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Medo de Alturas: Uma Abordagem Imersiva Em Realidade Virtual com Monitorização de Biosinais

Fear of Heights: An Immersive VR Approach with Biosignals Monitoring

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia de Computadores e Telemática, realizada sob a orientação científica do Doutor Bernardo Marques, Investigador do Instituto de Engenharia Eletrónica e Informática de Aveiro, Departamento de Eletrónica Telecomunicações e Informática da Universidade de Aveiro e da Doutora Susana Manuela Martinho dos Santos Baía Brás, Investigadora do Instituto de Engenharia Eletrónica e Informática de Aveiro, Departamento de Eletrónica Telecomunicações e Informática da Universidade de Aveiro.

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aknowlegdements

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palavras-chave

Realidade Virtual, Acrofobia, Distúrbios de ansiedade, Terapia de exposição, ECG, Meta Quest 2, Plux, Biofeedback, Monitorização, Biosinais.

resumo

O ser humano é afetado por vários distúrbios, sendo os distúrbios de ansiedade um dos mais prevalentes. Um exemplo destes distúrbios é a fobia específica, que é um medo opressivo, ainda que irracional, de um objeto, sítio ou situação. Esta condição pode ser um impedimento na vida de indivíduos fóbicos pois estes fazem mudanças de modo a evitar o que lhes causa medo, que por sua vez agrava a situação.

Sendo um campo de investigação ativo, a terapia de exposição é a opção de tratamento por excelência para fobias específicas, tal como provado por inúmeros estudos. Existem vários tipos de terapias de exposição e a exposição *in vivo* é tida como sendo a mais eficaz. No entanto, apesar de todas as suas vantagens, a exposição *in vivo* também tem desvantagens, tais como custo e excessivos níveis de stress aquando da exposição.

A recente introdução da Realidade Virtual (RV) ao público geral permitiu que esta fosse explorada com novas finalidades, além do entretenimento. Assim sendo, um novo tipo de terapia de exposição (Terapia de Exposição em Realidade Virtual) viu um aumento no seu uso e foram conduzidos vários estudos quanto à sua eficácia. Foi provado que a Terapia de Exposição em Realidade Virtual pode ser tão eficaz como exposição *in vivo*, sendo que ao mesmo tempo é mais barata, mais segura e mais fácil de apresentar o estímulo desejado.

Nesta dissertação, propomos Up(Date) Your Fear, um sistema portátil e acessível a nível económico que pode ser usado como alternativa/complemento à terapia *in vivo* tradicional. O sistema usa RV para apresentar estímulos relacionados com alturas a indivíduos fóbicos e monitoriza a sua reação fisiológica através de um dispositivo externo (electrocardiograma - ECG e Respiração). Os estímulos são apresentados sob a forma de um jogo com mundo aberto, permitindo aos indivíduos explorar o mundo e os estímulos ao seu ritmo. O sistema também suporta armazenamento, processamento e visualização de dados.

Através da realização de dois estudos com utilizadores foi possível comprovar a usabilidade do sistema e a eficácia dos estímulos na geração de uma resposta cardiovascular por parte do utilizador. Esta resposta verificou-se em todos os participantes, mesmo nos que não reportaram medo de alturas, pelo que é possível afirmar a eficácia dos estímulos e a validade do sistema.

Keywords

Virtual reality, Acrophobia, Anxiety disorders, Exposure therapy, ECG, Meta Quest 2, Plux, Biofeedback, Monitoring, Biosignals.

abstract

The human being is affected by several disorders, one of the most prevalent being anxiety disorders. One example of these disorders is a specific phobia, which is an overwhelming, yet irrational, fear of an object, place or situation. This condition can be an impairment in the lives of the phobic individuals because they go out of their way to avoid what causes the fear, which in turn will only aggravate the matter.

Being an active field of study, exposure therapy is the quintessential treatment option for specific phobias, as proven by a plethora of studies. There are several types of exposure therapy and in vivo exposure is regarded as the most effective one. However, despite all its advantages, in vivo exposure also has drawbacks, like cost and excessive levels of stress during exposure.

The recent introduction of Virtual Reality (VR) to the mainstream allowed it to be explored for new purposes, other than entertainment. As such, a new type of exposure therapy (Virtual Reality Exposure Therapy) saw an increase in usage and several studies about its effectiveness were conducted. It has been proven that Virtual Reality Exposure Therapy can be as effective as in vivo exposure, while at the same time being cheaper, safer and easier to present the desired stimulus.

In this dissertation, we propose Up(Date) Your Fear, an affordable and portable system that can be used as an alternative/complement to the traditional in vivo therapy. The system uses VR to present height related stimuli to phobic individuals and monitors their physiological response using an external device (electrocardiogram - ECG and Respiration). The stimuli are presented under the form of an open-world game, allowing the individuals to explore the world and stimuli at their own pace. The system also supports data storage, processing and visualization.

By performing two user studies it was possible to verify the system's usability and stimuli's efficacy in the generation of a cardiovascular response by the user. This response was verified in every participant, even the ones who previously didn't report fear of heights, and that states the efficacy of the stimuli and the validity of the system.

Content

List of Figures

List of Tables

List of Acronyms

API – Application Programming Interface

AR – Augmented Reality

ARET – Augmented Reality Exposure Therapy

ECG – Electrocardiogram

EDA – ElectroDermal Activity

ET – Exposure Therapy

HMD – Head-Mounted Display

HR – Heart Rate

IP – Internet Protocol

NPC – Non-Player Character

PC – Personal Computer

USB – Universal Serial Bus

VR – Virtual Reality

vHI – Visual Height Intolerance

VRET – Virtual Reality Exposure Therapy

1. Introduction

Humankind has thrived for thousands of years thanks to its developed intelligence. The development of the brain allowed the evolution of civilizations and humans as a species. That being said, it also made people more susceptible to mental illnesses, like anxiety disorders. According to the World Health Organization, 374 million people worldwide suffered from anxiety disorders in 2021 [1] One of the most common manifestations of anxiety disorders are specific phobias, which are characterized by an overwhelming and incapacitating fear of being put in a situation where the sufferers must be in contact with the feared element. This element is often present in a person's day to day life and the fear felt is an impairment, which makes it a problem that must be dealt with.

One of the most effective methods of treating a specific phobia is ET [2] and it consists in having the phobic individuals approach the feared object, place or situation. The idea behind it is that, by having gradual contact with the phobic stimuli, phobic individuals develop coping mechanisms in order to reduce the anxiety they feel towards those stimuli. Even though its effectiveness can't be denied, some phobic individuals with higher anxiety levels report that this type of therapy is too distressing. This led to the creation of ET variants which are less aggressive like Imaginal Therapy, where the phobic individual imagines the feared element, Multimedia Presentation, where the phobic individual is shown pictures and sounds related to the phobic stimuli, and VRET, where the phobic individual is in contact with the phobic stimuli in a virtual world.

Most of therapy methods mentioned previously have one flaw in common: they are performed in a laboratory environment. This environment is highly controlled, isolated and unfamiliar to the subjects, which makes the therapy lose the day-to-day life context relevancy. This means that phobic individual may learn how to deal with its fear and anxiety when alone but may also feel even more anxious when having to face the stimuli around other people. Furthermore, the fact that the lab is not familiar to the phobic individual may cause the therapy process to be less effective, as the individual may not be comfortable. The ability to simulate any environment and interaction is where VRET shines.

In VRET, the phobic individual wears an HMD to get immersed in a virtual world where the interaction happens. This way, it is possible to minimize the risk of something going wrong, as everything is controlled. The understanding and knowledge that the environment is virtual, allows a less intrusive therapy and a higher acceptance from the phobic individuals, allowing a smoother desensitization of the fear. Besides the previously mentioned advantages, VRET has proven to be as effective as in vivo therapy [3] and the progress made in the virtual world can be translated to the real world [4].

With all of this in mind, we set out to create a portable system that can be used as a complement or as an alternative to traditional ET. The system would be used to perform VRET and should be able to collect physiological data to monitor the phobic individual's progress.

1.1 Goals and Contributions

In this dissertation, we propose Up(Date) Your Fear, an innovative and interactive alternative and/or complement to the traditional ET done in medical offices. This alternative uses VR to create a virtual world where the phobic individual can be exposed to different intensity levels of a specific phobic element while monitoring its physiological response. The system's validity lies in the realistic scenarios that immerse the phobic individual and the fact that progress made in the virtual world can be translated to the real-world [5].

When compared to in vivo therapy, the system offers a less aggressive and much more predictable contact with the phobic element. Moreover, the system can be used (depending on the case) either as a replacement to in vivo therapy or as first contact solution, where the phobic individuals would first be subjected to the virtual phobic stimulus and, after a positive response to the virtual environment, they would undergo in vivo therapy, making it a gradual process and much more likely to be accepted by phobic individuals.

Goals:

- Development of an alternative/complement to conventional ET, able to be used in any environment and by anyone.
- Mask the therapy process through the use of an interactive game with varying levels of exposition to the phobic element.
- Use VR to create and present realistic scenarios and stimulus while safeguarding the user from any real danger.
- Creation of an architecture capable of presenting the scenario, as well as collecting, processing and storing physiological data.
- Test the system in order to collect data and receive feedback to help in the development process.

Contributions:

- Using Unity and the Meta Quest 2 HMD we were able to create a virtual word where individuals with a specific phobia can interact with the phobic stimulus.

- Our solution is based on existing components for physiological data collection (Plux device) for monitoring purposes.
- The system supports the acquisition of ECG and Respiration data as physiological indicators and is able to calculate the HR based on the ECG data.
- The system is capable of collecting, processing and storing data correspondent to the user's physiological response.
- We tested our solution two occasions: one public event and one user study, both with the intention of gathering feedback and data to fine-tune the system and also to serve as proof of concept.
- The use of the alternative developed and the analysis of the data that came with it gave us a precious insight on the role that VR can play in the treatment of individuals who suffer from specific phobias, mainly acrophobia, as VR treatment for this phobia is much more feasible and safer.

1.2 Dissertation Outline

Not counting this one, this document comprises 6 chapters:

- Chapter 2 presents a bibliographical revision on the state of the art related to our system and introduces concepts mentioned throughout the document, like VR, acrophobia and ET. It finishes with a brief justification of why we chose VR over AR.
- Chapter 3 describes in detail the various aspects of the game developed, from the choice of Game Engine to the objectives and gameplay and also the features present in the game and its purpose.
- Chapter 4 explains the system's architecture and presents each individual component and the role they play in bringing everything together, while also going over the system's workflow and some failed attempts.
- Chapter 5 describes our preliminary user study, its participants and analyses of the results that came from it, while taking conclusions.
- Chapter 6 is relative to the second user study, what changes were made from the previous study, how those changes were received by the participants, if they were effective and, finally, an analysis of the physiological data collected, as well as results and discussion.
- Lastly, Chapter 7 draws conclusions about the viability and efficacy of our system and proposes additional work to be done in the future.

2. State of the Art

According to the World Health Organization (WHO), in 2020, before the COVID-19 pandemic, 298 million people worldwide lived with anxiety. After confinement, the Global Burden of Diseases, Injuries and Risk Factors Study 2020 (GBD 2020), conducted by the Institute for Health Metrics and Evaluation (IHME), determined that the number of people who suffered from anxiety went up to 374 million, which represents a 26% increase [1].

One of the main causes of anxiety are anxiety disorders, which are a common type of mental disorder and affect 18.1% of the U.S. population [6] and 301 million people globally [1]. Anxiety reduces the person's ability to deal with specific situations and increases the fear of being put in that situation again, generating even more anxiety which, over extended periods of time, can develop into a specific phobia[1].

A specific phobia is an overwhelming, unreasonable and crippling fear caused by the presence or thought of an object, place or situation. The symptoms include nausea, sweating and HR acceleration, among others. Phobic individuals tend to avoid the phobic stimulus altogether in order to avoid going through anxiety attacks, and that avoidance massively interferes with the person's normal life, whether it is at work, during holiday, or even in personal relationships. Individuals who suffer from specific phobias admit that the fear is exaggerated but are unable to overcome it without medical help. The American National Institute of Mental Health evaluates that 6.3 million adults are affected by some form of specific phobia. Phobias can occur in people of all ages and are more common in women. That being said, phobias in children usually go away with time, while phobias developed in adulthood start suddenly, if the person is exposed to the phobic stimulus, and last longer. It is estimated that only about 20% of specific phobias disappear without medical help[2].

[1] https://shorturl.at/hr267

[2] https://shorturl.at/kqwKL

Regarding the phobic element (object, place or situation), specific phobias can be classified in four categories [7]:

1. Animal Phobias - these are the most common types of phobias and are pertaining to the fear of a specific animal, like a dog or a snake, or to a group of animals, like reptiles or insects;
2. Natural environment Phobias - these types of phobias are relative to the fear of nature and its phenomena. These include fear of storms, tornados, heights, water and the dark;
3. Situational Phobias - these are related to the fear of being put in a specific situation, for example, flying, going over bridges or in tunnels or being in a closed-in place, like an elevator or a small room;
4. Blood-Injection - Injury Phobias - these are phobias regarding the fear of seeing blood or vomit, getting injured or being subjected to an invasive medical procedure, for instance injections, colonoscopies or even childbirth;
5. Other Phobias - includes other existing phobias that do not fit in any of the previously mentioned categories. These include fear of falling, fear of loud noises, fear of costumed characters, like clowns, and even fear of sexual acts and nudity[2].

2.1 Acrophobia

Acrophobia is a type of natural environment phobia and is characterized by an overwhelming fear of heights. Individuals who suffer from acrophobia tend to avoid at all costs any situation that involves heights, such as stairs, ladders, terraces, bridges and elevators [8].

Occurrences of fear of heights have been dated back to the Roman and Chinese civilizations and, although many people associate fear of heights with acrophobia, it is not always the case. The severity of fear of heights can be seen as a spectrum divided in three parts. The beginning of the spectrum (first part) represents a physiological height imbalance that results from an impaired visual control of balance, meaning that the person has some kind of vision condition (usually myopia, hyperopia or astigmatism) and thus cannot use the spatial reference system to correctly determine the real height it is exposed to, which causes loss of balance. The middle of the spectrum (second part) consists of a more or less distressing visual height intolerance. vHI is a phenomenon that happens when a visual stimulus creates the sensation of losing balance and falling [9]. Contrary to the first part of the spectrum, this sensation is not caused by a vision condition, but by the fear the person feels towards heights. The end of the spectrum (third part), which is the most severe, is acrophobia. Individuals who suffer from acrophobia can experience various symptoms, mainly musculoskeletal stiffening and severe anxiety. These symptoms increase in magnitude with the increase of height but saturate at certain height values. The former saturates at about 20m above the ground and the latter at about 40m for non-acrophobic individuals and 70m for acrophobic individuals [10].

Studies show that vHI (including acrophobia) affects 28% of adults and 34% of children. Like with other phobias, if it shows up during adulthood, it persists throughout life and only disappears with medical help, whereas if it manifests at an early age, it usually fades spontaneously [10].

Hence, attending to the amount of different specific phobias and how much it can affect a person's daily life, it is of the utmost importance to raise awareness to the existing diagnosis mechanisms and treatments. Moreover, considering the number of people that suffer from specific phobia, it is urgent to come up with new and more accessible methods of treatment. The recommended solution for this problem, which leads the field in the treatment of specific phobias, is ET, which has proven its effectiveness [2].

2.2 *Exposure Therapy (ET)*

Although avoiding a feared object or situation may decrease the fear in the short term, over the long term, it can make the fear worse. This is why ET exists, being used to treat many anxiety disorders, namely specific phobias. It does so by exposing the phobic individual to its phobia with no intention to cause any harm [7]. This is a gradual and iterative process, as seen in Figure **1**, where the strength of the phobic element is increased in every iteration. The goal is to help the phobic individual learn how to deal with the fear in a systematic way. By being in contact with the phobic element, the phobic individual, through inhibitory learning mechanisms, learns coping strategies that help decrease anxiety when in contact with said element. The efficacy of this treatment is well documented [2] and its use in phobic individuals who suffer from anxiety disorders is widespread.

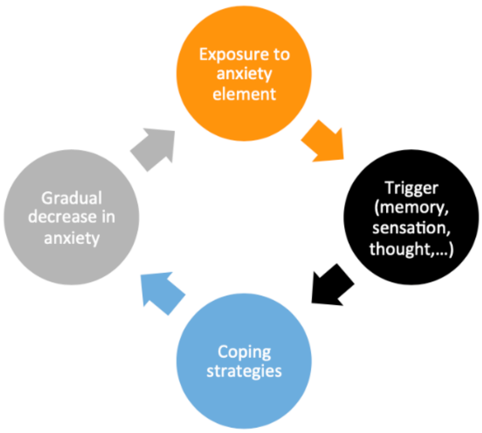

Figure 1 - Exposure Therapy cycle: The exposure to anxiety elements triggers memory, sensations, feelings and thoughts, allowing the sufferer to learn coping strategies, which will allow a gradual decrease in anxiety. [11]

ET can be classified according to the type of exposure and the pace of exposure. Regarding the type of exposure, there are four categories:

- **In vivo exposure -** being directly in contact with the feared object or situation. Even though it is effective in treating phobias, it may be impractical. For example, handling rare/dangerous animals or having to travel to faraway places. Besides, some people might not react well to such a direct exposure;
- **Imaginal exposure -** imagining situations where the phobic stimulus is present. It does not suffer from impracticality, like the previous type of exposure, but it also is not nearly as effective, seeing that no real-world knowledge or experience is gained. Furthermore, this type of exposure is the cheapest and easiest to apply;

- **Digital Realities exposure -** using a virtual reality headset or an augmented reality device and a computer-generated world to expose the individual to its phobic stimulus. It solves both previously mentioned problems, as anything can exist in the computer-generated world and, in that world, the individual is in contact with the phobic element. This is as effective as in vivo exposure because it is possible to provide the sights, sounds and smells of the real world in the computer-generated world, making the individual believe it is real. In addition, it also adds security, which cannot be guaranteed with in vivo exposure. This method also as the advantage of being able to be performed in a clinical environment or in a home environment alike;
- **Interoceptive exposure -** using physical sensations that are harmless yet feared. Realizing that the sensation is harmless will cause the individual to accept that there is no real danger, therefore reducing anxiety levels. This type of exposure is limited, as it only works with physical stimuli, which means it can only be used to treat a finite number of phobias.

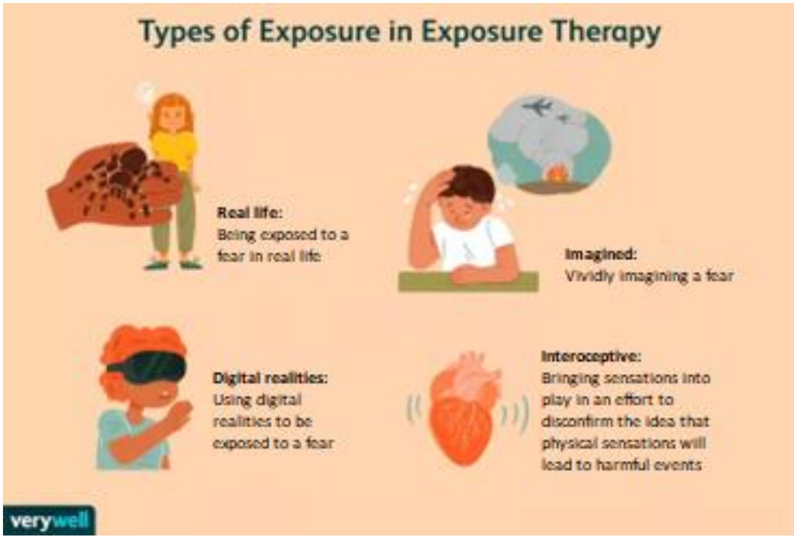

Figure 2 - Different types of ET with respective explanation and illustration[3].

Regarding the pace of the exposure, three different variants can be distinguished:

- **Graded exposure -** the clinician and the phobic individual work together to build a hierarchy of feared stimuli, ranking each fear according to how difficult it is to face. After that, the phobic individual is first subjected to the stimuli graded as easier and gradually progress to harder

[3] https://shorturl.at/fBFIX

ones. This form of exposure is easy on the phobic individual, but it can take a long time to get to the harder scenarios;

- **Flooding -** opposite to graded exposure, flooding first exposes the individual to the stimuli which are harder to face. This can be a shock to some people and might even result in an aggravation of the fear;
- **Systematic desensitization:** mixing exposure with relaxation exercises. Helps the phobic individual to associate feared objects or situations with relaxation, decreasing anxiety levels but, as in graded exposure, it can take a long time.

There are many benefits to ET, which include:

- **Habituation -** getting familiar with the phobic element and spending time interacting with it decreases the amount of anxiety felt towards that element;
- **Extinction -** exposure helps to break existing links between the phobic element and negative results;
- **Self-efficacy -** it can also help to show the phobic individual that it can confront its fears and control its emotions[4].

As stated before, our goal was to build a system that could perform ET while monitoring the phobic individual's behavior and physiological response through the analysis of biosignals. For reasons discussed later in this document, the focus of this dissertation was VR. Therefore, to combine all these topics, we decided to go with VRET, a type of Digital Realities ET, that immerses the phobic individual in a virtual world using a headset with the goal of producing real life-like stimuli while ensuring the individual's safety.

To find peer-reviewed research related to these topics, an extensive search was conducted on Scopus. The queries performed and results obtained can be seen in Table **1**. The table shows the number of results obtained when using relevant keywords to this dissertation as a search query. As more keywords were added to the search, less and less results came up, and especially recent results. In fact, when using *biosignals* as a search term, the results got drastically low. Given the fact that there weren't many results, we concluded that there wasn't a lot of research on the topic, making this dissertation even more relevant.

[4] https://shorturl.at/jnzE4

Table 1 - Queries performed and number of results obtained when researching the topics of this Dissertation on Scopus.

Query	Number of Results	Accessed On
TITLE-ABS-KEY (exposure AND therapy)	143,893	January 2023
TITLE-ABS-KEY (exposure AND therapy) AND PUBYEAR > 2020	18,771	January 2023
TITLE-ABS-KEY (acrophobia)	331	January 2023
TITLE-ABS-KEY (acrophobia) AND PUBYEAR > 2020	45	January 2023
TITLE-ABS-KEY (virtual AND reality)	167,834	January 2023
TITLE-ABS-KEY (virtual AND reality) AND PUBYEAR > 2020	27,903	January 2023
TITLE-ABS-KEY (virtual AND reality AND exposure AND therapy)	2,218	January 2023
TITLE-ABS-KEY (virtual AND reality AND exposure AND therapy) AND PUBYEAR > 2020	478	January 2023
TITLE-ABS-KEY (virtual AND reality AND exposure AND therapy AND for AND acrophobia)	105	January 2023
TITLE-ABS-KEY (virtual AND reality AND exposure AND therapy AND for AND acrophobia) AND PUBYEAR > 2020	17	January 2023
TITLE-ABS-KEY (virtual AND reality AND biosignals)	83	March 2023
TITLE-ABS-KEY (exposure AND therapy AND biosignals)	4	March 2023
TITLE-ABS-KEY (virtual AND reality AND exposure AND therapy AND biosignals)	2	March 2023

This research resulted in the acquisition of important knowledge that helped taking some decisions related to the design of the system like the method for exposition, the height value for symptoms saturation and the biosignals to collect.

2.3 Digital Realities

One of the most notable technological innovations of the past decade was the introduction of Virtual and Augmented Reality to the mainstream. From VR HMDs in video games to AR overlays in weather forecast, education, architecture and, more recently, sports (VAR), and even several applications in the medical field (SpineAR SNAP, CureSight-CS100, etc.)[5], VR and AR are everywhere nowadays.

[5] https://shorturl.at/ksX16

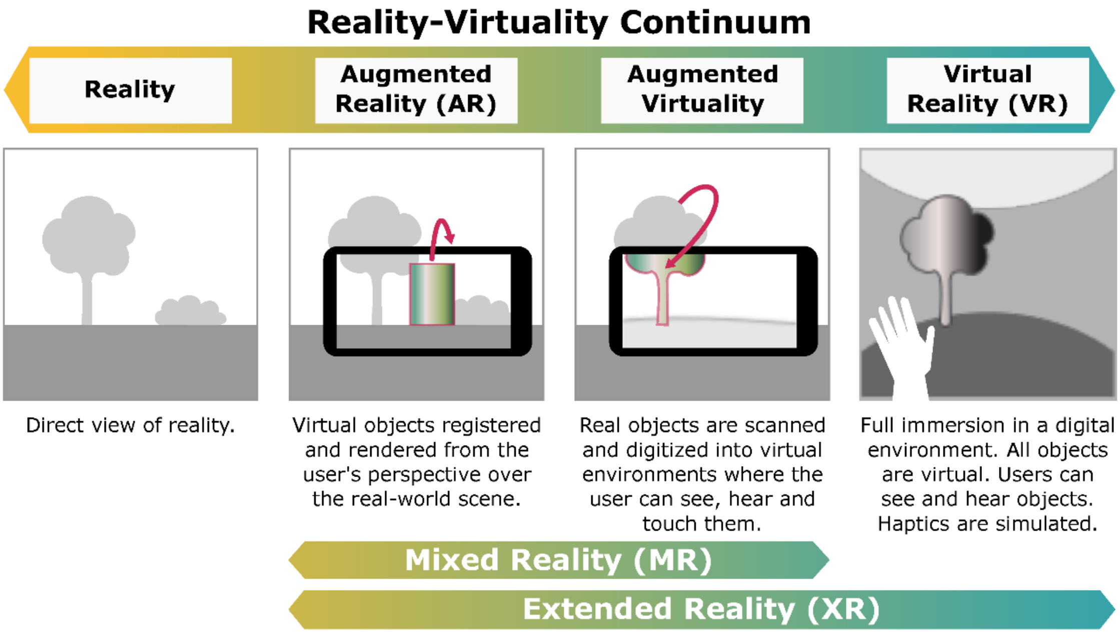

Figure 3 - Different types of Digital Realities with explanation and illustration [12].

This increase in accessibility (and, consequently, in popularity) occurred because there was an untapped market for VR and AR related products, which led several tech giants like Microsoft, Sony and Facebook to invest and develop products for this market. With this race, headsets became portable, more affordable and of a higher video quality, which allowed its use in leisure activities and made it easier to be used in work related environments. Another factor which had a huge impact in the popularity increase of VR and AR was the release of the mobile AR game *Pokémon GO*, which had millions of users.

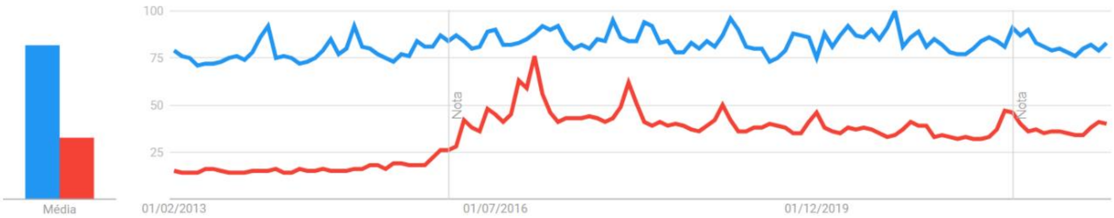

Figure 4 - Popularity comparison between VR (red) and AR (blue) Source: Google Trends.

As mentioned before, AR and VR can be used in the medical field, namely in therapy, rehabilitation and even telemedicine. This dissertation has two objectives: the first one is to choose the most suitable medium between VR and AR, and the second one is to create a digital environment where the user can interact with the phobic element with the intent of performing digital reality ET.

2.3.1 Augmented Reality (AR)

AR has had many different definitions over the years, but the current and most complete one is that it is "*a technology that overlays digital information on objects or places in the real world for the purpose of enhancing the user experience. Augmented reality is the process of overlaying computer-generated information on reality, whether that reality is a geographic place or an object. In AR there is the blending of the digital with the real. The digital information is supplied to enhance the experience or understanding of the user, thus augmenting reality with useful information*." [13].

Categories

AR can be divided into two major categories: Triggered and View-Based. Triggered augmentation requires the use of triggers to activate the augmentation. These triggers can be physical, like paper markers, or they can be intangible, such as GPS location, dynamic augmentation or complex augmentation, which mixes the previous triggers. On the other hand, View-Based augmentation includes digitized augmentations without accounting for what is in view and augmentation of a static view.

Triggered augmented reality technologies

There are four types of Triggered augmentation: Marker-Based, Location-Based, Dynamic Augmentation and Complex Augmentation. They are distinguished based on the nature of the triggers used and how they function. Firstly, Marker-Based AR needs a physical marker to initiate the augmentation. These markers can be paper-based or other objects with a distinct and identifiable pattern. Secondly, Location-Based AR accesses the device's GPS location and uses it as a trigger to provide relevant points of interest near that location, like restaurants or theaters. Thirdly, Dynamic Augmentation responds to the view of an object as it changes, while also being able to scale the augmentation to fit the object. Finally, Complex Augmentation uses all three types of triggers mentioned previously to display information gathered from the internet regarding the objects in view. This type of augmentation can be seen in the original concept for Google Glass.

Figure 5 - Example of Location-Based AR where information about nearby facilities and services is being shown[6].

View-Based augmented reality technologies

View-Based augmentation has two types: Indirect Augmentation and Non-Specific Digital Augmentation. Indirect Augmentation augments a static view, for example, being able to change the color of an object in a picture or applying a filter to it. Non-Specific Digital Augmentation augments a dynamic view without using the objects in view as a reference, which is very common in mobile games [14].

[6] https://shorturl.at/lmpAP

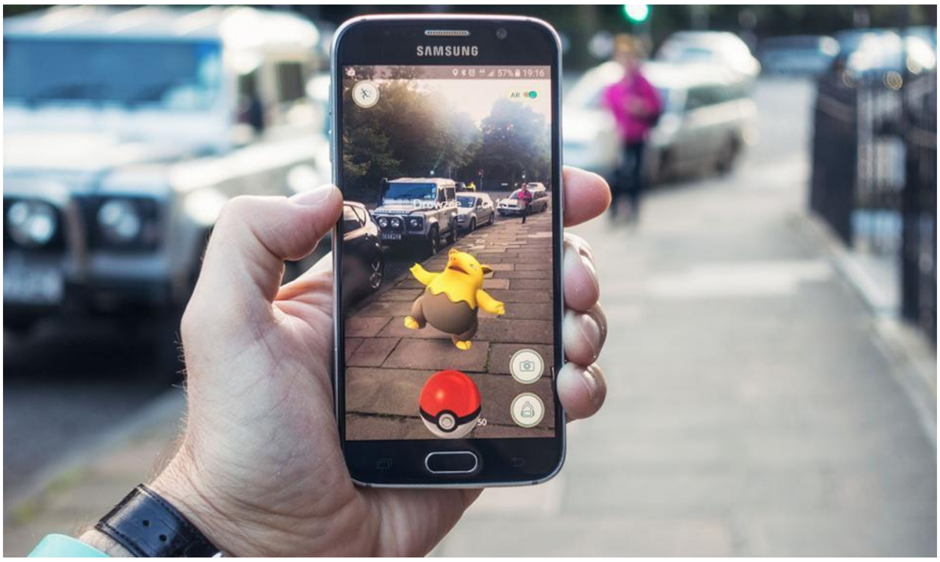

Figure 6 - Example of Non-Specific Digital Augmentation in the form of a mobile game[7].

The differences between the various types of AR can be seen in Table 2 below.

Table 2 - Differences between the various types of AR [14].

Category	**Type**	**Characteristics**
Triggered	Marker-Based	Marker activates augmentation
	Location-Based	Overlay of digital information on a map or live camera view. Location triggers the augmentation
	Dynamic Augmentation	Meaningful, interactive augmentation with possible object recognition and motion tracking
	Complex Augmentation	Augment dynamic view and pull internet information based on location or object recognition
View-Based	Indirect Augmentation	Static image of the real world augmented intelligently
	Non-specific Digital Augmentation	Augmentation of any camera view regardless of location

[7] https://shorturl.at/ayOS2

Applications

As mentioned before, there are plenty of applications for AR that go from overlays in weather forecasts and sports games to uses in the medical field. Furthermore, AR has been used in the treatment of small animal phobias [15], [16], in the facial and emotional recognition in phobic individuals with autism [17] and in assistance of visually impaired older drivers [18]. AR is also widely used in mobile games and the cinematography industry.

2.3.2 Virtual Reality (VR)

VR can be described as “an advanced technological communication interface in which the user is actively participating in a computer-generated 3-dimensional virtual world that includes computer sensory input devices used to simulate real-world interactive experiences.” [19].

VR has the goal of immersing the user in a virtual world where everything looks and feels real. One of the main components necessary to achieve immersion is presence. Presence can be described as not only the sensation of being in the virtual environment, but also the ability to perform different actions in that environment. Presence in a virtual environment is important for immersion purposes, but it also has other significative applications, as we will see in the next section. One of the main ways to achieve presence is to create a realistic environment, not only in terms of graphics, but also in terms of perception. For example, in an environment without shadows, the user would realize something is missing and would not be immersed, decreasing the degree of presence. The same can be said if the body proportions and movements are incorrect or if actions do not produce the appropriate consequences [20].

Both types of reality technologies are designed to immerse the user, although each one does it in its own way. VR offers a new virtual world for the user to explore, while AR aims to complement the existing physical world with overlayed virtual elements that the user can interact with. This means that AR, in contrast to VR, does not intend to replace the physical world but to overlay it with virtual elements to enhance it. Although the sense of presence is felt in both options, the degree of immersion is lesser in AR than in VR, seeing that in AR the overlays are not a normal part of the physical world.

Categories

The different types of VR can be divided into three different categories based on the degree of immersion provided and the technological equipment used. According to that categorization, the three existing types of VR are: non-immersive VR (also known as Desktop VR), semi-immersive VR and fully immersive VR.

Non-immersive

Usually called Desktop VR and being by far the most widely used VR system, this type of VR uses the image displayed on a monitor and the standard input devices (mouse and keyboard) to display and interact with the virtual world. Even though this is the type of VR that provides the lowest degrees of interaction, presence and immersion, it can achieve good enough results in terms of graphic quality, user comfort and convenience and has the advantage of having the lowest cost out of all the types of VR.

Figure 7 - Example of Non-immersive VR[8].

Semi-immersive

A semi-immersive VR system, sometimes called hybrid system, is constructed by projecting the virtual world onto the real world and using various input devices to interact with it. These devices can be standard input devices, like mouse and keyboard, VR input devices, like headsets or sensors, or even non-conventional input devices, like wheels or touch screens. It provides a fairly high degree of interaction, presence and immersion and comes at a moderately high price.

[8] https://shorturl.at/yQR29

Figure 8 - Example of Semi-immersive VR[9].

Fully immersive

Fully immersive VR uses a headset that tracks the user's movements and other types of VR input devices and encases the user's visual perception in the virtual world, cutting out all visual stimuli from the real world. In some cases, a sensation (smell, sound, touch) produced in the real world and felt by the person immersed can help increase the immersion level. An instance of this is if a person is touching an orange in the virtual world and can feel the smell of orange in the real world. Although the comfort and image quality in this type of VR aren't as good as in others, the levels of immersion and interaction are far greater than any other type of VR. That being said, the price is also higher, comparatively [21].

[9] https://shorturl.at/hqQTW

Figure 9 - Example of Fully immersive VR[10].

Table 3 summarizes the pros and cons of every type of VR system.

Table 3 - Pros and cons of different types of VR [21]

	Fully immersive	**Semi-immersive**	**Non-immersive**
Resolution	Medium-Low	High	High
Sense of immersion	High	High	Low
Interaction	High	Medium-High	Medium-Low
Price	Very Expensive	Moderately Expensive	Lowest Cost
Comfort	Medium	High	High

Applications

The improvement of software and hardware and the need for innovation has led to the use of VR in the most diverse areas. One of the most useful and helpful applications of VR is in the medical field. VR is used in computational neuroscience, molecular modelling, treatment of phobias and ultrasound echography, among others. It can also be used in learning and training, as is the case of simulators. A VR simulator for training airplane pilots, crane operators or surgeons can save a lot of time and money and presents no risk, as everything happens in a virtual world. The usage of VR can also be extended to the engineering field, where a 3D representation of a component can help to better understand its functionality and accelerate its testing in a real-world scenario with low-costs and low time consumption. VR can be employed in architecture, where the architect can make use of VR to take itself or its clients on a tour of a building that is being designed, letting them explore the entire building

[10] https://shorturl.at/DQSV8

freely. Another field that benefits from the use of VR is data visualization, in which complex 2D and 3D data structures can be made easier to understand if represented in more intuitive ways. Finally, the most frequent use given to VR comes in the form of leisure activities such as playing video games or watching movies [21].

2.4 Virtual Reality Exposure Therapy

A literature review on the effectiveness of VRET and ARET in the treatment of specific phobias revealed that VR has been successful in the treatment of multiple types of specific phobias, namely animal phobia, natural environment phobia, situational phobia and blood-injection-injury phobia. In turn, ARET has only been able to treat one type of specific phobia, which is animal phobia [7]. Considering that VRET has been able to treat natural environment phobias (and acrophobia in specific) while ARET has not, choosing VR over AR as the medium for delivering ET was clear. Besides, VRET also has a wider range of specific phobias treated, meaning that this form of treatment can be modified for several other types of specific phobias, making it a more flexible option.

By mixing VR with ET, we obtain a new form of therapy called Virtual Reality Exposure Therapy (VRET). VRET utilizes the same principles and has the same goals as traditional ET but is performed in a virtual world, where the phobic individual is in contact with the phobic element.

Some of the reasons why VRET is attractive as a treatment option are the fact that it can be performed anywhere, is safe, confidential and seems to be more easily accepted by phobic individuals due being interactive [22]. Furthermore, VRET is able to reproduce all kinds of stimuli (which can be impractical for in vivo therapy in some cases) and control the quality, intensity, duration and frequency of those stimuli. It can also be applied to phobic individuals that are unable to perform in vivo therapy due to extreme anxiety [23], the treatment uptake may be higher due to the engaging and entertaining nature of VRET and the phobic individuals can be more willing to expose themselves to situations that they normally would not because they know it is not real, even though it feels like it is [24].

That being said, there are innumerous studies that prove the efficacy of VRET in the treatment of specific phobias [25],[26],[27],[3],[28] and in the transfer of the knowledge gained in the virtual world to the real world [4]. It does, however, also have some limitations that need to be considered. One of the most well-known limitations of VR technology is cybersickness, which happens when a user experiences nausea, headaches or dizziness when using VR. This is documented as a possible barrier to some individuals [29]. Additional disadvantages include further health risks, such as eyestrain, and other diverse factors like non-intuitive controls, the virtual environment can be a distraction from the main focus and the fact that many of the earlier generations' products are wired, which translates to reduced mobility and, consequently, reduced immersion [30].

In certain situations, VRET can even be performed without the need for a therapist, making it more accessible, as it can be done solo. By monitoring and analyzing the vital signs and considering the decisions made by the user during exposure, the treatment can be automated to the point of giving feedback on how well the session went, what the phobic individual needs to improve on for future sessions and how to improve. This means that clinic-level therapy can be done on low-cost, consumer-grade hardware, increasing accessibility even further [24].

When talking about VRET, the degree of presence influences the anxiety felt by the phobic individuals, which is one of the conditions necessary for treatment to occur. As said before, realism is one of the main factors for presence. However, studies show that a greater level of anxiety toward a phobic stimulus in real life leads to a greater degree of presence in the virtual environment which, in turn, generates more anxiety toward the virtual phobic stimulus. Nonetheless, the level of anxiety does not influence the effectiveness of the treatment, i.e., as long as the phobic element generates anxiety, the treatment can occur, but it is more likely to work in individuals that are highly phobic [31].

2.5 VRET for Acrophobia

One of the first times that VR was used in the treatment of mental health disorders was for treating fear of heights, which is the most common phobia [32]. A study selected 33 people with fear of heights and randomly divided them in two groups. One of the groups did VR ET, while the other group did in vivo ET. In both cases, the subjects did three one-hour sessions and the sessions were all conducted by a therapist. The results showed that the treatments were equally effective and that the benefits remained after six months [24]. In fact, the benefits can be seen for, at least, a year [5]. This goes to show that VRET is a valid method for acrophobia treatment and is, at least, as effective as in vivo ET [23].

Further studies show that VRET is capable of triggering physical and emotional reactions [33] and is effective in the treatment of acrophobia, as participants show a reduction in fear of heights after the experiments [24],[4],[23],[34], showing once again its validity as a treatment method for this specific phobia.

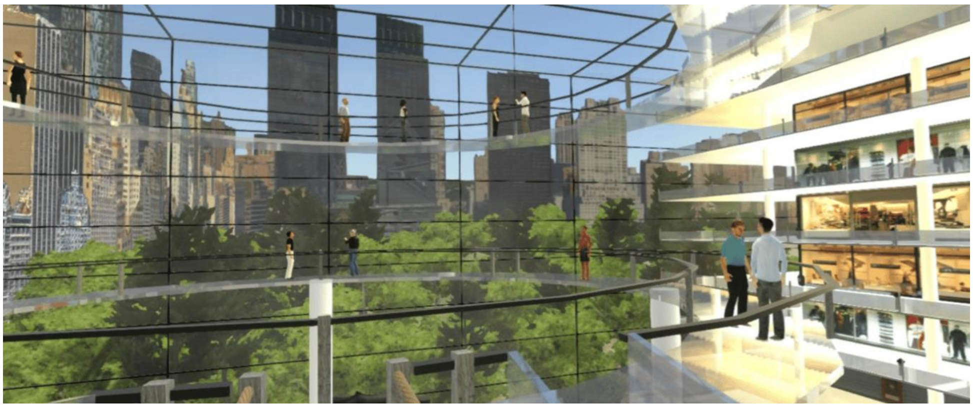

Figure 10 - VR scenario used in a study conducted in the Oxford University for the treatment of acrophobia using VRET [24].

3. Up (Date) Your Fear

Up(Date) Your Fear (UDYF) is our proposal to create a versatile and easy to use system that allows phobic users to interact with their phobic stimuli in a virtual and safe environment through the use of VR. Besides allowing exposure, UDYF also allows the monitoring of the user's behavior and physiological response while in VR. Given the wide range of possible phobias, we chose acrophobia, as it is a recent and impactful research area [34], [35].

Being set on the use of VR, there were still decisions to be made about the SW/HW used to accomplish our goal and also conceptual decisions regarding the specificity of acrophobia and what would be beneficial/harmful for an acrophobic individual using our system.

This consisted in evaluating the following:

- The specificity of the phobia and what would be adequate as a treatment;
- An approach to the scenario the user would see during the treatment;
- A Game Engine and a Target Hardware to be used.

We decided that the users should have contact with the phobic element through a game, which is in line with previous work, namely Veracity, by Bernardo Marques [11],[36]. The goal of this light-hearted approach was to create a virtual environment where the user could experience realistic height stimuli while being completely safe at the same time. This would also help to camouflage the ET aspect, making the user more immersed. In fact, by knowing it is a game, the user is more prone to try it, something they would never do in real life. The game aspect also enables the user to experience situations that, because of certain constraints or danger, would not be possible in the real world. We believe that this approach is suited to be a first point of contact with the phobic element and helps prepare the user for an interaction with said element in real life. For the exposition pace we chose a mixture between the presence and absence of stimuli (systematic desensitization) to provoke habituation and extinction.

3.1 The Game

The scenario of the game is a park (Figure **11**) where the user finds a woman crying because she lost her dog. The idea behind this choice was for the game to take place in an environment that might resemble something the user has already experienced or might come to experience in the real world, so that the user feels more comfortable and relaxed. Additionally, this scenario allows for the creation of a story that is designed to make the user deal with specific height related challenges, namely reach high places for tasks, sudden changes in height and even unobstructed panoramic views from a certain height.

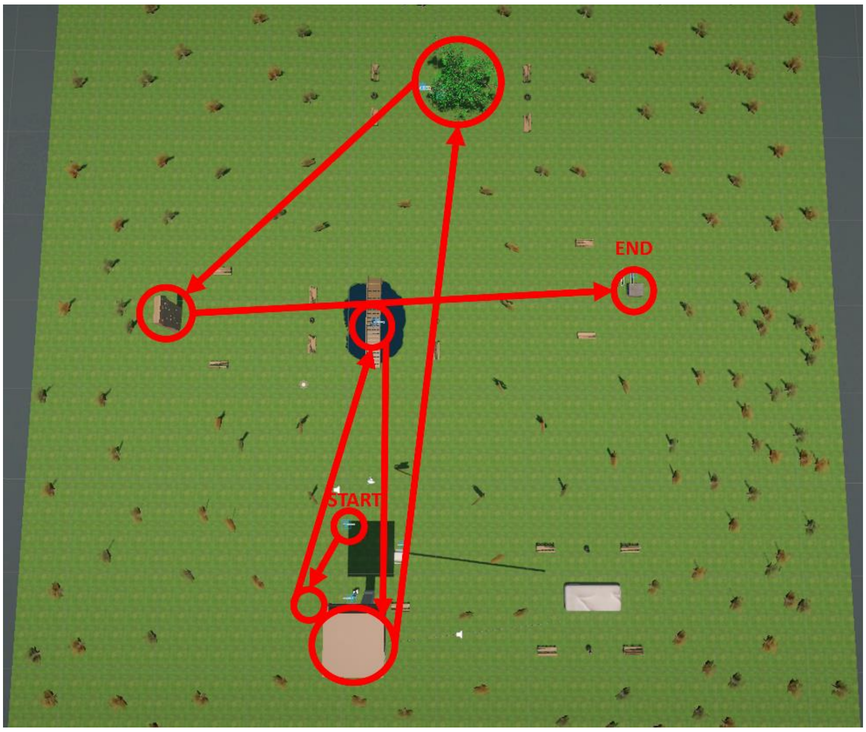

Figure 11- Aerial view of the map highlighting the path the user must take.

The user must then navigate through the open-world map and various obstacles to find and free the dog, which has been trapped in a cage (Figure **12**). These obstacles, even though mundane, involve height related stimuli of different degrees with the goal of exposing the user to its phobic element and perform ET in a controlled and safe environment and with a ludic element.

Figure 12 – Caged dog that the user has to set free.

This approach allowed us to have the game divided in several tasks. The first tasks serve as a way of getting the user familiar with the environment, letting the user know what the controls of the game are and creating a baseline for the HR of the person playing the game. The subsequent tasks have the purpose of exposing the individual to phobic stimuli of varying intensities.

The user is spawned in a park where it hears someone crying and a prompt is presented to let the user know it should go see why the woman in front of it is crying. This prompt also lets the user know what the basic controls of the game are. After talking to the crying woman, the user learns that a dog went missing and is instructed to check the lake, as the dog enjoys water. Arriving to the lake, there is a small bridge that the user must go on top of the bridge (first height obstacle) to ask another woman if she saw a dog (Figure **13**).

Figure 13 – Bridge where the second woman is standing.

This woman says that she didn’t see any dog, but the user can go up the elevator (Figure 14) to get to the top of the tower and look from higher ground. The elevator is see-through so that it is possible to have a perception of being lifted off the ground (second height obstacle).

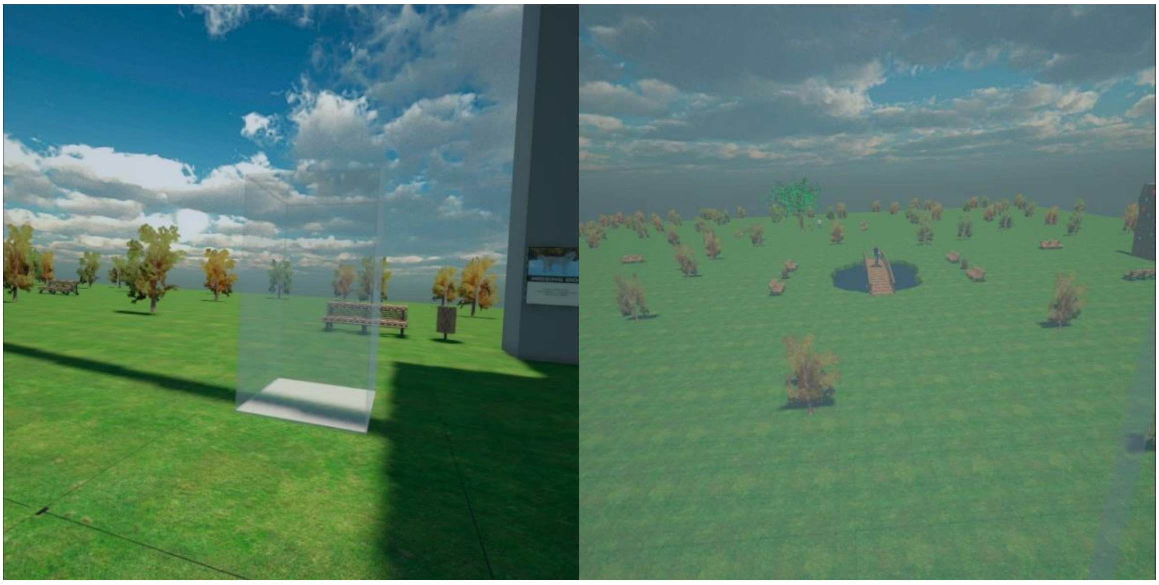

Figure 14 - Elevator used to go up to the tower: on the left, elevator viewed from the outside; on the right, view from inside the elevator when it is going up.

Upon arriving on top of the tower (approximately 15 meters high) (Figure 15), there is a man that says he locked the dog in a cage because it was barking very loudly but there is a way to free it. The user must then follow the instructions and go talk to another man near an apple tree. But before that, the user must also choose a way to go down the tower. This can be done in one of two ways: taking the elevator down or using a boomerang to ride a zipline (third height obstacle).

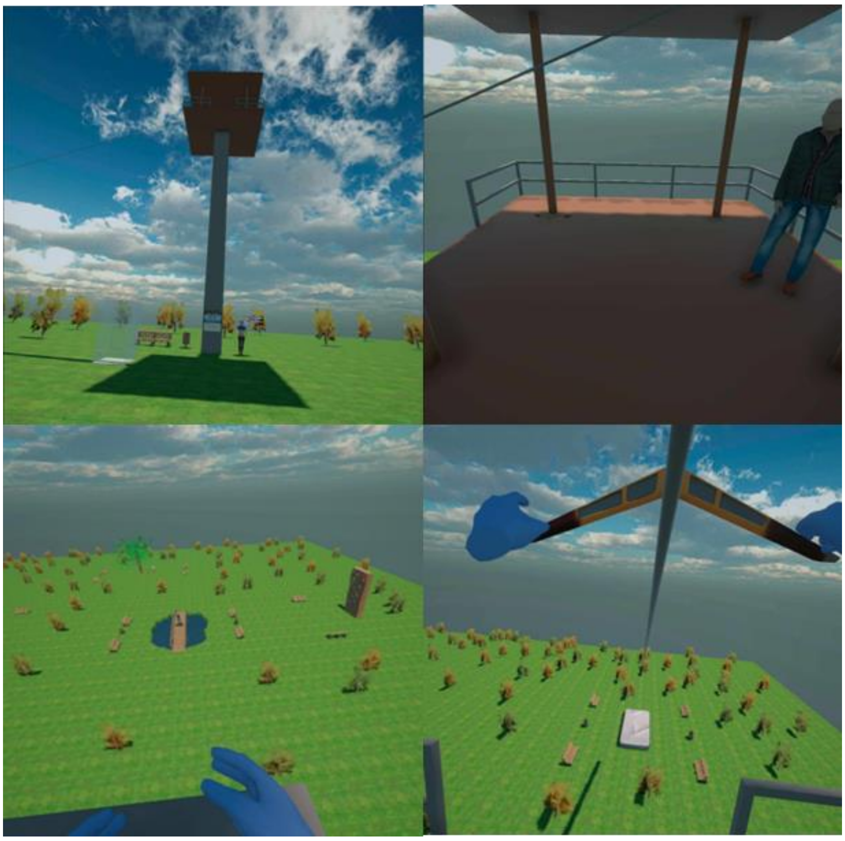

Figure 15– Top left: tower viewed from the ground; top right: tower interior; bottom left: view from atop the tower; bottom right: zipline going down the tower.

After going down and reaching the apple tree, the man asks the user to climb the tree (fourth height obstacle) and pick five apples in exchange for information on how to save the dog (Figure **16**).

Figure 16- On the left: the tree that needs to be climbed in order to get to the apples; on the right: picking up an apple.

When this task is completed, the man tells the user to go up the climbing wall (fifth height obstacle) (Figure 17) and grab a key that is on top of it.

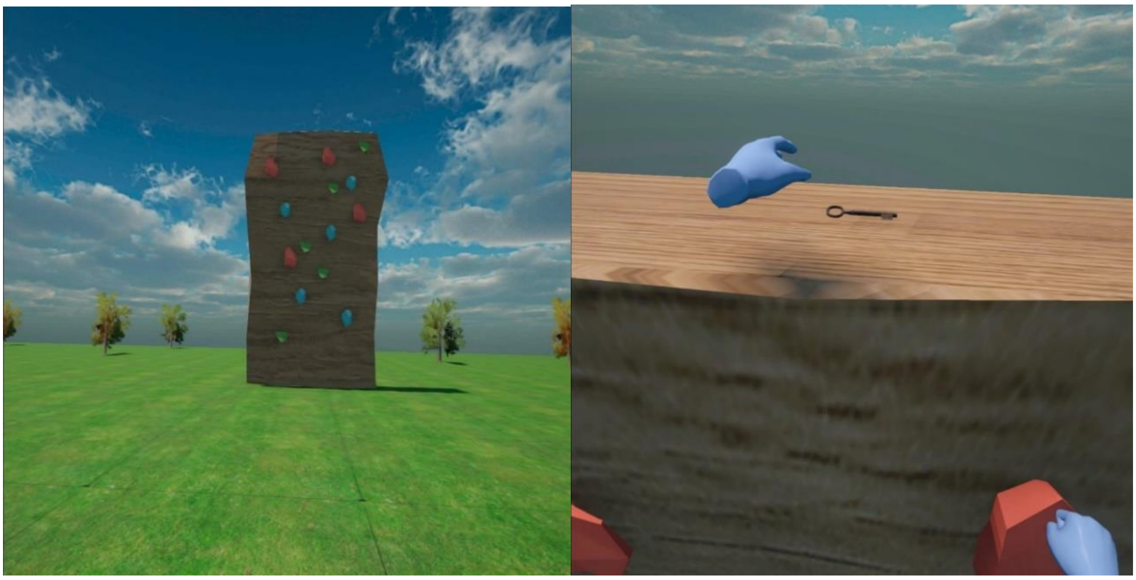

Figure 17 – On the left: climbing wall seen from the ground; on the right: key on top of the climbing wall.

That key is used to open the cage and finally free the dog (Figure 18). After the game is completed, another prompt appears, letting the user know the game is finished and how much time it took.

Figure 18 – Dog after being set free.

A gameplay demonstration of the game can be found here https://youtu.be/XO7ziB5Yzx8.

3.2 Models Used

The various models and assets used in the construction of the game were found in multiple websites, namely: the unity asset store (https://assetstore.unity.com/3d), sketchfab (https://sketchfab.com/tags/unity3d), turbosquid (https://www.turbosquid.com/Search/3D-Models/free/unity), free3d (https://free3d.com/3d-models/unity) and cgtrader (https://www.cgtrader.com/3d-models/unity). The human models were created using a plugin for Blender called MakeHuman, which automatically generates human avatars (Figure **19**). The goal was to find realistic models and assets that fitted the target environment and made sense to exist in that environment, which would be impossible if only the asset store was used. In addition to that, there were other models that were built using Unity's primitive objects, such as cubes and cylinders.

Figure 19 – Avatars used in the game to serve as NPCs that guide the user.

3.3 Game Engine and Target Hardware

To build a virtual environment, along with interactions in that environment and the necessary phobic stimuli to perform ET, the use of a game engine was necessary. Although there were several options to choose from, one of those options seemed more suitable than the others-Unity. Unity is the most used game engine in the world due to its ease of use and learning curve, ability to create diverse and realistic environments and ability to easily build applications for multiple platforms. All of this, allied with previous experience using this game engine, made us choose Unity.

A similar choice had to be made, this time regarding the target hardware where the game would run. This time, there were only two options to choose from: the HTC VIVE and the Meta Quest 2. Upon testing both systems, the HTC VIVE proved to be unsuited for what we were looking for. Taking into consideration that the user of the game may not have a spacious room to move around, an additional method of locomotion needed to be implemented. The most intuitive method is the use of a joystick, which is not available on the HTC VIVE, leading to it being discarded as a possibility. However, the Meta Quest 2 controllers have a joystick, making it the perfect choice.

After all of this, what was left to do was changing some settings in Unity to allow it to build the game for Android (seeing that the Meta Quest 2 runs on Android) and make some optimizations. With all the configurations done, the setting up of the scene involved the use of a device based XR Rig, an XR Interaction Manager and a Locomotion System, all provided in the XR interaction Toolkit plugin, and also some models and other assets. During the development process, the default Locomotion System proved to be ineffective, as it was very difficult to perform some actions, such as climbing and ziplining. Therefore, a change was made so that the Locomotion System was now Physics based, allowing for more freedom of movement and actions.

3.4 Features

The game offers many different activities, such as climbing a tree and a climbing wall, riding a see-through elevator and sliding down a zipline, to expose the user to many different height stimuli. All of this was designed using a Physics-based approach instead of a Device-based one to make the interactions seem more realistic. In addition to the game, our solution has a biosignal acquisition component that allows to collect ECG and respiration data to monitor the user's state while immersed and provide biofeedback. This is done by applying signal processing to the ECG data acquired using a Python library called NeuroKit2. The sampling frequency of the ECG signal is 500Hz, which means 500 values are collected every second. These values are added to a list and when that list has ten thousand values in it (which means every twenty seconds), a filter is applied to the signal in order to reduce noise. After that, the signal is analyzed to detect the R peaks and, finally, those peaks are used to calculate the HR, which is then sent to the device where the game is running, and the list is cleared. In that device, the value is parsed, and we consider the first HR value received as a baseline. Therefore, if the HR increases 25% or more relatively to the baseline, a prompt is shown to let the user know that its HR is accelerated, and it should slow down and take deep breathes to calm down. Putting it in simpler terms, the HR of the user is analyzed every 20 seconds and if there is an increase of 25 % or more in comparison to the initial value, the game provides biofeedback to let the user know it needs to calm down. This prompt disappears when the HR is restored to its initial values and reappears if needed. In this context, a high value for the baseline is common, seeing that the participants know what they are about to do and that alone is enough reason for stress, which causes an increase in HR.

4. Architecture

In this section, we describe the architecture of our solution, as well as some small details that make the system come together and initial iterations that ended up not working. We designed our architecture to be modular, meaning separate modules work together to achieve a final goal (Figure 20).

The main modules of the system are:

- The ECG/Respiration data acquisition device (a);
- The Node.js server running on a computer serving as a WebSocket server (b);
- The visualization platform (c);
- The game developed in Unity that is running on the Meta Quest 2 (d);
- The Meta Quest 2 device serving as an interaction device with the game (e).

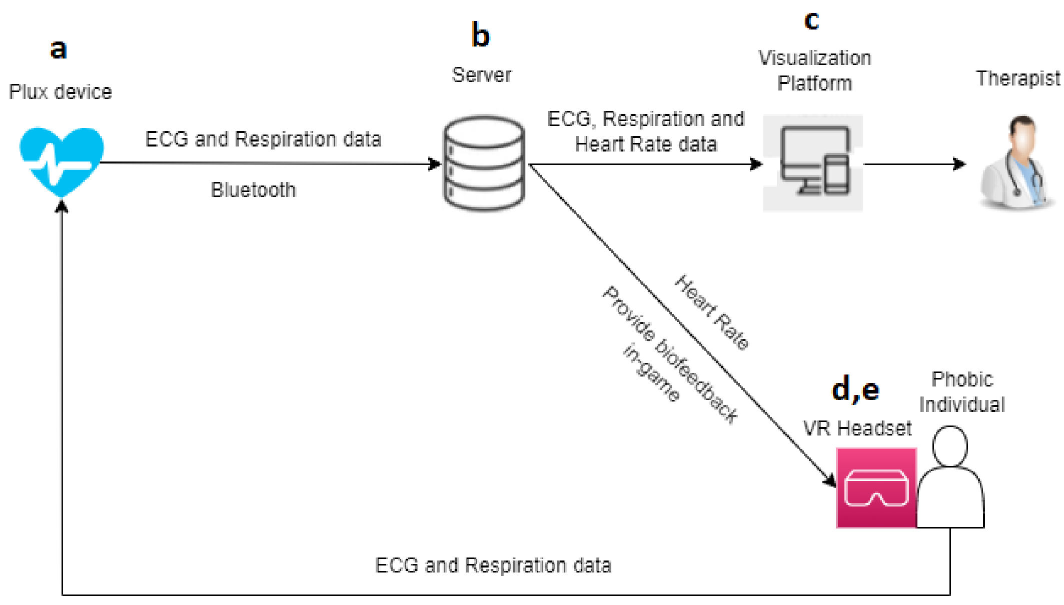

Figure 20 - System architecture.

4.1 *Current Architecture*

Game

One of the key modules of our architecture is the game, as it is the way to expose the user to the phobic element. Furthermore, it contains two very important submodules: the GameLogic, which handles all events in the game, and the WebSocketManager, which connects to a WebSocket server and receives the HR data. This second submodule acts as the WebSocket client and, assuming the PC and the Meta Quest 2 are on the same network and that the PC has a static IP address, connects to the WebSocket server to receive the HR data. These two submodules were developed in C# and are closely intertwined, as the data received from the server is used to show or hide a prompt inside the game, depending on the values. This is how we implemented biofeedback.

Meta Quest 2

As mentioned before, the Meta Quest 2 device serves multiple purposes: it is used as the device that runs the game and as the device used to interact with the game. The sense of realism and immersion provided by this device allows the user to believe the stimuli in the virtual world are real, making it easier to perform ET.

Figure 21 – Representation of the Meta Quest 2 hardware.

Node.js server

To establish a communication channel between a computer and the Meta Quest 2 device, we used a Node.js server as a WebSocket server. Node.js is a runtime environment that allows JavaScript to be ran on the server-side, outside of a web browser. It is asynchronous and event-driven by nature, and is optimized for real-time applications, with native support for WebSockets. However, this was not the initial approach. As will be discussed further ahead, we tried other options that, due to hardware restrictions, did not work. Upon analyzing the failures of the first attempts, we realized that we needed a technology that could transmit events in real time and was not dependent on the programming language it was implemented in, as it would have to be Python on the computer side and C# on the Unity side. The obvious choice here were WebSockets, as they met the requirements and were easy to use.

WebSockets work by having the server running and letting the client establish a connection to it. When the client sends an HTTP request to establish a connection, the server sends an HTTP response to confirm the connection. After that, some more messages are exchanged to ensure synchronism. This is called handshake mechanism. After the handshake process is complete, the client and the server send and receive messages from one another, creating a bidirectional connection. This connection can handle multiple clients, which means it is scalable and the communication process can be improved in the future. Finally, one of the sides, when it has no more messages to send or receive, can close the connection (Figure 22).

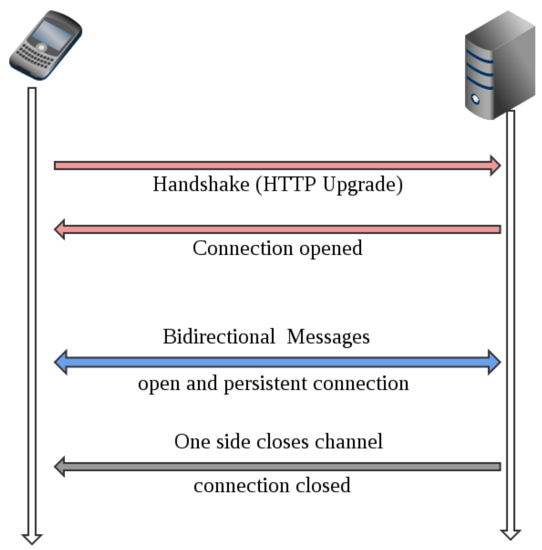

Figure 22 – Illustration of the WebSocket architecture used [37].

In the scenario of our system, the communication happens between the game, which acts as the client, and a Node.js server running on a computer, which acts as the server. The server waits for the client to connect to it and, when the connection is established, it runs a Python program to acquire data from the ECG/Respiration device and sends it in real time to the client, that analyzes it and decides what to do based on it, thus implementing biofeedback.

ECG/Respiration device

The device used to acquire ECG and Respiration data is a Plux device (biomedical device developed by PLUX wireless biosignals S.A.). This device has four mini-USB ports where various types of sensors can be connected. For our project, we chose ECG and Respiration sensors, as the data they provide is best suited to prove that our solution is valid. The Plux device connects to the computer via Bluetooth and a Python program is used to access the device's API with the intent of fetching the data acquired by the sensors. However, that data is raw, meaning it is simply values between 0 and 65536. After the data is acquired, a transfer function needs to be applied to it in order to convert it to an amplitude on mV units([-1.5mV, 1.5 mV]) and Respiration ([-1.5V, 1.5 V]) data. This transfer function is different for every sensor and, therefore, the Python program first needs to check which sensor is connected to each port to apply the correct function to the acquired data. After all that, the Respiration data is ready to be used, but the ECG data still needs some processing, to evidence the underlined information. With that in mind, a Python library called NeuroKit2 is used to first clear the signal using a filter, then detect the R Peaks (Figure 23) and finally calculate the average HR based on those peaks, which is then used in-game triggering evaluation. During the acquisition, the ECG and Respiration values are each stored in a list and, when the acquisition is over, the list are written in text files and stored in a folder, where the file name is composed by the acquisition start date and type of data the file stores. For the sampling rate of the Plux device we chose 500Hz, which is the standard acquisition frequency for an ECG.

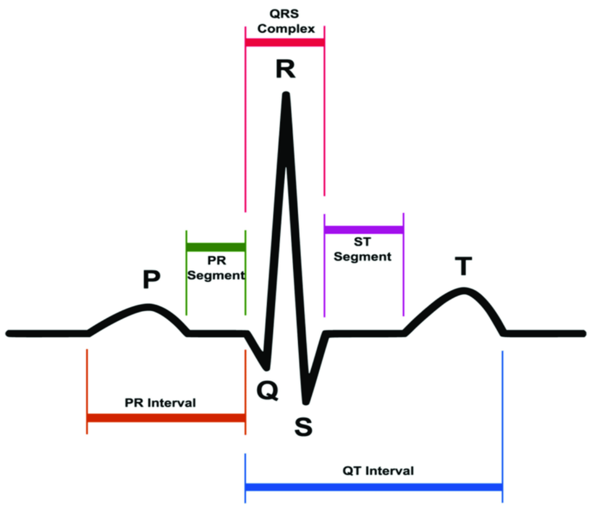

Figure 23 – Illustration of an ECG wave [38].

Visualization platform

The visualization platform (Figure 24) shows the graphs for ECG, HR and Respiration throughout the duration of the session. The objective of this platform is to be used by the therapist to evaluate the progress made by the patient over the course of multiple sessions. The platform is a dashboard built in Python using the Dash library, which is built on top of Flask. Dash was chosen because it provides a higher-level abstraction and additional components specifically designed for creating interactive dashboards and data visualization applications. The server, after the client disconnects, runs another Python program to build the dashboard. This program goes through the base directory and looks for the files that were just created for each type of data. After that, it iterates through the files to extract the data contained in them and uses that data to construct a line graphic for the ECG data, another line graphic for the HR and a third line graphic for the Respiration data. Additionally, it also tells the average, maximum and minimum HRs observed during the acquisition. Once that program finishes running, the dashboard is available for visualization on port 8050 of the localhost. Therefore, the server also opens a web browser with that address and port to show the visualization platform. As seen in Figure 24, the dashboard shows the HR values and graphics for both types of data. These graphics can be zoomed in to better see the data represented and can also be saved to analyze with other software, if needed. In a practical scenario, this dashboard is meant to be visualized by the therapist conducting the ET session to evaluate the user's performance and improvement.

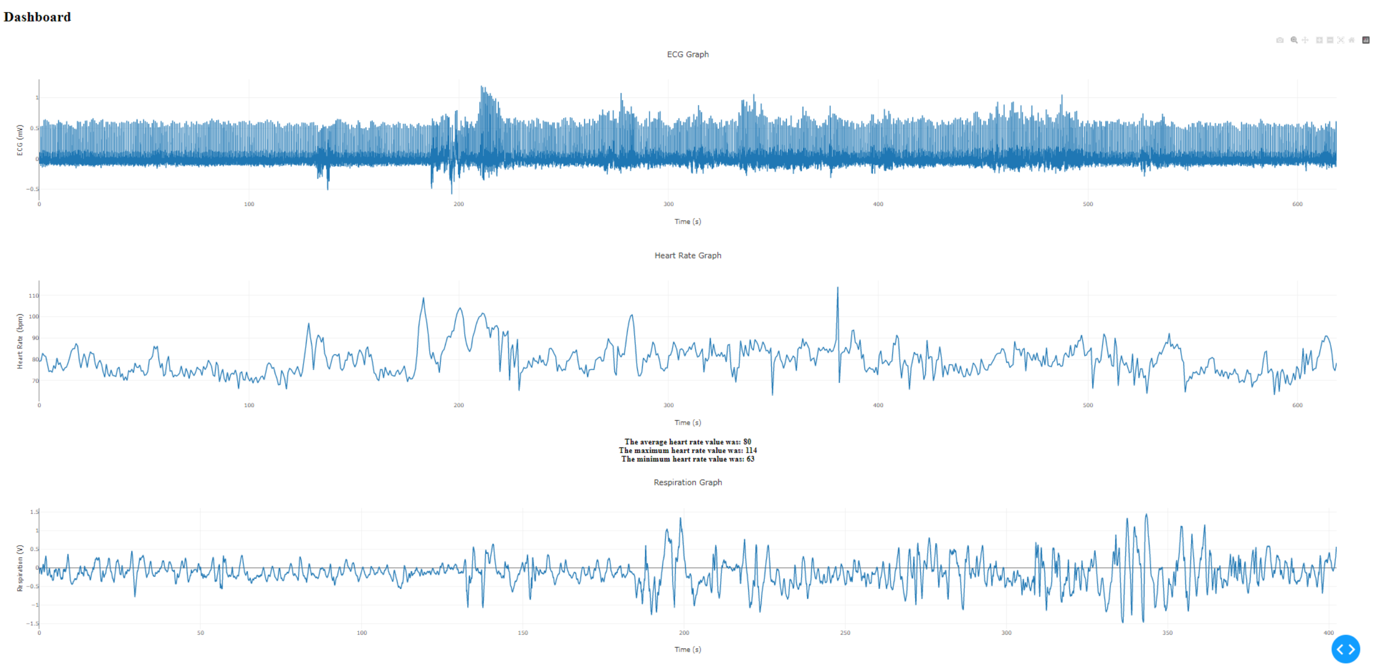

Figure 24 – Interface of the visualization platform, representing 3 distinct signals for a single user, namely: top- ECG; middle- HR; bottom- Respiration. Data displayed for post-processing analysis.

4.2 Overall Workflow

Figure 25 shows the workflow of our system. On the PC side, the only thing needed is to start the server. After that, the Plux device needs to be turned on so that the data acquisition program can connect to it. Assuming the PC and the Meta Quest 2 are connected to the same network and the PC has a static IP address, when the game is launched on the Meta Quest 2, the client in the game connects to the server in the PC and, when the server detects that a client connected to it, it runs the data acquisition program. This program starts by creating two files, whose names are a string containing the current time followed by the type of data that will be stored in it. After that, it connects to the Plux device, scans for what sensor is connected to each port and reads the data from each sensor. That data is then written to the correspondent file and the ECG data specifically is used to calculate the HR value, which is then sent to the game. Upon receiving this value, the game checks if it is greater than a certain threshold and, if it is, it shows prompt letting the user know their heart is accelerated. Otherwise, it hides the prompt. When the game finishes, the client disconnects from the server and, when this happens, the server stops the data acquisition and runs another program to build the dashboard with the data that was written in each file. Additionally, it also uses the HR data to make another graphic, as well as show the average, maximum and minimum values for it. Finally, the server opens a web browser to show the dashboard.

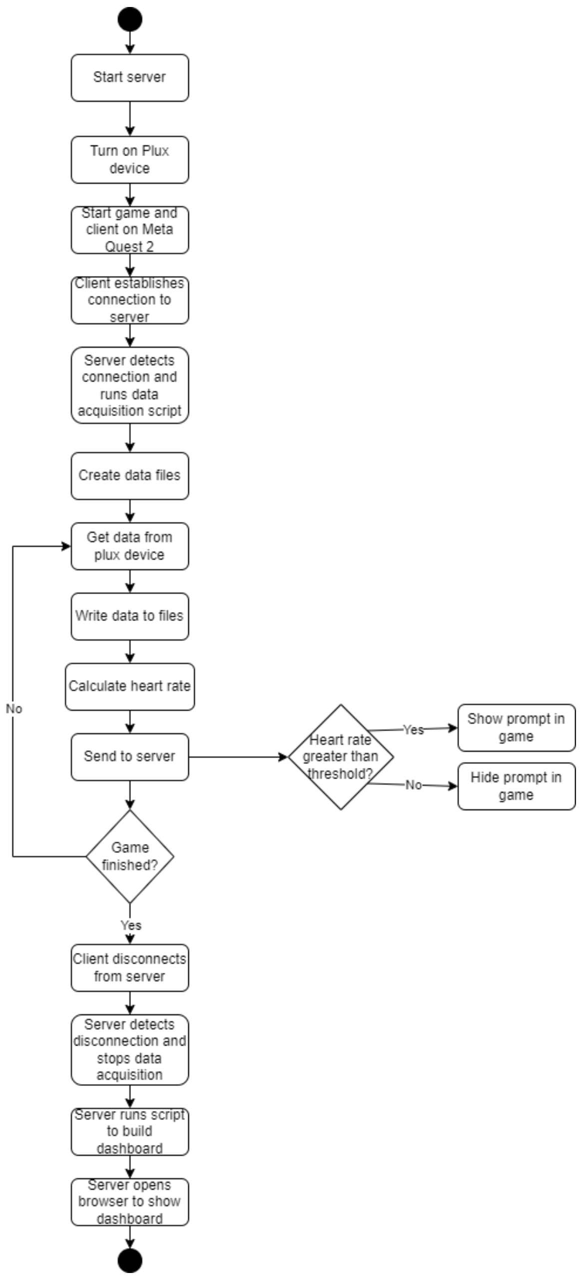

Figure 25 – Workflow Diagram.

4.3 Initial Iterations

Even though the current architecture accomplishes everything we want, we had some initial ideas that ended up not working, namely in the way the communication between the computer and the Meta Quest 2 was going to function. As we needed a solution to transmit data from the PC to the Meta Quest 2 in real-time, we first looked at Kafka.

Apache Kafka is an open-source distributed streaming platform that is designed for high-throughput, fault-tolerant, and real-time data streaming and processing. It follows the Publish-Subscribe model, where a producer (application or system that produces data) publishes messages containing data to a topic. At the same time, a consumer (application or system that consumes data) subscribes to a topic and reads the messages published by the producer on that topic. This decouples the producers and consumers, allowing for flexible data consumption. Kafka also uses brokers to store and distribute data between producers and consumers, which means the broker acts like the bridge between the multiple components. When a producer wants to write a message to a topic, it establishes a connection to a broker in the cluster and the message is written in the broker, specifying the topic. Similarly, when a consumer wants to read data from a specific topic, it establishes a connection to a broker and reads the messages stored in the broker under that topic.

When looking at ways to implement Kafka, the first thing we tried was running a local Kafka cluster using Docker. This of course would not work, as the cluster was running on the PC but the Meta Quest 2, only having the code of the consumer, would not be able to connect to a broker to consume messages. After that realization, we tried to use an online cluster running on the Confluent Cloud. In this version, we had success establishing a communication between two PCs even on different networks. However, when trying to establish a connection between the PC and the Meta Quest 2, even with both devices being connected to the same network, it would not work. Looking at the dashboard provided in Confluent Cloud, we could see that the data was being published to the topic, but it wasn't being consumed, meaning that the consumer on the Meta Quest 2 wasn't able to connect to the broker. We are not sure why this happened, but we hypothesize that it might be because the Meta Quest 2 is a closed system and blocks some communications.

After these failures, we turned our attention to WebSockets. As mentioned before, WebSockets easily fulfill the requirements we needed and are easy to use. Our first approach was to build a server in Python and a client in C#. Once again, we managed to establish a connection between two PCs in different networks. But much like what happened in the previous attempt, when trying to establish a communication between the PC and the Meta Quest 2, even in the same network, it did not work. After some debugging, we realized that the client wasn't even trying to establish a connection with the server. And once again, we are not sure why this happened, but we hypothesize that it might be because the Meta Quest 2 is a closed system and blocks some communications. After some trial and error, we came up with the Node.js version, which ended up working.

Another idea that did not work was the initial vision we had for the visualization platform. Initially, we wanted to have the graphics updating in real time, so that the user's progress could be tracked throughout the session. When trying to implement this, we used a Python library called Plotly[11]. This library helps with drawing various kinds of graphics, including line graphs, which is what we wanted. However, the graph's drawing speed was very slow and was introducing an exponential time delay because, instead of drawing the points as they were acquired, the only way to draw the graphics was to draw every point in every iteration, making the drawing process very slow, seeing that 500 new points were acquired every second. Due to this, we decided to make an offline visualization platform, that is only constructed after the data acquisition is finished. This way, we are able to show the graphs as soon as the game ends and also reduce the load on the system during the acquisition.

[11] https://plotly.com/

5. Preliminary User Study

A preliminary user study was conducted to test the initial prototype usability, as well as navigation, interaction and manipulation aspects. This occurred within the scope of the workshop "Immerse yourself in a fight against your fears: Using VR and physiology assessment for Phobia Treatment" https://eneeb.aneeb.pt/workshops/, which was part of the 18th edition of ENEEB (National Encounter of Biomedical Engineering Students) that took place at the University of Aveiro. The goal of this user study was to present and test an early build of the solution and gather important feedback to help in the development process.

5.1 Experimental Setup

The study was conducted in a spacious room with normal lighting conditions where the subjects could move freely, and the Meta Quest 2 HMD (Qualcomm Snapdragon XR2, 6 GB LPDDR4X RAM, Adreno 650 Graphics, 128 GB Storage, 1832 x 1920 per eye Resolution and 90 Hz Refresh Rate) was used to immerse the subjects in the virtual world. The experience was being streamed to a monitor, so that every participant could see what was happening.

Figure 26 - Photos taken during the preliminary user study where the participants are trying the game.

5.2 Tasks

The participants were asked to complete six tasks: 1- pick up the boombox and see how it works, 2-cross the bridge, 3-climb the climbing wall and pick up the boomerang at the top, 4-cross the bridge to the other side again, 5-go up the elevator and 6-use the boomerang to go down the zip line. The first task was created to establish a baseline and teach the participant what the controls are and how to interact with objects, while the other tasks were defined with the objective of exposing the participants to different heights to see how they responded.

5.3 Data Collection

After the participants tested the solution developed, they were asked to fill a survey about it (see Annex). The participants started by answering some questions about their demographic data and then about the system, its usability and specific questions, followed by a question about acrophobia and finally a suggestions box. Excluding some demographic questions and the last question, which was optional and open-ended, all of the questions were multiple choice and the answer options followed a 7-point Likert scale.

5.4 Participants

To ensure fairness during the study, and due to time constrains, six participants (five female, one male) were chosen at random from a pool of sixteen people. The participants selected were all between the ages of 18 and 25 and were all students. These six participants all tested the solution and answered the survey mentioned previously. However, due to this study being conducted within the scope of a workshop, all the sixteen people were present during the study, which allowed the people that did not participate to also give feedback from what they were seeing, as the participant's experience was being broadcasted on a monitor.

5.5 Procedure

From the pool of 16 people, one person at a time was chosen at random to be a participant. After giving their informed consent, participants were asked to put on the HMD and were introduced to the virtual world. Inside the virtual world, as soon as the game started, players were able to see a list with instructions and tasks to fulfill. The participants were then able to explore the virtual world and interact with it freely. If any questions about the system or the tasks arose, we would answer them promptly. After the last task was completed, the participants were asked to answer a survey about their experience.

5.6 Initial results and next steps

From the analysis of the answers to the survey, we could see that most of the participants have never had any contact with VR and were not acrophobic. Moving on to the usability questions, the overall feeling about the game was very positive, as were the ease of use, controls, coherence and ease of learn. However, many participants thought the game was too simple, which can be justified with the fact that it was an early build with simple tasks but can also be considered in the development process. Regarding the specific questions, map navigation (M= 6.83), object interaction (M=6.33), task clarity (M=6.67), realism (M=5.33), immersion (M=5.67) and sound effects (M=6.5) were all graded highly, meaning a good acceptance. Contrarily to these results, the question about the realism of the height stimuli averaged a lower score (M=3.17), which means some work needs to be done regarding this aspect. Finally, the open-ended question brought some useful suggestions like being able to see the whole body, making the elevator more transparent and showing instructions and tasks as they are needed, instead of showing them in the beginning of the game.

Overall, interesting feedback was collected during this preliminary evaluation, which helped elicit next steps of the development phase. As it stands, the next steps include building upon the already existing solution with the goal of creating a more complete and more realistic solution that can be used to treat acrophobia.

This can be accomplished by:

- Creating new tasks which involve a more direct contact with the phobic element;
- Implementing the suggestions given by the participants of the study;
- Expanding the scenario with more opportunities to expose the individual to the phobic element;
- Building a narrative to guide the user through the game;
- Putting the system to the test and gathering feedback again.

6. User Study

After the whole system was put together, another user test was conducted with the goals of evaluating the solution, figuring out if the data collection while playing the game and the data visualization were performed correctly and analyzing how easy it was to detect changes in the participant's physiological response. With this in mind, we recruited a total of 13 participants (5 female) to take part in our study and help us evaluate our solution. The participants were selected from our friends, families and colleagues, and we carefully selected people from different age groups, with different backgrounds, different tech savviness and, of course, fear (or lack of it) of heights, so that we could analyze all scenarios (Table 4). To know if a person was acrophobic or not, we asked them how they felt about heights and based on their answer, we selected them. No formal diagnosis was performed.

The participants gave their written consent and were informed that they could withdraw from the study at any time and that all the data collected would be private and only used in this dissertation. After testing the solution, in which they had to complete the tasks described previously, the participants were asked to fill a survey about their experience. This survey has the same questions and answer options as the survey used in the preliminary user study. However, we chose to separate the two surveys so that we could better see and analyze the difference in answers given in each of the two situations. This allows us to have a better perception of the evolution of the system and helps us realize if the changes made worked out or not.

Table 4 - Demographic information of the user study participants.

	Age	**Gender**	**Height Phobia**	**First time using VR**
Participant 1	18-25	Male	No	Yes
Participant 2	41-60	Female	Yes	Yes
Participant 3	18-25	Female	No	Yes
Participant 4	18-25	Male	Yes	Yes
Participant 5	41-60	Male	No	Yes
Participant 6	18-25	Male	No	No
Participant 7	18-25	Male	No	Yes
Participant 8	18-25	Female	Yes	Yes
Participant 9	18-25	Female	No	Yes
Participant 10	18-25	Male	No	No
Participant 11	41-60	Male	No	Yes
Participant 12	18-25	Male	Yes	Yes
Participant 13	13-17	Rather not say	Yes	Yes

6.1 Experimental Setup

The experimental setup used was mostly the same as the one used in the previous user study: the study was conducted in a spacious room with normal lighting conditions and no outside noise where the participants could move around freely, and the Meta Quest 2 was used to immerse the participants. That being said, a few adjustments were made regarding the initial setup. The major difference was that fact that, this time, the participants had the ECG and Respiration sensors attached to them, so that the Plux device could acquire physiological data. Another difference was that the experience was not streamed to a monitor since there was no need for it outside of the workshop setting. The final difference was that there was a stopwatch measuring the length of the experience and the duration of each task. This is because, when looking at the HR graphic, we had no way to correlate the spikes observed with what happened in-game. By measuring the time each task took, we could at least know in what part of the game the participant was when looking at the ECG graph. Although not perfect, this is a way we found to validate our solution.

Figure 27 - User study participant trying out the complete system.

6.2 Comparison Between the Two Studies

As mentioned before, the major difference between the two versions of the solution presented in each study is the inclusion of physiological data monitoring. The integration of the Plux device and its sensors and the data they provide allowed us to monitor the user's performance and, more important than that, give them biofeedback. In addition to that, and taking into consideration the feedback received in the previous study, some changes were made to the game. The elevator was more transparent this time, so that the user could have a better height perception when going up or down, and a new task was presented as the old one was completed, instead of showing all the tasks in the beginning. However, we did not implement a full body avatar for the player, as it would require animations, which we considered to be out of the scope of this dissertation. Finally, we created new tasks and added mechanics and a narrative to make the game more interactive and immersive.

As seen in Figure 28, the acceptance and sentiment towards the game was relatively the same (previously M=6.17, now M=5.69). The lowering of the score might be explained by the average participant age, as some of the participants in the second study are a little bit older and are not as used to technology, especially VR. It might also be because some of the participants (3/13) experienced motion sickness, which caused them to rate the game lower.

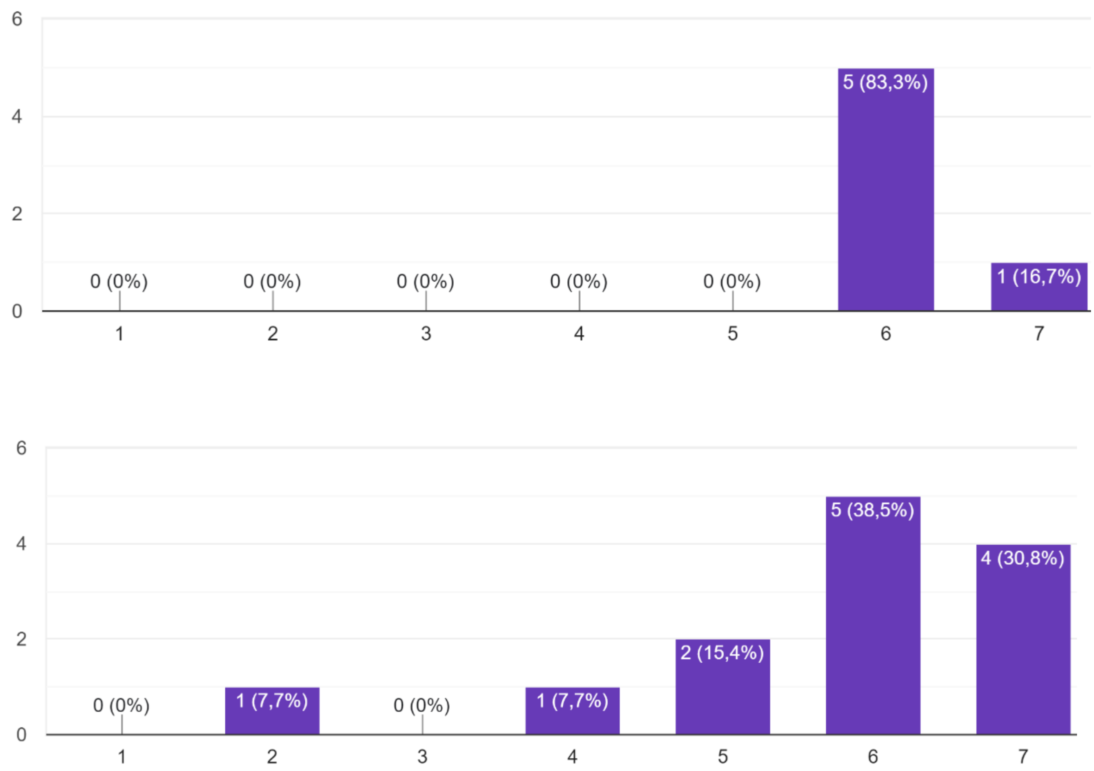

Figure 28 - Answers to the question about the game: first study on the top; second study on the bottom.

Regarding the complexity, Figure 29 shows a clear improvement when comparing to the previous study (previously M=4.33, now M=5.92). In this case, a score of 7 doesn't mean the game is too complex, it means the complexity is best suited for what the game is. From this, we can conclude that the changes made to the game were a success and contributed to a better experience.

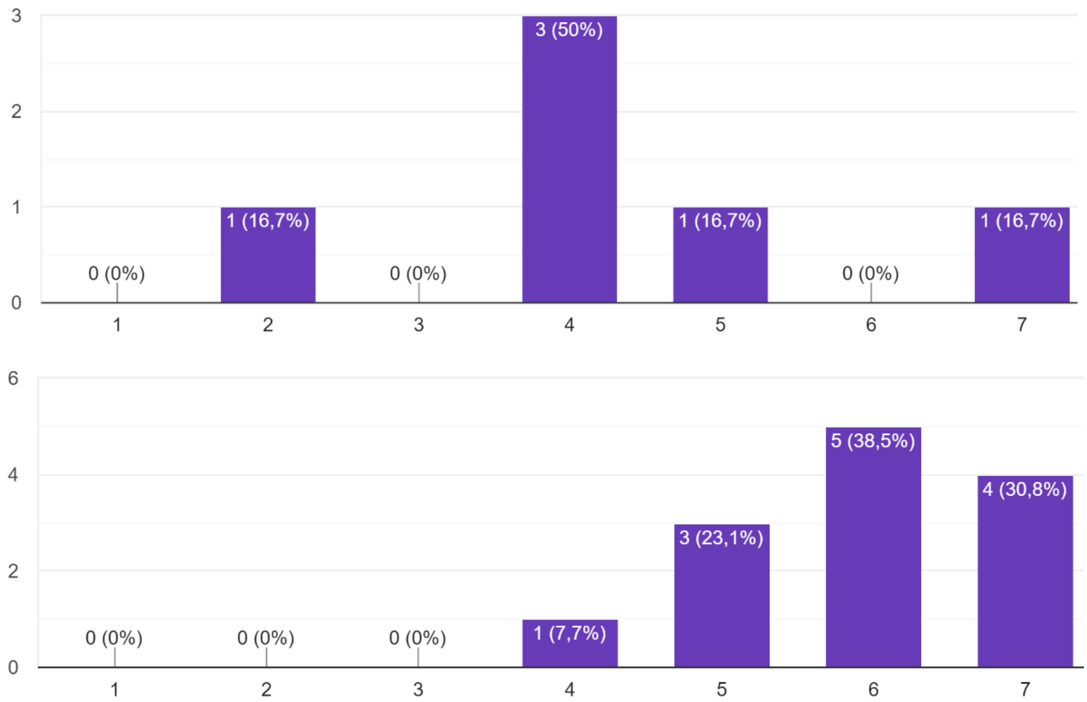

Figure 29 - Answers to the question about the complexity: first study on the top; second study on the bottom.

Regarding the game realism, Figure 30 shows an increase of almost one point when comparing the two studies (previously M=5.33, now M=6.31). This indicates that the changes made to accentuate the height stimuli, like making the elevator more transparent, were effective in enhancing the realism of the game.

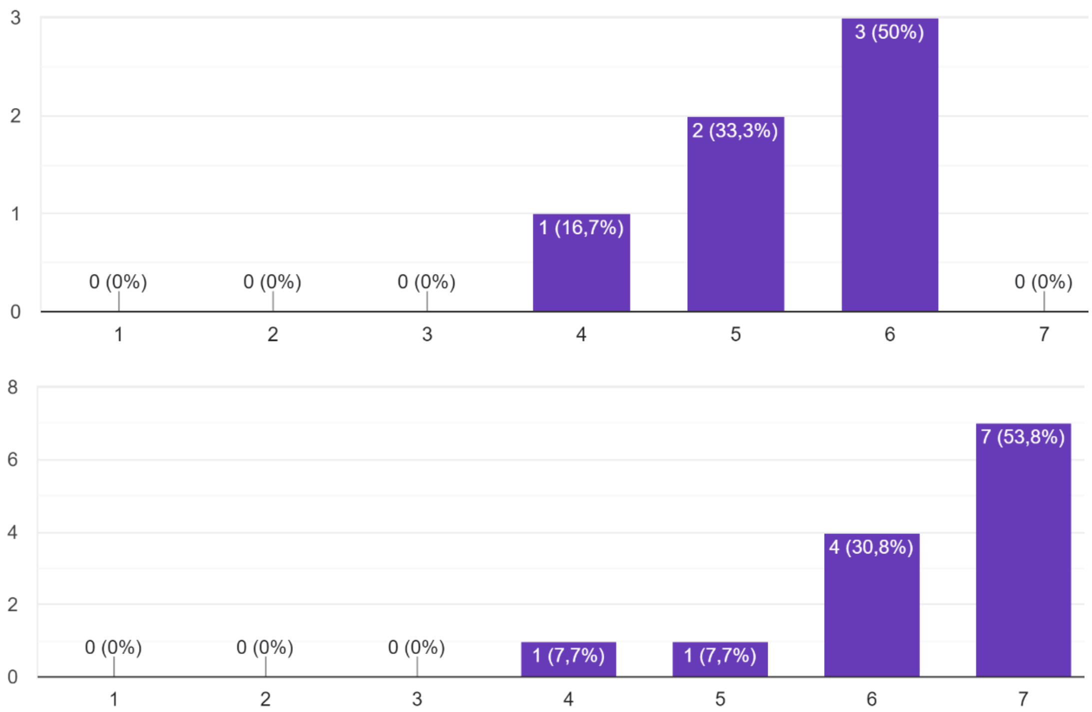

Figure 30 - Answers to the question about the realism: first study on the top; second study on the bottom.

A similar effect has been observed in immersion. In Figure 31, we can see that the addition of a narrative and mechanics granted the game a higher level of immersion, resulting in an increase of more than one and a half points (previously M=5.67, now M=6.46).

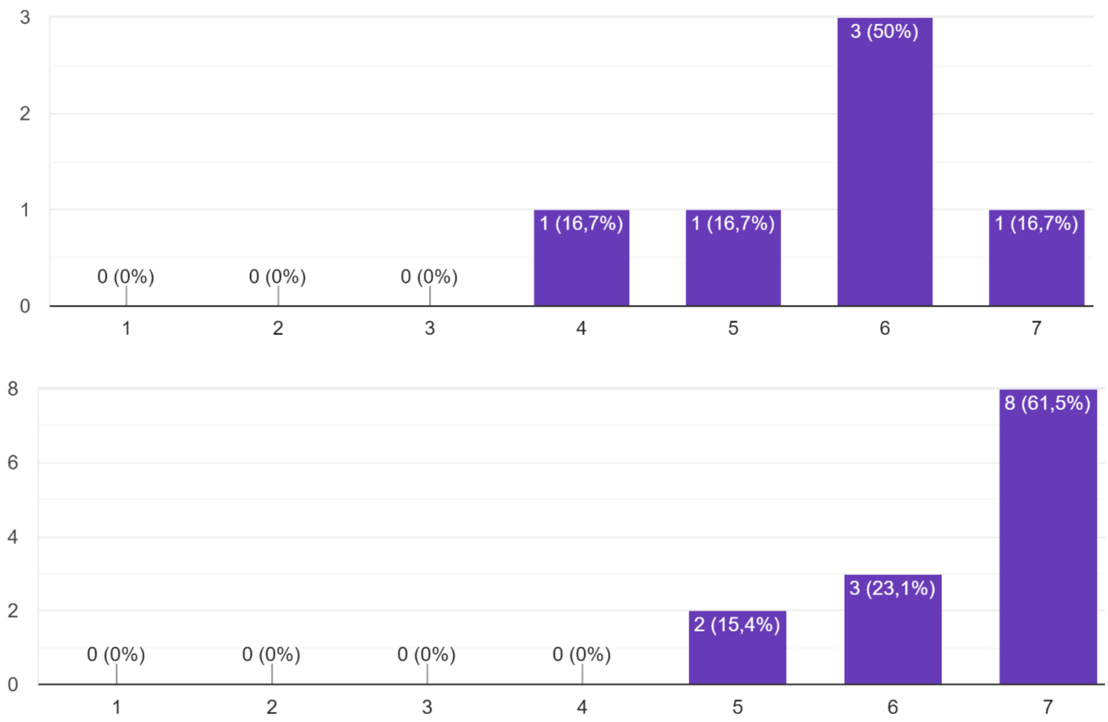

Figure 31 - Answers to the question about the immersion: first study on the top; second study on the bottom.

Finally, regarding the realism of the stimuli, Figure 32 shows an increase of almost two points (previously M=3.17, now M=4.15). Once again, this leads to the conclusion that the changes made in the game from one study to the other were successful and made the game more realistic and immersive.

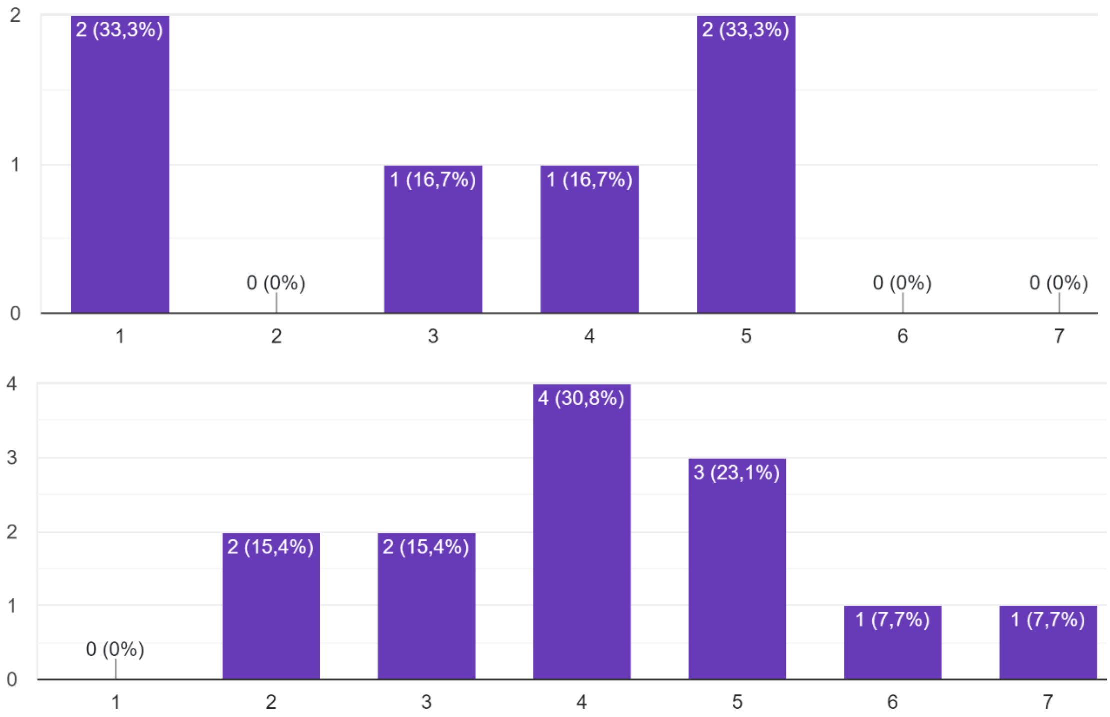

Figure 32 - Answers to the question about the realism of the height stimuli: first study on the top; second study on the bottom.

The remaining questions either stayed at the same score or had their score lowered a little bit (less than half a point) which, again, can be explained by the average participant age being higher.

6.3 Data Analysis

In the study evaluation 13 participants were involved. During the data gathering process for participant 1, the electrodes kept falling, which made it so the data for that participant couldn't be used in the analysis. Therefore, all the analysis performed was done using the data gathered from the remaining 12 participants. It is relevant to mention that participants 2, 4, 8, 12 and 13 said in the survey that they were afraid of heights. It is also relevant to mention that participant 2 did not complete the study due to extreme fear of heights and participants 5 and 13 also did not complete the study due to motion sickness.

In Figure 33 it is possible to see the correspondence of some in-game activities with the HR changes of a user of the system.

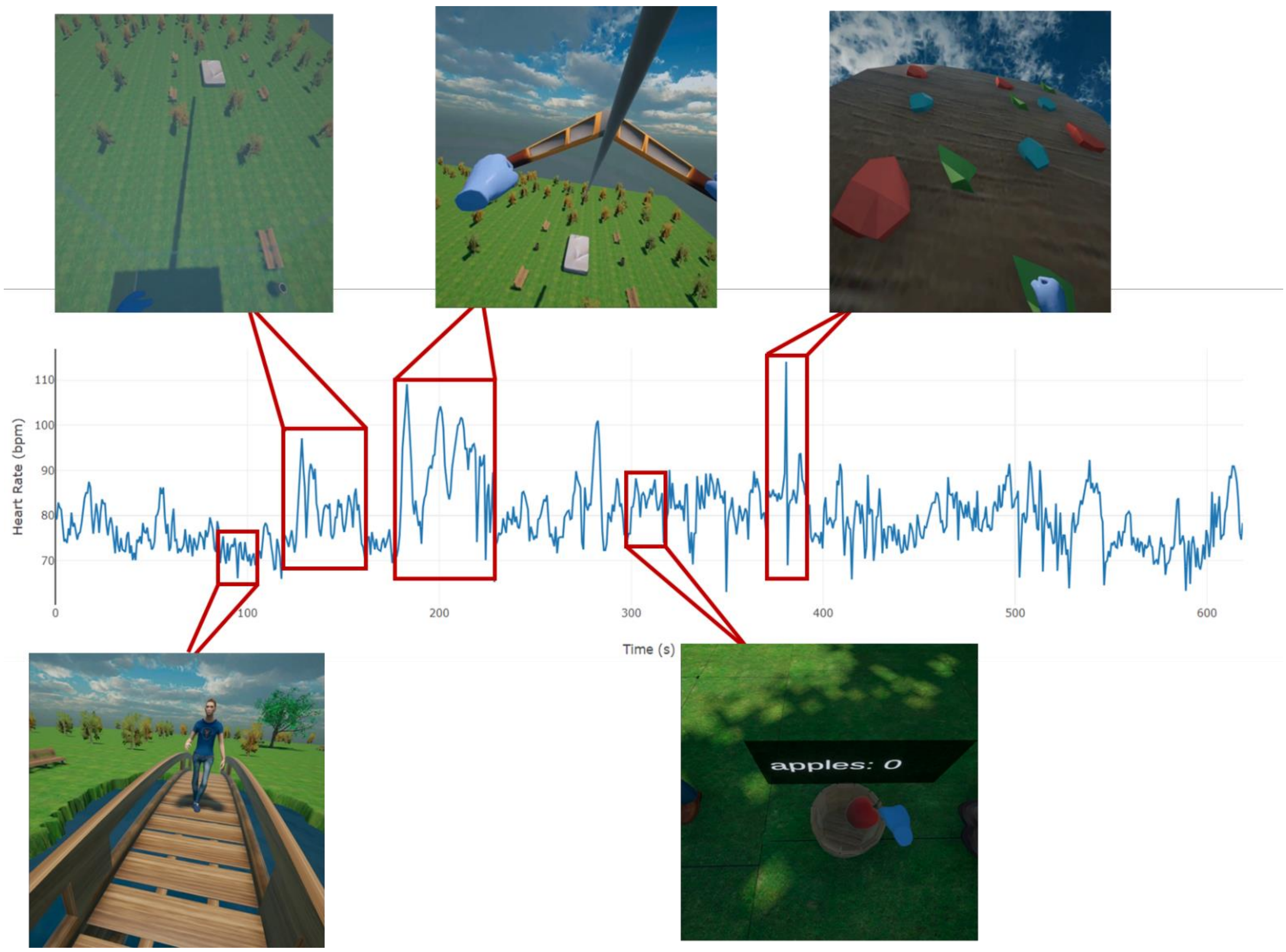

Figure 33 - Matching HR highs and lows to in-game actions.

To evaluate the stimulus effectiveness, we performed several statistical analyses of the HR values collected. But before that, we segmented the HR values by task using the timestamps collected with a stopwatch, like mentioned previously. The logic behind this segmentation is to evaluate the HR variance throughout the tasks of the game. According to the tasks, we ended up with eight segments: the first segment, which we will be calling segment zero, is from the start of the game until right before the bridge section (which is the first stimulus) and the mean of the HR values collected during this segment is used as a baseline. The second segment is from the bridge to the entrance of the elevator, the third segment is the elevator ride to the tower, the fourth segment is being in the tower, the fifth segment is going down the zipline, the sixth segment is climbing the tree, the seventh segment is the climbing wall and the eighth and final segment is freeing the dog.

With that in mind, and with the help of Python, we created a line chart with the mean HR value in each segment for each participant, while only distinguishing between those who were afraid of heights and those who were not (Figure 34).

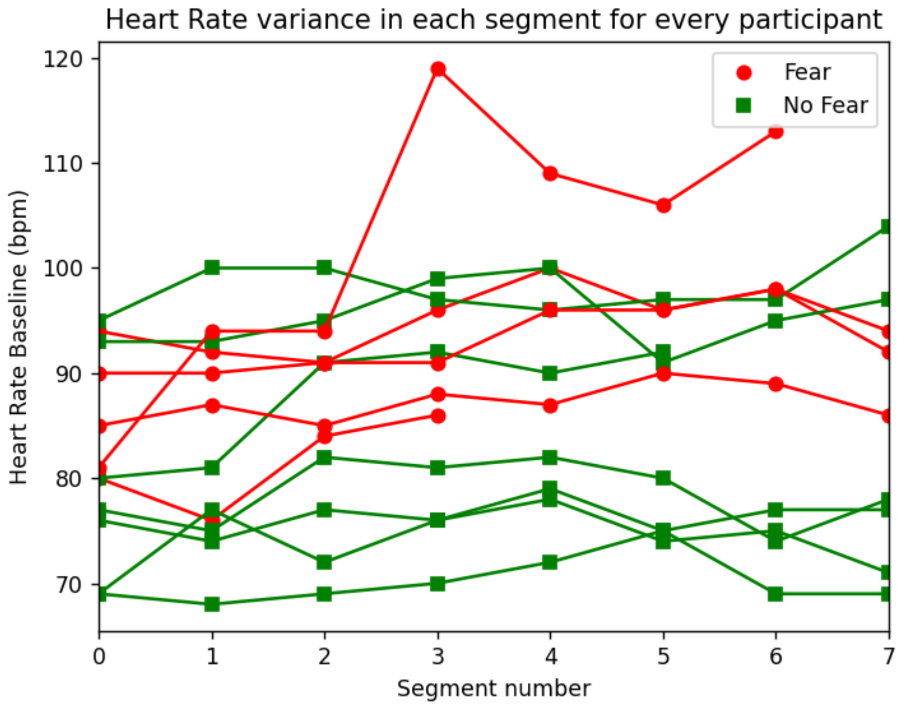

Figure 34 – Comparing the HR evolution for each participant throughout the segments.

By looking at this graphic, we can see that the participants that reported fear of heights are mostly on the top part of the chart, meaning phobic individuals had the highest HRs. Even though this can be a good indicator of the validity of our system, it can also simply mean that those individuals have a higher HR in general and the values aren't at all related to the phobic stimuli. For that reason, we decided to compare the HR values of the phobic and non-phobic participants in a different way.

Figure 35 shows a boxplot of the percentage difference between the baseline and the mean HR value in each segment for the two types of participants. Analyzing this chart, we can see that the median value is similar for both plots, which means that, on average, there is no significant difference in the percentage change in HR between the two groups. However, the interquartile range is a little bit bigger for participants with no fear, meaning that, for this group, the variability of values is greater than in the other group, which makes sense because if an individual is in a "normal" state, the HR may be lower, but the variability is higher, while if an individual fears something, the HR tends to be higher but with a lower variability. The length of the whiskers also attests to this hypothesis, as the interval of values it covers is greater in the group without fear, meaning a higher variability.

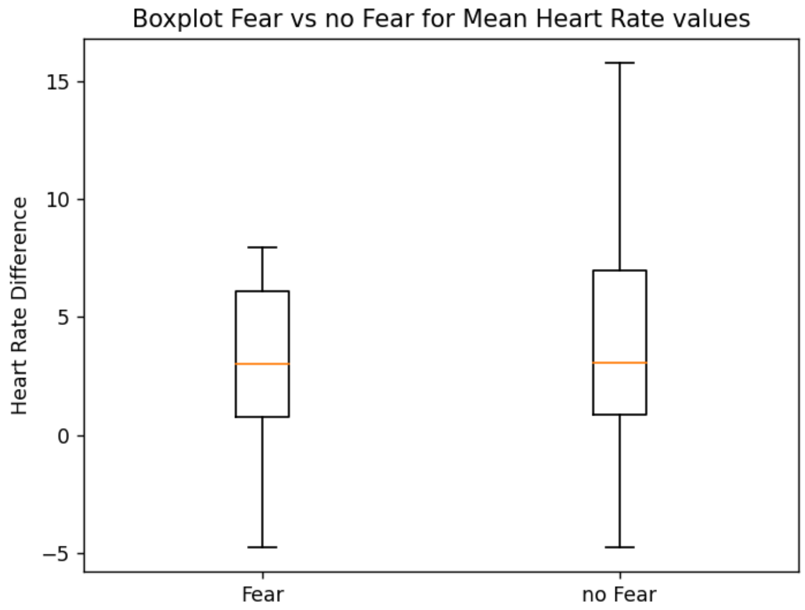

Figure 35 - Percentage difference between the baseline and the mean HR value in each segment.

With that in mind, we performed a similar analysis, but this time we used the percentage difference from the baseline to the maximum HR value in each segment (Figure 36). While the median is higher for the participants in the group with no fear, it can simply mean that the participants in this group have a higher HR naturally. However, both the interquartile range and the whiskers' length show that there is a higher slope between the mean baseline HR and the maximum value observed in the group with fear, which goes to show that the stimuli the participants were exposed to in the virtual world affected them. This is in accordance with our hypothesis and, once again, shows the validity of our solution.

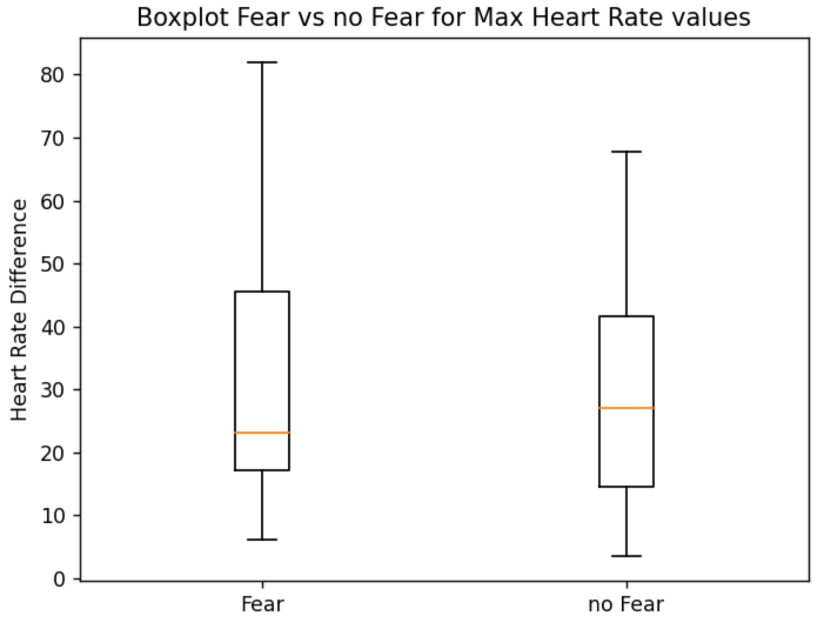

Figure 36 - Percentage difference between the baseline and the maximum HR value in each segment.

One final analysis was performed with the help of a lollipop chart made in Excel (Figure 37). This chart shows the difference in percentage from the baseline to the average value of minimum, mean and maximum HR for each participant. With the data present in this chart, it is possible to perform an individual analysis for each participant.

As mentioned before, participant 2 reported fear of heights. The disproportional increase in the maximum HR attests to that, has the value nearly doubled, which means the participant was in a panic state when those HR values occurred. The mean and minimum values, when compared to the maximum, are neglectable, especially the mean value, as it is very small.

Participant 3 shows a larger difference in the maximum than in the minimum, which might indicate fear. The mean value, which for this participant describes an increase in the average HR of each segment (i.e., an increase in HR throughout the game), might corroborate the fear hypothesis. However, this participant did not finish the game due to motion sickness. With that in mind, the increase in HR can also be attributed to the motion sickness instead of the fear of heights.

The maximum and minimum values for participant 4 are very similar and the mean value is very low, which means there was no significative increase in HR during the experience. Knowing that this participant reported to be afraid of heights, but also that fear of heights is a spectrum, we can conclude that participant 4 is in the lower end of the spectrum.

Like participant 4, participant 5 shows similar maximum and minimum values and the mean value is the lowest out of every participant. In this case, it is safe to conclude that this participant is not afraid of heights.

In the case of participant 6, the minimum value is greater than the maximum value and the mean value is very low, which means that this participant isn't afraid of heights.

Participant 7 shows a maximum value greater than the minimum value and a small mean value. Looking at the answers given in the survey, this participant didn't report fear of heights but reported a certain level of fear during the game, which explains the discrepancy between the values.

Another participant that reported fear of heights was participant 8. As it can be seen, the maximum value is far greater than the minimum value, which suggests that it is not the natural variance of the HR. This data, allied to the observed behavior (screaming), allows us to conclude that the reported fear is most likely true.

Participant 9 fits the same situation as participant 7, the maximum value is greater than the minimum value and no fear of heights was reported. However, there was a certain fear reported during the experience, which explains the values.

For participant 10, who didn't report fear of heights or motion sickness, the difference between minimum and maximum, and the high mean value (being one of the highest) become difficult to explain, as it does not fit any possible scenario. This participant also didn't report any fear during the game, which leads to the conclusion that participant 10 should also be in the lower end of the spectrum.

Following the situation of participant 5, participant 11 as similar and low values in every case, which leads to the conclusion that this participant isn't afraid of heights.

Participant 12, much like participant 4, reported fear of heights but has very similar maximum and minimum values and a low mean value. However, just like participant 4, this participant reported a certain fear during the game, leading to the same conclusion that this participant is in the lower end of the spectrum.

Participant 13 shows very high mean and maximum values, which alone would be enough to say this participant is afraid of heights. However, this participant did not finish the game due to motion sickness. As we've seen before, motion sickness can affect both the mean and maximum values, but not to this extent. Therefore, and considering that this participant reported fear of heights, we can conclude these values are a product of both fear of heights and motion sickness.

It is important to note that, for every participant, the difference between the baseline and the mean HR value is positive, which means that the average HR increased throughout the game and allows us to conclude that the stimuli presented had an effect in every participant. That effect, if not fear, is at least vHI, which the system developed and the data acquired can attest to.

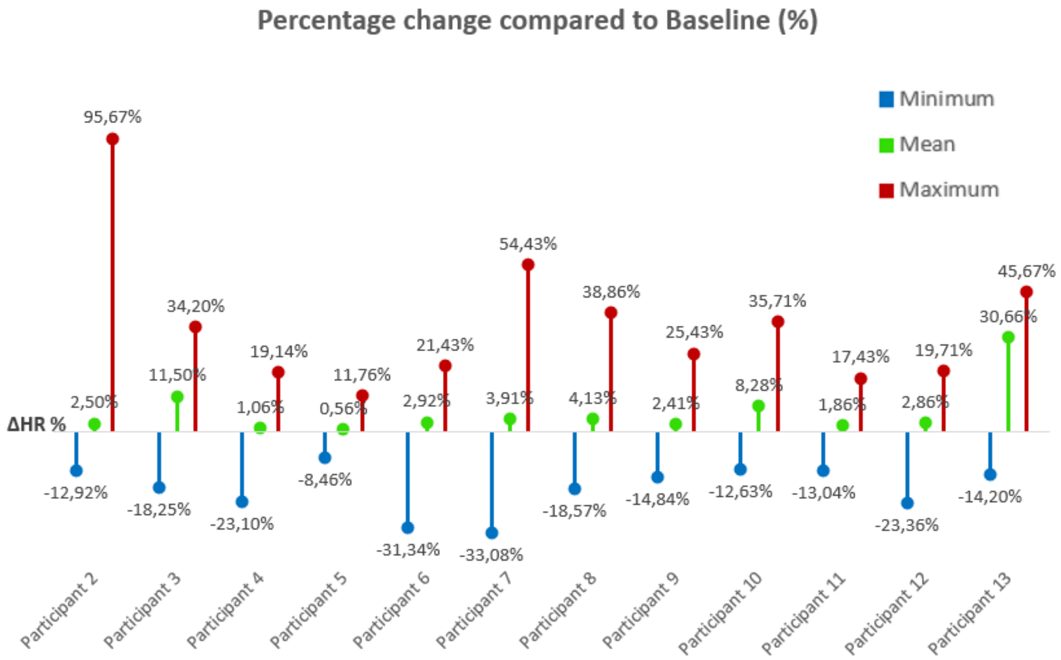

Figure 37 - Minimum, mean and maximum percentage change from baseline for every participant.

6.4 Discussion

Looking back on the goals we set, we were able to achieve all of them. The initial plan was to develop a system that could be used as an alternative and/or complement to traditional ET and that could be used by anyone, anywhere (i.e., outside of a clinical environment). This system would make use of VR to present the phobic stimuli to the user in the form of a game with the goal of masking the therapy process. The system would also need a way to gather, store and analyze physiological data during the process with the intent of evaluating the user's performance and evolution. We achieved all these goals by creating a VR game using Unity that allows users to be in direct contact with height related stimuli. We used the Meta Quest 2 HMD to present the game to the users and a Plux device to acquire the physiological data, along with a Python library to analyze it.

There was one last goal we defined, which was testing the system. To achieve it, we put the system to the test twice. The first time, we tested an early build of the system without data acquisition in a workshop scenario and did a preliminary user study. The second time, we tested the complete system and gathered participants to perform another user study. By looking at the data and feedback collected in both studies, we can clearly see that our solution is viable and accomplishes what we want. First, it is portable and easy to set up, as it only needs a PC, the Meta Quest 2 and the Plux device, and is also affordable compared to traditional therapy costs. Secondly, through the analysis of the answers given in the survey, the participants in the studies agreed that the game is immersive, realistic and has the ability to present real life-like height related stimuli that can trigger anxiety and fearful reactions in phobic individuals that are acrophobic, proving that our solution works.

In addition to the goals defined in the beginning, we did some extra work. After finishing the system, we thought it would make sense to have a way of presenting the physiological data in a more visually pleasant manner, as a set of numbers wouldn't mean much to someone who doesn´t know how to interpret it. With that intent, we created a visualization platform that, after the session is over, reads the physiological data from the respective files and creates graphs with that data, so that the user can look at the progress made throughout the session or sessions. The other piece of extra work was the implementation of biofeedback. For that, we used the HR that we were already calculating for the dashboard and passed it to the game through the communication channel. The game interprets those values and lets the user know if the HR is too accelerated, using the user's own physiological data to provide feedback.

In retrospect, most of the development process went smoothly, although we can point out two main difficulties. The first one was establishing a communication channel between the Meta Quest 2 and the PC. As previously mentioned, we are not sure why the initial attempts did not work, but we managed to come up with a solution after a few weeks of trial and error. Another thing that didn't go as expected was constructing the dashboard in real-time. Despite our attempts, the data throughput was too large for the library we were using to handle, resulting in massive delays. That is the reason why we opted to create the dashboard after the acquisition was over, but we believe that, given more time, it is something we could do.

7. Conclusions

In this dissertation, we present a solution that exposes a participant to height related stimuli in order to desensitize the fear. The system makes use of a VR headset and a biomedical device to immerse the user in a virtual world where it has to complete a game while interacting with height related stimuli. With this, we provide a fully immersive experience to the user while performing physiological monitoring in a non-intrusive fashion. The gamification of the therapy process helps to mask it so that the user isn't self-conscious about it and also incentivizes the user to try something that it normally wouldn't try in real life due to the fear. The game was designed to be open world and have only one level with several height stimuli of varying difficulty so that the user could explore at will. This solution is relevant because many individuals who suffer from phobias don't want to seek treatment given that they don't want to be in contact with the cause of their fear and that is where our solution is valuable. It can be used as a first contact solution (complement) to existing therapy or as a replacement, given the time to develop and fine-tune the system.

The system is flexible in the sense that it can be used in the treatment of any kind of phobia, the only thing needed is to use a different game to present different types of stimuli. It is also easy to set up, affordable, user-friendly and offers a simple way of monitoring. The data acquisition synchronization mechanism is a plus because it starts and stops the acquisition when the game starts and finishes, respectively, which saves a lot of time because no manual synchronization is needed.

The system was put to the test in a public event at the Aveiro University ("Immerse yourself in a fight against your fears: Using VR and physiology assessment for Phobia Treatment" workshop) and later in a user study with 13 participants. The results gathered show that the system is capable of generating convincing stimuli, making it a viable tool in the treatment of specific phobias, and that it was well accepted by the participants.

7.1 Future Work

Looking back on what we developed, there are some clear improvements that can be done. One of those improvements, which we consider to be essential, is adding a way to know in which part of the game the peaks in HR and ECG data happen. Although our solution for this works, it is clearly not the most efficient. A better and more automatic solution could be, as the data acquisition starts, also start a recording of the gameplay in the headset. That way, the acquisition and recording times would be synchronized and a simple analysis of the video in the time indicated by the peaks would be enough to tell if they were caused by a height stimulus. Another possible solution to this problem would be to make use of the communication channel to send periodic updates to the server like, for example, the player's position. This would allow to tell where the player is on the map and estimate if the peak is height related. The second solution would be less computationally heavy but would be less precise, as a small desynchronization between the clocks of both devices would lead to errors in pinpointing where the player is at a certain time.

Another improvement that could be done is changing the visualization tool to work in real-time. Even though our initial intention was to have it showing the data as it was acquired, for hardware reasons, it proved to be impossible. That being said, a dashboard showing data in real-time would be an asset for both the phobic individual and the therapist. And it ties in perfectly with the previous improvement, as both the position of the player and a live feed from what was happening in the game could be shown in the live dashboard.

Improving on the versatility of our solution, we could modify the game to be divided into several levels, each one with a different intensity for the height stimuli. That way, the phobic individual could skip to a certain level depending on the progress made previously and would not have to repeat the same level multiple times. Even more than that, the game could be expanded upon in such a way that allowed for the treatment of multiple phobias, not just one. The addition of other phobic stimuli (spiders, for example), allowing both stimuli to be provided individually or at the same time, would enhance the flexibility of the system even further. Also, the inclusion of gamification elements, such as rewards, achievements and leaderboards could help increase engagement and motivation.

Taking into consideration the valuable physiological data acquired, another clear improvement to the system would be the addition of different sensors to collect more data. One interesting sensor to add would be the EDA sensor, as it can be used to better interpret the stress levels of the user and, together with the ECG data, provides insight on how the user reacts to the phobic stimuli.

One final improvement would be the addition of type of users and user specific functionalities. Depending on if the user is a phobic individual or a therapist, the system could allow different actions. For example, for the phobic individual playing the game, the system would let the user simply play the game. On the other hand, the therapist would be able to adjust the difficulty manually or even provide remote assistance, allowing for the system to be used in a more familiar environment, such as the user’s home, and enabling the collection of data in a more ecological way, as no travelling is needed.

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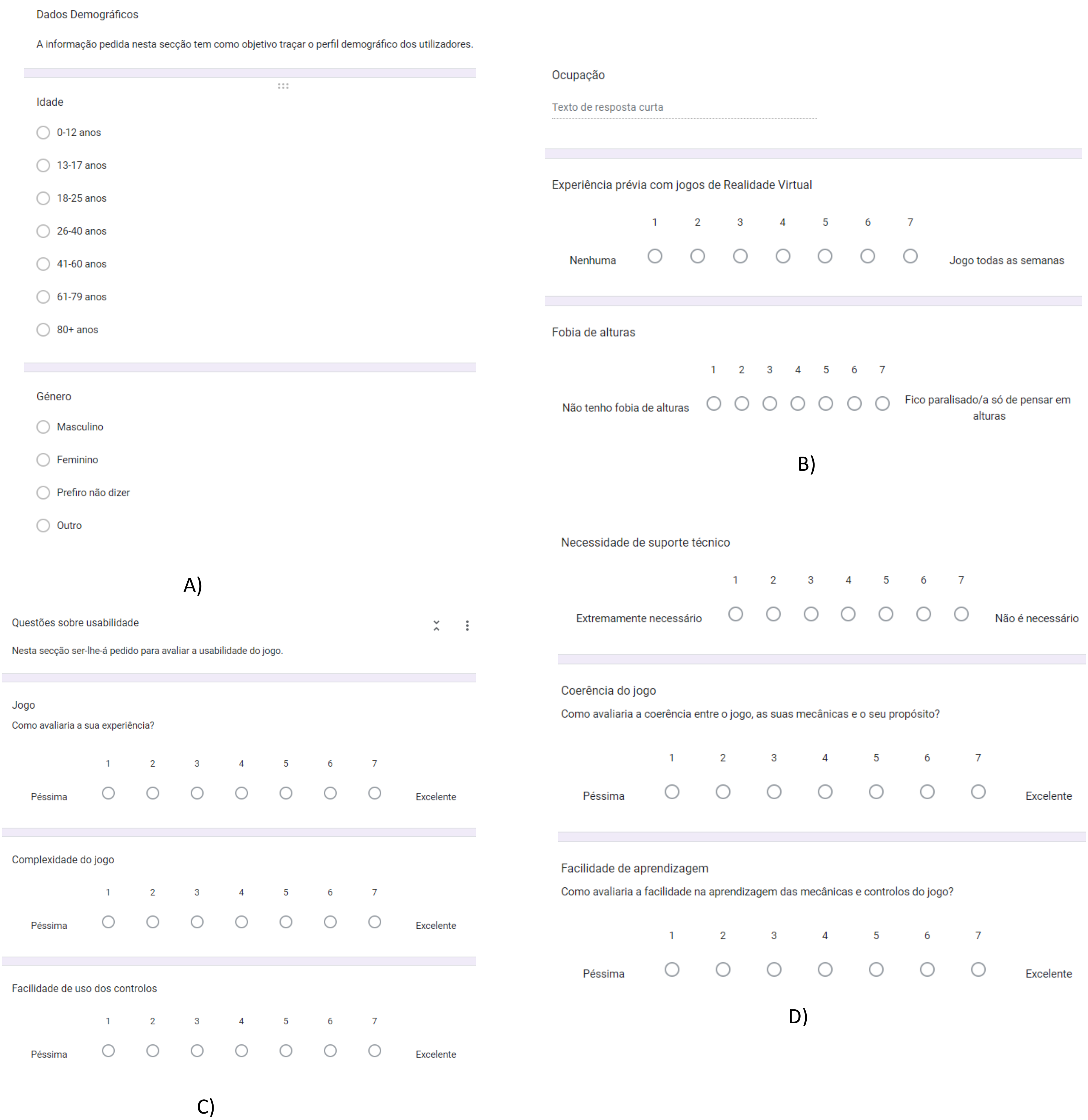
9. Annex

9.1 System Usability Scale Test

The questions composing the SUS Test used in the user studies can be found below.



Dados Demográficos

A informação pedida nesta secção tem como objetivo traçar o perfil demográfico dos utilizadores.

Idade

- 0-12 anos
- 13-17 anos
- 18-25 anos
- 26-40 anos
- 41-60 anos
- 61-79 anos
- 80+ anos

Género

- Masculino
- Feminino
- Prefiro não dizer
- Outro

A)

Ocupação

Texto de resposta curta

Experiência prévia com jogos de Realidade Virtual

	1	2	3	4	5	6	7	
Nenhuma	○	○	○	○	○	○	○	Jogo todas as semanas

Fobia de alturas

	1	2	3	4	5	6	7	
Não tenho fobia de alturas	○	○	○	○	○	○	○	Fico paralisado/a só de pensar em alturas

B)

Questões sobre usabilidade

Nesta secção ser-lhe-á pedido para avaliar a usabilidade do jogo.

Jogo

Como avaliaria a sua experiência?

	1	2	3	4	5	6	7	
Péssima	○	○	○	○	○	○	○	Excelente

Complexidade do jogo

	1	2	3	4	5	6	7	
Péssima	○	○	○	○	○	○	○	Excelente

Facilidade de uso dos controlos

	1	2	3	4	5	6	7	
Péssima	○	○	○	○	○	○	○	Excelente

C)

Necessidade de suporte técnico

	1	2	3	4	5	6	7	
Extremamente necessário	○	○	○	○	○	○	○	Não é necessário

Coerência do jogo

Como avaliaria a coerência entre o jogo, as suas mecânicas e o seu propósito?

	1	2	3	4	5	6	7	
Péssima	○	○	○	○	○	○	○	Excelente

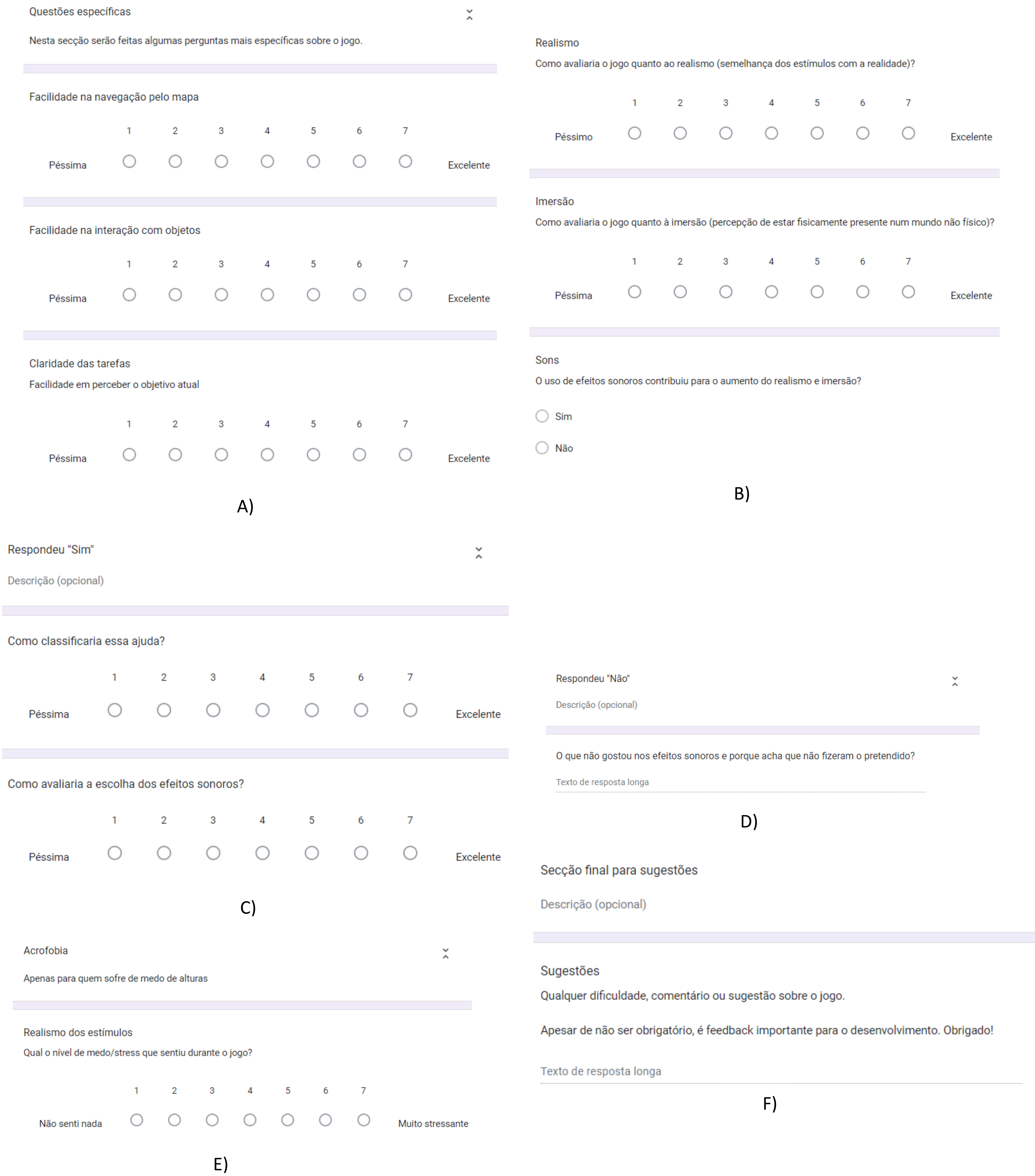
Facilidade de aprendizagem

Como avaliaria a facilidade na aprendizagem das mecânicas e controlos do jogo?

	1	2	3	4	5	6	7	
Péssima	○	○	○	○	○	○	○	Excelente

D)

Figure 38 – First part of the questions in the SUS Test



Questões específicas

Nesta secção serão feitas algumas perguntas mais específicas sobre o jogo.

Facilidade na navegação pelo mapa

Péssima 1 2 3 4 5 6 7 Excelente

Facilidade na interação com objetos

Péssima 1 2 3 4 5 6 7 Excelente

Claridade das tarefas

Facilidade em perceber o objetivo atual

Péssima 1 2 3 4 5 6 7 Excelente

A)

Realismo

Como avaliaria o jogo quanto ao realismo (semelhança dos estímulos com a realidade)?

Péssimo 1 2 3 4 5 6 7 Excelente

Imersão

Como avaliaria o jogo quanto à imersão (percepção de estar fisicamente presente num mundo não físico)?

Péssima 1 2 3 4 5 6 7 Excelente

Sons

O uso de efeitos sonoros contribuiu para o aumento do realismo e imersão?

Sim

Não

B)

Respondeu "Sim"

Descrição (opcional)

Como classificaria essa ajuda?

Péssima 1 2 3 4 5 6 7 Excelente

Como avaliaria a escolha dos efeitos sonoros?

Péssima 1 2 3 4 5 6 7 Excelente

C)

Respondeu "Não"

Descrição (opcional)

O que não gostou nos efeitos sonoros e porque acha que não fizeram o pretendido?

Texto de resposta longa

D)

Acrofobia

Apenas para quem sofre de medo de alturas

Realismo dos estímulos

Qual o nível de medo/stress que sentiu durante o jogo?

Não senti nada 1 2 3 4 5 6 7 Muito stressante

E)

Secção final para sugestões

Descrição (opcional)

Sugestões

Qualquer dificuldade, comentário ou sugestão sobre o jogo.

Apesar de não ser obrigatório, é feedback importante para o desenvolvimento. Obrigado!

Texto de resposta longa

F)

Figure 39 – Second part of the questions in the SUS Test