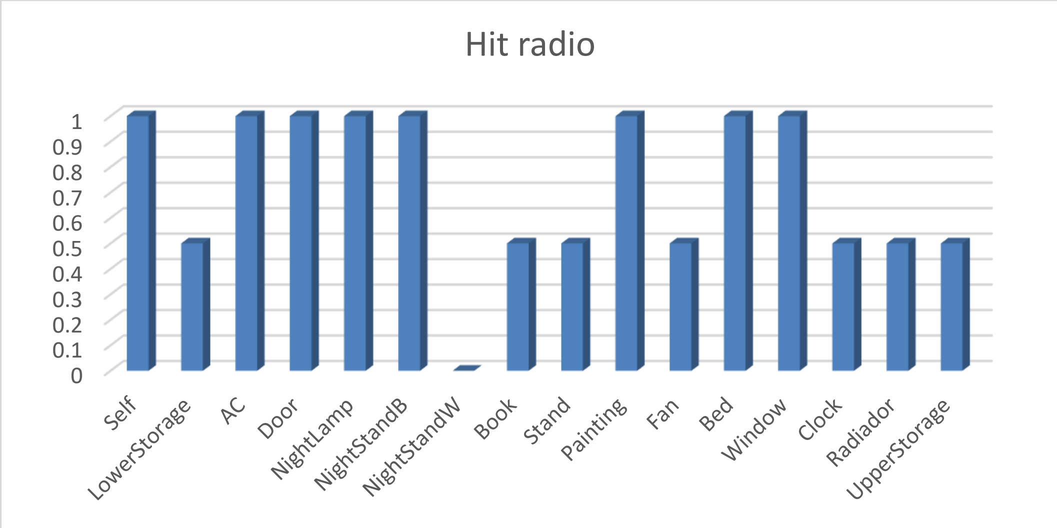


Figure 4.29 Hit radio for Bedroom

The participants did not pay attention to the left nightstand. Maybe because the bed was blocking the view from half of it and did not have nothing placed on it. On the contrary, the right nightstand was seen by all and the lamp too which was on top of it, while the book next to the lamp was seen from half of them.

<u>Kitchen</u>

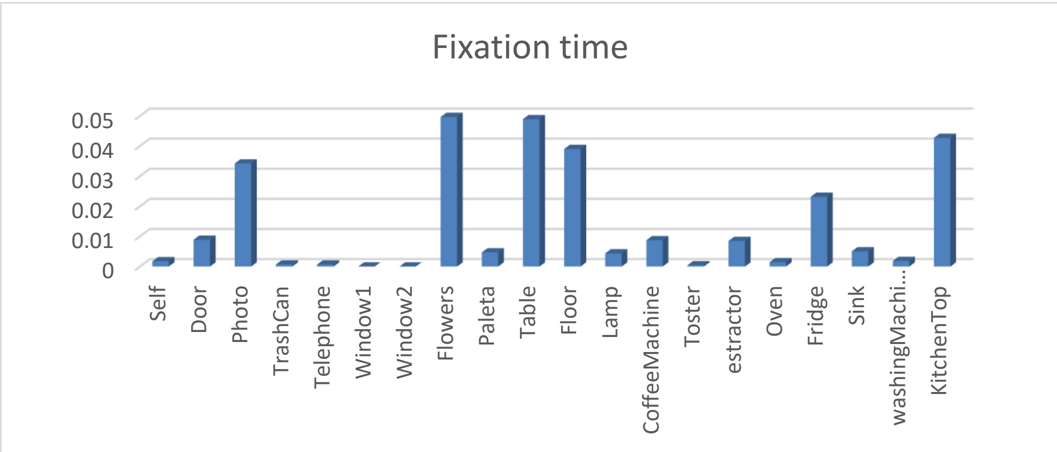


Figure 4.30 Fixation time for Kitchen

Kitchen was crowded with areas of interests. The biggest fixation time was in the flowers, which were in between the kitchen and the table. Moreover, he had a lot of focus in the photo behind the table of the family and the kitchen top where all the kitchen items were placed. From the electric devices the fridge was the most interesting to the participants while the toaster did not draw their attention at all. Although the telephone was the closest thing to the participants no one paid attention to it.

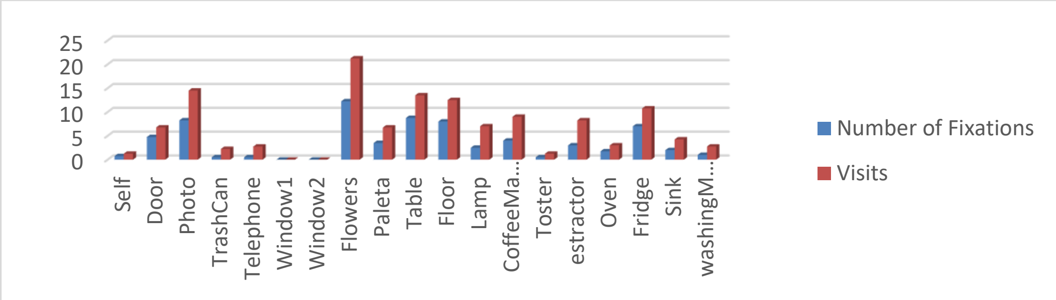


Figure 4.31 Number of fixations and visits for Kitchen

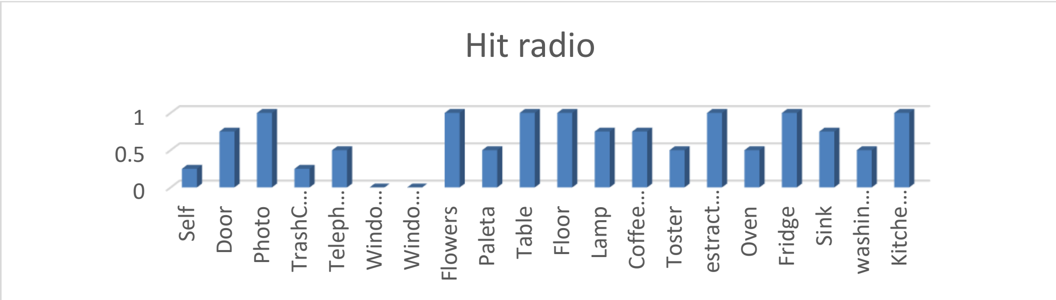


Figure 4.32 Hit radio for Kitchen

Above we present the other two graphs confirming our observations above. In the hit radio graph, we can see that most of the participants looked at all the kitchen gadgets at least once during their session.

<u>Living room</u>

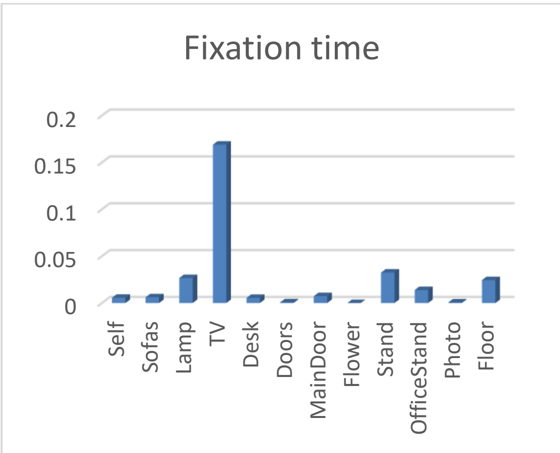


Figure 4.33 Fixation time for Living room

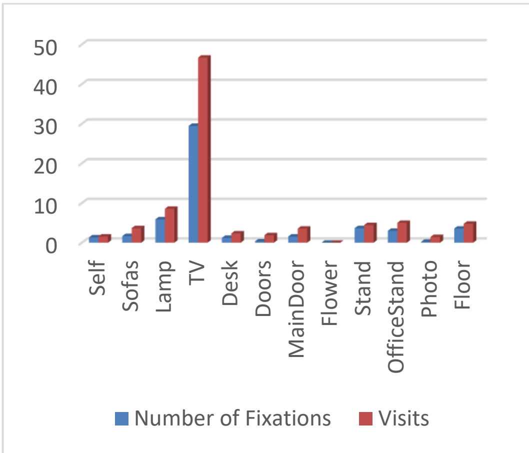


Figure 4.34 Number of fixations and visits for Living room

Right away we can tell the massive difference in fixation time between the TV and the rest of the area of interest objects. The reason is because we had Traditional Cypriot dances showing in the TV with music and that drew the attention of the users. After they focused on the TV, they continue to watch to see what happens and enhanced their immersion to the environment. The other two most focused on objects were the ceiling lamp which was in the center of the room, and the stand with the flower, which was the closest thing to the participants.

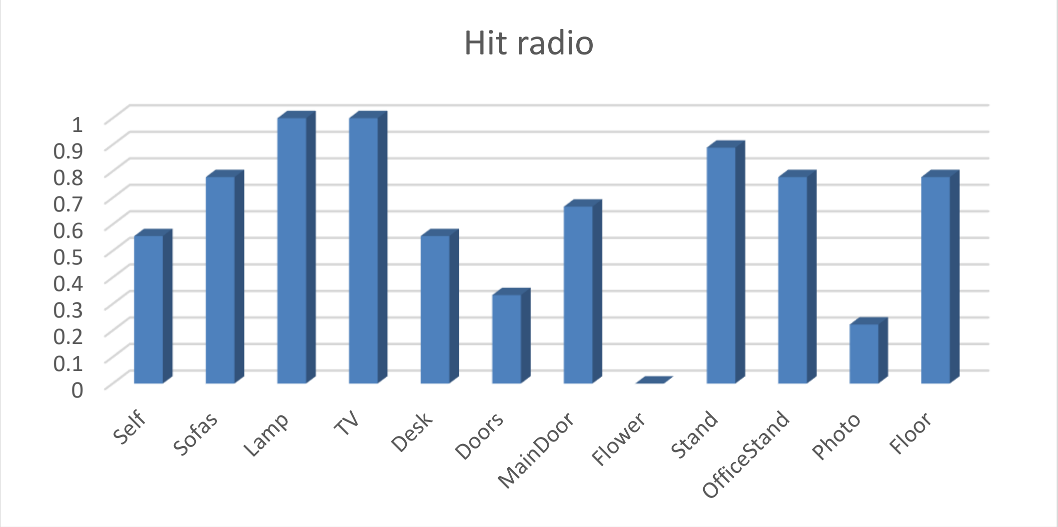


Figure 4.35 Hit radio for Living room

Of course, as we can see everyone saw the TV and the lamp while in this room the photo of the family, which we had in the kitchen too, did not draw a lot of attention despite being in a similar position. The items closer to the TV and the stand were seen from the users while objects in the back of the room, like the desk and doors were less noticeable.

Temple

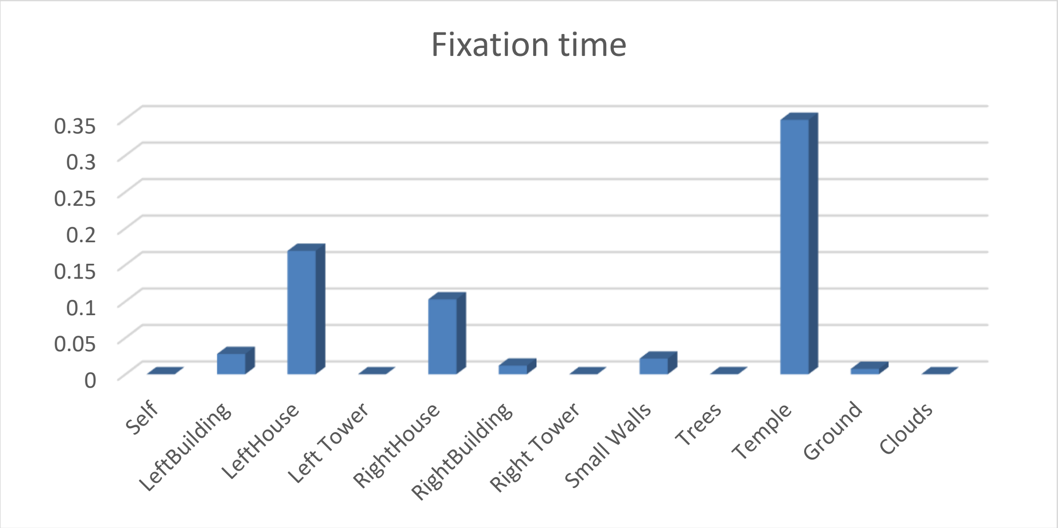


Figure 4.36 Fixation time for Temple

As we expected, in the temple environment for 35% of their time inside they were looking at the temple. First of all, because it was massive and imposing. Moreover, it was in front of the user and everything else was surrounding the temple. Aside from the Temple, participants showed interest in the buildings on the sides.

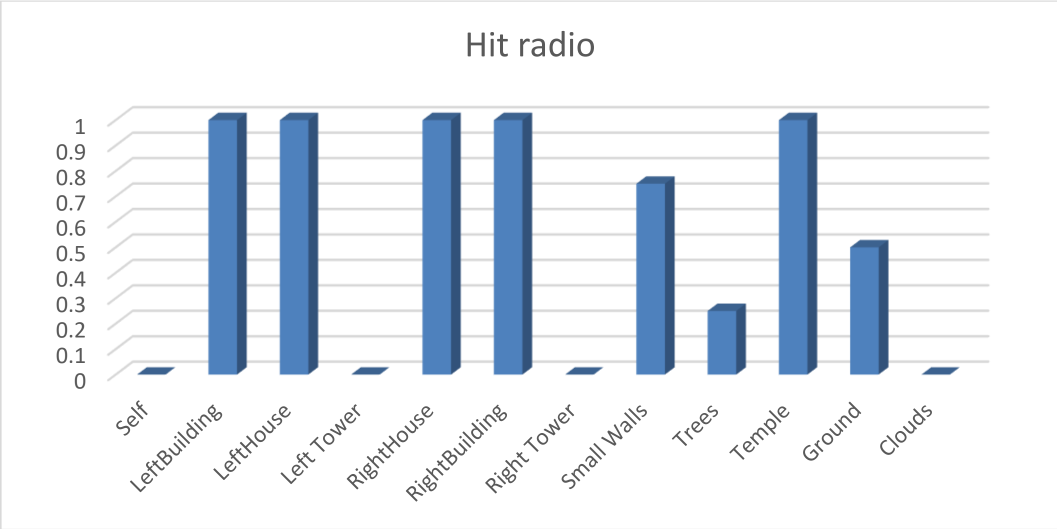


Figure 4.37 Hit radio for Temple

The most obvious conclusion from here is that everyone saw the buildings of the environments, except the towers which were far behind. Also, it is the only environment where the trees were mostly ignored from the user, maybe because we did not have many and they were blended to the environment to not draw attention.

Nauplio

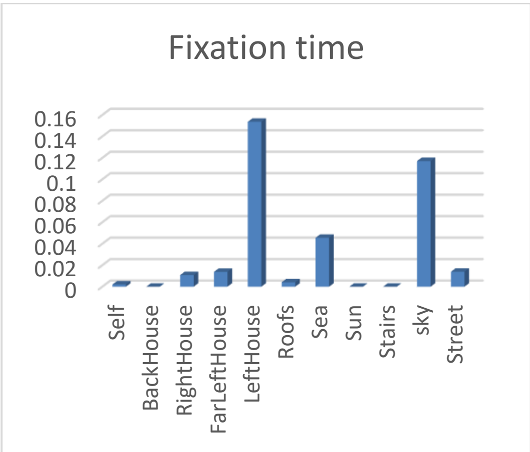


Figure 4.38 Fixation time for Nauplio

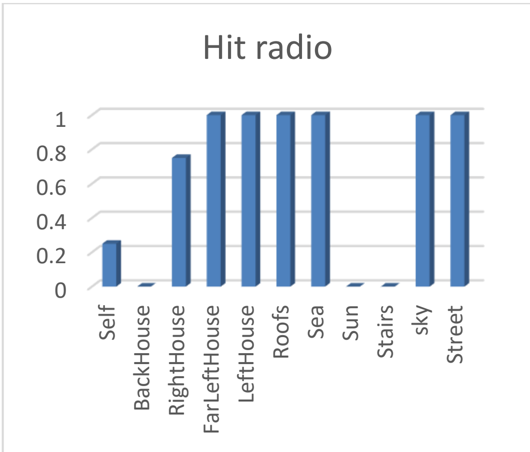


Figure 4.39 Hit radio for Nauplio

In the Nauplio environment we only had 2 observations. The first is that the most fixation time was to the Left house which was the closest to the participant. The second and more interesting one was that even though the sea was perceivable from a small gap between the buildings, it was the third most seen area of interest. From the second graph we see no one saw the sun or stairs.

Venice

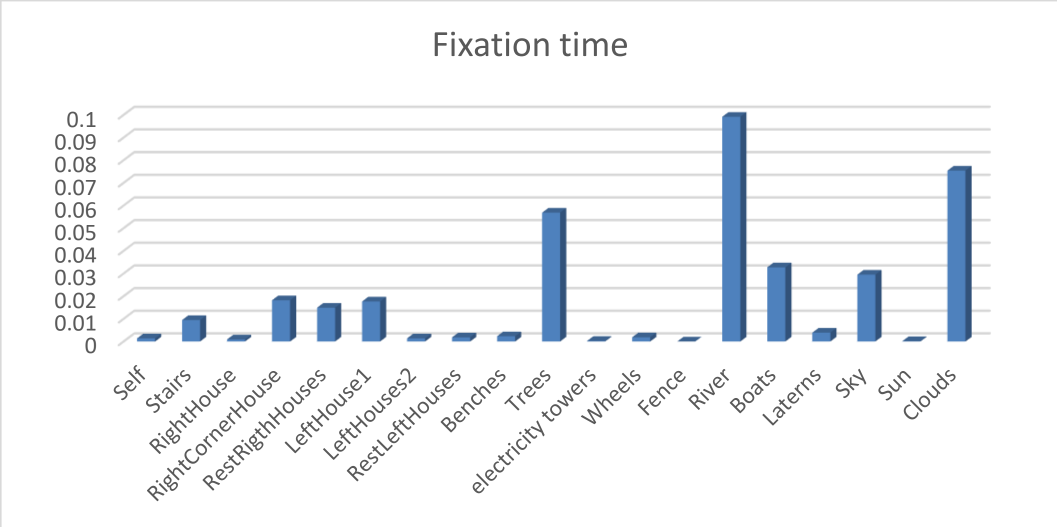


Figure 4.40 Fixation time for Venice

Venice was the most popular environment chosen by the participants from which we can have a clearer picture of what was interesting and drew their attention. First of all, as we also noticed in the previous environments, natural areas of interest had the most fixation time. Moreover, the participants looked at the clouds for longer time than the sky. Next, we have the boats which are the fourth highest since they are inside the river and usually the eye was drawn to them. Lastly, users looked at the closer buildings on their sides.

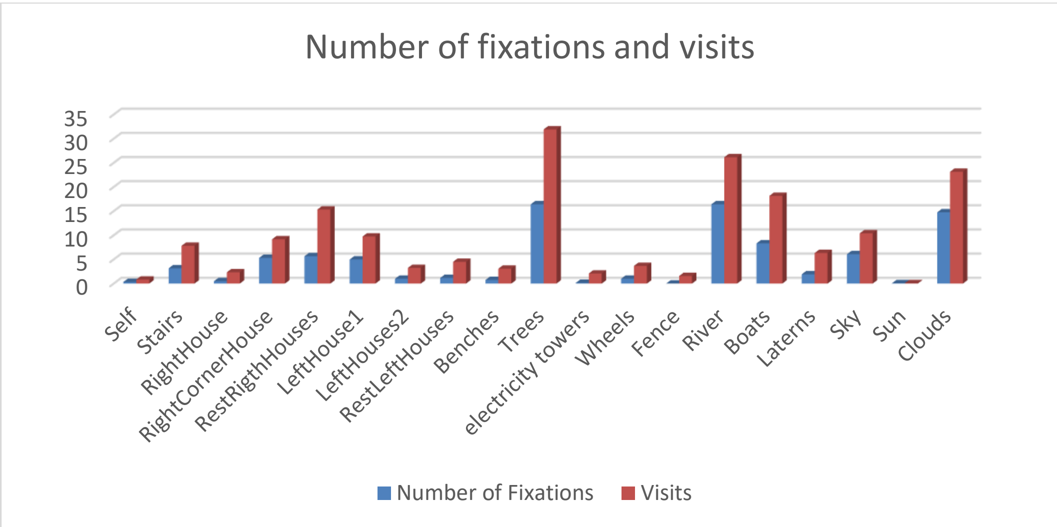


Figure 4.41 Number of fixations and visits for Venice

From the above graph we notice that the ratio of fixations to visits for the river was closer to 1:1 than the trees. This means that the participants were looking at the river for longer durations while at the trees for less time but more times.

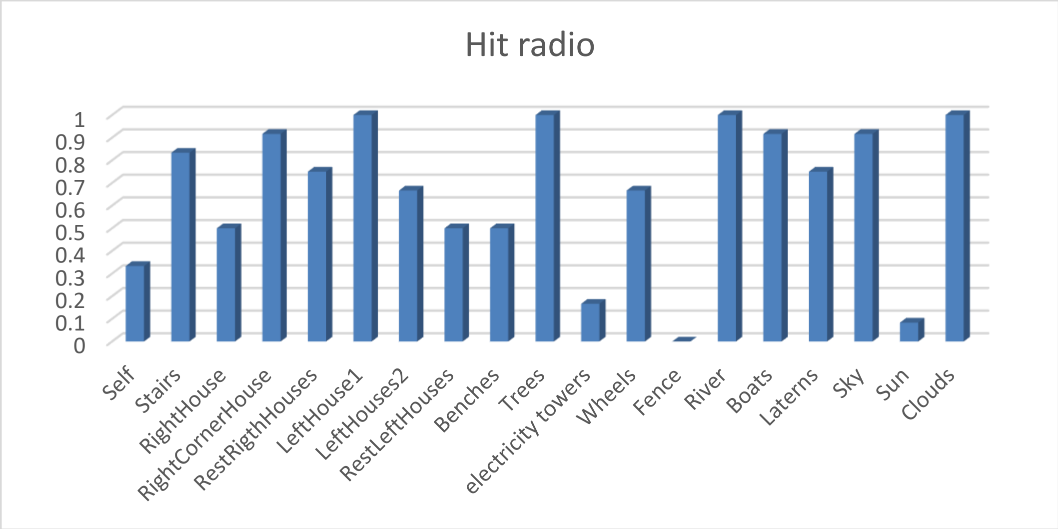


Figure 4.42 Hit radio for Venice

For our last graph, we see that everyone saw the trees, river, clouds, and the left building. Fewer people saw the electricity towers and sun while no one saw the fences in the edges of the pavements. For the rest of the areas of interest, we had different people looking at some of the areas and other people to the rest.

4.3 Heart Rate

In this section we will present the heart rate graphs. X-axis is the name of the object the participant was looking at and the Y-axis is the heart rate value. Some values are -10 which means in those times the smartwatch was unable to measure the heart rate. If the participant was not looking at an area of interest, we defined it as "Void". In all the sessions, after every scene we had 2-3 minutes to ask about the Quantitative measures. These parts of the session can be seen in the graphs, when we have back-to-back Voids, however it is still possible to have this phenomenon when the patient is in the scene too. In most graphs during the end, we notice a spike in the heart rates. This is during the usability and SEQ questionnaires, where we told the participants that we are done, and they could move freely their arm. This could present false metrics since the hand must be as stable as possible but the heart rate during the (pre, during and post) interviews is not important for us and we do not take it into account.

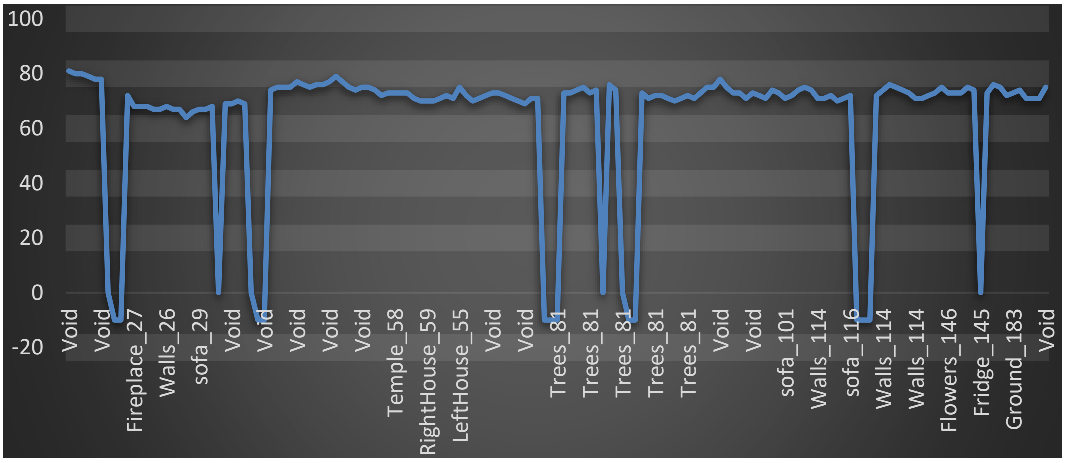


Figure 4.46 First participant's heart rate

As we can see, participant's initial heart rate was around 75. When she entered the Christmas environments, she dropped to 67 overall for the whole duration. The reason might be the familiarity with the festive atmosphere of Christmas, with all the joyful memories. Her next environment was the Temple, where she had an increase in the heart rate, however it was gradually decreasing. She got relaxed in the environment as she was getting more familiar each second with her surroundings. For the next four environments (forest, living room, kitchen and Venice) we don't notice anything particular, and the heartbeat was in the 70 to 75 range.

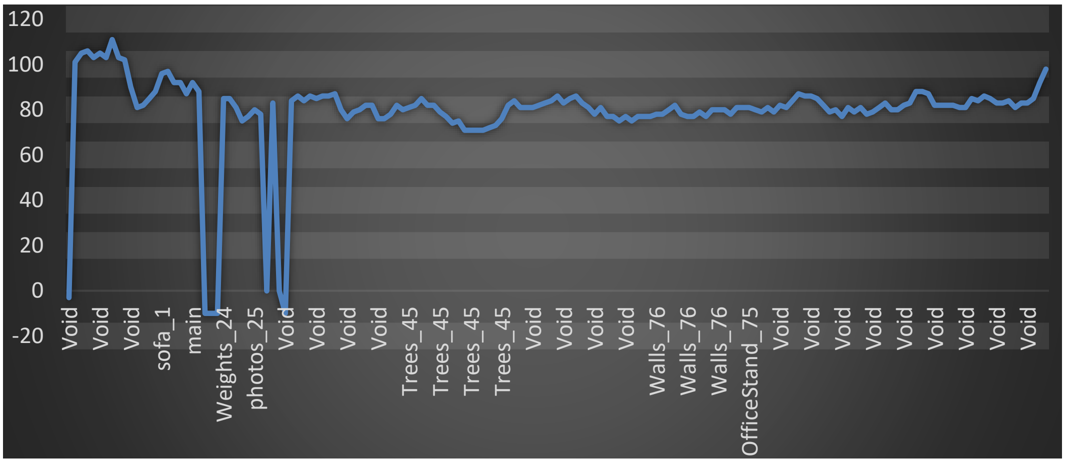


Figure 4.47 Second participant's heart rate

Initially heart rate was high. The reason might be that he was not in an environment yet and was looking in a grey and brown screen. As soon as we loaded the gym environment his heart rate dropped significantly and like the previous observations, the longer he stayed in the environment, he was getting more relaxed. Next environment was the forest. As we can see from 80, he dropped to 71 while the eye tracking shows that he was looking at the trees. The last environment was the living room where his heartbeat was stable within 77 to 81. The rest of the graph where we have loads of Voids is the part where we interviewed him about the usability of the system.

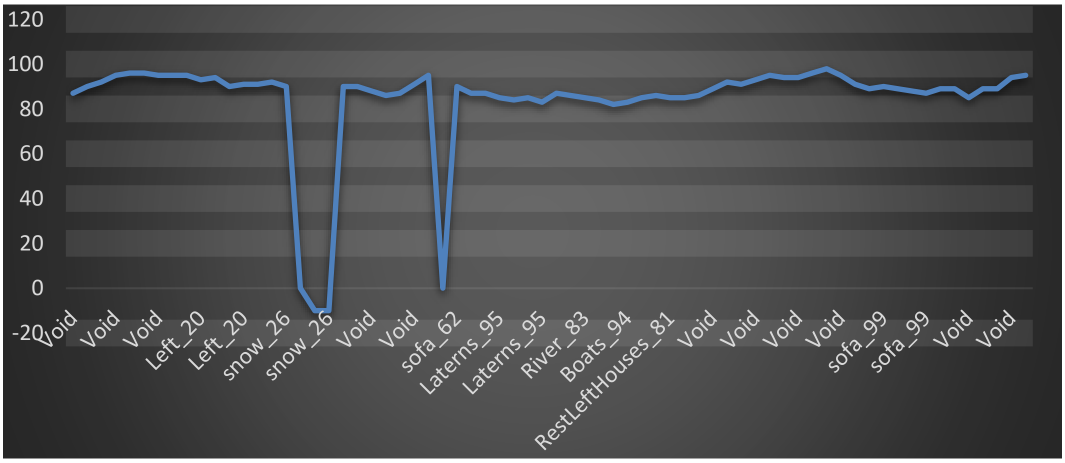


Figure 4.48 Third participant's heart rate

In this graph, we have the highest heart rates during the loading of the environments. As soon as the scenes loads, we notice a decrease in the heart rates. In the first environment, the mountains, we have a higher average heartbeat than the other two, the first park and Venice. We assume it is because in the snowy mountains you are in a high altitude and gives you the adrenaline rush you fell when you look down from somewhere high.

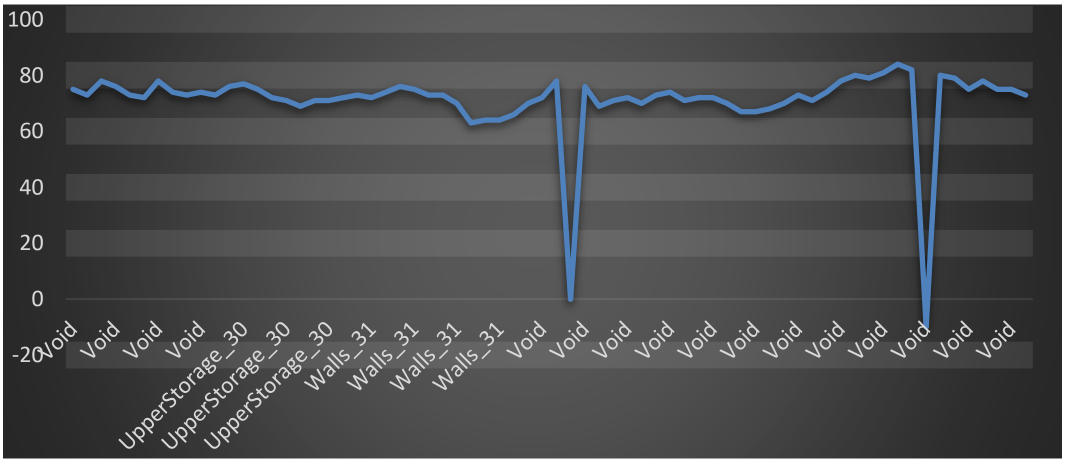


Figure 4.49 Fourth participant's heart rate

The first environment shown to this participant was the bedroom. The only noteworthy mention here is his initial heart rate was 76 and decreased to 71 in the end. On the second environment we observe that the participant was very relaxed. He commented that kitchen seemed small and felt like a giant. When asked how he feels, he responded “Perfect, I feel like a giant”. This can explain how relaxed he was because he was confident and not afraid at all. Between the kitchen and living room transition, participant’s heart rate started increasing during the quantitative measures but when the living room loaded his heart rate decreased and become stable for the rest of the scene. In the Venice environment heart rate was also stable between 70 and 73 and the spike in the end is when we asked about the usability of the system.

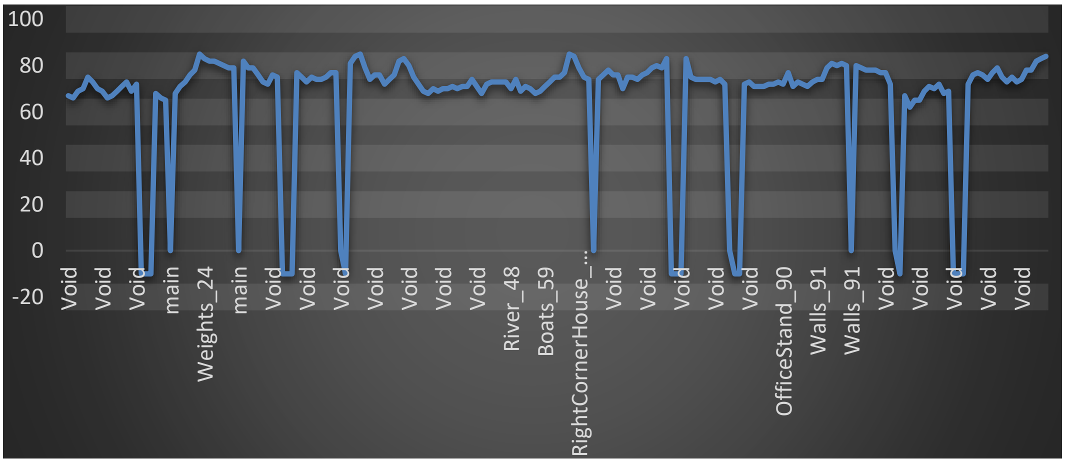


Figure 4.50 Fifth participant’s heart rate

The following participant picked the gym, Venice and living room environments in the specified order. When he entered the gym environment his heart rate went from 71 to 85. This can be because we had energetic music in that environment and since a gym is somewhere you work out, it might stimulated his brain to thinking he will work out. In the other two environments we see a lower overall heart rate where the user sees nature and a typical living room.

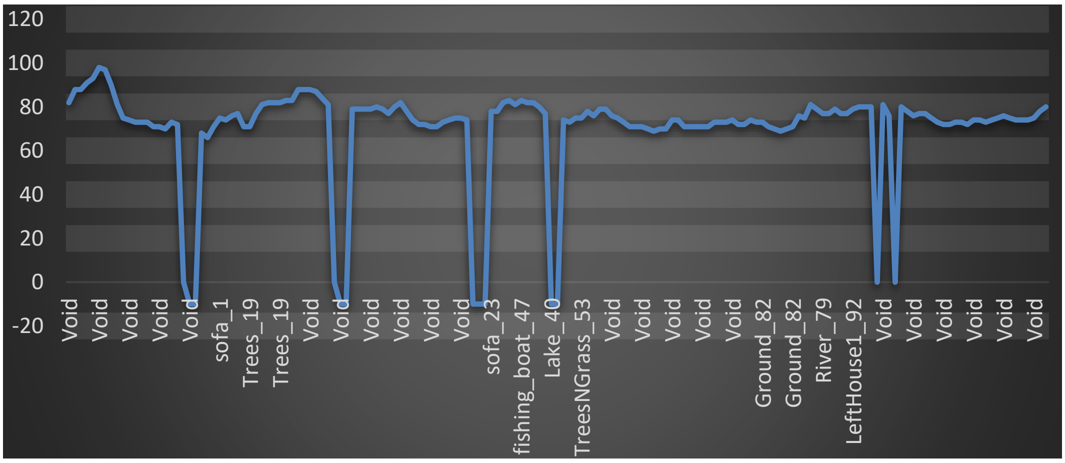


Figure 4.51 Sixth participant’s heart rate

In the above graph we notice that the participant was very relaxed for the whole duration of the session except at the start where we still did not load any scenes and two-three times, when we transitioned during the environments. One speculation might be because all the environments were from nature or had elements of it with the Forest, Lake and Venice's river.

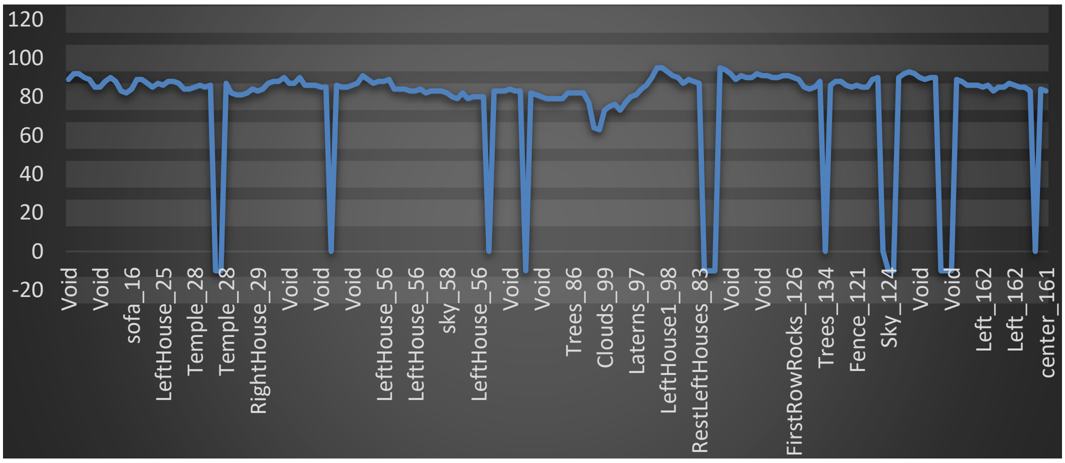


Figure 4.52 Seventh participant's heart rate

Here we can observe a stable heartbeat during the temple and Nauplio environment. When she entered Venice, she became very relaxed, having overall heart rate around 70, but afterwards started going up reaching 89 pulse. The only cause we could really find is she told us during the interview for the environment, she felt anxiety for less than 16 seconds because she thought she could fall from the bridge. The fourth environment was the forest where the heart rate was stable and relaxed, while in the last environment, the mountains, we observed the same. One odd observation was that she felt anxiety for the whole duration of the snowy mountain due to thinking she was going to fall, however her heart rate remained stable between 84 and 86.

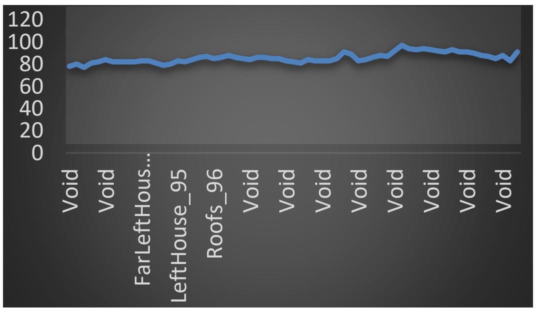


Figure 4.53 Eighth participant's heart rate

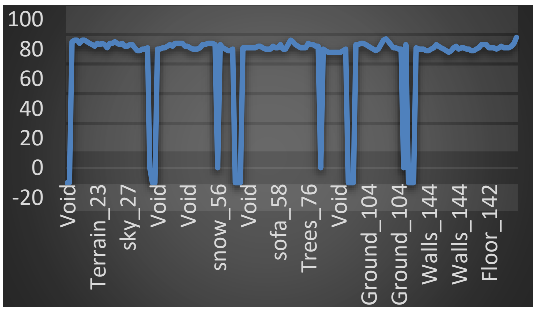


Figure 4.54 Ninth participant's heart rate

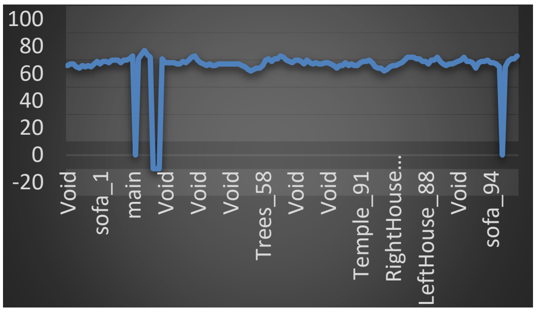


Figure 4.55 Tenth participant's heart rate

The above heart rate hearts do not have anything noteworthy since they are stable for the whole duration of the session, however we can still say that there was nothing causing them anxiety and the environments kept them calm.

Additionally, besides analyzing the data for each participant, we analyzed it based on the environment. Below we present a graph showing how the heart rate was affected with the exposure to each environment. Because the normal resting heartbeat is unique for each participant, we calculate the average heart rate during the whole session and the averages for each environment he visited. Then we compared the overall heart rate with every heart rate of each environment by subtracting session's average from the environment's heart rate. If the value is positive, it means we had an increase in heart rate with the corresponding value and if it is negative the heart rate decreased.

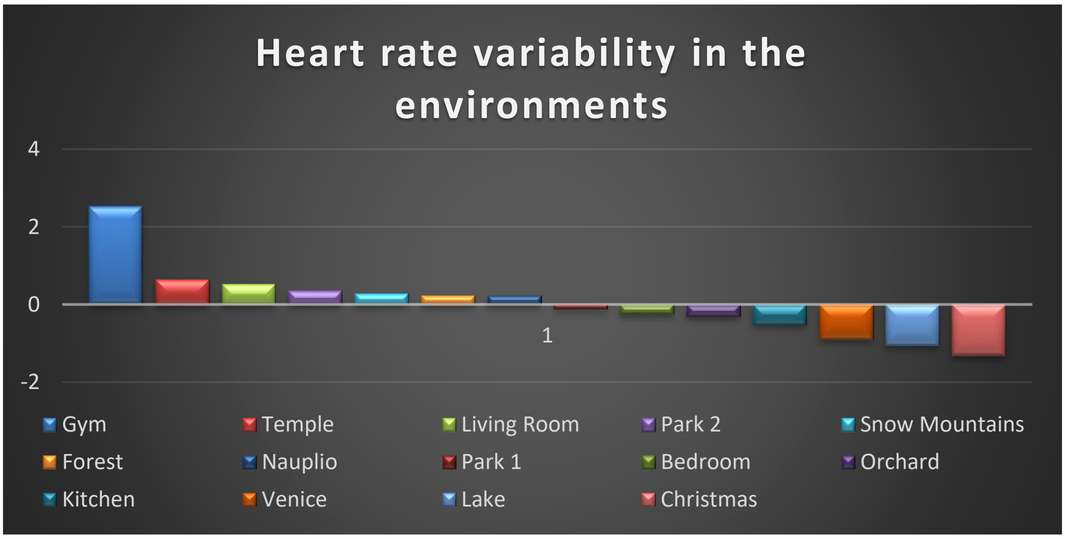


Figure 4.56 Heart rate variability in each environment

In general, we do not observe a significant increase or decrease in the heart rate since the maximum change is by 2 units. Moreover, most of the natural environments have value below zero, validating our previous observations that environments with nature tend to relax and lower the heart rate of the user. The maximum increase was in the gym environment while the decrease was in the Christmas environment.

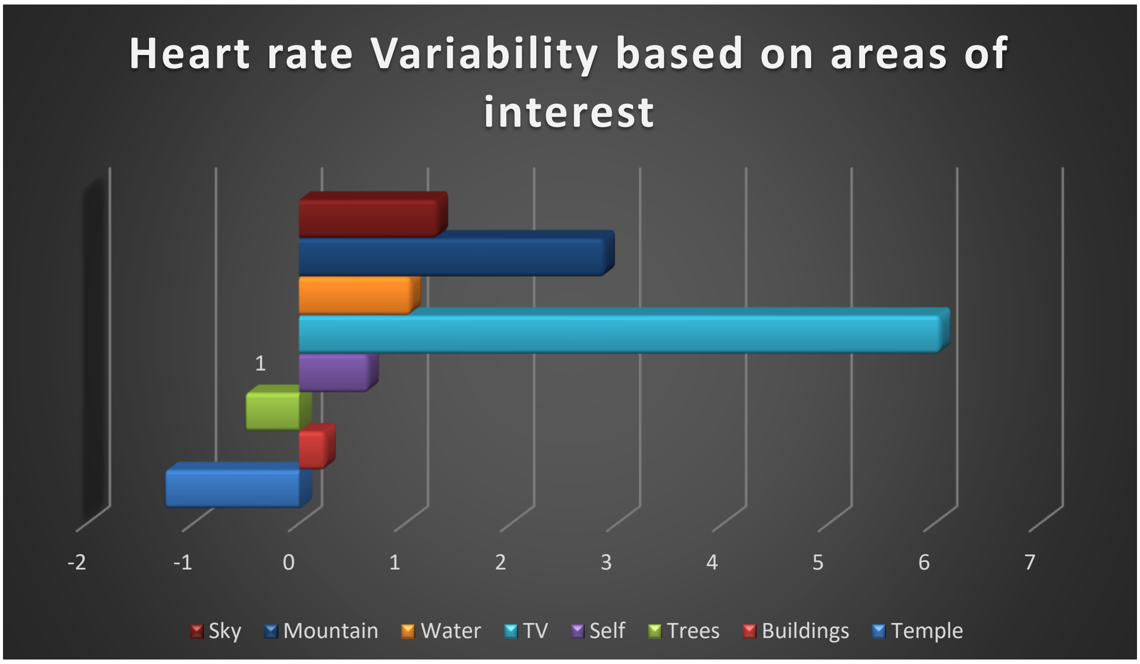


Figure 4.57 Heart rate Variability based on areas of interest

Similarly, we defined the most important areas of interest based on our results from eye-tracking and heart rate analysis to create this graph. First of all, when participants were looking at the temple, their heart rate was lower than their average pulse by 1.2 units. Most probably because it was enormous, and participants felt captivated with awe. As expected, trees also were below zero. Final observation is when participants were looking at the TV, their heart rate was 6 units above average. Our explanation is because TV was dynamic and was associated with dancing raising participants' heartbeat.

Chapter 5

Discussion

5.1 Discussion

The use of VR technology to influence individual perception is a relatively new approach to improve their well-being. From our study, we found that VR through Altered Visual Feedback strategy (AVF) interventions appeared to be very effective for this sample of 15- to 83-year-old participants of both genders.

First, we succeeded on significantly increasing the pleasure during and after the VR exposure. In addition, during the session, not even one participant felt angry or sad and if they got anxious it was only for less than 16 seconds. Of course, the participants were from the healthy population. If we tested our system with patients suffering from dementia, we would expect more changes in their emotions like anxiety and anger. Furthermore, the immersion of the users was high, and we can justify that with the score of 5.02 of the presence questionnaires. Last but not least, our system was considered very usable, despite the complexity behind it, it was simple to them.

Based on our heart rate results, we can reckon that during the VR exposure, heartbeat was stable. Minor fluctuation was observed, which can be explained. The first cause was the type of place. When the participant was in a natural or house environment, we observed lower heart rate. Studies verify our observations [68], associating lower heart rate in natural environments rather urban ones. Furthermore, when participants were in high altitude like the mountains or above the bridge in Venice, they had an increase in their heartbeat and felt little anxious. These environments were the only ones we noticed anxiety on the patients. Another research found similar findings [69], with participants in high altitude environments having higher heart rates relative to lower altitude environments. The final reason was the duration a user stayed in the environment. The longer he stayed in the environment, the lower his heartbeat fell. The simple answer to why this was happening is because, at first, the participant entered a new environment. By scanning the area and becoming more familiar with the environment, he started to relax and feel more confident. All in all, heart rate findings prove that participants did not stress or got angry during the VR exposure since heart rate remained stable, and in some environments, they were more relaxed.

Lastly, from our eye-tracking results we can conclude that the human tends to pay more attention to nature rather than build-made objects. For example, trees were the area of interest with the most fixation time in three environments, the forest, and the parks, while coming third in the Venice environment. In addition, in the Lake environment, most attention was drawn to the lake, in Nauplio it was the sea and in Venice it was the river, all considered water elements. This is not odd, and studies concluded that a nature-based environment can arouse more attention than a build-made [70]. Another conclusion is that humans were drawn to more dynamic objects which had movement and sound. This is reasonable since it was something interacting with them. Objects in our scenes like that were the TV, fireplace, and fishes, with all being placed high on fixation time, number of fixations and hit radio. Our final finding was that the objects highly linked with the environments had higher attention than other objects. A few examples are the Temple environment with the Temple, similar with the Lake environment, the lake, the Christmas environment and the Christmas tree, the kitchen and the Kitchen top with the various electrical devices, and the two parks with the main sculpture and the big fountain.

5.2 Future Research

The system created for the diploma project is fully functional and ready to offer patients with dementia an opportunity to visit places they are unable to. However, we can improve the system with more features as listed below.

Test it on patients.

Although our system was highly rated as usable and we improved participants' emotional behavior, people suffering from dementia might react differently. Because of their cognitive decline, they might fear some environments like the lake which has fishes and birds. Also, we must make sure caregivers can operate our system because during our study, the one operating the system was us, who had a lot of experience with the system.

Make it affordable.

One drawback of our research is the high equipment cost, making it unaffordable for the patient. Accordingly, we designed the application as portable as possible to not force our patients to buy our product. Instead, institutions would buy the product and offer sessions to the patients within the nursing home, free or charged by the hour. Another approach is to modify our system to run on a less expensive equipment so anyone can buy it, such as "Google cardboard", since the eye-tracking is not needed. We used eye-tracking to validate and modify our system based on impact.

Make use of 360-degree videos.

360 videos are video recordings where a view in every direction is recorded at the same time, shot using an omnidirectional camera or a collection of cameras. They offer greater immersion rather than a 3D computer-generated environment and it is very easy to implement them in unity. If we also want to apply eye tracking, it will be more challenging because the area of interest is the background and cannot be divided. Our solution to that is to use invisible objects in front of the object we want to track. It will hit the object we placed and track the eye movement however the user will not understand anything from the whole process.

Personalize the environments.

Current environments were created based on a general sample of experts and patients. The next step would be to learn more about the patient's interests, memories and needs to create personalized environments just for them. We can collect this information from interviews with the patients, relatives, or caregivers. This will be a massive boost to their immersion and experience because the environment will be a part of them instead of something generic.

Reminiscence Therapy

Reminiscence therapy is a treatment that uses all the senses — sight, touch, taste, smell and sound — to help individuals with dementia remember events, people and places from their past lives. As part of the therapy, care partners may use objects in various activities to help individuals with the recall of memories [64]. Various studies [65-67] applied this kind of therapy to demented people and had very positive results in the cognizance and emotional state of the patient. Using the virtual reality system, we can easily apply the common practices of reminiscence by recreating memories, putting pictures of them in the virtual environment etc.

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