



**Diana Rafaela  
Gomes Silva**

**Andando pela Estrada da Memória: Uma abordagem  
de Realidade Virtual para suporte ao estudo do  
Ajuste Mnemónico para a Contaminação**

**Walking Down Memory Lane: A Virtual Reality  
Approach to Support the Study of the Mnemonic  
Tuning for Contamination**





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## Palavras Chave

Realidade Virtual, Videos 360º, Sistema Imunológico Comportamental, Memória, Psicologia Experimental

## Resumo

Biologicamente, os seres humanos evoluíram para se adaptarem contra os agentes patogénicos, mas, uma vez que combatê-los pode ter implicações negativas no corpo, um conjunto de mecanismos evoluiu para evitar a contaminação, chamado Sistema Imunológico Comportamental (BIS). Para melhor compreender o BIS, a Psicologia Experimental estuda o seu impacto através da realização de experiências em que um participante é exposto a vários objetos, alguns dos quais são apresentados como tendo estado em contacto com uma fonte de contaminação (por exemplo, uma pessoa doente). Para garantir a segurança dos participantes, estas experiências normalmente contam com fotografias dos objetos e indivíduos e em histórias de fundo que estabelecem a ligação entre ambos, o que requer algum esforço de imaginação, do participante, e afeta o realismo da experiência. Para mover a pesquisa sobre o BIS e a memória para um cenário potencialmente mais válido ecologicamente, o trabalho atual propõe uma abordagem baseada em Realidade Virtual (VR) onde vídeos de 360º são usados como estímulos, durante as experiências. Para tal, foi concebido um conjunto de ferramentas para apoiar a criação e catalogação de vídeos, e para configurar e controlar a sua apresentação ao participante, no ambiente virtual. Numa fase inicial, uma versão parcial da plataforma serviu de base a um estudo piloto com o objetivo de avaliar a adequação global da proposta e validar os parâmetros de aquisição para os estímulos. Os resultados positivos deste estudo informaram o desenvolvimento do sistema completo de suporte a experiências e, na sua fase atual, uma avaliação com dez utilizadores mostrou um bom nível de usabilidade. Tendo em conta que o sistema proposto já apoia a implementação do protocolo experimental concebido, estabelece um terreno promissor para uma maior evolução da investigação do ajuste mnemónico para a contaminação.



**Keywords**

Virtual Reality, 360° Videos, Behavioral Immune System, Memory, Experimental Psychology

**Abstract**

Biologically, humans have evolved to adapt against pathogens but, since fighting them can have negative implication to the body, a set of mechanisms have evolved towards avoiding contamination, called the Behavioral Immune System (BIS). To better understand the BIS, Experimental Psychology studies its impact by conducting experiments where a participant is exposed to several objects some of which are presented as having been in contact with a source of contamination (e.g., a sick person). To ensure the safety of the participants, these experiments typically rely on photographs of the objects and individuals and on background stories establishing the connection between both, which requires some imagination effort, from the participant, and affects the realism of the experiment. To move the research on BIS and memory into a potentially more ecologically-valid setting, the current work proposes a Virtual Reality (VR) based approach where 360° videos are used as stimuli, during the experiments. To this end, a set of tools were devised to support creating and cataloging videos, and to configure and control their presentation to the participant, in the virtual environment. At an early stage, a partial version of the platform served as grounds for a pilot study aiming to assess the overall adequateness of the proposal and validate acquisition parameters for the stimuli. The positive outcomes of this study informed the development of the complete Experiment Support System and, at its current stage, results from an evaluation with ten users show a good level of usability. Considering that the proposed system already supports the implementation of the designed experimental protocol, it establishes a promising ground for further evolving the research regarding the Mnemonic Tuning for Contamination.



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# Acronyms

<b>BIS</b>	Behavioral Immune System	<b>MRI</b>	Magnetic Resonance Imaging
<b>CAVE</b>	Cave Automatic Virtual Environment	<b>SUS</b>	System Usability Scale
<b>CSS</b>	Cascading Style Sheets	<b>VE</b>	Virtual Enviroment
<b>CE</b>	Contamination Effect	<b>VET</b>	Virtual Enviroment Technology
<b>HCI</b>	Human-Computer Interaction	<b>VR</b>	Virtual Reality
<b>HMD</b>	Head Mounted Display	<b>VRET</b>	Virtual Reality Exposure Therapy
<b>HTML</b>	HyperText Markup Language	<b>UCD</b>	User-Centred Design
<b>MTC</b>	Mnemonic Tuning for Contamination	<b>UI</b>	User-Interface



# Introduction

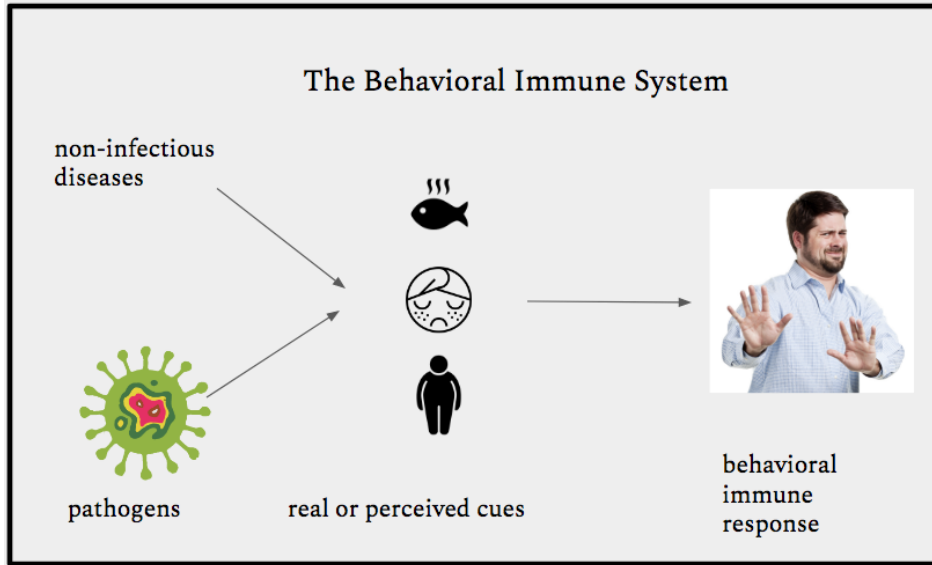
In this chapter, an introduction to the subject of this dissertation is given. In this regard, the motivation that led to this project will be presented, as well as the challenges and objectives that guided the development of this work. Lastly, a brief explanation of the structure of the document is enlightened.

## 1.1 MOTIVATION

Since the beginning of time, humans and their ancestors have adapted for and against various problems, both physically and mentally. One of these recurring problems is the threat posed by pathogens. To respond to these threats, humans have developed a series of biological responses aimed at eliminating these pathogens that invade the body, which is called the Biological Immune System[1].

Some authors have defended that natural selection has also favored the development of the Behavioral Immune System (BIS), which consists of a set of psychological mechanisms that contribute to the detection and prevention of potential infectious pathogens in a given environment. More recently, Fernandes and collaborators proposed that memory is also a key component of the BIS [2]. In their studies, they found a mnemonic advantage for contamination, i.e., an enhanced retention for potential contaminated objects (e.g., touched by sick people) compared to non-contaminated objects (e.g., touched by healthy people)- the Contamination Effect (CE). This effect has been replicated in various laboratories [3].

Such studies rely on the participants imagination, i.e., visual or verbal stimuli are presented accompanied by descriptive scenarios participants were asked to imagine. Considerable efforts have already been made to increase the ecological validity of such procedures (e.g., [4]), but much can still be improved[5].



**Figure 1.1:** The Behavioral Immune System protects us from contamination by eliciting behaviors to prevent contact with potentially contaminated sources<sup>1</sup>.

## 1.2 CHALLENGES

Images or words have long been used as stimuli in memory research. Although the presentation of such stimuli on a computer screen is generally believed to be a reliable method for exploring memory, it is more and more highlighted the need to develop experimental procedures that closely resemble real-life environments.

As Peeters (2018) [6] noted, "the use of more ecologically valid stimuli significantly increases the odds of experimental findings being generalizable to everyday situations" (p. 1048). Pandemic situations, such as the COVID-19 outbreak, illustrate the importance of scientific knowledge in this area. Therefore, Fernandes and collaborators [2] sought to replicate and extend initial findings on the CE by increasing the ecological validity of their experiments.

Considerable efforts have already been made to increase the ecological validity of experimental procedures (e.g., [4]). Such studies typically rely on participants' imagination (i.e., visual or verbal stimuli are presented along with descriptive scenarios that participants are asked to imagine), but much can still be improved to reduce the amount of the procedure relying on participants' imagination. One of the challenges in increasing ecological validity is to increase the sense of presence and immersion in situations of potential contamination while maintaining control over how the stimuli are presented (which in this case precludes repetition by a human actor).

Fernandes et al. have taken some steps to achieve this goal (such as [5]). However, VR might be a better option to enhance the sense of presence and immersion in situations of potential contamination while providing experimental control and, in theory, the results and impact of using VR are expected to be more pronounced compared to those normally achieved

<sup>1</sup>[https://upload.wikimedia.org/wikipedia/commons/f/f0/Quick\\_simple\\_diagram\\_of\\_the\\_behavioral\\_immune\\_system.png](https://upload.wikimedia.org/wikipedia/commons/f/f0/Quick_simple_diagram_of_the_behavioral_immune_system.png), [last accessed: 28/10/2022]

with traditional procedures.

Nowadays VR has great popularity in various fields of Psychology, especially in applied areas such as the treatment of phobias, rehabilitation and others. However, its use for research purposes has been considerably less common for several reasons: first, raises the question of whether the extra effort will be necessary to achieve the same results; second, its use brings some mishaps, such as simulation sickness. These limitations have been overcome by adopting less costly and resource-demanding strategies (e.g. 360-degree videos).

Nevertheless, the value of VR in Experimental Psychology is unquestionable. VR not only increases studies' ecological validity and experiment control [7], [8], but also provides rich multisensory simulations, allows an active exploration of the environment, enables the collection of multiple data related to participant behavior, and increases the replicability and reproducibility of procedures [9]. This can be accomplished due to a verisimilitude between virtual environments and the real world [10], meaning that, in virtual environments, subsequent perceptual changes are treated by the human mind in an identical way as those of the equivalent real environment [11]. Therefore, it was deemed a suitable option to test for BIS research.

### 1.3 OBJECTIVES

Considering the potential of VR to improve Experimental ecology, this work aims to propose novel tools and methods to enable considering a VR-based approach to Experimental Research on Mnemonic Tuning for Contamination (MTC). To this end, the work carried out should entail:

- Acquire knowledge regarding the research methods used so far in the field of memory and contamination in Psychology.
- Review the methods and understand the applicability of using VR in Experimental Psychology alongside the use of VR.
- Work closely with experimental psychologists to establish the requirements of a novel experimental approach to research on the MTC towards improved ecology.
- Develop and validate a novel set of tools and methods to support VR-based Experimental Psychology studies on MTC.

### 1.4 PUBLICATIONS

The work described in this document was also been partially published in an international conference:

- Diana Silva, Samuel Silva, Lisandra Fernandes, Sónia Santos, Beatriz Pedro, Bernardo Marques, Beatriz Sousa Santos, Josefa Pandeirada. "*Supporting Research in Memory and Contamination through a Virtual Reality Approach*". ICGI 2022 - International Conference on Graphics and Interaction.

## 1.5 DOCUMENT STRUCTURE

This document is structured in 6 chapters organized as follows:

**Chapter 2** presents some background and related work about the MTC and VR, previous work of the research team conducting the experiments about the MTC, the use of VR in Psychology and ,using a user-centred design approach, the various tools and frameworks needed to develop a VR system for Experimental Psychology.

**Chapter 3** shows the method used to describe potential users, identify their needs and expectations, along with scenarios to retrieve the requirements of this project.

**Chapter 4** presents the initial developments, like prototyping, defining the tools and frameworks that will be used and an overall architecture, as well as a first concept validation (being able to reproduce stimuli on Virtual Enviroment (VE)), that include a pilot study and its results.

**Chapter 5** presents the development of the systems proof of concept and usability testing.

**Chapter 6** presents a conclusion of the dissertation and some ideas for future work are proposed to optimize and improve the system.

# Background and Related Work

The Mnemonic Tuning for Contamination is an important study to analyse how people react to different situations in real life. For this reason, and for a better understanding, an overview of the research will be given in this chapter to get familiar with the concept and the current way of conducting these type of experiments. The goal of the MTC research team is to have a more ecologically-valid way of conducting experiments, and, to this end, VR seems to be a strong option to explore. Considering these facts, one can also find in this chapter a background research on Virtual Reality and its use in Psychology, and in order to assess the requirements and objectives, a human-centred design approach was used, as it also provides different forms and ways to do so.

## 2.1 MNEMONIC TUNING FOR CONTAMINATION

### 2.1.1 Behavioral Immune System

Since ancient times, humans have faced various threats to their survival and reproduction, which include contact with pathogens. To deal with these threats, natural selection has created a set of different strategies, being one of the best known the Biological Immune System, which is a set of biological responses that detect and eliminate invasive pathogens in the body[12][13].

The Biological Immune System is not a perfect tool, although it brings benefits, these can come with a high cost by preparing and executing an immune response (e.g., consume resources that could be used in other psychological systems [14]), and pathogens can evolve faster than our immune system, both of these issues favored the development of The Behavioral Immune System (BIS) [1]. The BIS consists of a set of psychological mechanisms that detect signs of the presence of infectious pathogens in the environment (e.g., vomit, rats, spoiled food). When such signs are perceived, the BIS triggers a series of emotional (e.g., disgust), cognitive (e.g., attention and memory), and behavioral (e.g., avoidance) responses, aimed at preventing acquisition and transmission of infection ([15]; [1]).

To avoid possible errors, BIS has evolved to be sensitive to stimuli that are identical on the surface to the actual symptoms of infectious agents. Since this system responds to superficial

signals, it can lead to aversive responses to things or people that do not present a real threat (e.g., chocolate fudge sculpted into the shape of dog feces; [16]), making it more susceptible to false-positive errors.

### 2.1.2 Emotion

Emotional experiences play an important role in the psychology of self-defense [17]. They are triggered by different signs that indicate danger, and facilitates the engagement in functionally specific adaptive responses [1]. For example, fear motivates escape or fighting behaviors, whereas disgust motivates withdrawal and avoidance behaviors [17].

Disgust is one of the key components of the BIS, as it is posited to serve a disease-avoidance function [18]. Sensory cues known to accommodate pathogens are particularly likely to elicit the emotional experience of disgust [19][20]. Accordingly, researchers suggest that there is a direct relationship between disgust triggers and forms of contagion from pathogens [19] [18] [21].

The emotion of disgust can be triggered by many different stimuli, including bodily excretions (feces, vomit, semen), possibly contaminated animals (e.g., ticks, flies, rats), food (e.g., tainted, contaminated, unknown), injuries to the body (blood, deformities), death, and visible signs that indicate possible infections [18] [22]. It can also be induced by to behaviors of other living beings that violate expectations considered normal in the functional domains associated with disease transmission (e.g., food preparation, personal hygiene, sexual interaction, etc.) .

Objects that are considered disgusting constantly convey the possibility of contamination because they are directly associated with infectious sources. Interestingly, people treat neutral objects that have been in contact with disgusting objects or people in a peculiar way, as if certain contaminating properties of these objects could be transmitted through contact [23]. This spread of contamination is referred to as the "law of contagion", which supports the idea that "once in contact, always in contact" [24] [25].

Morales and Fitzsimons (2007)[26] recently addressed the law of contagion by conducting an experiment in which they presented neutral objects (e.g., cookies) in contact with objects considered disgusting (e.g., tampons, pads). Results, demonstrated participants' aversion to these neutral objects (i.e., they evaluated more negatively and are unlikely to interact with neutral objects that have come in contact with disgusting objects). Other interesting examples, people were hesitant to drink if a sterilized dead cockroach was briefly dipped in the drink [16], to eat food that had been tasted by either unsavory or disliked persons [27]. This type of response results from the fact that animals/humans who avoid potentially contaminated objects are more likely to survive and reproduce.

Disgust does not only occur when there is a real risk of infection by pathogens. This emotion is also evoked by objects or persons that superficially resemble real risks without actually posing a risk (e.g., chocolate fudge resembling feces)[16]. Disgust can be specially triggered when the body's immune defenses are temporarily suppressed (e.g., if a person has been recently ill)[28].

But what about neutral objects that have come in contact with disgusting stimuli (i.e.,

potential sources of contamination)? Would the law of contagion also leave its footprints in people’s memory?

### **2.1.3 Memory**

Memory, like emotion, has evolved to respond to adaptive problems related to survival and reproduction [2]. Being able to process and remember survival-relevant information would have utmost adaptive value. For example, researchers have shown that people retain animate items (e.g., baby) particularly better than inanimate objects (e.g., doll), which are more important and relevant to people’s survival and reproduction [29].

Health-relevant information should also be remembered well because of their relevance to fitness. Accordingly, disgusting stimuli (i.e., words, images and behaviors that are perceived as disgusting) have been shown to be more easily remembered than those that arouse other emotions [30][31][32]. For example, Chapman et al. (2013)[33] found in their study that repulsive stimuli (e.g., bodily excretions, diseases, deformities) are more strongly remembered compared to fearful stimuli (e.g., threats, catastrophes) and neutral stimuli (e.g., everyday objects).

## **2.2 CURRENT RESEARCH IN THE MNEMONIC TUNING FOR CONTAMINATION**

Previous studies that have compared memory performance between repulsive and non-repulsive objects have typically compared different stimuli (e.g., [33] [31]), which introduces other uncontrolled features of the objects themselves that may be relevant to memory[34]. To avoid object selection concerns, and inspired by the law of contagion, Fernandes and collaborators have developed a procedure in which everyone remembers exactly the same neutral items, but their fitness-relevance was manipulated between conditions(see also [32]).

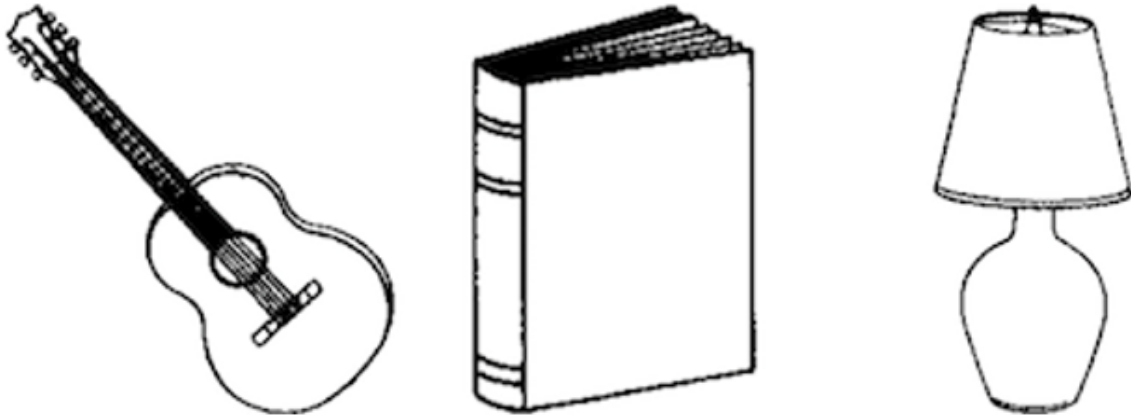
Several studies have been conducted, showing that memory for potential sources of contamination does not depend solely on the visual cues, but also on the context that is presented along with the object (i.e., whether establishes a real possibility of contamination) [2].

Different stimuli have been used in the above mentioned studies: line drawings and photographs.

### **2.2.1 Line Drawing**

Fernandes and collaborators started to explore the CE by using black-and-white line drawings of objects (see Figure 2.1 for examples) presented along with possible signs of contamination. These included verbal stimuli (i.e., short descriptors, see Table 2.1) or, visual stimuli (i.e., photographs of faces, see Figure 2.2), that indicated whether the object had come into contact with a sick or a healthy person. During encoding, participants had to distinguish whether the presented object had been touched by a sick or a healthy person. At the end, a surprise memory task for the objects was presented, in which it was found that participants remembered more objects that were associated with signs of illness than when they were associated with signs of health, i.e., participants remembered more potentially contaminated objects.

Notwithstanding, the contribution of the initial studies conducted by Fernandes et al. (2017) [2] and those that followed (e.g., Bonin et al., 2019)[35] the stimuli that were used (i.e., line-drawing of objects) lacks ecological validity.



**Figure 2.1:** Examples of object stimuli used in Fernandes et al. (2017), selected from the Snodgrass and Vanderwart (1980) picture set[36].



**Figure 2.2:** Examples of visual stimuli used in Fernandes et al. (2017).

Sick	Healthy
person with a high fever	person with a round face
person with a sore throat	person with a straight nose
person with a runny nose	person with brown hair
person with a rash on the skin	person with green eyes
person with a constant cough	person with long fingers

**Table 2.1:** Examples of verbal stimuli used in Fernandes et al. (2017).

### 2.2.2 Photographs

As highlighted by Brodeur et al. (2014) [37], using photographs “increases the chances of activating the same neuronal circuits that are activated in daily tasks” (p.2). Therefore, in order to increase ecological validity, the experiment of Fernandes et al. (2017) [2] above described was replicated, using photographs of objects associated with possible signs of contamination descriptions or faces. Again, participants remembered objects associated with sources of contamination significantly better than control objects. In previous experiments, participants had to rely on their imagination to imagine contact between objects and signs of contamination (descriptions or faces), due to the fact that both objects and signs of contamination were displayed side by side without visible contact.

For this reason, another experiment was conducted, in which objects were presented in direct contact with potential sources of contamination (i.e., dirty or clean hands; see Figure 2.3). For some participants, the hands holding an object (e.g., a bowl) were clean, but for others, the hands were wrapped in a substance that served as a potential source of contamination (i.e., each participant saw each stimulus in only one of the conditions). This substance was described as vomit. Again, results confirmed that objects that came into contact with potential sources of contamination were more easily remembered.

Also to serve as potential source of contamination, it was used a different type of contaminating substance, diarrhea, which carries a high risk of infection. Chocolate and peanut butter were used to mimic this substance. One of the aims of this experiment was to test whether the attribution of fitness-relevance is necessary to obtain the CE. For this purpose, participants were divided into two groups: in one group the substance covering the hands was described as diarrhea, while in the other group it was described as chocolate. Participants were shown the same images with the same objects, only the context was changed. As expected, participants remembered significantly more objects contaminated by contact with the source of contamination (hands soiled with diarrhea).

As denoted, considerable efforts have already been made to increase the ecological validity of such procedures but much can still be improved. As mentioned before, by using VR, we can increase the sense of presence and immersion in situations of potential contamination while ensuring experimental control and at the same time not exposing participants into any danger. Thus, the aim of the current work is to develop and validate a potentially more ecologically-valid setting to further explore the mnemonic tuning for contamination. Dynamic environment technologies such as VR may provide an interesting route to take a step further



**Figure 2.3:** Examples of stimuli used in the different experiments. (A) Used in Experiments 1a and 1b associated with cues (both in the item presentation and the immediate memory phase), and in Experiments 2 and 3 as belonging to healthy people (presentation phase); (B) Used in Experiment 2 as the contaminated items (presentation phase); (C) Used in Experiment 3 during the presentation phase: described as covered with chocolate spread (non-disease context) or as covered with diarrhea (disease context); (D) Used in the immediate memory test of Experiments 2 and 3. [Retrieved from [5]]

in this area of research (cf., benefits of VR in Section 1.2).

### 2.3 VIRTUAL REALITY

Several definitions of Virtual Reality can be found in the literature. For example, a more technically clear definition of VR is:

*Virtual Reality is a scientific and technical domain that uses computer science and behavioral interfaces to simulate in a virtual world the behavior of 3D entities, which interact in real time with each other and with one or more users in pseudo-natural immersion via sensorimotor channels.*

—Fuchs et al. (2011), *Virtual reality: concepts and technologies*. [38]

In other words, VR is a technology that can be seen as the result of the evolution of existing communication interfaces for different levels of immersion [39], because the difference between the different media and VR is the transmission of the feeling of presence, i.e., the "feeling of being there" [40], as virtual environments are able to invoke the same cognitive modules as their equivalents in real experimental environments [41]. According to Jason Jerald [42], VR is defined as a computer-generated environment that can be experienced and interacted with as if it were real, stating that an ideal VR system allows users to physically walk around in the environment and touch objects as if they were real. There are different terms to define the world of Virtual Reality, namely Virtual Environment Technology (VET) or Virtual Environment (VE). Taking into account the various and different definitions of Virtual Reality, we can conclude that there are some common characteristics between them, summarized in digital computer-generated environments, interaction, and immersion [43].

Virtual Reality is not exactly a new element in the technological world. It emerged in the 1950s and was used primarily by the military as simulators, as it was an expensive and bulky technology at the time. Virtual Reality may be traced back to the vision of Ivan Sutherland about the "ultimate display" [44], making him a huge booster of this virtual world, but he was not the first to attempt it. Morton Heilig developed a multisensory simulator that included color videos, sounds, smells, wind, and vibrations, this being the first approach to creating a non-interactive virtual reality system, which they called Sensorama [45], shown in Figure 2.4.

In the following years, Ivan Sutherland proposed and developed the first virtual reality hardware system in 1968, shown in Figure 2.5. It was the first device to be considered Head Mounted Display (HMD), as it already included head tracking and adjusted the image according to the user's head position, with the hardware being attached to the ceiling as it was extremely heavy [45].

After these initial developments, the world of virtual reality has become more and more refined and has appeared in various formats, and example presented in Figure 2.6. Compared to the first versions, today it is a more compact, portable and affordable technology, which has

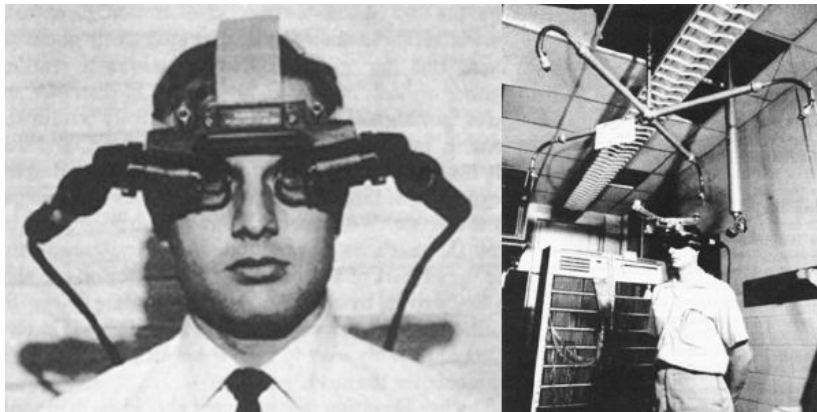
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<sup>1</sup>[https://www.researchgate.net/figure/Figura-1-Maquina-de-Realidade-Virtual-Sensorama-criada-por-Morton-Heilig-fig1\\_310481138](https://www.researchgate.net/figure/Figura-1-Maquina-de-Realidade-Virtual-Sensorama-criada-por-Morton-Heilig-fig1_310481138), [last accessed: 28/10/2022]

<sup>2</sup><https://alchetron.com/Ivan-Sutherland#ivan-sutherland-29ca240f-472b-4ddc-abbe-2be7474f130-resize-750.jpeg>, [last accessed: 28/10/2022]



**Figure 2.4:** Virtual Reality Machine, Sensorama, created by Morton Heilig in the 50s<sup>1</sup>



**Figure 2.5:** "The Sword of Damocles", Ivan Sutherland, 1968<sup>2</sup>

made it easier for ordinary consumers to access, this has led to an exponential increase in the number of devices on the markets.

With the constant evolution of virtual environments and their technologies, it is possible to create an even more realistic and immersive feeling, even making it difficult for the user to distinguish what is real and what is virtual. Given this, interaction has become a crucial component that distinguishes VE from simply watching a video from a first-person perspective. This ranges from having complete control over navigation and manipulation of objects - active interaction - to the ability to simply turn one's head to observe different areas of the virtual environment - passive interaction [10]. The recent popularity of Virtual Reality caused people to be more interested on its potential, especially on the entertainment industry, but so much industries more benefits of its use, as it has been successfully deployed in oil and gas exploration, scientific visualization, architecture, flight simulation, therapy, military training,

<sup>3</sup><https://unsplash.com/photos/NN9HQkDgguc>, [last accessed: 28/10/2022]



**Figure 2.6:** People experimenting with different VR systems nowadays<sup>3</sup>

theme-park entertainment, engineering analysis and design review. VR has been used as a way to reduce time and money of design, provide a safer environment compared to in vivo environments and easier way to analyse data when compared to traditional methods [42]. As Jason Jerald said in his book [42], in VR communication is a key component defining it as a "transfer of energy between two entities, even if just the cause and effect of an object colliding with another object.". He states that VR design worries about communication of how the virtual environment works, how is controlled and the relationship with the user. Given the technological advances in VR, different VR systems have been developed, usually classified into 3 different sub-types:

- **Desktop-VR** - refers to any virtual environment that uses a standard computer monitor as a visual display (including standard computer mice and keyboards) [46]. Although the graphical environments in a Desktop- VR exist in 3D, they are presented in a 2D-Display, which reduces the level of immersion compared to other sub-types of VR. With the help of special software and 3D glasses, it is possible to use the stereoscopic 3D view on a normal monitor to improve the user experience.
- **Headset-VR** - refers to head-mounted displays (HMDs). These are placed on the participant's head and computer-generated images are displayed directly in front of the eyes [42]. The HMD position and orientation tracking is essential for VR to allow the display and sounds to move with the head, meaning the participant is able to "look around" [46]. You can include hand controllers as inputs to enable interaction with the environment.
- **Simulator-VR** - a normal Simulator-VR setup has multiple projected screens or display panels that surround the user completely or partially with images of the virtual environment. A highly immersive system that is considered a Sim- VR are the Cave Automatic Virtual Environment (CAVE) (see [46]), which are rooms completely dedicated to the reproduction of virtual environments that can also provide head-tracking, special glasses

that allow the user to stereoscopically follow the view of the environment, and floor-to-ceiling graphic screens that completely envelop the user in the computer-generated world [47]. However, one of the major drawbacks to developing a system of this caliber is the high cost, which can have a price tag in the millions [48].

### **2.3.1 Virtual Reality in Psychology**

As said before, the use of virtual environments has great benefits in several fields, including Psychology. VR has the potential to provide more ecologically valid and accurate data by combining the experimental control afforded by a laboratory study with relatively high verisimilitude and veridicality of VR tools (e.g., [49]). Smith (2019) defined verisimilitude as "the extent to which an experimental task realistically simulates the real-life situation of interest" [10] (p. 1213) meaning that movements in virtual spaces and the perceptual changes that accompany them are processed by the brain in the same way as in the corresponding real space [11]. The concept of veridicality, on the other hand, refers to "the extent to which experimental results accurately reflect and/or predict the psychological phenomenon of interest" ([10], p. 1213). Researchers aspire to maximize these two components (verisimilitude and veridicality) for achieving high ecological validity.

Traditional procedures rely on the participants' ability to imagine themselves in a hypothetical situation, which differs from person to person and is beyond the control of the researcher. As denoted by Loomis et al. (1999) [50], the effectiveness of described scenarios in triggering emotional and cognitive responses varies depending on the attentional, motivational, and imaginative abilities of participants. Rather than asking participants to imagine the situation of interest, VR facilitates participants' immersion in the situation of interest. By recreating realistic-looking settings, enriched with multisensory information, VR transports the participant to a more real-world-like immersive environment, significantly enhancing their sense of presence and making their experience more comparable to reality.

Whereas the amount of contextual information in described scenarios is limited and participants are free to imagine their own details, virtual environments provide more rich and extensive information, while ensuring these details are consistent across participants. Thus, VR offers greater experimental control (e.g., researchers have control over what the participant sees or hears); and reproducibility (e.g., provides researchers the ability to replicate the experiment as many times as needed without changing the environment and its characteristics). VR can also be used combined with different physiological (e.g., blood pressure, heart rate, galvanic skin response) and/or behavioral measures (e.g., physical distance between participants and objects, hands and head movements), providing more accurate information about participants' responses and increasing the generalizability of findings.

In fact, one of the added values that VR have brought to research is that it can be combined with other "devices" and techniques that help measure other types of human responses [51]. For example, Bermo et al. (2020) used Magnetic Resonance Imaging (MRI) to observe brain activity of people with pain-full injuries while using VR as an analgesic action, allowing the patients to "get distracted" from their pain. MRI results showed significant suppression of

pain-related brain activity in the insula, thalami and secondary somatosensory cortex [52].

VR technology is widely used in the assessment and treatment of mental health problems (e.g., schizophrenia [53]; eating disorders [54]; phobias [55]; psychosis [56]), memory and attention deficits (e.g., Alzheimer's disease [57]; attention deficit hyperactivity disorders [58]), and sensorimotor deficits (e.g., post-stroke unilateral spatial neglect [59]; hemiparesis [60]) since it's preferred over traditional methods such as In Vivo exposure [61].

VR has been increasingly used in experimental research to explore topics as diverse as spatial cognition (e.g., [62]), episodic memory (e.g., [10]), visual perception (e.g., [63]), emotion induction (e.g., [64]), motor control (e.g., [65]), among others.

For example, Spatial Cognition is one of the areas that has benefited most from the development and use of 3D computer technology, aimed to study the cognitive mechanisms that are triggered in the perception of the environment and the representation of spatial information in the environment [66]. The methods used so far in the research on this topic have been based on measurements of spatial behavior, both in real environments and in laboratory simulations, although in the first option it becomes difficult to control the environmental parameters in real configurations and in the second it becomes an unrealistic simulation. VR came to "correct" these problems by allowing continuous measurements during navigation and designing 3D environments with varying degrees of complexity and realism, with positive results like the ones shown in [67], [68]. The latter authors found that navigating large-scale virtual spaces can produce disorientation effects, especially when navigating the space with a VR Headset.

To prove the positive results of using VR in Psychology, the Table 2.2 shows examples of using VR in treatment or experiments in Psychology. In this table are represented: (a) what was used for; (b) which VR equipment it was used to reproduce the experiment; (c) if extra stimulus were used besides the VE; (d) information about the VE; (e) how the participants navigated through the environment; (f) if it was used external tools to control the VE; (g) some notes taken about VR in this examples (for more detailed information about this examples, see Table C.2).

Context	VR Equip.	+Stim.	VR Environment			Notes
			type	nav.	ctrl	
Disorder treatment [69]	eMagin Z800	Audio; Scent	Modeled	Controls	Ext.	Environment logical and credible
Phobia [70]	IISVR-VFX3D	Audio		Seated		safety of the therapist's office
Phobia [71]	Oculus development kit 2	Audio; Scent		Seated	Ext.	cybersickness post-VRET; strong presence and realistic VR experiment
Phobia [72]	Samsung Gear VR		360 Videos			the habituation effect sought in traditional in-vivo exposure therapy is also possible in 360°VRET
Disorder Treatment [73]	HTC Vive	Audio	360 Videos		Ext.	VR exposure may be perceived less aversive than in vivo; more time-efficient; eases accessibility to relevant stimuli; facilitate exposure in clinics;
Experiment [74]	NVIS nVisor SX60	Audio	Modeled	Seated	Ext	



**Table 2.2:** Examples of the use of VR in Experiments and Treatments in Psychology.

## 2.4 DEVELOPING VR SYSTEMS FOR EXPERIMENTAL PSYCHOLOGY

The increasing accessibility and popularity of VR systems were key factors that contributed to researchers in the field of Psychology beginning to adopt this technology to investigate its effectiveness in providing reliable results and to improve the quality of experimental methods previously used in their studies. Experimental Psychology is a scientific field that is increasingly using VR to conduct its experiments, and its utility is being continuously evaluated in Psychology. Notably, most works in literature (a few notables examples are presented in Table 2.2) using VR for Psychology are developing just the virtual environment, and rendering it, and not much information is provided to the experimenter, e.g., state of the experiment, data collected. From the current protocol used for Mnemonic Tuning for Contamination studies, it appears that other purposes should be served besides the presentation of the stimuli in virtual reality, a companion tool might be the answer to allow the experimenter to control the flow of the experiment. In this regard possibilities of which frameworks could be used for the development of the virtual environment rendering, and possibilities of which frameworks could be used to create a companion tool, are shown on Table 2.3 and on Table 2.4, respectively.

## Virtual Environment Rendering and Exhibition

The world of virtual reality is becoming increasingly sophisticated and has evolved into a variety of formats. The demand for VR experiences are increasing with its accessibility and popularity, which has motivated the development and improvement of VR development tools. Although there are several VR development frameworks, such as Amazon Sumerian, Google VR for everyone, CRYENGINE, Blender and others, Unity and Unreal Engine are the two most popular and widely used in VR development, and they are also known as game development engines. They also enable the creation of applications for various fields, such as architecture, filmmaking, simulations, live events, and others. Table 2.3 describes the two frameworks.

Framework	Characteristics	Conclusion
Unity <sup>4</sup> 	Developed by Unity Technologies. It uses C# as a programming language. It is Cross-platform game engine. Has an Intuitive Interface. Graphics are good, but not the best.	Easy to learn because of its intuitive interface. Good documentation includes many tutorials for various features and a large community that provides resources to help with development. <b>Has a library specific for development of VR human behaviour experiments - Unity Experiment Framework (UXF).</b> C# which makes it faster. Unity offers a wide range of supported platforms <sup>5</sup> .
React <sup>6</sup> 	Developed by Epic Games. It uses C++ as a programming language. It is Source available engine. AAA quality graphics.	Difficult learning. Unreal Engine offers a wide range of supported platforms <sup>7</sup>

**Table 2.3:** Frameworks discussed for VR application.

## Companion Tool

A companion tool will allow the experimenter to control the flow of the experiment, e.g., when and how the stimuli are presented, to obtain feedback on the course of the experiment, and to support the collection of data from sensors deemed relevant to the experimental context. A companion tool is normally an app that supports the system, it serves as co-operative agent assisting in particular tasks [75]. A web application is the better type of application to develop a companion tool since it can be used in any type of device. Given the fact that are multiple frameworks that could help with this task, the ones shown in the Table 2.4

<sup>4</sup>Unity <https://unity.com/> [last accessed: 28/10/2022].

<sup>5</sup>Unity Multiplatform, <https://unity.com/solutions/multiplatform> [last accessed: 28/10/2022].

<sup>6</sup>Unreal Engine <https://www.unrealengine.com/en-US> [last accessed: 28/10/2022] .

<sup>7</sup>Unreal Engine Multiplatform, <https://www.unrealengine.com/en-US/features/multi-platform-development> [last accessed: 28/10/2022].

are the most famous, and used. In the table are represented: (a) the framework; (b) the languages used on that framework; (c) if the framework is cross-platform; (d) if the framework is SEO-friendly (Search Engine Optimization - SEO); (e) the learning curve to learn how to use the framework; (f) if it has good documentation; (g) where is the rendering performed; (h) if has any requirements to work; (i) information about what the framework is better for. For a more detailed information about the advantages and disadvantages about the frameworks, see Table C.1 on Appendix C.

Framework	Languages	Cross-Platform	SEO-Friendly	Learning Curve	Doc	Rendering	Requirements	Best For
Angular	HTML TypeScript JavaScript CSS	YES	NO	Steep	Lacking	Client	JavaScript Engine	single page apps that update single view at a time.
React	HTML JavaScript CSS	YES	YES	Steep	Poor	Server		single page apps that update multiple views at a time.
Flutter	Dart	YES	NO	Mid	Good			single page interactive apps with animations and heavy UI elements.
Vue.js	HTML TypeScript JavaScript	YES	YES	Easy	Language Barrier			creating single-page applications and user interfaces.

**Table 2.4:** Frameworks discussed for web application.

## 2.5 USER-CENTRED DESIGN

The development of tools to supporting Experimental Psychology entails tackling complex technical aspects, but one of the most prominent challenges is to understand the problems and the needs of the users involved, experimenters and participants. Creating a Human-Centred Design for a VR project is all about the user experience, as Jason Jerald once said that VR is "ideally where users are focused on the experience rather than the technology", so obtaining feedback from real users is a must in the early iterations of the project, so that human-centred design errors are found early to avoid major errors that could spoil the entire project [42]. Therefore, the use of a User-Centred Design is a crucial step in the development of these tools to facilitate and simplify their use by users.

*People ignore design that ignores peoples.*

—Frank Chimero

Systems and applications are regularly designed with a focus on business goals, sophisticated features, and technological hardware or software capabilities. All of these design approaches overlook the most important part of the process - the end user. UCD is a set of processes in which designers focus on users and their needs to develop a product design [76]. This can lead

to systems that are not intuitive to use and do not meet user expectations, and does not meet the business desired result. The solution to this adversity is User-Centred Design.

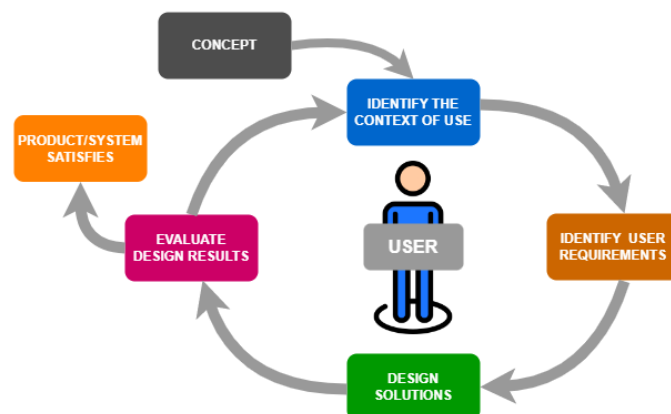
User-Centred Design (in american english User-Centered Design) (UCD) is a set of iterative processes in which designers focus on users and their needs to develop a product design [77]. At UCD, design teams involve users in all design processes by applying a variety of research and design techniques, taking into account user requirements, goals, and feedback. The goal is to create usable products that meet users' needs and desires.

Because it is an iterative process, designers use a set of investigative (e.g., surveys and interviews) and elaborative (e.g., brainstorming) methods in UCD to understand user needs. Typically, the UCD process involves 4 distinct phases:

- **Identify the context of use:** The team is trying to understand which users will use the product and in what context they can use it.
- **Identify requirements:** They identify and specify users requirements or goals.
- **Build Design Solutions:** They develop design solutions, backing up the defined requirements.
- **Evaluation phase:** In this phase the results are evaluated in relation to the context and user requirements. This phase verifies if the product meets the users' expectations to satisfy their needs.

After these 4 phases, the team iterates between them until the results are as expected. The use of UCD is beneficial to the development of a solution, and some of these benefits are listed below:

**Improve sales:** people are more likely to buy a product or service that meets their needs; **Better usability and boost Competitiveness:** people use products or services that meet their needs as effectively as possible; **Building positive user experiences:** increase loyalty and reputation of a product or service; **Helping improve or develop future products or services:** could lead to innovative new products or services; **Cost effectiveness:** by testing things with end users when it is still cost effective to make changes.



**Figure 2.7:** Diagram of the iterative process between the 4 UCD phases (Adapted from [78])

Different ways are adopted by design teams to design a better user experience, one of the most commonly used methods is user research, where designers imagine and try to understand which users will interact with the product and how, by creating personas, developing scenarios, defining requirements and materials or frameworks to be used, and evaluating the product, that are described in the subsections below.

### **2.5.1 Identify The User and The Context Of Use**

#### *Personas*

One of the mechanisms by which the design of a product or system is conceived and developed to be successful is based on the creation of a model. A model puts the user at the center and is essential to understand and visualize the important aspects of the relationships between users, the social and physical environment, and the products being designed. These models are called Personas [79].

Personas are based on behavioral patterns and motivations of real people observed during the research phase. This type of model is used to develop an understanding of users' goals in specific contexts, making it an important tool for informing and justifying a project. To be an effective design tool, personas must identify significant patterns in user behavior in a rigorous and subtle way so that they can be transformed into prototypes. Although there are several useful models that serve as design tools, such as workflow models and physical models, Alan Cooper et al.[79] argue that creating personas is a stronger and simpler tool for modelling when other techniques are included.

Personas help address many problems that design may face, such as determining the functionality of a product, communicating with stakeholders such as developers and other designers by providing a common language that creates a space for design decisions, and remaining user-centred. Before a persona is created, a research phase is usually conducted to gather information about potential users. Then, significant behaviors are identified, relevant traits and goals are summarized, and descriptions of traits and behaviors are expanded. For the successful construction of a persona, there are usually certain points that are mandatory, such as the following: Name; Age - can influence the language and knowledge of the product; Education - helps with the language used in the product; Activities; Difficulties; Goals.

Being the last one, Goals, an important aspect of a Persona, given the fact that Personas are responsible for providing the context for the observed behaviors, it is their motivations that drive them to engage in these behaviors. While an aimless Persona can serve as a communication tool, its utility as a design tool is insufficient. User motivations must be considered by designers as a tool for developing or optimizing product features. We can infer usage patterns from the combination of goals and motivations, as they provide an answer to why and how personas will use the product.

#### *Scenarios*

In a work done by the Human-Computer Interaction (HCI) community, in 1990, the concept of scenario emerged, generally used to describe the use of an informal narrative, a form of

problem solving for projects in which a story is used to elaborate and illustrate solutions for a project.

John Carroll [80] discusses the various concepts about scenarios in his book, focusing on describing how users perform tasks. These scenarios consist of the composition of the environment and include actors that are substitutes for users and have names based on roles, such as programmers or collaborators.

Consequently, the actors that take the place of the users can be replaced by Personas, making the scenarios based on these personas that describes one or more personas that use the product with a specific goal. This method is used to focus on the users and how they think and act while using the product.

When building a scenario, there are some essential points that must be considered, such as:

- Context
  - Who? - personal data
  - What are their goals?
  - When will they accomplish the tasks, including obstacles?
  - Where will they perform these tasks, including obstacles?
  - Why will they perform these tasks?
- Explain the circumstances that lead to interaction with the product and possible factors that may affect its use.
- Make the scenario understandable to people who don't have a technical background.
- Keep the user-centered scenario.

As an alternative to using scenarios with Personas, it is also possible to use Personas together with use cases that describe a user's interactions in a system. Use cases are detailed descriptions of the system's functional requirements, but say little or nothing about how those requirements are presented to users. They also treat all user interactions as equally likely and important, making this method software-centered rather than user-centered.

Scenarios are an effective and convenient way to share ideas between the design team and stakeholders. Experiences designed around a scenario tend to be more comprehensive and engaging, making their use an advantage in product design.

### **2.5.2 Identify User Requirements**

To begin the process of developing a product, it is necessary to study the requirements of a product from the user's point of view [81]. After developing Personas, and creating Scenarios in which personas interact with the product, the design team has enough information to create a list of requirements. Requirements describe the main features that a product must have. The information needed for the requirements is taken from the scenarios, and it must be determined what is needed to achieve the goals and motivations of the personas. There are 3 essential types of requirements [82]:

- **Functionality:** specifies the functionality of the system and what the user can do with the system.

- Quality: defines the characteristics and qualities of a product.
- Usability: focuses on the usability of a system.

### 2.5.3 Design Solutions

The User-Interface (UI) Design phase of an application is about designing the layout of the user interface to meet all requirements, focusing on the style and interactivity of the system, which should be easy to use and aesthetically pleasing to the user. To plan the layout of an application that best meets the user's needs, all the interactions and behaviors that a user may have with a product are usually explored. To create a product with these features and get feedback for possible changes, different methods are used depending on the current stage of design and development of the product. In the initial stages, low-fidelity tools can be used to validate the overall concept, and from there, fidelity can be improved as the product progresses to more complex system features. The different methods that can be used in this process are: [83]:

- Wireframes - are a type of low-fidelity prototyping, usually used to create and test the flow of an application, known as the skeleton of an application. There are several free or freemium applications that help in creating a Wireframe, which are also used in VR, such as:
  - Use of paper and pen
  - Digital Design Tools
    - \* Moqups Wireframe<sup>8</sup>
    - \* Balsamiq Wireframes<sup>9</sup>
    - \* Uizard Wireframes<sup>10</sup>
    - \* UXPin Wireframe<sup>11</sup>
    - \* Proto.io Wireframe<sup>12</sup>
- Mockups - are a type of prototyping with medium/high fidelity. This type of prototyping usually involves design decisions for the overall look and feel of the product, such as color schemes, layout, typography, iconography, navigation elements, and others. It is considered the skin of an application. It is a way to get a realistic idea of how the final application will look, even if it is static. To create a mockup, there are several applications that help with this process, such as:
  - Moqups<sup>13</sup>
  - Balsamiq<sup>14</sup>
  - Uizard<sup>15</sup>

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<sup>8</sup>Moqups Wireframe <https://moqups.com/wireframe-tool/> [last accessed: 28/10/2022].

<sup>9</sup>Balsamiq Wireframe <https://balsamiq.com/wireframes/> [last accessed: 28/10/2022].

<sup>10</sup>Uizard Wireframes <https://uizard.io/wireframing/> [last accessed: 28/10/2022].

<sup>11</sup>UXPin Wireframe <https://www.uxpin.com/studio/wireframing/> [last accessed: 28/10/2022].

<sup>12</sup>Proto.io Wireframe <https://proto.io/wireframe-tool/> [last accessed: 28/10/2022].

<sup>13</sup>Moqups <https://moqups.com/> [last accessed: 28/10/2022].

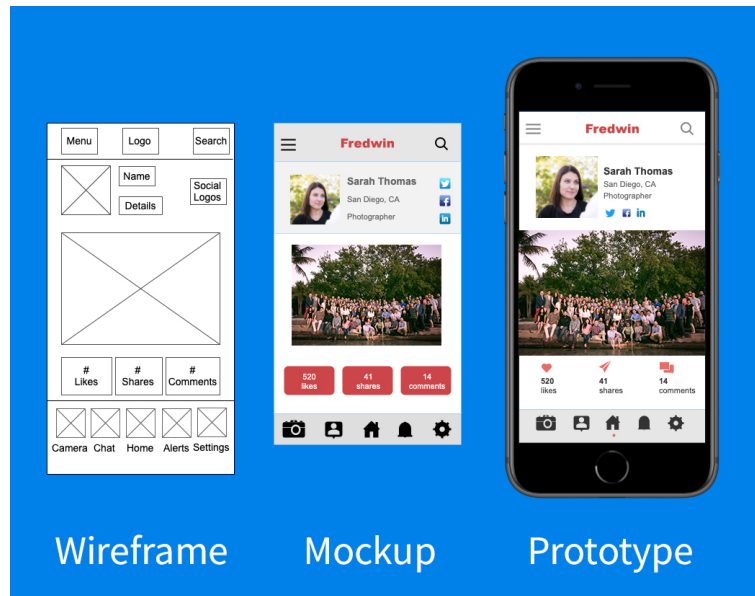
<sup>14</sup>Balsamiq <https://balsamiq.com/> [last accessed: 28/10/2022].

<sup>15</sup>Uizard <https://uizard.io/> [last accessed: 28/10/2022].

- UXPin<sup>16</sup>
- Proto.io<sup>17</sup>

A VR interface has different properties, and so do the applications used to create a mockup for a virtual environment. Some of the most commonly used applications in these environments are:

- Photoshop<sup>18</sup>
- A-Frame<sup>19</sup>
- Sketch plugin for A-Frame<sup>20</sup>
- Draft XR plugin for Adobe XD<sup>21</sup>
- Prototypes - are a type of high-fidelity prototyping. They can usually be used to simulate how a user will interact with the product, i.e. the behavior of an application. Since they are functional, they are used to run tests with typical users and get feedback for possible changes before the product is launched. The same applications are usually used to create a prototype as to create a mockup.



**Figure 2.8:** Differences between Wireframe, Mockup and Prototype<sup>22</sup>

#### 2.5.4 Evaluate Design Results

Any person or company building a system wants the user's needs to be met. To achieve this goal, various methods are used, one of which is evaluation. There are several evaluation methods that can be performed with or without the user to help with the intermediate or

<sup>16</sup>UXPin <https://www.uxpin.com/> [last accessed: 28/10/2022].

<sup>17</sup>Proto.io <https://proto.io/> [last accessed: 28/10/2022].

<sup>18</sup>Photoshop <https://www.adobe.com/pt/products/photoshop.html> [last accessed: 28/10/2022].

<sup>19</sup>A-Frame <https://aframe.io/> [last accessed: 28/10/2022].

<sup>20</sup>Sketch plugin <https://www.sketch.com/extensions/plugins/> [last accessed: 28/10/2022].

<sup>21</sup>Draft XR plugin <https://www.draftxr.com/> [last accessed: 28/10/2022].

<sup>22</sup><https://www.aha.io/roadmapping/guide/product-management/wireframe-mockup-prototype>, [last accessed: 28/10/2022]

final evaluation of the design, i.e., the evaluation must be considered throughout the life cycle of the design [84], all of these methods can also be performed to evaluate virtual reality applications.

### *Analytical methods*

Analytical methods are an approach in which users are not directly involved. This type of evaluation usually involves an expert who acts like a user and whose goal is to analyze and identify potential problems. Some of the analytical evaluation that test the usability of systems are:

- Heuristic Evaluation - Heuristic Evaluation, originally proposed by Nielsen and Molich in 1990 [85], is a method that helps find usability problems in the design of an interface. It involves examining and evaluating the interface using heuristics.
- Cognitive Walkthrough - Cognitive Walkthrough, proposed by Polson et al. in 1990[86], is a method that helps find usability problems by identifying user goals and finding interface learning problems by focusing on appropriate tasks.

Although both are good options, heuristic evaluation is most commonly used because cognitive walkthrough is more time consuming, as a series of questions must be answered for each task tested. Therefore, in order to perform a heuristic evaluation, it is necessary to have a small group of evaluators, with the recommended number being between 3 and 5 people, who will examine and evaluate the interface according to the heuristics. One of the advantages of using this method is that it provides quick feedback, can be performed at different stages of the process, and can be used in conjunction with other usability tests.

### *Empirical Methods*

Empirical methods are approaches that involve users. In this type of evaluation, users perform activities/tasks that provide data that is analyzed by an evaluator to identify potential problems. Some of the empirical evaluations that test the usability of systems are:

- Observer Studies - Observer studies have their roots in Psychology, but have always played an important role in HCI. They are conducted with participants observed by evaluators who monitor their interaction with the system, and the evaluators may take notes in real time or a posteriori.
  - Think Aloud - The Think Aloud method described by Nielsen in 1993 [87] is a usability evaluation technique that uses thinking aloud. Nielson defines this technique in his book as follows: "In a thinking aloud test, you ask test participants to use the system while continuously thinking out loud -that is, simply verbalizing their thoughts as they move through the user interface."
- Query - Query studies have two variants:
  - Usability Questionnaires - better explained later in this section.
  - Interviews - Interviews are where a researcher asks potential users questions to obtain understanding about of their goals, thoughts and feelings. Interviews are the most used technique for obtaining information and qualitative data.

Both methods can be easily used in studies as they are cheap, flexible, and easy to learn and apply. Some of the limitations are that the Think Aloud technique creates an unnatural situation that can alter the user's behavior and that observational studies, if the indirect method of recording user interactions is not used, can lead to human error on the part of the evaluator.

One of the advantages of using these evaluation techniques is that you only need to recruit representative users, deliver a series of tasks about the system being evaluated. They also provide quick feedback, can be conducted at different stages of the process, and can be used in conjunction with other usability testing methods.

### *Usability questionnaires*

Usability questionnaires are tools used to quantify and qualify the quality of a product in terms of its usability. There are several questionnaires and their derivatives that can be used to evaluate the usability of systems. The following questionnaires or their derivatives are the best known and most commonly used:

- System Usability Scale (SUS) - The SUS, proposed by John Brooke in 1986 [88], is one of the most widely used questionnaire scales for assessing the usability of a system. It typically includes about 10 questions on a scale of 1 to 5, where 1 means you strongly disagree with the statements about the product and 5 means you strongly agree with the statements.
- User Satisfaction Evaluation Questionnaire (USEQ)- The USEQ is a questionnaire used by Gomez et al. [89] that was developed to virtually evaluate the satisfaction and some of the usability of virtual rehabilitation systems.
- VRUSE - VRUSE is a questionnaire developed by Kalawsky [90] to measure the usability of VR systems. This questionnaire was developed specifically for evaluating virtual environments and serves as a diagnostic tool that provides information from the user's perspective about the interface in a virtual environment. This questionnaire contains about 100 questions that evaluate various important usability factors of VR systems. Since this is an extensive questionnaire, several derivations with fewer questions were used to evaluate VR systems. To answer the questions, similar to SUS, a scale of 1 to 5 is used to count the agreement with the statements about the product, where 1 means that the user completely disagree and 5 means that the user completely agrees with the statements.

## 2.6 CONCLUSIONS

Considering the goal of the research team to move towards a more ecologically-valid setting in studying the role of the Mnemonic Effect of Contamination in the BIS, an approach based on VR is proposed in this work. The use of 360° videos seems to be a promising option as they can replicate real-world actions in a more credible and quick manner, than a modeled environment. To this end, a set of User-centered tools has been designed in collaboration with experts to support the creation and execution of experimental studies adopting this

novel paradigm, using two applications: a VR application to display the experiment and a companion tool to be able to control this environment.

# Personas, Scenarios, and Requirements

As mentioned in the previous chapter, Personas and Scenarios are good tools to understand the users' needs and motivations and specify the overall features and contexts of use leading to the requirements. For this reason, it was decided to use these methods to start developing the design and the system proposed for this dissertation. The Personas and Scenarios were built in close contact with domain experts through initial brainstorming and iterative refinement of the Personas and Scenarios according to their feedback and aligned with the envisaged approaches, the result of which are presented below.

## 3.1 PERSONAS

Having an idea of user motivations is beneficial for the development of an application, as the usage patterns can be derived from the motivations, i.e., they provide answers as to why and how a user will use the system. Three personas were created to represent the three types of users who will use this system: (a) researcher in the field of memory and contamination, typically the person who controls and configures how the experiment will run (Filipa Marques Persona); (b) person responsible for monitoring the experiment and data collection, in this case a Psychology student, in the frequent cases where people who run the experiment are not part of the group designing the experiment (Lucas Martins Persona); (c) a secondary persona, that represents a typical participant on the experiment (Maria Fernandes Persona). A more detailed description of each persona and their motivations is shown next.

Filipa Marques, researcher in the field of Psychology.



**Figure 3.1:** Filipa Persona

Filipa Marques, a 35-year-old psychologist, works full-time at the University of Aveiro. Her idea of success is the various researches and studies she conducts on the human mind, especially memory. As a researcher currently working in the MTC research, Filipa has conducted and continues to conduct several tests and experiments with people to prove her theories. Some of the most recently conducted experiments in the MTC research were done with images and instructions displayed on a computer screen. Although this way of conducting experiments is quite feasible and produces the expected results, it is not the best for ecological validity. Filipa wants her experiment to have greater ecological validity. Therefore, she has explored different ways to conduct the experiments in a more immersive manner. One of these ways is to conduct the experiment in a virtual environment, which gives Filipa greater control, greater subject immersion, and

an easier way to replicate the experience, along with the fact that the ecological validity is significantly greater. In the end, the psychologist wanted to compare the results she had obtained with the images with the results she would obtain in a more immersive environment when using virtual reality to determine if the additional effort would really make a difference in the data compared to the data already collected, thus increasing ecological validity.

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**Motivation:** Filipa wants to explore and implement more ecologically valid stimuli in their experiments while maintaining control of the experiment progression and its replicability.

Lucas Martins, Psychology Student.



**Figure 3.2:** Lucas Persona

Lucas Martins, a 19-year-old Psychology student at the University of Aveiro. He started his studies about 1 year ago and wants to be more involved in the developments in his field. Since he had already conducted a small experiment with participants for a course unit, he thought it would be a good opportunity to conduct an experiment on a larger scale and with different methods that he used before. However, although he wishes to learn new things, he noticed that bigger experiments have more complicated protocols, with a lot of steps that need to be followed by the experimenter and he is afraid to make mistakes and ruin the results. To this end, he searched for researchers who were looking for volunteers to conduct experiments and found the MTC research. Since combining new technologies with Psychology is one of Lucas' great interests, he volunteered to be an experimenter to help with this research and gain knowledge for his future.

**Motivation:** Lucas would like to acquire knowledge of Experimental Psychology by participating in a way that would make him more confident of not doing any mistake while implementing the protocol

Maria Fernandes, Student of Computer Engineering and Telematics.



**Figure 3.3:** Maria Persona

Maria Fernandes, a 22-year-old student of Computer Engineering and Telematics at the University of Aveiro. She enjoys being in the university environment and experiencing different things, such as volunteering. Maria was invited by her friends from the Psychology Department to participate in an experiment about memory. Having already participated in some experiments of the same genre, she thought that it would not be worth it because she found these experiments were too artificial, as she had to use her imagination to create a scenario by looking at pictures instead of actually experiencing the situation. The student changed her mind when her friends showed her the details of the experiment, which were that it would be conducted in

a more immersive and believable environment and that she would just have to look at what she sees and answer a few questions.

**Motivation:** Maria wants to try new things and learn more about Experimental Psychology by volunteering to participate in studies.

### 3.2 SCENARIOS

For the scenarios, we considered information regarding current practice in Experimental Psychology for studying memory and contamination, obtained from discussions with the domain experts, and the motivations of the Personas. This was an iterative process and representative examples of the devised scenarios are presented in next.

#### *Preparation and Configuration of the stimuli:*

Filipa and her team are studying how memory responds to different stimuli related to contamination. She and her team choose Virtual Reality as a means to conduct experiments more immersively, with the goal of increasing ecological validity. Filipa and her research team prepare the stimuli to use in the experiment. They do this by displaying subjects holding objects that may or may not show signs of contamination, using chocolate for this purpose. After preparing the stimuli and adding the stimuli to the research database, Filipa was left with the task of configuring sequences of how the stimuli can be present during the experiment. For one of the experiments, she filters the stimuli by selecting healthy males holding apples, oranges, and water bottles, contaminated and non-contaminated. After making this selection of stimuli, Filipa determines that they should be presented randomly to the participants.

Together with the research team, she prepares questionnaires and forms, and identifies possible reasons for exclusion from the experiment, in order to prepare a guide for the experimenters.

### ***Presentation of stimuli***

---

**Participant Preparation** - Lucas welcomes the participants and explains all the procedures and possible side effects of the experiment and later asks them to sign a consent form if they agree to participate, in this case Maria. Then Lucas starts a new session and registers the necessary data about Maria in the system, looking for elements that exclude the study. After Maria has been accepted, he asks her to fill out a questionnaire on the subject of the experiment in question.

**Training Period** - To avoid interruptions, a training phase is carried out for Maria to get used to the virtual environment. To do this, Lucas asks Maria to enter the room, sits down, and explains the experimental procedure to her. Once in the virtual environment, Lucas asks Maria to explore it, test it and clear any doubts.

**Display of stimuli (Immersive environment)** - Lucas follows on the platform the experimental script created by Filipa, in which he introduces the previously established sequence of stimuli and gives Maria brief description of what is about to happen, with no detailed information about the content and gives her instructions on the placement of the device that will be used to generate the virtual environment. When he notices that Maria is ready, he starts the experimental protocol. Lucas watches for possible interventions and focuses on the data that the system continuously reads to make sure there are no errors, and also pays attention to Maria's well-being.

**Final phase of participation** - At the end of the presentation of the experiment, Lucas waits for the start of the memory test, on the virtual environment system, about the stimuli presented. Lucas confirms that the responses given by Maria along with the data collected during the experiment are stored on the platform. Noticing some aversion from Maria during the experiment, he asks her how she felt during the presentation, to which she responds that she was nauseous in the middle of the presentation but felt better at the end. Lucas notes this effect of Maria on the platform along with the other data, closes Maria's session, and moves on to the next participant.

**Platform feedback** - Lucas is about to begin an experiment with Maria and asks Maria to use the immersion device. After starting the experiment protocol, he has not noticed any head movement from Maria, Lucas wonders whether or not the stimuli are being presented. To assess the situation, Lucas looks at the platform and checks the status screen of the experiment. There he can see what is being presented to Maria and what data the device is continuously retrieving during the session. Since the experiment is running as expected and there were no obstructions from Maria, Lucas allows the experiment to continue until the end.

### *Participation in the experiment*

---

**Preparation** - Maria decided to participate in the experiment that was taking place in the Psychology department. When she arrived there, all the procedures and possible side effects were explained to her. To participate in the experiment, Maria was asked to sign a consent form and fill out a questionnaire. Next, Maria received a brief description of what she should expect, was instructed to enter a room and take a seat, and was told how to use the device in front of her. To be acquainted with the experimental apparatus and task, a testing phase was introduced, where Maria was introduced to a small example of a virtual environment where she could explore and test how it worked and ask any questions she had.

**Presentation of stimuli** - During the experiment, Maria was given some sensory cues, such as one in which the woman who appeared coughed to an apple. After the presentation, still in a virtual environment and using the virtual environment devices, a memory test appeared consisting of a question appearing and the possible answers, e.g., an image of the apple shown before and a question asking if the object she saw before was touched by a Healthy or Unhealthy person. At the end, Lucas helped Maria remove the device, questioned her about her comfort during the experiment, and led her out of the room to end her participation in the experiment.

### *Alternatives to the second Scenario(Presentation of stimuli) Stimuli Display:*

---

The above scenarios show what is possible to do with the resources available for this project, but there are many more possibilities for this type of experiment that allow for other senses to be tested and the collection of more data about the human body and its response to stimuli. Some alternatives of the stimuli display are presented below.

**Alternative 1 - Display of stimuli (Immersive environment + Stress Control)** - Lucas follows on the platform the experimental script created by Filipa, in which he introduces the previously established sequence of stimuli and gives Maria brief description of what is about to happen, with no detailed information about the content and gives her instructions on the placement of the device that will be used to display the virtual environment and the device of stress measurement. When he notices that Maria is ready, he starts the experimental protocol. Lucas watches for possible interventions and focuses on the data that the system continuously reads to make sure there are no errors, and also pays attention to Maria's well-being.

**Alternative 2 - Display of stimuli (Immersive Environment + MRI-FONAR)** - Lucas follows on the platform the experimental script created by Filipa, in which he introduces the previously established sequence of stimuli and gives Maria brief description of what is about to happen, with no detailed information about the content, tells her to sit on the MRI-FONAR machine and place the device that is being used to display the virtual environment. When he notices that Maria is ready, he starts the experimental protocol. Lucas watches for

possible interventions and focuses on the data that the system continuously reads to make sure there are no errors, and also pays attention to Maria's well-being.

**Alternative 3 - Display of stimuli (Immersive Environment + Olfactometer)** - Lucas follows on the platform the experimental script created by Filipa, in which he introduces the previously established sequence of stimuli and gives Maria brief description of what is about to happen, with no detailed information about the content, instructs her on how to place the device that is being used to display the virtual environment and to place her nose of the olfactometer. When he notices that Maria is ready, he starts the experimental protocol. Lucas watches for possible interventions and focuses on the data that the system continuously reads to make sure there are no errors, and also pays attention to Maria's well-being.

### 3.3 REQUIREMENTS

The scenarios made it possible to identify the contexts, the functionalities, and the actions that gave rise to the requirements needed to develop the platform, functional and non-functional (for illustration purposes, the scenarios shown above show this actions/functionalities underlined). An analysis of the scenarios allowed identifying four core stages for the experimental workflow, each leading to its list of requirements: Video Annotator (Stimulus Preparation), experiment configuration, experiment controller and experiment rendering. After analyzing the scenarios and further discussion with domain experts, the non-functional requirements included: the framework must be cross-platform, since it is unknown on which platform or operating system the application will be deployed, e.g., users can use this application on a computer or tablet; Prefer a framework that is easy to learn, has good documentation, and has an active community to help in the development phase if needed; To facilitate its use, it was chosen to use a web application that can be used on any operating systems and platforms, being its main target a computer. Like any other system, it must have good usability and be user-friendly, for this reason, a place for usability requirements is also included in the list of requirements. The functional requirements are presented in below, organized by the overall stage they refer to.

#### *Stimulus Preparation*

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- Allow recording 360° videos for stimulus preparation
- Creating a stimulus catalog
- Insert new stimulus in a catalog
- Remove stimulus from catalog
- Choose frame in which the stimulus appears
- Saving this frame in the catalog
- Adjust the beginning and end of the video
- Insert information about stimulus content, e.g., tags
- Have a set of pre-established tags

- Create new tags

### ***Experiment Configuration***

---

- Searching the catalogs using filters
- Preview of stimuli
- Configure dynamic view mode, e.g. the stimuli to present
- Set the order of videos as desired
- Experiment preview
- Saving experiment configuration
- Configuring different phases of the experiment, e.g., training period, experimental phase,
- Configure the static display mode, e.g. demonstration of the frames, for the creation of the questionnaire.
- Define questionnaires and the moment of their application during the experiment

### ***Experiment Controller***

---

- Introduce a new participant
- Load experiment configuration
- Experiment flow control dictated by the experimenter, e.g., start, pause, stop
- Provide the experimenter with information about what is being viewed
- Provide information on participant performance
- Allow taking notes during and after the experiment
- Save experiment data and survey responses

### ***Experiment Rendering***

---

- Displaying the stimuli to the participant in a virtual environment
- Allowing the participant to answer small questionnaires without leaving the virtual environment

Since it will be used a User-Centred Design it also implies that the tools must meet usability requirements: (while usability as whole is crucial for any interactive system for our work the following usability requirements are top priority)

### ***Usability Requirements***

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- Learnability - Users can easily use the features and even easier the next time they use them.
- Intuitiveness: the interface is easy to learn and navigate; buttons, headings, and help/error messages are easy to understand.
- Efficiency of use: goals can be achieved easily, quickly and with few or no user errors

### 3.4 CONCLUSIONS

In this chapter, together with domain experts it was defined a set of Personas, their needs, and motivations that guided the proposal of a set of scenarios illustrating a novel solution to support the experimental setting for studying the Mnemonic Tuning for Contamination. From these, several stages for the experimental workflow were identified leading to a list of requirements that will inform the following stages of the work. After analyzing the requirements It was considered appropriate to use 360° videos as stimuli for the experiments because it was the quickest and easiest way to obtain stimuli that most resemble reality. A modeled environment was considered, but this method would be time consuming and, if not done properly, would not look as real as 360° video.

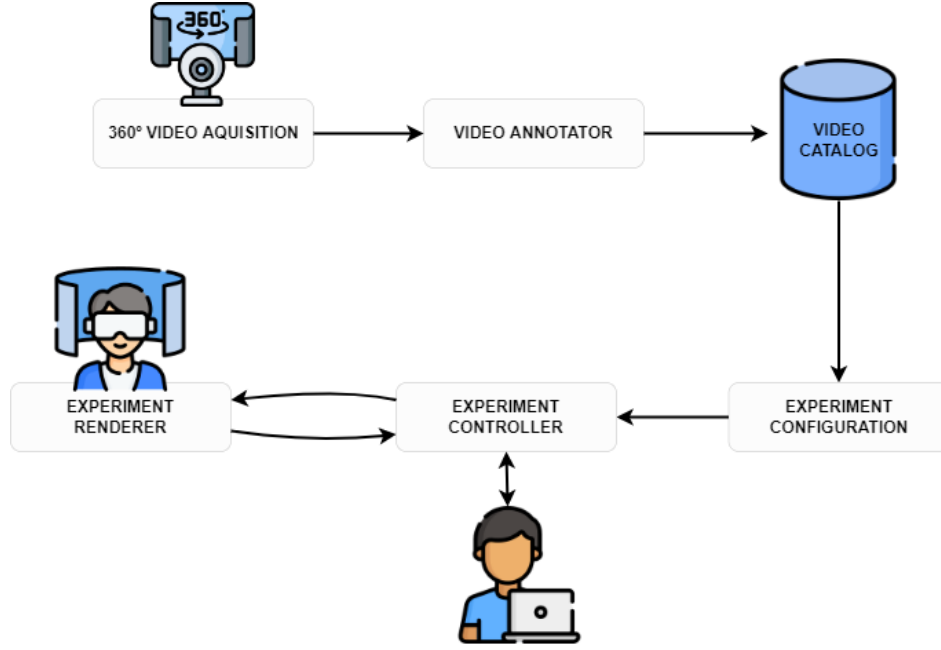


# Initial Development and Concept Validation

At the beginning of the development of the system, prototypes were created and evaluated in several meetings with the MTC research team to better clarify their needs for conducting experiments. It was then deemed appropriate to conduct concept validation, which meant presenting the stimuli in a VE. For this reason, a pilot study was conducted in collaboration with a researcher involved in the MTC research, the implementation and results of which are presented in this chapter.

## 4.1 OVERALL INFRASTRUCTURE

Considering all the requirements for the development of the different phases of this platform, we have created a diagram depicting the different high-level modules as presented in Figure 4.1: capture 360° videos serve as stimuli for the experiments; then in the platform, saving these videos in the Video Catalog, via the video annotator, complemented with information about their content. The next step would be to configure future experiments using the experiment configuration tool by, for instance, defining the sequence of videos that will be played and possible questionnaires, with the ability to resort to the Video Catalog for this purpose. For the experiments, the Experiment Controller is used to control the Experiment Rendering, by specifying which configuration to use and controlling experiment flow, e.g., what to show in the virtual environment and when.



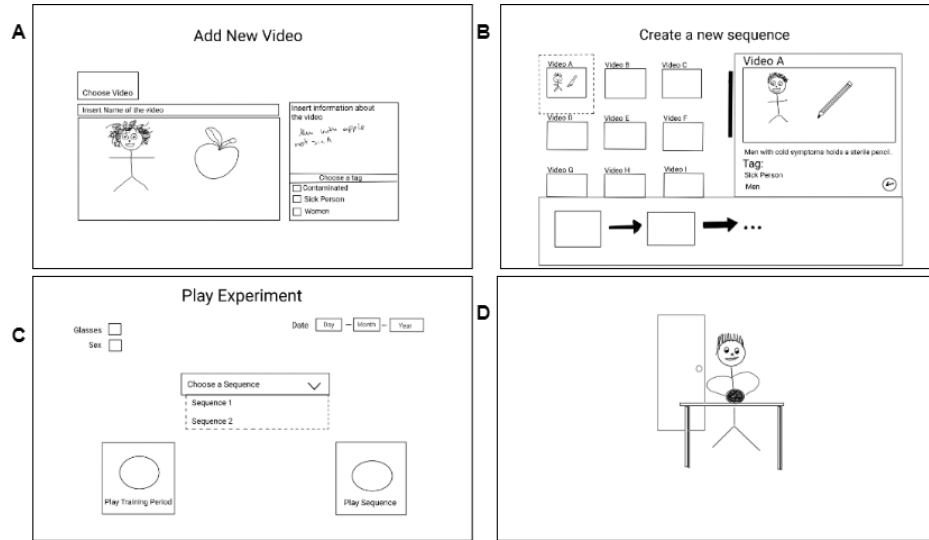
**Figure 4.1:** Overall diagram depicting the different high-level modules envisaged to address the requirements established.

## 4.2 NON-FUNCTIONAL PROTOTYPES

In line with the adopted UCD approach, two major stages can be identified in the work carried out. The first stage concerned the design and refinement of low-fidelity prototype to support the definition of the overall approach to inform the development of the functional prototype in the subsequent stage. Considering that video recording can be tackled by 360° camera software, the system should support the three remaining phases, i.e., dealing with the preparation, configuration, and display of the stimuli. Therefore, two different applications were envisaged: one for the preparation, configuration and controlling of the stimuli/experiment running on a Desktop PC or tablet, and another for the display of the experiment, running on Oculus Quest 2. In this regard, mockups were created that contained the initial ideas for the implementation of these applications.

The initial idea of both platforms led to the proposal of the wireframe mockup depicted in Figure 4.2 (A) showing the initial idea of how a stimulus could be added to the video catalog, the video annotator. It consisted of the option to loading the video used as stimulus, a preview of the video, add a small description about the stimulus, and indicate which tags belong to the stimulus, e.g., whether it is contaminated, sterile, fruit. 4.2(B) Shows the initial idea of the Experiment Configuration, i.e., how the stimulus sequences could be created. Here, all the videos from the catalog were displayed, and by selecting one of them a small preview, the description, and the associated tags appeared. By selecting a video it would appear the option to add it to the sequence, and it would appear at the bottom of the screen, along side with the other selected videos. Figure 4.2 (C) shows the original idea of the Experiment Controller, where the experimenter would prepare the experiment for exhibition, enabling

adding some needed information(e.g. about the participant), selecting the sequence to be presented to the participant, and the option to choose between playing the training period or beginning the experiment by playing the sequence. The Figure 4.2 (D) also shows an example of an environment that would appear in the virtual environment, the Experiment Render.

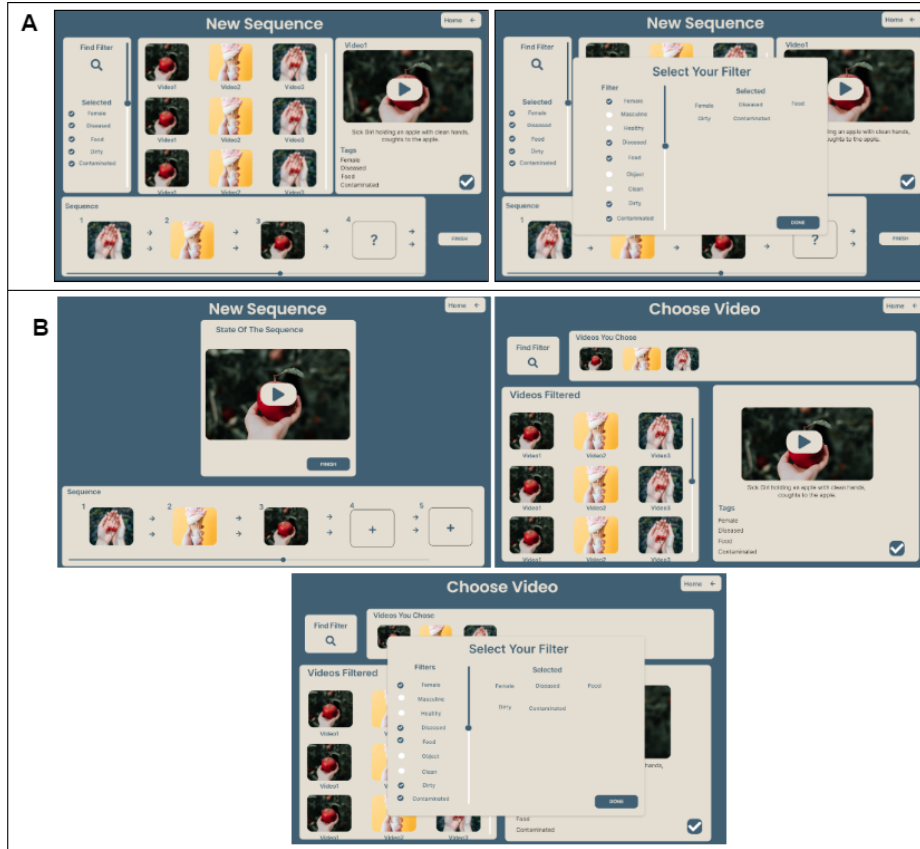


**Figure 4.2:** Representative examples of low fidelity mockup used for initial discussions about the user interface design. (A) Video Annotator; (B) Experiment Configuration; (C) Experiment Controller. (D) Story Board of the Experiment Render.

Taking into account that the system would be used by the researchers directly involved in the MTC research, the various mockups were evaluated by them in the various meetings held together with HCI experts. The low fidelity mockup served to identify the need, while adding a video to the catalog, to provide a set of predefined and custom tags that could be associated to the video being added and later used as a method for filtering the videos in the Experiment Configuration to facilitate the creation of the sequence of videos. Considering the feedback obtained for the wireframe mockup, the concept was refined and a new mockup was designed with a higher level of detail of the interface.

This refined mockup (see Figure 4.3 for illustrative examples) was also used as grounds for discussion in another session with HCI experts and researchers directly involved in the MTC research. The overall mockup was well received, but the user interface for the Experiment Configuration, shown in Figure 4.3 (A) was heavily criticized for being confusing to use. Further discussion identified that this was due to our attempt to have all the required features accessible on the same screen, i.e., video catalog (for video selection), video sequence builder, and video previewer. To solve this problem, the task was more carefully analyzed and decomposed and the Experiment Configuration page was redesigned to make it simpler and clearer to the user by splitting video selection from the video sequence builder, resulting in the set of screens presented in Figure 4.3 (B).

No mockup was created for the virtual environment because it was clear from the beginning that the virtual environment would be a 360° video with a specific set of actions. For this reason, there were no prototypes for the scenes, only a small storyboard was created, as seen



**Figure 4.3:** Representative examples of the refined mockups: (A) Experiment Configuration demonstrated in the meetings. (B) Experiment Configuration after taking into consideration the discussion with the domain experts.

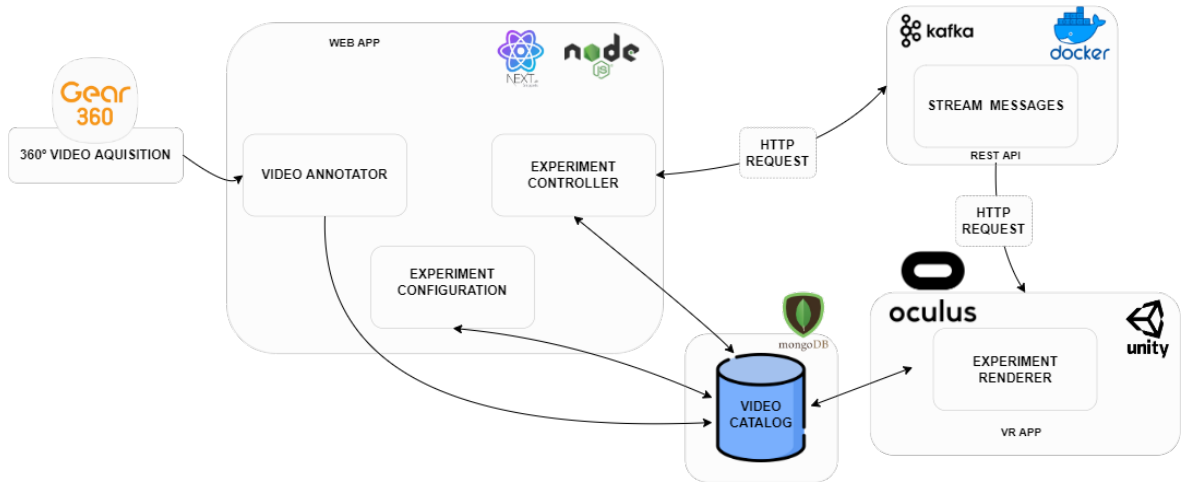
in Figure 4.2 (D), to show the idea of the actions.

### 4.3 DEVELOPMENT OF FIRST PROOF-OF-CONCEPT

Following on the feedback obtained for the low-fidelity and medium-fidelity prototypes it was deemed appropriate to move into the development of a first functional prototype. In this context, its architecture was defined and, based on the requirement priorities, first modules of the platform were developed as described in what follows.

#### 4.3.1 Overall Architecture

Considering the requirements presented in section 3.3, the feedback obtained during the discussions with the domain experts and the available equipment for VR (Oculus Quest 2), we defined an overall system architecture as depicted in Figure 4.4. The architecture diagram



**Figure 4.4:** Overall system architecture depicting the main modules and the adopted technologies to support their development.

includes two main parts: (a) add videos to a catalog, configure the experiment, and control it with an application implemented in ReactJs; (b) exhibition of the experiment implemented in Unity and shown in Oculus Quest 2.

The first step in this project, as shown in the diagram in Figure 4.4, is the acquisition of the 360° videos (in this initial case, using a Samsung Gear 360° camera). Considering that the technical requirements needed to develop the Video Annotator, Experiment Configuration and Experiment Controller are identical, it was decided to develop everything in the same application using Node.js to develop the back-end and ReactJS framework to develop the front-end. To store the data required to support the envisaged features (e.g., stimuli and information about them, experiment configurations) it was adopted MongoDB database.

To execute the experiment, the Experiment Render, implemented using Unity, needs to retrieve the information required from the database, and display it in the VR equipment (in this case, the Oculus Quest 2). The information of which videos to play or other information that needs to be exchanged between the Experiment Controller and the Renderer, e.g., to play the experiment or to update the experiment status, is sent through message streams implemented using Kafka.

### *Web Application Framework*

React is a JavaScript-based UI development library widely used in web development. React makes it easier to build dynamic web applications by requiring less coding and providing more functionality, plus components can be reused throughout the application. React is used for both web and mobile applications, as it is a cross-platform framework. Due to its low learning curve, extensive documentation, and good tool for developing client-side and server-side applications, React was chosen as the framework for developing the web application needed for this project. To develop a low latency and high functionality application, ReactJS and Node JS were combined for the front-end and back-end respectively. Chakra UI component was also added to the development of the frontend application, being an easier, simpler and modular way of building blocks needed to build React applications, facilitating the development of more interactive interfaces.

### *Database*

To store the data required to support the envisaged features (e.g., the information about the stimuli, and experiment configurations, etc.) and since the data comes from different sources — its structure is not the same for all data, there are no relationships between the data and they are stored in JSON files in order to facilitate communication between applications — so it was decided to use semi-structured data, and for this reason a NoSQL database adopting MongoDB, an open source NoSQL database tool that manages, stores, or retrieves document-oriented information.

### *Virtual Reality Application Framework*

Unity is one of the most widely used frameworks for developing virtual environments, for which there are tons of documentation on the Internet. It offers high-quality visual effects, highly customizable rendering technology and is an easy framework to learn due to its intuitive user interface.

Taking into consideration the analysis performed on Chapter 2 Unity was elected to develop the VR components of the work. From a technical perspective Unity can be used to create 2D/3D environments, which are usually composed of Scenes. A Scene consists of GameObjects, which serve different purposes, containing components that adds functionalities to them. These functionalities use C# as the primary scripting API. It can also, render the GameObjects using Materials (defining how a surface should be rendered), Shaders (small scripts that computes the colour of each pixel rendered, used in the Material configuration) and Textures (bitmap images). In addition, Unity fully supports development for Oculus, as it integrates an Oculus SDK that includes important assets, such as OVRCamera (which replaces the VR camera rig that controls the camera view in an environment).

Developing in Unity may enable integration with a special library/framework that can be added for developing VR human behavior experiments (UXF - Unity Experiment Framework). Considering all these advantages, Unity was the VR framework chosen for developing the VR

application. However, for this project, it was decided not to use this library and a framework was developed to meet the needs of the project.

#### *Message Streams*

The idea in this project is to have two applications on different devices that need to communicate with each other in real time to perform tasks. The solution found to achieve this goal is a broker that follows the publish/subscribe pattern, and among all the options, Kafka was chosen for the project. Kafka is an open source distributed event streaming platform that combines messaging, storage, and stream processing to enable storage and analysis of both historical and real-time data. Because Kafka is a fast, scalable publish-subscribe messaging system, made it a perfect candidate for streaming messages needed between applications (web and VR applications).

#### **4.3.2 Development**

For a initial development, requirements were analyzed and prioritized based on the system components that would allow the conceptual approach to be tested, as early as possible, to ensure that it was feasible and had the overall expected features and impact on the participants. At its core, the proposed approach has the Experiment Renderer, and the control over it, provided by the Experiment Controller, making them the two most important modules for first testing of the concept.

#### *Message Exchange between applications*

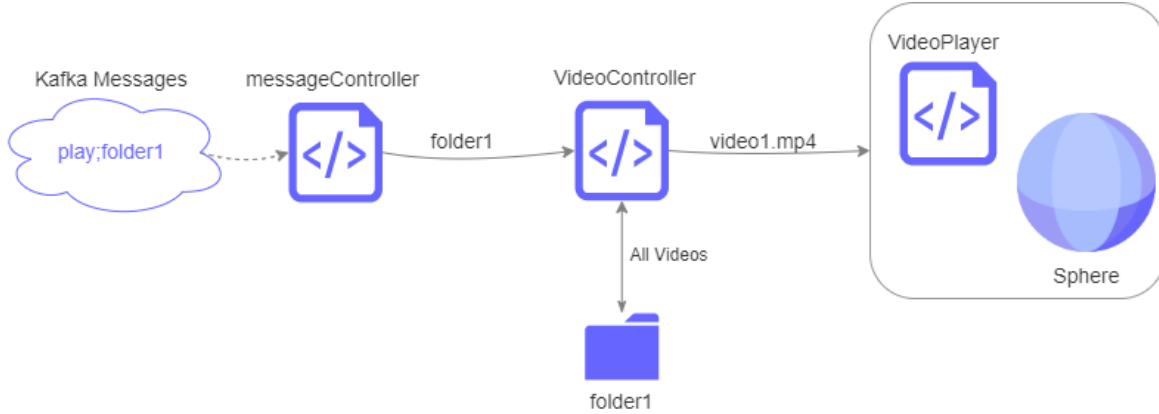
As mentioned earlier, this project involves two applications on different devices that need to communicate with each other in real time to perform tasks, and the solution found was Kafka. It was deemed necessary to implement Kafka on both applications, but due to incompatibilities between Kafka and the Oculus Quest 2, it was necessary to mediate communication through a REST API interface. A Docker container was used to deploy Kafka REST API, which is virtualized and can be deployed on any machine where Docker is installed without any additional steps.

#### *Experiment Renderer*

One of the most important features in this project is the ability to display the stimuli in VR. The challenge for this module is that it works independently and needs to run on VR glasses in this regard, this feature was developed in Unity. A first prototype was developed to understand and learn how to display a 360° video on the Oculus Quest 2 Headset. To accomplish this task, a Sphere was used as a GameObject that was used to play a video via scripting. A special material was created with a shadder that would invert the image to see the video from inside the sphere, using the OVRCamera in the centre of the sphere.

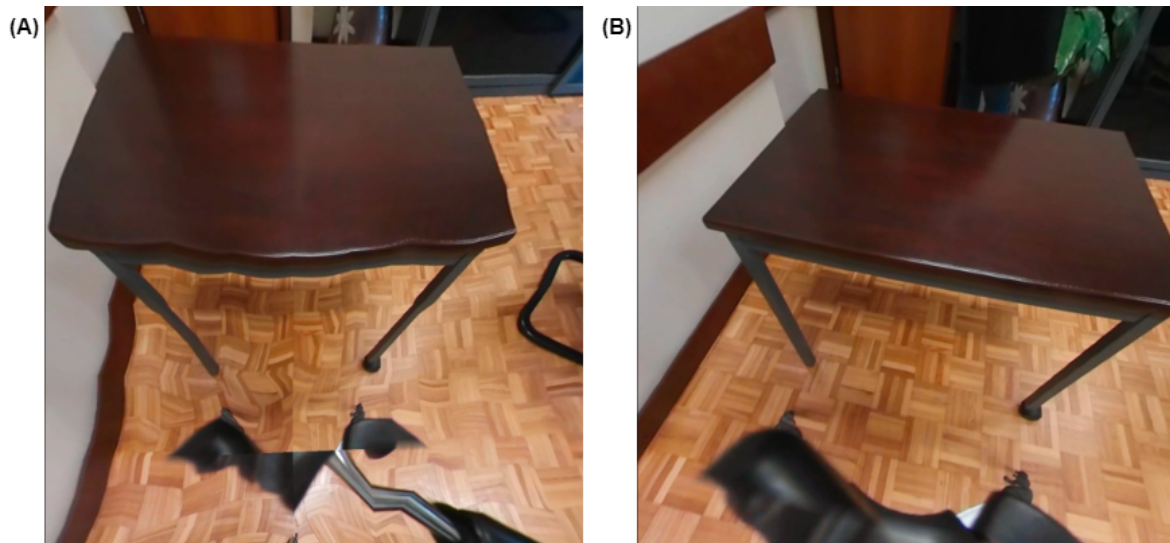
After being familiarized with the concepts, and given that the initial idea was that multiple videos would be played, the initial script was split into two parts: (A) one that controls which videos are played, and (B) one that plays the videos. To test this concept, a set of 360° videos in a folder stored locally on the Oculus Quest 2 were played whenever the app

was opened. After testing the concept, as shown in Figure 4.5, another script was created to control the stream messages received by the controller using Kafka messaging, receiving the "play" command and the folders from which to play the videos.



**Figure 4.5:** Experiment Renderer first proof-of-concept component with Stream Messages. This component plays all videos in a folder.

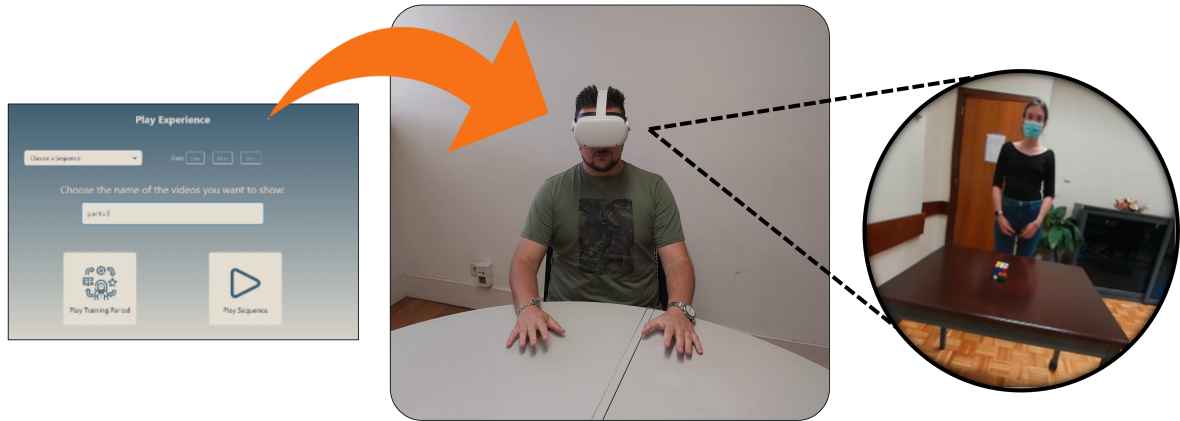
During the development of the tools for this first phase, several meetings were held with the research team and some feedback was received on what should be improved. For the Experiment Renderer, two main problems were mentioned as needing improvement: (1) The videos appeared distorted at the top and bottom, as seen in Figure 4.6(A), which diminished the sense of presence. To address this issue, the shadder used to reverse the image was optimized, the result can be seen in Figure 4.6(B); (2) There was a 1-second break between the videos that showed a gray background that also reduced the sense of presence, this problem was solved by optimizing the script used to play the videos.



**Figure 4.6:** Distortion that occurred in the 360° videos (A) and the optimized version (B).

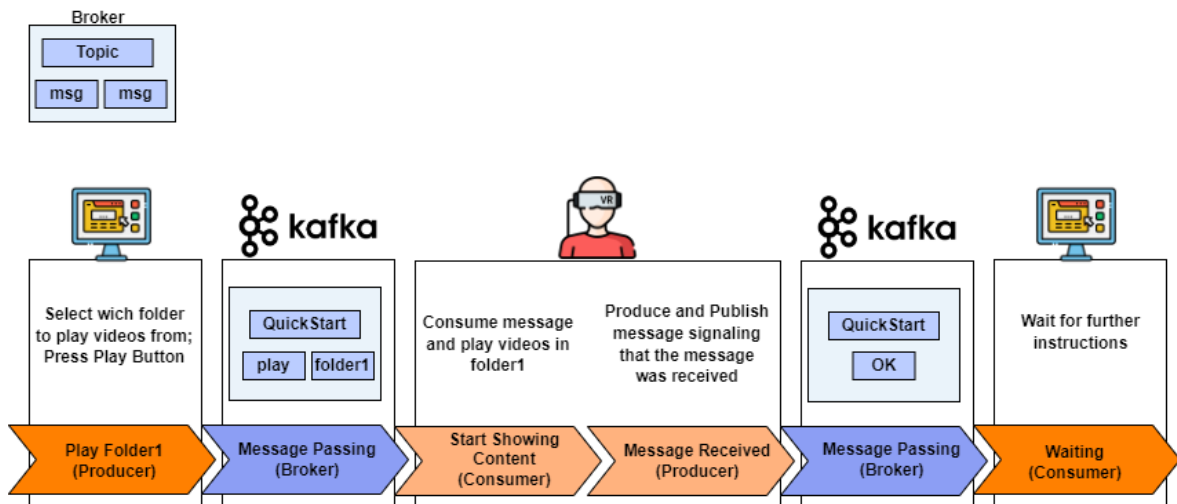
## Experiment Controller

In order to have control over the Experiment Renderer and know which videos are playing and when, a web-based control dashboard was created. When this tool was created, messaging was added for communication between the two modules, making it possible to select which videos to play by name or folder. Figure 4.7 shows the Experiment Controller and an example of a video exhibited in the Experiment Renderer.



**Figure 4.7:** Example of the state of the platforms for the pilot study: Left - Experiment Controller; Right - Experiment Renderer.

The messages exchanges for this first-proof-of-concept between the Experiment Controller and the Experiment Renderer are shown in Figure 4.8.



**Figure 4.8:** Example of messages exchanged between the Experiment Controller (Web App) and the Experiment Renderer (VR App) in the Pilot.

## 4.4 CONCEPT VALIDATION

The pilot study was conducted with help of an expert in conducting Experiments in Psychology, thus, this Preliminary Evaluation was carried out and written with her insight so that the results could be better explained. Two main goals motivated the first preliminary evaluation of the proposed system. The first was to validate the overall features of the current stage of the prototype to assert the ability to: (a) display a set of 360° videos in the headset, followed by a questionnaire scale; and (b) control the experiment (e.g., which set of videos to display). The second goal was to test which video capturing conditions are the most successful in approaching the virtual environment to real-world experiences. Specifically, the need to explore how the camera height and distance between the camera and a table, where an object would be placed, influenced the participant's experience.

### 4.4.1 Experimental Conditions

For recording the different 360° environments a Samsung Gear 360 camera was used mounted on a tripod. Six environments (filmed in the same room), two camera heights  $\times$  three distances to the table, each comprising of three 25-sec 360° videos, were created (total duration of each environment was 75-sec). Each video depicted a similar set of actions: a person approaching and putting an object on top of a table positioned in front of the participant who was seated on a chair (see Figure 4.9). Videos were recorded at different heights (110 and 115 cm), with a table positioned at different distances from the camera (35, 45, and 55 cm). Selection of these conditions was based on a literature review exploring the effect of camera height on virtual environments [91] and on preliminary testing of different conditions by the team. The prototype was subject to a series of tests before the pilot study was carried out and adjustments were made accordingly (e.g., a 1-second break between consecutive videos was occurring and interrupted the sense of realism and presence and, thus, was decreased).



**Figure 4.9:** Different events of the considered stimuli (360° video) with a person entering the room, placing an object on the table, picking it up after a few seconds, and leaving the room. While this is not shown, the participant was not limited to a single orientation and could freely look around to inspect the room.

#### 4.4.2 Protocol

Twelve participants participated in this pilot study (females = 7). Participants were asked to carefully explore each environment, while seated on a chair, they could look around, in the virtual environment, to inspect the room around them. The order of the three videos within each environment was counterbalanced across participants. The order of the presentation of the six environments was randomly determined for each participant. At the end of each environment, participants rated 12 items on a 5-point Likert-type scale ranging from 1 (nothing) to 5 (very much). Some of these questions were from the Presence Questionnaire [92], and others were created specifically for this study, shown on Table 4.1. Other subjective feedback was also collected (e.g., "How comfortable did you feel in the virtual environment?", "How involved you felt in the virtual environment?"). The questions were presented verbally so that participants would not have to remove the Oculus.

### Questionnaire used for the pilot

**Scale:** 1–nothing; 2–little; 3–reasonable; 4–quite a lot; 5–a lot

1. How natural did the environment feel to you?
2. How similar did the experience in the virtual environment seem to you compared to the real-world experience?
3. Did the size of the table seem suitable for you?
4. Did the person’s size seem appropriate to you?
5. How well were you able to examine the objects?
6. How well did you examine people?
7. How present did you feel in the virtual environment (i.e., feeling of being there)?
8. How involved did you feel by the virtual environment?
9. To what extent did you feel that you were sitting at the table?
10. How aware were you of the real world while in the virtual environment?
11. How comfortable did you feel in the virtual environment?
12. To what extent did you feel unbalanced, dizzy or sick during your experience in the virtual environment?

**Table 4.1:** Questionnaire used for the pilot.

#### 4.4.3 Results

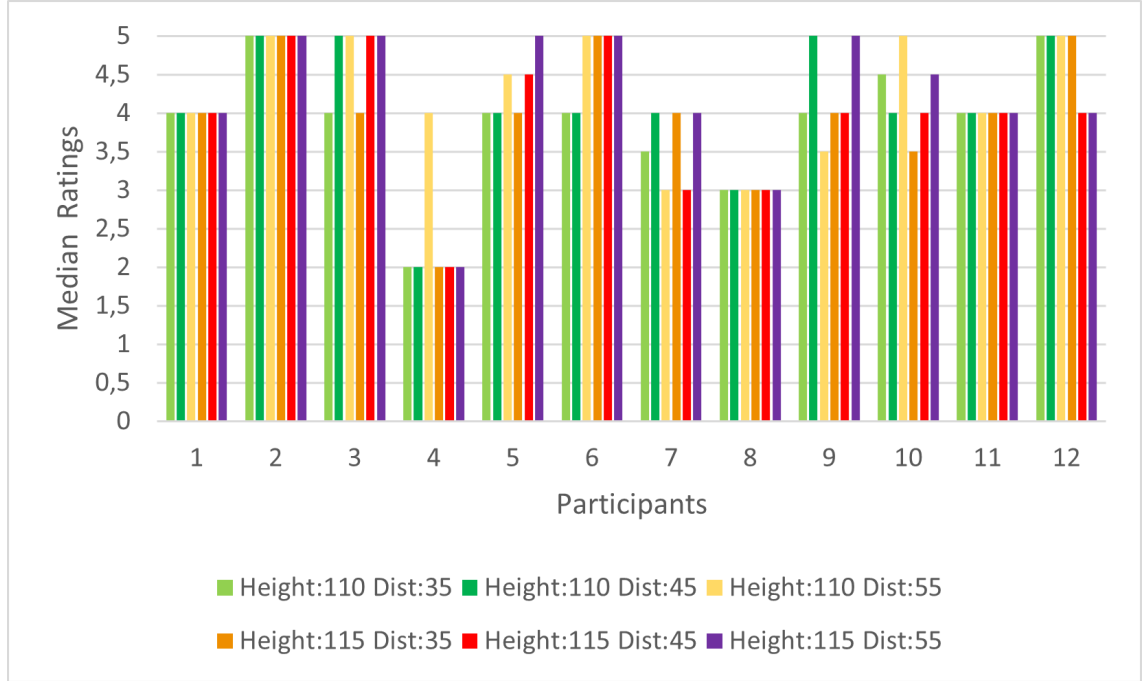
The median values obtained on the considered set of items for each environment are presented in Table 4.2. Overall, when looking at the median values across participants, the highest values were obtained for the environment captured at the height of 115 cm and the distance of 55 cm and for the environment captured at the height of 110 cm and the distance 55 cm.

exp. cond.	height (cm) distance (cm)	110			115		
		35	45	55	35	45	55
responses	median	4	4	4.25	4	4	4.25

**Table 4.2:** Results of the validation study: median for the responses given by the participants to queries about the naturalness of different characteristics of the VR environment.

When we look at the median rating provided by each participant to each environment (see Figure 4.10), we see that the environment captured at the height 115 cm and distance 55cm and the height 110cm and distance 55 cm obtained the highest rating for 2 of the 12 participants each (total 4 of 12 participants). Thus, there is a consistent choice on the distance (55 cm); the preference for different heights (110 or 115 cm) might be due to variability on the participant’s own height.

At the end of the task, participants verbally expressed a higher preference for the environments presented last. Because the order of presentation was determined randomly for each participant, we opted to formally explore a possible influence of the order of presentation of the environment and the preference rank ordering derived from the participants’ ratings. A Spearman’s correlation revealed a moderate significant correlation effect between the presentation and the rating rank order,  $rs = .403$ ,  $p < .001$ . This suggests that, indeed, participants



**Figure 4.10:** Median rating provided by each participant for each environment.

tended to rate higher those that were presented last. It also hints that the repeated exposure (or habituation) to these types of environments tend to increase the sense of presence which is a positive indication for using it in the envisaged experimental settings.

#### 4.5 CONCLUSION

In this chapter, a set of tools was conceptualized to support creating and running the experimental studies adopting this novel paradigm. At this first stage of development, the core modules of the proposed solution were developed to support a pilot study and include: (a) the Experiment Renderer, which allows showing the 360° video stimuli in the VR environment; and (b) the Experiment Controller, running on a desktop PC, responsible for controlling which videos are presented to the participants and when. In the initial evaluation, the results suggest that the system is adequate for supporting the experiment, being able to present the desired sequences of videos in a credible manner, and already allowed the validation of the acquisition parameters for the 360° videos. Overall, the preference of the participants for the environment that was presented last, and since the order of presentation was random, hints on the positive effect of repeated exposure in increasing the sense of presence. The gathered results and feedback motivates the development of the remaining modules.

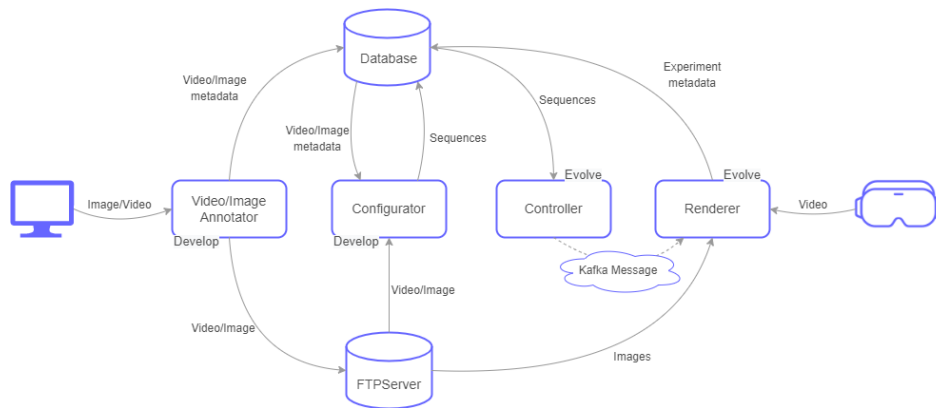


# Supporting the Full Experimental Protocol

Chapter 4 was devoted to a first validation of the conceptualized solution and, to that purpose, a minimal viable approach was developed to support it. After the very positive results obtained, this chapter is about the development of the first full version of the system in order to provide the researchers with a system to support them before, during and after the experiments. To guarantee the system has a Human-Centred interface and is usable, it also presents some evaluations made to the system usability.

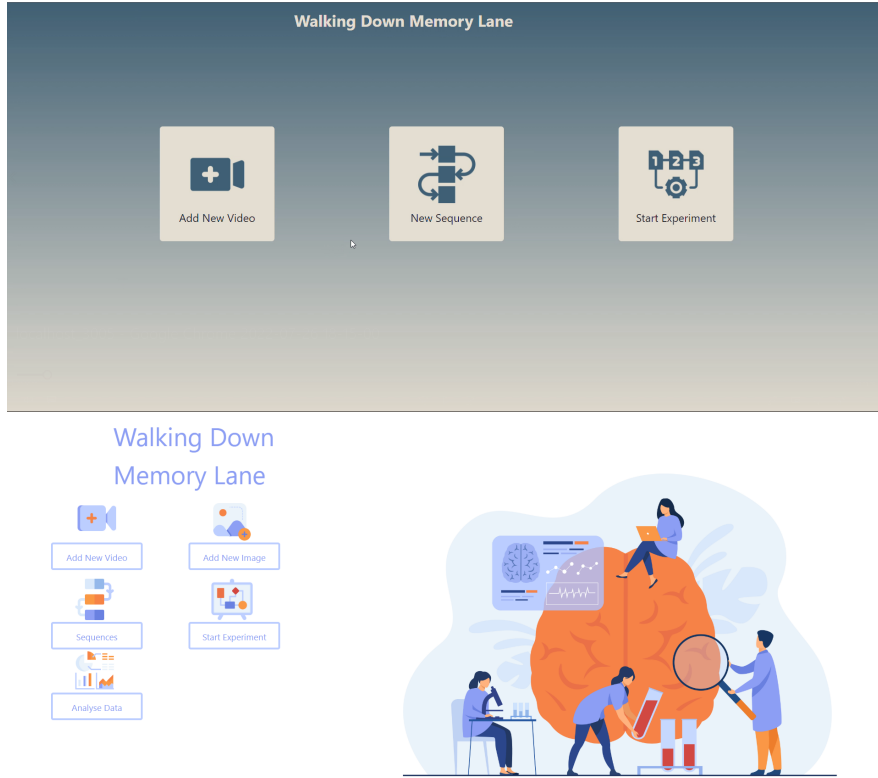
## 5.1 CURRENT SOLUTION

Considering all the requirements presented in Section 3.3 and the feedback obtained about the pilot study, Section 4.3, we defined a solution to the proposed problem, depicted in the system presented in Figure 5.1, a more detailed description of each module will be provided in what follows.



**Figure 5.1:** Diagram depicting the overall modules and components required to accomplish the proposed solution from stimuli creation to their presentation on the VR glasses.

The iterative process of the web application, brought also the need to improve the user interface taking into consideration the domain experts' feedback and an overall example can be seen in Figure 5.2.



**Figure 5.2:** Different stages of user interface development: Older Version of Interface Appearance, on top; refined interface of the Home Page, on bottom.

### 5.1.1 Video and Image Annotator

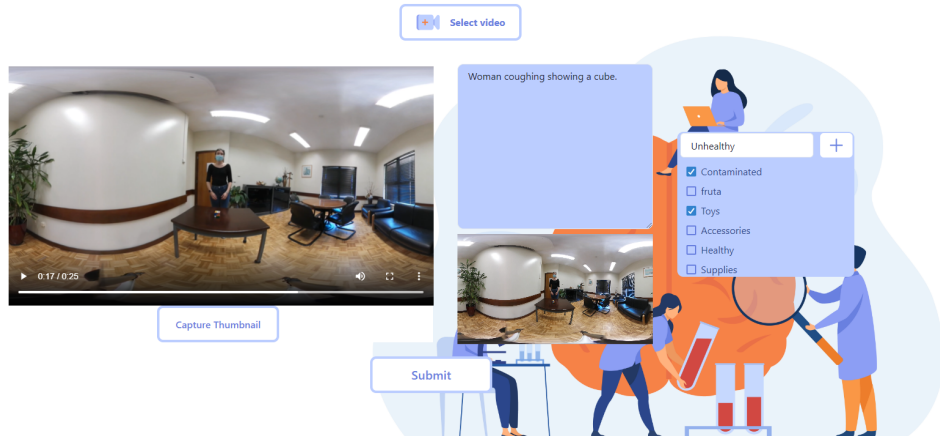
The proposed project is a platform to assist psychologists in their research, as it was deemed appropriate to create a way that would allow them to create a database for their studies and for that reason a way to add new stimuli to the system. With this intention, the Video Annotator was created, a place where new video stimuli can be added to the research database. Taking into account the feedback received in the multiple meetings with the research team, the information needed for the database to be used later was defined.

In this module, as shown in Figure 5.3 (Top), the user can upload a video from a folder, preview the same video, select the main video frame to be used as a thumbnail, add a description of the video content, add or select tags that match the video, and, finally, submit it.

The modules interface is mostly straight forward, but there are a few things in the submission phase to be taken into account. The fact that the videos occupy a large amount of storage space, makes them less suitable to be stored in a database due to the limited storage space in the containers and the delay felt during the download times. A solution that keeps

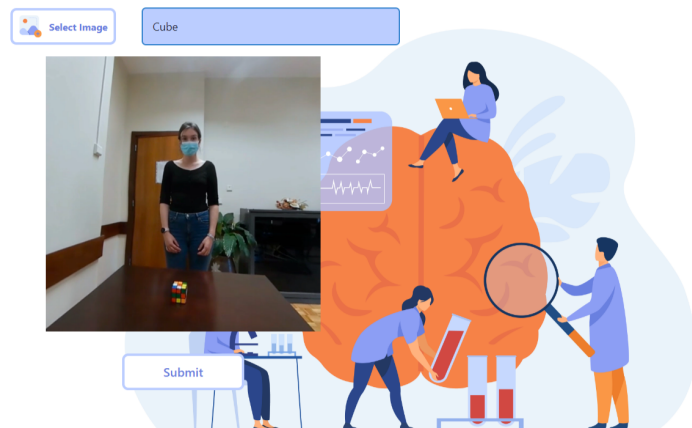
## Add Video

Home Page



## Add Image

Home Page



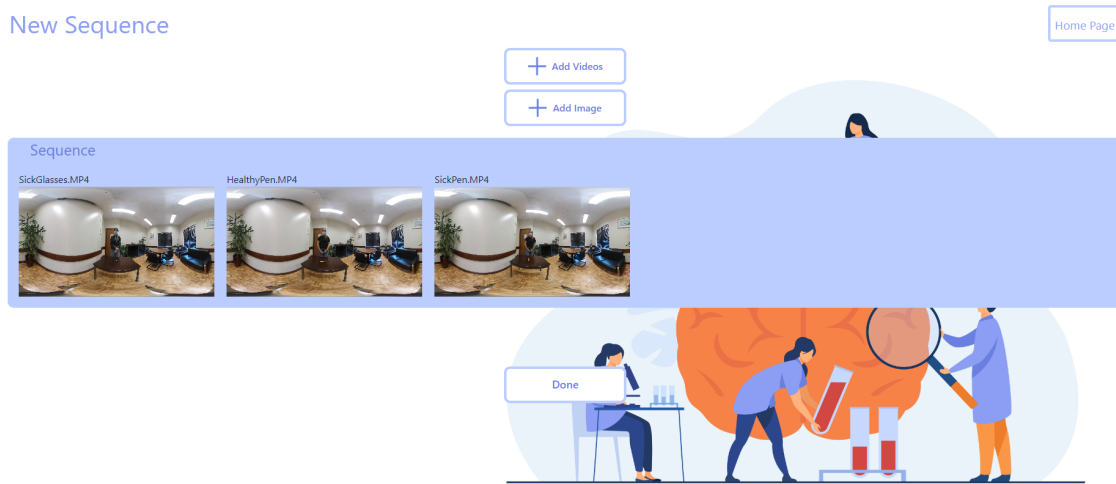
**Figure 5.3:** Example of the user interface created for the Video Annotator, on top, and the Image Annotator, on bottom.

the videos as readable independent content is more compatible with the idea of a dataset that can be shared, in the future. So, the solution found was to create a common storage space and establishing an FTP server, allowing using the videos in other modules, while their metadata is stored in the database. Both, database and the FTP server, were deployed via a Docker container to simplify the deployment and replication of the system.

Later, in the discussion with the team, it also seemed necessary to also annotate images that could be used in the memory tests to be presented in the virtual environment. As can be seen in Figure 5.3 (Bottom), it is possible to upload an image, give it a name and submit it in the same way as the videos.

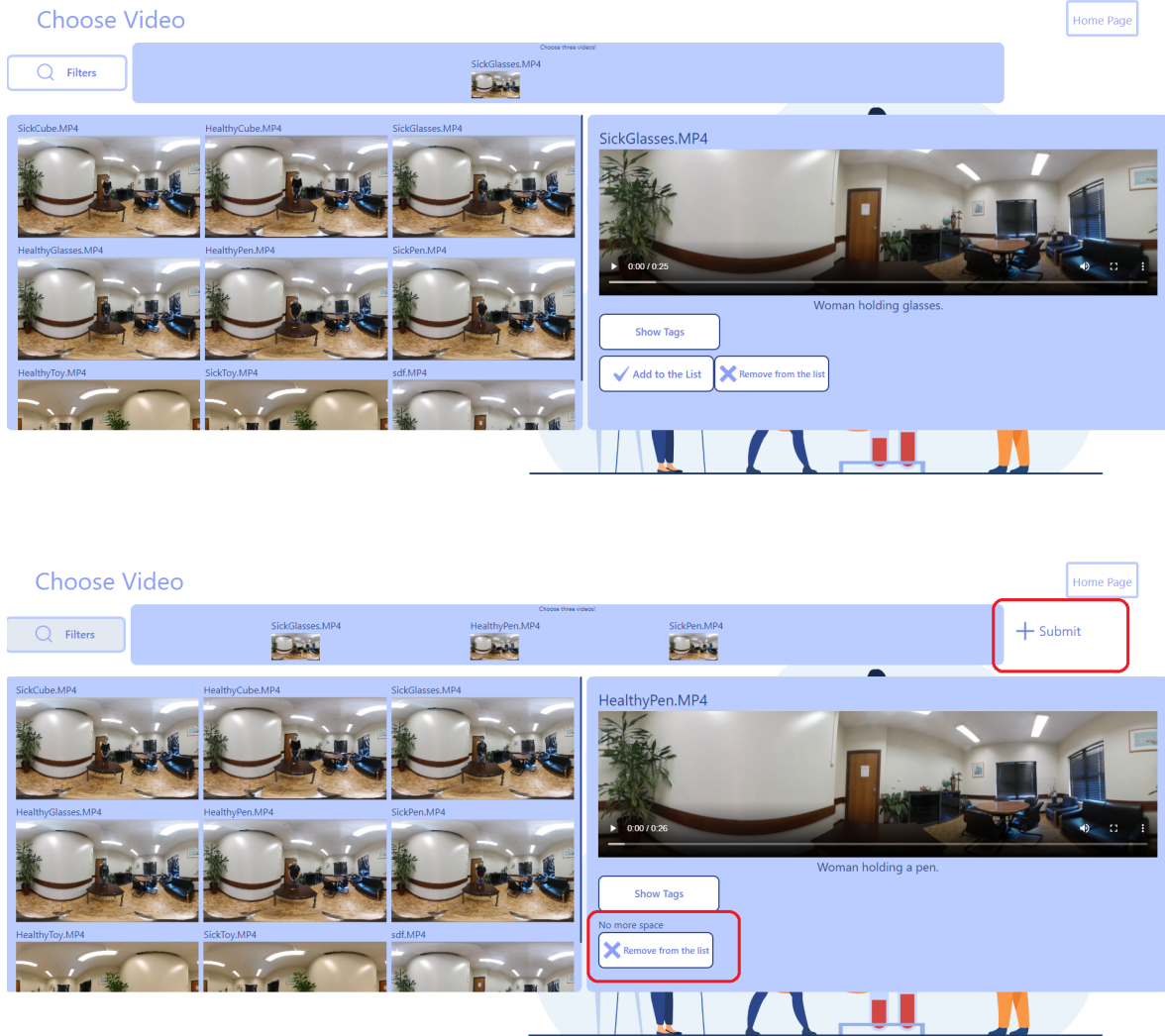
### 5.1.2 Configurator

The next step in this system was to allow researchers to configure experiments in advance. To accomplish this task, the configurator module was developed, divided into four different pages. The first page allows the user to see which sequences are already in the database. The following page, as shown in Figure 5.4, allows the user to create a sequence, in this case a sequence of multiple sets of three videos and three images. Here there are two buttons to choose from depending on what the user wants to add to the sequence, videos or images, and this sequence is displayed at the center of the page. After the user is satisfied with the created sequence, they can submit it, name the sequence and it will be saved in the database.



**Figure 5.4:** Example of the user interface created for the Configurator: State of the sequence.

The remaining two pages, which are structurally similar, present how to add a video or an image to the sequence, as shown in Figure 5.5 (Top), where all the videos and images contained in the database and on the FTP server are displayed, the possibility to filter them using the tags in their metadata, and when a video/image is selected, a preview of the video/image and its metadata is displayed, as well as a button to select the video or image to be added to the sequence. After reaching the limit of three videos or images selected, a submit button appears and the possibility of adding new videos disappears to show the user that they cannot select more videos or images, these difference can be seen in Figure 5.5 (Bottom) encircled in red. This submit process sends the chosen videos/images to the previous page and adds them to the center of the page, as said before. This configuration, as mentioned earlier, is stored in the database to be later used in the controller to help optimize the time consuming task of the configuration of the sequence.



**Figure 5.5:** Example of the user interface created to Choose Videos, on top, and the differences encircled in red after reaching the limit of three videos, on bottom.

### 5.1.3 Controller

The development of the controller module, received small changes since the pilot trial, given the fact that already did what needed to be done. The changes in this module, were the possibility of selecting a sequence from the database, instead of having to write every name of the videos that the user wants to play in the virtual environment and add an id to the participant. After choosing the play button, this information would all go in the Kafka message to the Renderer. Then, after pressing the play button a page appears where some feedback can be seen, where the experimenter can see in real time which video or image are being shown to the participant, and take some notes to be saved later in the database.

Some changes were made to the message exchange, an example can be seen in the Figure 5.7, also a new topic was added, "trainperiod", to the Kafka messages allowing the train button

sequence1

Participant Name:

ex: 1,2,3

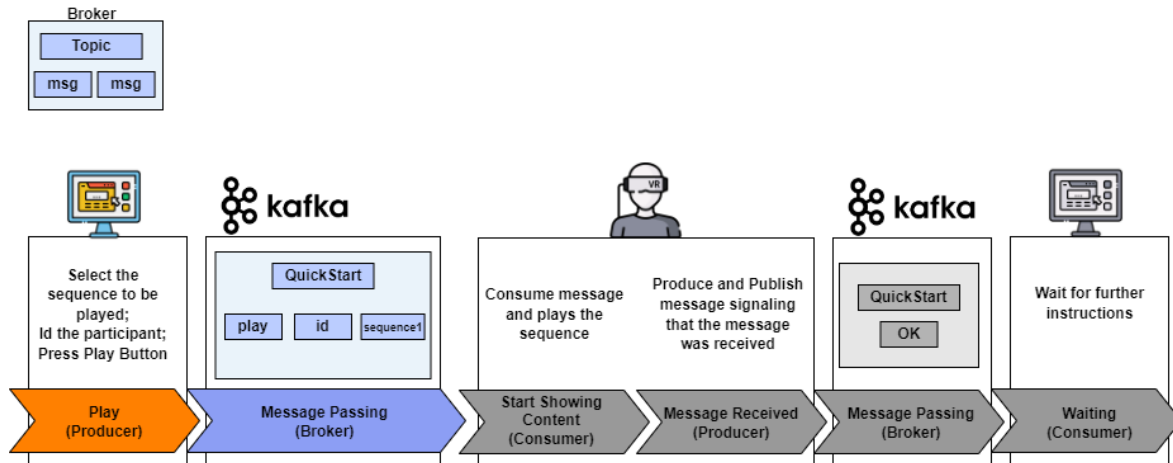
Play Training Period

Play Sequence



**Figure 5.6:** Example of the interface created for the Controller.

to be used to display a longer video in the Experiment Renderer to let the participant get acquainted with the environment. The repeated exposure (or habituation) to the virtual environment has been shown in the pilot trial, as said earlier, in section 4.4.3, to be a key element to the experiments, therefore the possibility to enable a period of habituation to the environment was created.

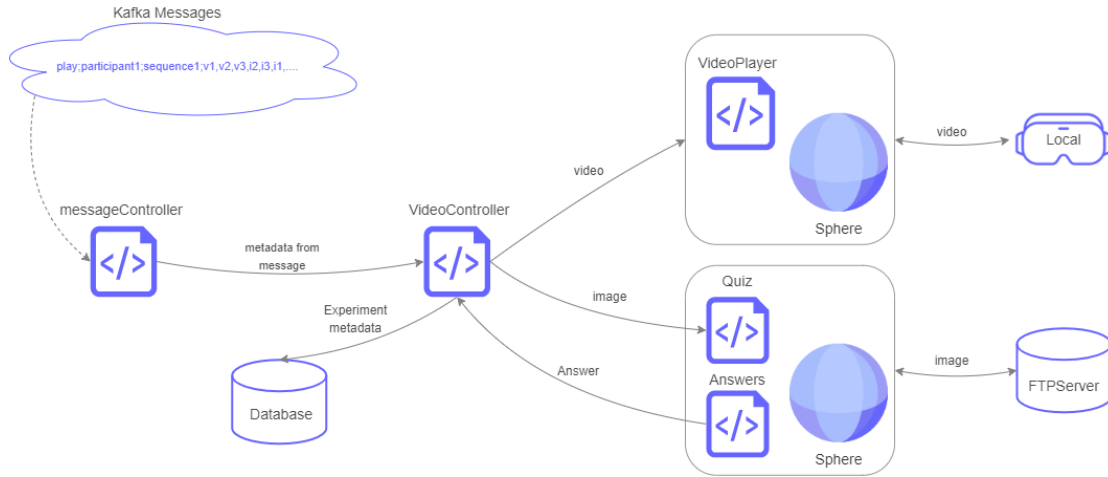


**Figure 5.7:** Changes made to the message exchanged between the Controller(Web App) and the Renderer (VR App)(Play Experiment)

#### 5.1.4 Renderer

The Renderer module has undergone some changes after the pilot trial. The possibility of answering a memory test was added to the previous content after the presentation of the videos, to include this feature another sphere was created that contained two scripts, one to get the images used in the memory test from the FTP server and show them, and another one to receive the answers, "healthy" or "unhealthy", from the user through the controllers.

The same script used in pilot trial to control which videos would be played was also used to control which images will be displayed and when, and to save all the answers from the memory test to be later send to the database. At the end of the experiment, all the answers from the memory test together with the participant’s identification, the sequence of videos and images that were shown to them are sent and stored in the database. In order to facilitate the researchers in properly analyzing and interpreting the experiment the answers are stored together with the images, as will be shown in Section 5.1.5.



**Figure 5.8:** Diagram depicting the overall components required to accomplish the proposed Experiment Renderer architecture solution.

### 5.1.5 Experimental Data

The analysis of the prototypes by the domain experts in one of the several meetings held during the work brought forth the requirement for an overview of the data collected. This new requirement was met by creating a page that displays a table with all the data from the experiments, presented on Figure 5.9. Researchers must also be able to analyse the data to draw conclusions from the experiment. To do this, they usually use Excel spreadsheets to facilitate the analysis. Therefore, the possibility of downloading a CSV file containing all the necessary information has also been added, accordingly to the researchers’ needs.

Experiments Data

Go back

PARTICIPANT	SEQNAME	IMAGE1.PNG	IMAGE2.PNG	IMAGE3.PNG	CUBE.PNG
participant1	Sequence1 Show Sequence	Unhealthy	Unhealthy	Healthy	
participant2	Sequence2 Show Sequence	Healthy	Unhealthy	Healthy	
participant3	Sequence123 Show Sequence	Healthy	Unhealthy	Healthy	
participant4	Sequence1273 Show Sequence	Unhealthy	Healthy		Healthy
PARTICIPANT	SEQNAME	IMAGE1.PNG	IMAGE2.PNG	IMAGE3.PNG	CUBE.PNG

Download

Data from all the experiments

**Figure 5.9:** Experiments Data Page.

## 5.2 RESULTS OF THE EVALUATION OF THE DESIGN

Considering that the experimental workflow has a complete version, it was deemed important to perform an evaluation of its usability and usefulness to inform further developments. In this regard, two evaluation methods were used: Heuristic Evaluation and Usability Study, as described on what follows.

### 5.2.1 Heuristic Evaluation

The system was modified in some aspects during the development in the multiple meetings held with the research team, mainly to meet their needs, and not just in a usability perspective. For this reason, a heuristic evaluation was considered to get better and faster feedback to make the system more usable, for a first complete version of the functional prototype.

Heuristic Evaluation is considered a Usability Inspection Method that focuses on the UI, i.e., how things are seen from the user's perspective. In this type of evaluation, the interface is examined by a small group of evaluators and evaluated against a set of usability principles. The usability principles used to evaluate this first part of the system are Jakob Nielsen's Ten Usability Heuristics<sup>1</sup>. These principles are presented in more detail in Appendix B.

To evaluate the interface of this project, three evaluators (two male and one female) conducted an evaluation using Nielsen's ten usability heuristics. The evaluators needed to have some knowledge about the topic and how to perform heuristic evaluations. For this reason, they all worked in the IT fields, had already performed heuristic evaluations and were between 24 and 28 years old. To help with the evaluations, they were given the table shown in Table B.1, and a severity scale was used that is commonly used in this type of evaluation, with zero representing a low-level usability problem and four representing a high-level usability problem. For more information about the Heuristic Evaluation and the severity scale <sup>2</sup>, see the Appendix B.

<sup>1</sup><https://www.nngroup.com/articles/ten-usability-heuristics/>

<sup>2</sup><https://www.nngroup.com/articles/how-to-rate-the-severity-of-usability-problems/>

## Results

After the three evaluators performed the heuristic evaluations, the results were collected and analysed to help solve the problems identified. The results are presented in the Table 5.1, where the severity scale is mapped to the Nielsen's Heuristics, the tables provided by the evaluators can be viewed in more detail in the Appendix B.

Evaluators	Nielsen's Heuristics									
	1	2	3	4	5	6	7	8	9	10
Evaluator1	2	0		1	3	1	2			
Evaluator2	3		4/2	0	4/2	2	3		4/2	
Evaluator3	1	2	2/3		2/3/3	2			3	

**Table 5.1:** Results of Heuristic Evaluation.

The results Table 5.1 show that there is a usability issue with a four on the severity scale, which means that this is one of the problems that must be solved first. This problem is related to lack of feedback and error prevention. To keep track of the problems found, a list of problems to be solved was created based on the feedback received, which is shown in Table 5.2.

Problems found by the Heuristic Evaluation

- 
1. No feedback if the videos/images are submitted or when - severity: 2/1
  2. Misunderstanding the meaning of the words "tags" and "filters" - severity: 1/0
  3. Sequence Name disappears while constructing the sequence - severity:3
  4. No feedback on how many videos/images can be added - severity:1
  5. Expected a video of what was happening in the experiment details - severity: 2/0
  6. The way of videos/images selected are eliminated - severity: 3/2
  7. The "Go Back" button wasn't specific enough - severity: 2
  8. Pressing the "Go Back" button deletes all the progress done - severity: 4/3
  9. User can't delete videos/images after they were submitted - severity: 2
  10. Selecting files that was not accepted later in the system - severity: 2
- 

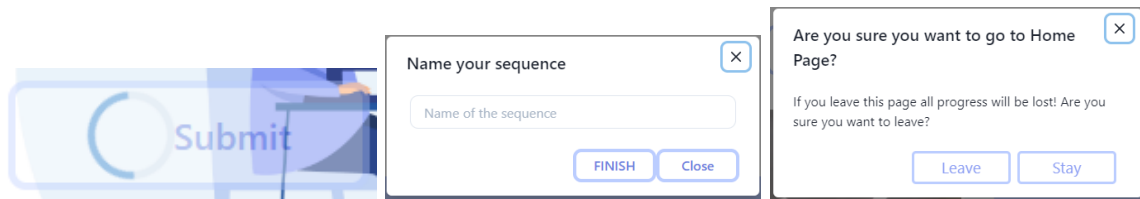
**Table 5.2:** List of problems to solve taken from the results of the heuristic evaluation.

Some of the items on the problem list could not be resolved in time for the usability tests presented below due to lack of time, but the more severe ones were corrected. The following items of the Table 5.2 have been corrected:

- Regarding item **1**: A waiting symbol appears while the information is being submitted and the submit button appears faded, presented in Figure 5.10(left);
- Regarding item **2**: All words "filters" were replaced with "tags" unless they are actually used as filters;
- Regarding item **3**: The input to add the sequence name only appears after the entire sequence has been configured, presented in Figure 5.10(center);
- Regarding item **4**: A message indicating that only three videos/images can be added;

- Regarding item **6**: Added the option to select a video from the preview list to be eliminated;
- Regarding item **7**: Changed the button name to "Home Page";
- Regarding item **8**: When pressing the "Home Page" button, a popup now appears informing the user that all progress will be lost if he/she actually wants to leave the page, presented in Figure 5.10(right);
- Regarding item **10**: Limited the video and image selection so that only accept .mp4 and .png files, respectively.

Regarding item **5**, it cannot be solved due to the network restrictions (e.g., network on the university campus) that did not allow the direct connection between devices that forced the use of a router without internet connection causing a lack of internet connection on the Oculus Quest and precluding the use of mirroring to understand on what is happening on the VR application from the web application side.



**Figure 5.10:** Example of some of the changes made to the interface to solve some issues found on the Heuristic Evaluation: waiting symbol on the submit button, on left, pop up created for the sequence name, center, and the warning that appears after pressing the "Home Page" button, on right.

### 5.2.2 Usability Tests

After addressing the issues identified in the heuristic evaluations, the next step was to test the usability of the companion tool. To test the usability of the application, a series of tasks were created to test the general features, these tasks were obtained by analysing the proposed scenarios, see Chapter 3. Ten participants participated on this usability test (female=6) with ages between 18 and 55 (not including any of the experts that performed the heuristics evaluation) were given these tasks, shown in Table 5.3, and asked to talk about their thoughts during the process, using the Think Aloud method. The intention was to make an initial assessment of general usability, but since there were few domain experts and the persona profile of the psychology student, see Personas on Section 3.1, is not very different from that of a person with no knowledge in experiments or in the MTC research, it was considered relevant to include participants in the evaluation who had no direct relation to the domain, since the goal was to find out how understandable and usable the developed interfaces were. The same usability tests were conducted with two different types of users, 60% of the participants were general users with no Psychology or Experimental Psychology background, and 40% were the target users with Experimental Psychology background, before they began the evaluation, they were informed about the conditions of the study and gave their consent for the evaluation. The same brief description of the purpose of the system was

read to both groups of users, presented on Appendix B Section B.2. During this evaluation, some observations were taken: (a) Whether the task has been accomplished; (b) The time needed to complete the task; (c) Whether the user made any mistakes in completing the task and, if so, what they were; (d) Whether the user got lost for a moment and where; (e) Whether the user asked for help and where; (f) The difficulty level of the task. The table used to note down this observations can be seen in more detail in Appendix B on Section B.2.

### Tasks created for the Usability Evaluation

---

1.	There are new videos to add to the "Walking Down Memory Lane" database. Add them, check if they are ok and add any relevant information about the videos.
2.	Add the "Image1.png" to the "Walking Down Memory Lane" and add information about it.
3.	Check if a sequence has already been saved with the name "SequenceTest"
4.	Create a new Sequence : <ul style="list-style-type: none"> <li>a) Add a video associated with "Healthy" and "Toys", and add the remaining videos associated with "Sick" and "Accessories".</li> <li>b) Add images associated with the previous added videos.</li> <li>c) Give the sequence the name "SequenceEvaluation" and Save it.</li> </ul>
5.	Start an experiment with "sequence1".
6.	Check if the video is playing and if so what video is playing.
7.	Check if there is experiment data available and if so how many participants were collected. <ul style="list-style-type: none"> <li>a) Save this data on your computer.</li> </ul>

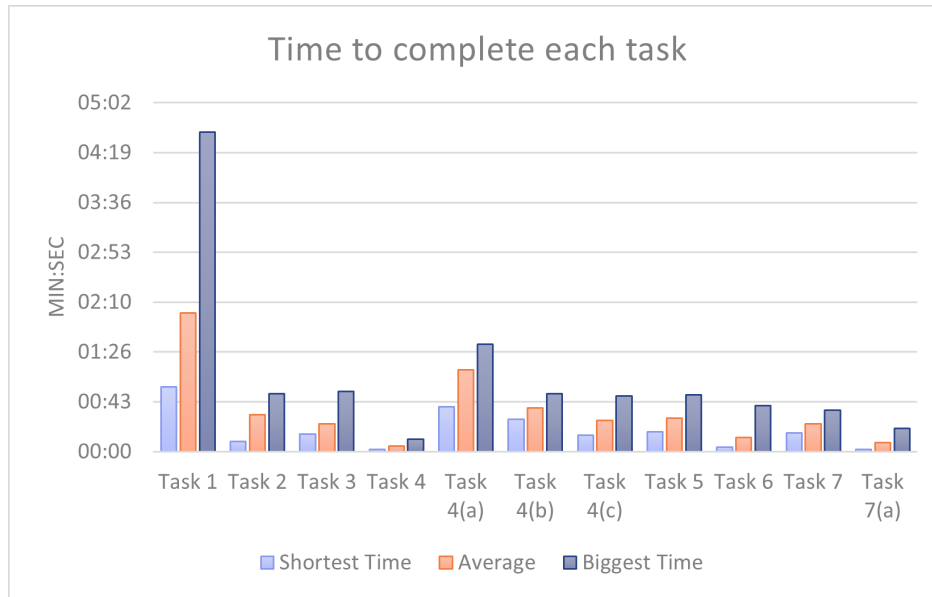
---

**Table 5.3:** Tasks performed by users during the usability evaluations.

### Results

After all the participants performed their evaluations, the results were analysed and transformed to a graphical format for better understanding, the results graphs for each metric are presented on Appendix B Section B.2. Even though 60% of the participants do not have knowledge in the domain all participants completed the tasks with or without help, but participants with a background in Experimental Psychology required a much lower percentage of help and were less lost in the application than general users. The Figure 5.11, shows the shortest, average and biggest times to complete each task by the participants. It can be seen the tasks that takes more time to complete are the ones that are more complex,i.e., tasks that have more information to be added by the users (e.g., task 1 adding a video and information about it) or task that have more information to be looked for (e.g., looking for a video to complete task 4 (a)).

The Figure 5.12, shows the number of errors made by each participant while performing the tasks. As can be seen, the number of errors made when using the companion tool were significantly different for each type of user, showing that the group of users with a background in experimental psychology (target users - right graph ) made significantly fewer errors. The same type of difference can also be seen in Figure 5.13 by analysing the difficulty level perceived



**Figure 5.11:** Time spent on each task.

by each participant, it can be seen that the users without a background in experimental psychology (general users - left diagram) had more difficulty completing each task compared to the target users (right graph ).

Analysis of the graphs shows that the group of target users felt more comfortable performing the tasks, made fewer errors, and needed less help. It is hypothesised that these differences between the groups are due to the fact that the target users already know what they need to do to construct an experiment, even if they have never seen the companion tool being used.

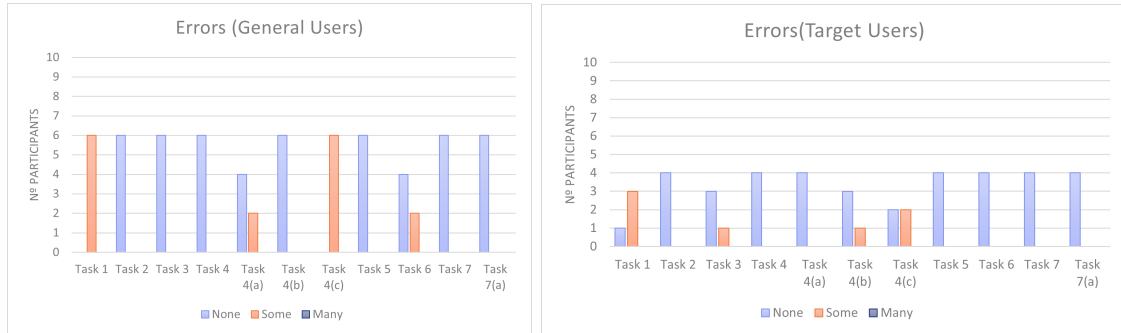
Analyzing more deeply the graphs in Figure 5.12, there were two tasks that generated more errors:

- Task 1 - the majority of the errors were due to the fact that the participants did not fill all the fields needed to add a new video to the database, and that would create problems later on the other features, e.g., a video would appear without thumbnail on while creating a sequence.
- Task 4(c) - some of the participants pressed multiple spots on the application and did not know where to press to add a name to the sequence.

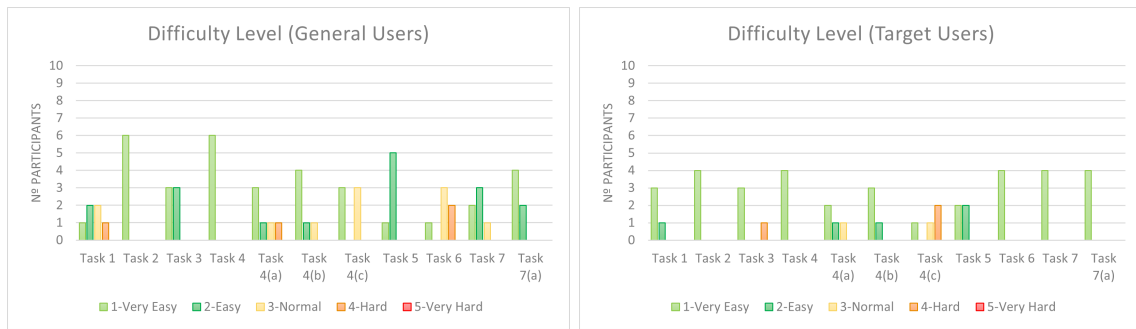
These problems found were easy fixes, to solve the problem on task 1 a popup was created that would appear to let the user know that some information was missing, and for task 4(c) the problem was that the name of the button that allowed to add the name to the sequence was a little vague, so it was changed for a more specific one "Name & Save it". Further looking into the Figure 5.13 the users add more difficulty to:

- Add a video to the database (task 1), general users felt more difficulty to complete this task mainly because they needed to fill all the information about the video.
- In task 4(a), the general users felt more difficulty because they did not see that the sequence was only three videos, and were somewhat confused of what healthy or unhealthy object means.

- Task 4(c), as said previously, the button made to add the name of the sequence was not specif enough to be the first option they take.
- Task 6 created some difficulty due to the fact that the users were looking for a videos instead of text.



**Figure 5.12:** Number of errors - None (0 errors), Some (1 or 2 errors), Many (>2 errors) - made by the participants for each task on the companion tool (web application) for general users, on left, and for target users, on right.



**Figure 5.13:** Difficulty level of the companion tool (web application) for general users, on left, and for target users, on right.

### 5.2.3 Questionnaires

#### *System Usability Scale and Results*

After completing the usability evaluation, all participants were asked to answer a SUS questionnaire consisting of 10 questions (see Table 5.4) and rated on a scale of 1 (strongly agree) to 5 (strongly disagree).

The average of the results of the total score of each participant in the companion tool is 80,5. Taking into consideration a score of 68 in the SUS questionnaire is considered to correspond to a usable system, the results for this system show that is considered an excellent usable system. A more detailed table with the scores given by each participant are presented in Appendix B in Figure B.10.

Analysing the answers given by the participants, it can be seen that the question "I think i would like to use this system frequently." received a less good score due to the fact that the general users will not use this system in their regular life, since it was made specifically for the MTC research and as it can be seen some of the better results on this question are from

### System Usability Scale Questions

- 
1. I think that I would like to use this system frequently.
  2. I found the system unnecessarily complex.
  3. I thought the system was easy to use.
  4. I think that I would need the support of a technical person to be able to use this system.
  5. I found the various functions in this system were well integrated.
  6. I thought there was too much inconsistency in this system.
  7. I would imagine that most people would learn to use this system very quickly.
  8. I found the system very cumbersome to use.
  9. I felt very confident using the system.
  10. I needed to learn a lot of things before I could get going with this system.
- 

**Table 5.4:** Questions used on the System Usability Scale Questionnaire [93]

the target users that will eventually use this system or a version of it. And it can also be seen that some brief explanation about some details in the system would be needed, at least for general users or for target users without knowledge about the MTC research.

#### *Virtual Reality Questionnaire and Results*

An additional questionnaire was made to the participants to retrieve some needed information about the Experiment Renderer, as it did not have a user interface beyond answering questions after the stimuli were shown. After watching a small example of a experiment (3 videos and 3 images (with questions)) it was asked to the participants to answer a set of questions, presented on Table 5.5. Some of the questions used were taken from the pilot study conducted on Section 4.4 (1-6), other questions were made to test the quality of the different 360° cameras used to record the stimuli and to test the platform with different video recording equipment to ensure everything worked the same (7-9) and the remaining questions were made to test the usability of the system when the participants have to answer questions on the virtual environment (10-12).

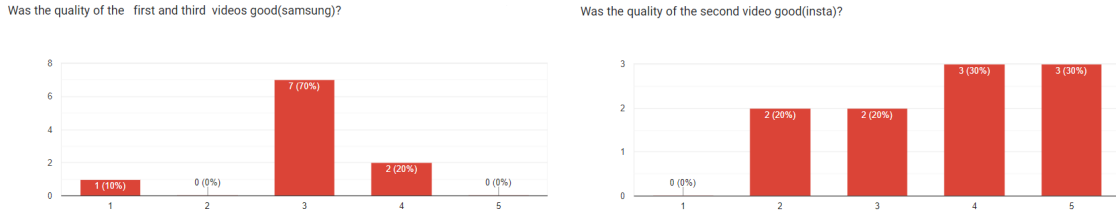
The videos shown to the participants in this stage of the questionnaire were filmed with the highest rated values on the pilot study, found on Section 4.4.3: camera distance from the table 115cm and camera height 55cm. Since it was applied the same questionnaire as in the pilot study the answers in this quiz were almost the same so, no new information to analyse. It was also added to the evaluation, videos recorded with different 360° cameras with the same environment with the intent to verify which camera would the participants prefer, and the results have shown a preference in the Insta360 One X2 camera, as we can see in Figure 5.14.

The remaining questions included the testing the new phase added to the VR application where the user was able to answer questions while on the virtual environment. Here it was found that the way of responding to the questions and how was intuitive, but the inconsistency about how many questions were answered, in this case were three questions to answer by each participant, presented in Figure 5.15, show that the lack of feedback if a question was answered was a problem, because people would press the buttons without realizing that was the same question but about other objects.

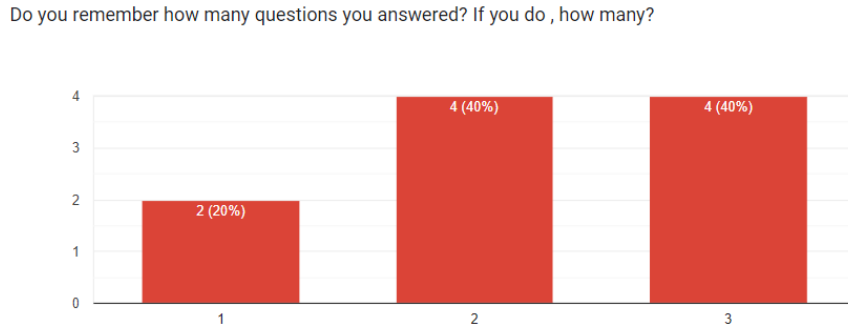
## Virtual Reality Questionnaire

1. How natural did the environment feel to you?
2. How similar did the experience in the virtual environment seem to you compared to the real-world experience?
3. How well were you able to examine the objects?
4. How well were you able to examine people?
5. How present did you feel in the virtual environment (i.e., feeling of being there)?
6. To what extent did you feel unbalanced, dizzy or sick during your experience in the virtual environment?
7. The same environment recorded with different cameras was shown, did you noticed any difference?
8. Was the quality of the first and third videos good (Samsung)?
9. Was the quality of the second video good (Insta360)?
10. Do you remember how many questions you answered? If you do , how many?
11. Did you find the way to answer the questions intuitive?
12. It was easy to read the questions?

**Table 5.5:** Questions used to evaluate the Experiment Renderer.



**Figure 5.14:** VR questionnaire: Preference between videos filmed with Samsung Gear360 camera, on the left, and filmed with Insta360 One X2 camera, on the right .



**Figure 5.15:** VR questionnaire: How many questions the participants thought they answered.

### 5.3 CONCLUSION

Considering the positive results obtained during concept validation, as presentend in Chapter 4, the aim of this chapter was to further develop the system to support the research

team in charge of the MTC research before, during and after the experiments. At the current stage of development, the modules, running on a Desktop PC, developed and optimized included: (A)Video/Image Annotator, which allows researchers to add new stimuli to the system, creating a database; (B)Experiment Configurator, which allows researchers to configure the sequences to be used later in experiments; (C)Experiment Controller is responsible for controlling which sequences are presented and when. It is also responsible for displaying feedback of the experiment and allowing researchers to take notes during the experiment. The module developed to show the 360° video stimuli in the VR environment has been optimized to allow participants to answer a set of questions without leaving the VR environment: the Experiment Renderer. Furthermore, based on the domain expert feedback an additional module was developed to support researchers after the experiments by allowing them to explore and download the data obtained from the experiments.

After the implementation of the architecture, the feedback received during the usability evaluation for general users and for target users was taken into account with good results, concluding that the system is efficient and user-friendly.

## Conclusions

The goal of this dissertation was to increase the ecological validity of MTC studies by allowing them to have an enhanced sense of presence and immersion, while allowing for experimental control and increasing the replicability and reproducibility of experiments. To this end, and in collaboration with the research team responsible for the MTC research, a system has been developed that meets the intended objectives, containing two applications: (A) a VR application that allows the experiments to be displayed to the participants, developed on Unity and running on Oculus Quest2; and (B) a Web application that serves as a companion tool to support the research team, developed on React and running on a Desktop PC.

The main goals for this project were established in close contact with the research team through initial brainstorming and iterative refinement of the context of use of the proposed work. Once the objectives were established, prototypes were created and evaluated in several meetings with the research team to clarify their needs for conducting experiments.

The initial objective, to begin developing the system, was that the conceptual approach should be tested as early as possible to verify its feasibility and to test its impact on participants. To achieve this, the Experiment Rendered and the Experiment Controller were developed first to test the concept.

To this end, a pilot study was conducted with the help of one of the MTC researchers. In this initial evaluation, the results indicate that the system is suitable for supporting the experiment, as it credibly renders the desired video sequences and it was possible to validate the recording parameters for the 360° videos.

After the positive results of the concept validation, the remaining modules were developed, leading to the current stage of the system. After creating this platform to support the research team, it was time to evaluate its usability. First, a heuristic evaluation was conducted by a group of experts to identify the prevailing usability issues in the companion tool. 80% of the issues were solved to the next usability evaluation.

The next evaluation, to new group of users were given a set of tasks that tested all features for usability. After completing these tasks, they were presented with a SUS questionnaire.

To also test the VR application, each participant was shown a set of videos and images with questions and, at the end, a custom questionnaire was presented to evaluate the application. The results of this evaluations show a high usability score, with minimal issues, indicating that the system is efficient and user-friendly.

During the development of this project, there were several challenges. One of the main problems was to enable the use of the equipment in networks that restrict direct connection between the devices (e.g., the university campus), which resulted in creating a local database and using an FTP server to provide access to the two applications. One of the issues that also took more time to solve was the incompatibility between Kafka and the Oculus Quest2, and it was necessary to mediate the communication through a REST API.

After surpassing this issues, the objectives for this dissertation were matched and a system that supports the full experimental protocol was developed with good results and good feedback from the MTC research team.

## 6.1 FUTURE WORK

Although the system has proven to be suitable and user-friendly for supporting experiments for the MTC research, there is still ways of improving, optimizing and enriching the current version of the system. Relatively to the current version of the system, some of the features could be improved:

- **Optimising perceived delay when loading, saving, or downloading content** - One solution to this problem would be to schedule backend tasks so they do not block the front end. Using task queues as a mechanism to distribute work across threads or machines would be one of the solutions to this problem.
- **Optimizing Message exchange between application** - Due to incompatibilities with Kafka and Oculus Quest2, it was necessary to implement an http endpoint to consume the Kafka messages, however, the Kafka messages needed to be consumed asynchronously, resulting in the consumer not catching some of the messages. A solution to this problem would be an interface with web sockets communication.
- **Provide some feedback on the VR memory test.** - This issue appeared on the usability evaluation of the VR application when participants did not know if the answer they gave through the controllers was received and since it takes longer to download the images, they pressed the buttons several times in a row and ended up not seeing all the questions presented. A solution to this problem would be a box surrounding the answer given or a pop-up window telling people to wait for the next question.

There are also new ways to enrich the system to support experiments, such as:

- **Automatic generation of sequences from the database** - To configure a sequence for the experiment, the user selects the videos and images one by one, which is a time-consuming task. To improve the time spent configuring sequences, it would be ideal to have a way to automatically generate the sequence by selecting a set of filters.
- **Insert custom questions and answers for the VR memory test.** - Normally, the questions and answers asked for the immediate memory test are always the same,

and for this reason, in the current version they are static information. An improvement to the system would be the ability for researchers to choose the questions and answers that they feel best fit the experiment.

- **Allow configuration of the number of videos and images** - It was determined from the beginning that this system would only allow a sequence to have sets of three videos and three images, as this was the way the researchers conducted the MTC experiments (three stimuli and three questions each in the memory test). The idea for the system is to later support different types of experiments, and for this reason the ability to define the number of videos and images to display would be an improvement to the system to better support the research team.
- **Mirroring the Experiment Renderer to the feedback page.** - In the evaluations, some participants have expressed their opinion on the feedback page, agreeing that they expected a live stream of what was happening, rather than information in text form, which would be an improvement for the system.
- **Connection to the Internet in both applications.** - One of the ways to facilitate the improvements for the system would be to set up a server that allows connection to the Internet.
- **Collection of participant behavioral and performance data** - One of the advantages of using a VR approach to experiments is the ability to retrieve a variety of data from participants. In the current version of the system, the only data that is collected is the data collected from the memory test. It would be an improvement for the experiments to be able to collect more data on the behavior and performance of the participants.



## User Manual



Figure A.1: Interface Manual: Home Page.

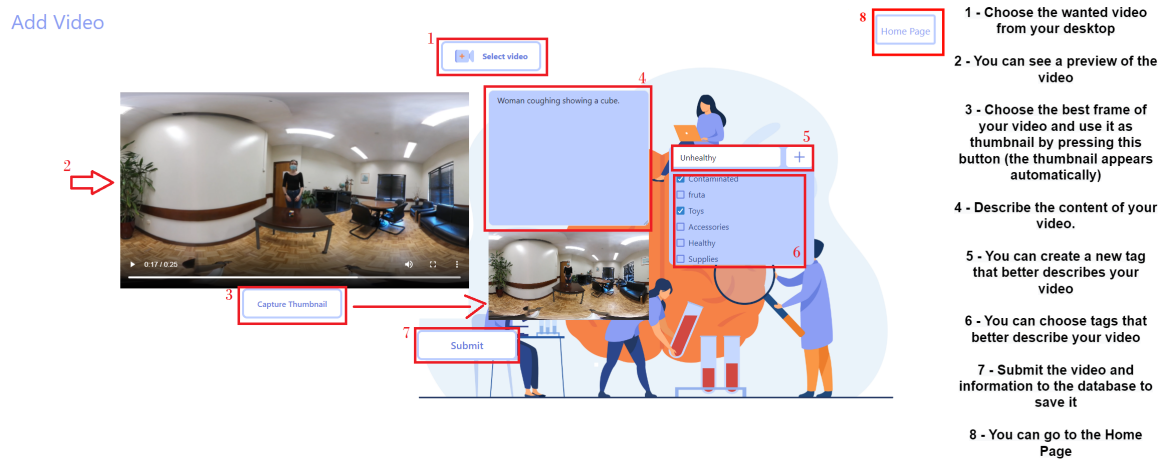
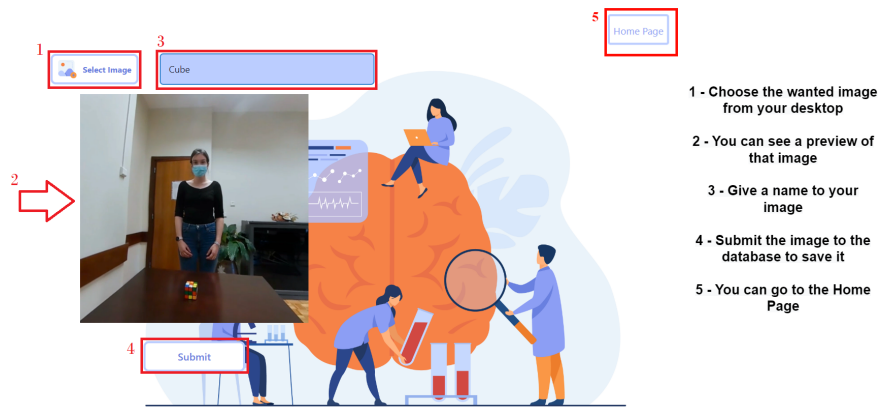


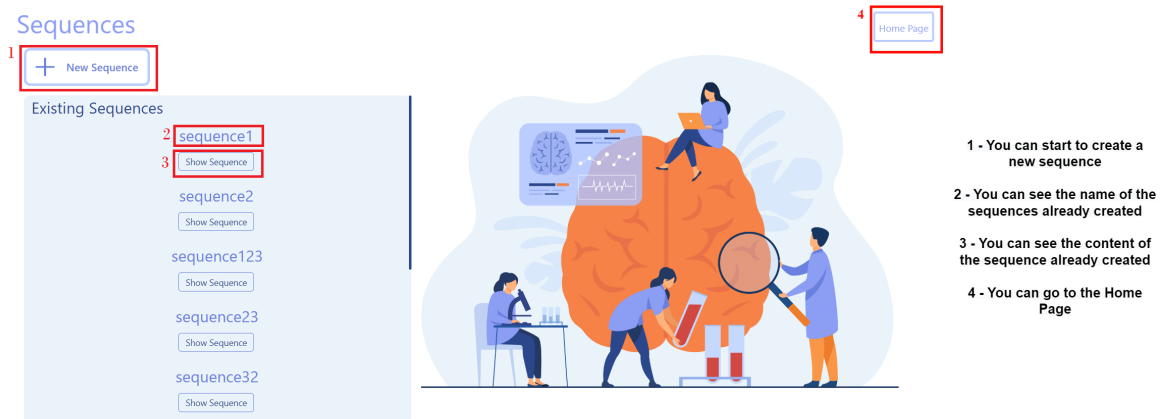
Figure A.2: Interface Manual: Video Annotator.

## Add Image



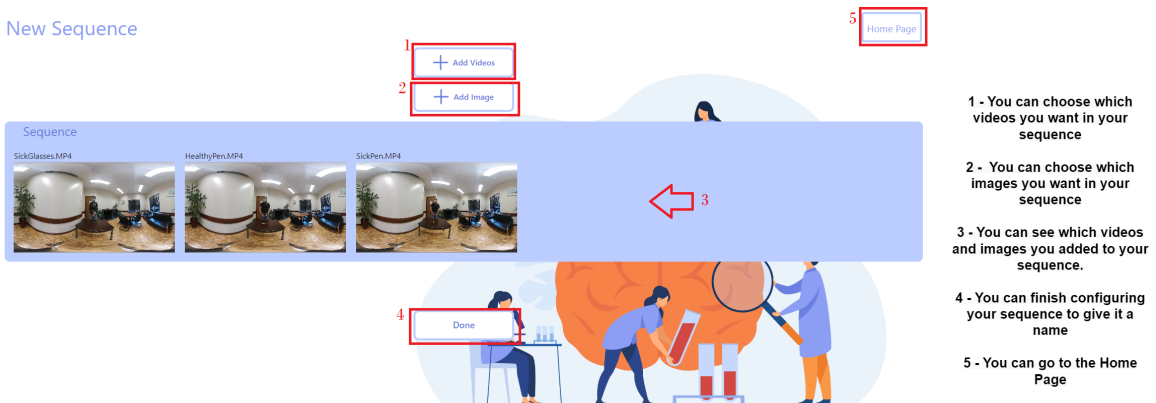
**Figure A.3:** Interface Manual: Image Annotator.

## Sequences



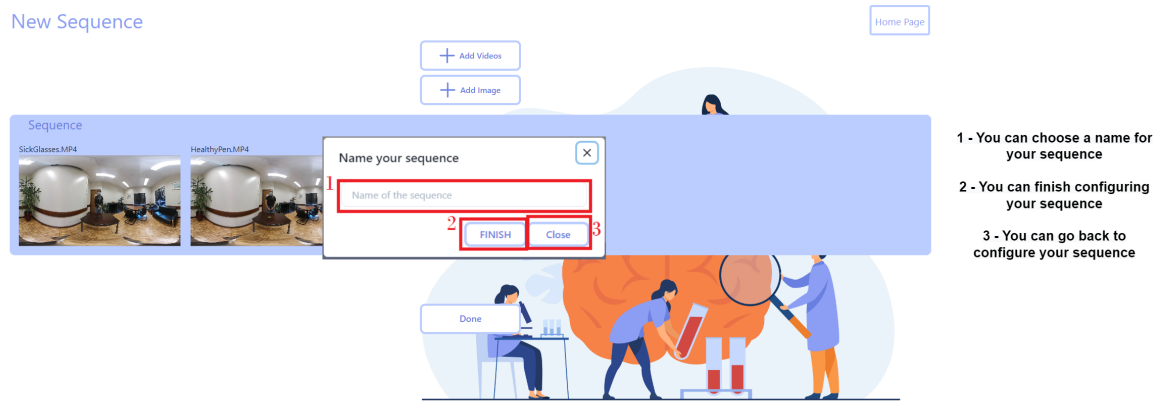
**Figure A.4:** Interface Manual: Experiment Configurator - Sequences.

## New Sequence

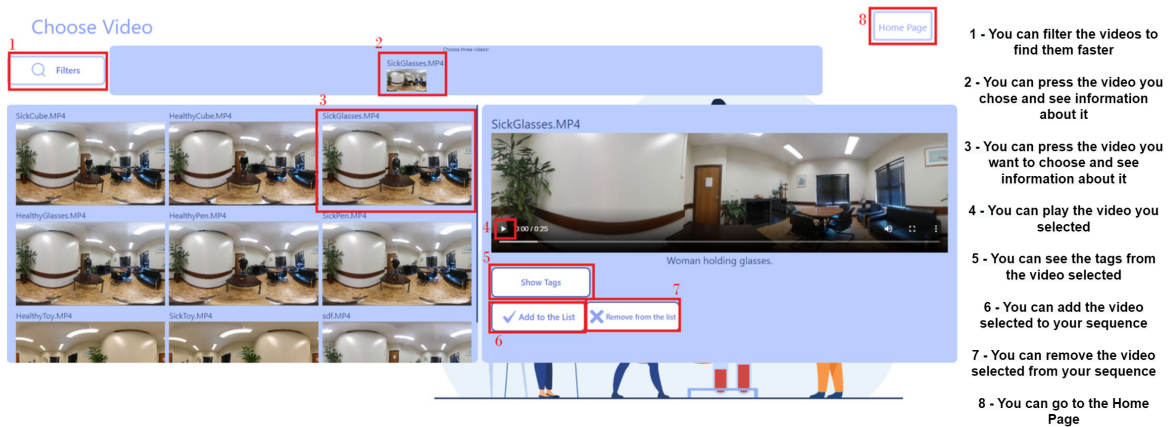


**Figure A.5:** Interface Manual: Experiment Configurator - State of the Sequence.

## New Sequence



**Figure A.6:** Interface Manual: Experiment Configurator - Pop up that appear to finish Configuration of the Sequence.



**Figure A.7:** Interface Manual: Experiment Configurator - Choose Videos to add to the sequence.



**Figure A.8:** Interface Manual: Experiment Configurator - Choose Images to add to the sequence.

## Play Experience

1

2 Participant Name:

3

4

5



- 1 - You can choose which sequence you want to play
- 2 - You can add some type of identification to the participant
- 3 - You can start the habituation period.
- 4 - You can start the experiment with the sequence you chose
- 5 - You can go to the Home Page

**Figure A.9:** Interface Manual: Experiment Controller - Play an Experiment.

## Details about the experience

1 Image showing:

2

3

4



- 1 - You can see what is being displayed in the Experimenter Renderer
- 2 - You can take notes to be added to the experiment data from this participant
- 3 - You can go to the previous page
- 4 - You can go to the Home Page

**Figure A.10:** Interface Manual: Experiment Controller - Details about the Experiment.

## Experiments Data

2

PARTICIPANT	SEQNAME	IMAGE1.PNG	IMAGE2.PNG	IMAGE3.PNG	CUBE.PNG
participant1	Sequence1 <input type="button" value="Show Sequence"/>	Unhealthy	Unhealthy	Healthy	
participant2	Sequence2 <input type="button" value="Show Sequence"/>	Healthy	Unhealthy	Healthy	
participant3	Sequence123 <input type="button" value="Show Sequence"/>	Healthy	Unhealthy	Healthy	
participant4	Sequence1273 <input type="button" value="Show Sequence"/>	Unhealthy	Healthy		Healthy
PARTICIPANT	SEQNAME	IMAGE1.PNG	IMAGE2.PNG	IMAGE3.PNG	CUBE.PNG
Data from all the experiments					
1 <input type="button" value="Download"/>					

3

- 1 - You can download the data from all the experiments to your computer
- 2 - You can see the data taken from all the experiments
- 3 - You can go to the Home Page



**Figure A.11:** Interface Manual: Experiment Data.

## Evaluations

### B.1 HEURISTIC EVALUATION

The subsequent ten Nielsen Heuristics, are used as a guidelines to evaluate if an interface is user-friendly<sup>1</sup>. The table B.1 was provided to the evaluators, where they can state which heuristics were violated, can add observations about the problem and propose a solution to them, and a severity scale.

1. **Visibility of System Status** - Design should keep users informed about whats going on, through appropriate feedback within a reasonable amount of time.
2. **Match between System and the Real World** - The design should speak the users'language. Use words, phrases, and concepts *familiar to the user*, rather than internal jargon.Follow real-world conventions, making information appear in a natural and logical order.
3. **User Control and Freedom** - User often perform actions by mistake. They need a clearly marked "emergency exit" to leave the unwanted actions.
4. **Consistency and Standards** - Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform and industry conventions.
5. **Error Prevention** - Good error messages are important, but the best designs carefully prevent problems from occurring in the first place. Either eliminate error-prone conditions, or check for them and present users with a confirmation option before they commit to the action.
6. **Recognition Rather Than Recall** - Minimize the user's memory load by making elements, actions, and options visible. Avoid making users remember information from one part of the interface to another.
7. **Flexibility and Efficiency of Use** - Shortcuts — hidden from novice users — may speed up the interaction for the expert user such that the design can cater to both inexperienced and experienced users.

---

<sup>1</sup><https://www.nngroup.com/articles/ten-usability-heuristics/>

8. **Aesthetic and Minimalist Design** - Interfaces should not contain information that is irrelevant. Every extra unit of information in an interface competes with the relevant units of information.
9. **Help users Recognize, Diagnose, and Recover from Errors** - Error messages should be expressed in plain language (no error codes), precisely indicate the problem, and constructively suggest a solution.
10. **Help and Documentation** - It's best if the system doesn't need any additional explanation. However, it may be necessary to provide documentation to help users understand how to complete their tasks.

The severity scale used to rate the problems found by the evaluators followed the following rating scale <sup>2</sup>:

- 0 - I don't agree that this is a usability problem at all;
- 1 - Cosmetic problem only: need not be fixed unless extra time is available on project;
- 2 - Minor usability problem: fixing this should be given low priority;
- 3 - Major usability problem: important to fix, so should be given high priority;
- 4 - Usability catastrophe: imperative to fix this before product can be released;

Problem	Heuristics	Severity 0- insignificant 4-catastrophe	Proposed Solution

**Table B.1:** Table used by the evaluators.

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<sup>2</sup><https://www.nngroup.com/articles/how-to-rate-the-severity-of-usability-problems/>

## Results

Evaluator 1

Descrição do problema	Heurística	Grau de Severidade 0- Insignificante 4-Catástrofe	Tem alguma proposta de solução? Qual ?
Não tem feedback do que está a acontecer após submissão nas páginas de adicionar vídeos e imagens	1	2	Dado que se tem de esperar para que as informações sejam submetidas ao adicionar vídeo/imagem , devíamos receber algum feedback de quando estivesse pronto ou do que está a acontecer.
tem a palavra "tags" e "filters" para coisas iguais	4	1	Escolher apenas um termo.
nome da sequência desaparece enquanto se constrói a sequência	5	3	guardar o nome da sequência enquanto se constrói ou pedir só no fim
Não tem como saber que só se pode escolher 3 videos/imagens até os botões desaparecerem	6	1	Alguma informação da quantidade de vídeos/imagens que se pode escolher.
Estava à espera que o feedback das experiências tivesse um vídeo	2(?)	0	
Não dá para retirar vídeos sem ter que andar à procura na lista	7	2	Possibilitar a escolha dos vídeos na barra em que aparecem os vídeos escolhidos

Figure B.1: Evaluator1

Evaluator 2

Descrição do problema	Heurística	Grau de Severidade 0- Insignificante 4-Catástrofe	Tem alguma proposta de solução? Qual ?
Perde-se tudo o que foi feito se carregar no botão "Go Back"	3;5;9	4	Mensagem de aviso que isso irá acontecer.
Sem feedback se foram submetidos os vídeos.	1	3	
Confusão na distinção do que são tags e o que são filtros.	4	0	Se significam o mesmo, limitar o nome a tags, por exemplo.
Não consigo apagar vídeos ou imagens depois de terem sido submetidos.	3;5;9	2	Dar essa informação no botão de submissão com uma mensagem de erro ou algo do gênero; ou permitir que se façam alterações da sequência;
Poucos detalhes sobre a experiência que está a decorrer	6	2	Fazer mirroring do que está a dar nos óculos VR.
Dificuldade em ter que procurar vídeos adicionados na lista para os poder retirar da lista.	7	3	Facilitar apagar vídeos já adicionados, adicionar um botão ou um icon de lixo perto das imagens adicionadas

Figure B.2: Evaluator2

Evaluator 3

Descrição do problema	Heurística	Grau de Severidade 0- Insignificante 4-Catástrofe	Tem alguma proposta de solução? Qual ?
Não sabia se tinha submetido vídeo até esperar um bocado e depois entendi que sim dado que desapareceu a informação do ecrã.	1	1	uma mensagem de que foi submetido
"Go Back" não é específico do que faz, pensei que ia para a página anterior e não.	2	2	Alterar o nome do botão para "Home" ou fazer com que vá apenas para o ecrã anterior
selecionei um ficheiro que não era nem imagem nem vídeo e permitiu e que pode causar problemas graves	3/5	2	limitar apenas para vídeos e imagens
Perdi tudo o que adicionei porque carreguei no botão "Go Back" sem querer e tive de refazer tudo.	3/5/9	3	algum tipo de aviso do que vai acontecer.
ao dar nome da sequência ele desaparece cada vez que adiciono vídeos ou imagem, tive de adicionar sempre que carregava em algum botão até acabar a sequência	5	3	guardar o nome da sequência enquanto se constrói
Não entendi que se podiam escolher só 3 videos.	6	2	Informação de quantos vídeos se pode adicionar ou algum pop up que diga atingiu o limite de vídeos

Figure B.3: Evaluator3

## B.2 USABILITY TESTS

In the beginning of the usability tests a small description of what the system was about was made for the participants to better understand the concepts, presented on Table B.2.

### Description used before the usability tests

---

Esta ferramenta foi criada com o intuito de ajudar investigadores na área de psicologia a prepararem e a realizarem experiências. Foram criadas duas aplicações:

- Uma em computador serve como ferramenta de apoio aos investigadores. Serve para criar uma base de dados para a investigação e criar as sequências de estímulos que irão ser apresentadas mais tarde aos participantes da experiência. Esta sequência é composta por vídeos, que servirão como estímulos, e imagens, que serão usadas para questionários.
  - Outra aplicação em Realidade Virtual apresentada nos Óculos, em que esta sequência criada irá ser apresentada aos participantes das experiências.
- 

**Table B.2:** Description made to all participants before the usability tests(in Portuguese).

The table used to take notes about the interaction between the users and the system is shown in Figure B.4. Here are presented the tasks made based on the features of the application. The next metrics were taken into account while performing the evaluations:

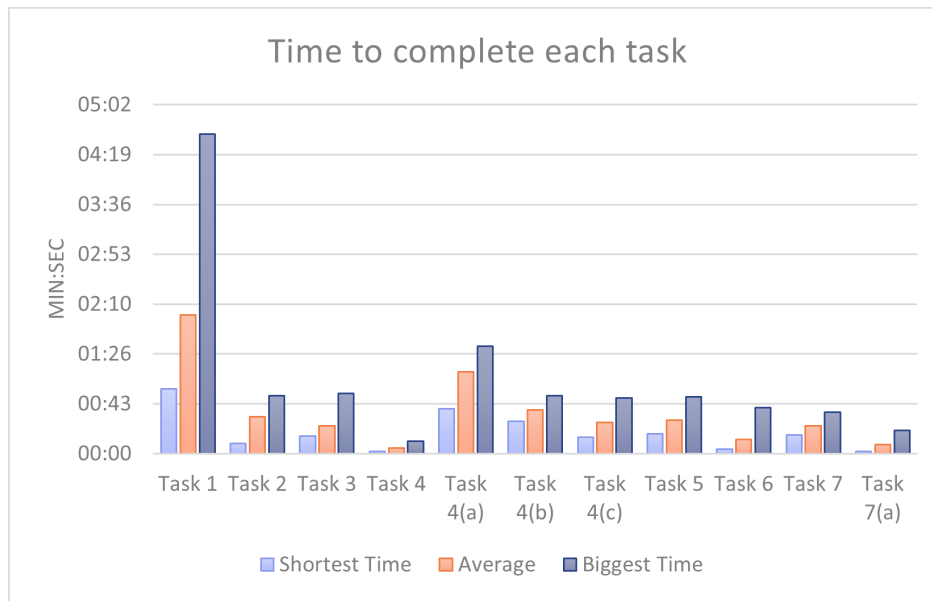
- Whether the task has been accomplished
- The time needed to complete the task(min:sec).
- Whether the user made any mistakes in completing the task and, if so, what they were
- Whether the user got lost for a moment and where
- Whether the user asked for help and where
- The difficulty level of the task.

Task	Description	Completed the task?	Time to compl. task	Any errors:	Got lost?	Asked for help?	Difficulty Level 1-Very easy 5-Very hard
1	There are new videos, add them to the "Walking Down Memory Lane" database, check if they are ok and add any relevant information.	<input type="checkbox"/> Yes <input type="checkbox"/> No	—:—	<input type="checkbox"/> None <input type="checkbox"/> Some <input type="checkbox"/> Many	<input type="checkbox"/> Yes <input type="checkbox"/> No Where?	<input type="checkbox"/> Yes <input type="checkbox"/> No What?	1 2 3 4 5
2	Add a Image1.png to the "Walking Down Memory Lane" and add information about it.	<input type="checkbox"/> Yes <input type="checkbox"/> No	—:—	<input type="checkbox"/> None <input type="checkbox"/> Some <input type="checkbox"/> Many	<input type="checkbox"/> Yes <input type="checkbox"/> No Where?	<input type="checkbox"/> Yes <input type="checkbox"/> No What?	1 2 3 4 5
3	Check if a sequence has already been recorded "SequenceTest".	<input type="checkbox"/> Yes <input type="checkbox"/> No	—:—	<input type="checkbox"/> None <input type="checkbox"/> Some <input type="checkbox"/> Many	<input type="checkbox"/> Yes <input type="checkbox"/> No Where?	<input type="checkbox"/> Yes <input type="checkbox"/> No What?	1 2 3 4 5
4	Create a new Sequence :	<input type="checkbox"/> Yes <input type="checkbox"/> No	—:—	<input type="checkbox"/> None <input type="checkbox"/> Some <input type="checkbox"/> Many	<input type="checkbox"/> Yes <input type="checkbox"/> No Where?	<input type="checkbox"/> Yes <input type="checkbox"/> No What?	1 2 3 4 5
4a	Add a video associated with "Healthy" with a toy, and add the remaining videos with "Unhealthy" and accessories.	<input type="checkbox"/> Yes <input type="checkbox"/> No	—:—	<input type="checkbox"/> None <input type="checkbox"/> Some <input type="checkbox"/> Many	<input type="checkbox"/> Yes <input type="checkbox"/> No Where?	<input type="checkbox"/> Yes <input type="checkbox"/> No What?	1 2 3 4 5
4b	Add images associated with the videos.	<input type="checkbox"/> Yes <input type="checkbox"/> No	—:—	<input type="checkbox"/> None <input type="checkbox"/> Some <input type="checkbox"/> Many	<input type="checkbox"/> Yes <input type="checkbox"/> No Where?	<input type="checkbox"/> Yes <input type="checkbox"/> No What?	1 2 3 4 5
4c	Give the Sequence the name "SequenceEvaluation" and save it.	<input type="checkbox"/> Yes <input type="checkbox"/> No	—:—	<input type="checkbox"/> None <input type="checkbox"/> Some <input type="checkbox"/> Many	<input type="checkbox"/> Yes <input type="checkbox"/> No Where?	<input type="checkbox"/> Yes <input type="checkbox"/> No What?	1 2 3 4 5
5	Start an experiment with "sequence1"	<input type="checkbox"/> Yes <input type="checkbox"/> No	—:—	<input type="checkbox"/> None <input type="checkbox"/> Some <input type="checkbox"/> Many	<input type="checkbox"/> Yes <input type="checkbox"/> No Where?	<input type="checkbox"/> Yes <input type="checkbox"/> No What?	1 2 3 4 5
6	Check if the video is playing and if so what video is playing.	<input type="checkbox"/> Yes <input type="checkbox"/> No	—:—	<input type="checkbox"/> None <input type="checkbox"/> Some <input type="checkbox"/> Many	<input type="checkbox"/> Yes <input type="checkbox"/> No Where?	<input type="checkbox"/> Yes <input type="checkbox"/> No What?	1 2 3 4 5
7	Check if there is experiment data available and if so how many participants were collected.	<input type="checkbox"/> Yes <input type="checkbox"/> No	—:—	<input type="checkbox"/> None <input type="checkbox"/> Some <input type="checkbox"/> Many	<input type="checkbox"/> Yes <input type="checkbox"/> No Where?	<input type="checkbox"/> Yes <input type="checkbox"/> No What?	1 2 3 4 5
8	Save the data on your computer.	<input type="checkbox"/> Yes <input type="checkbox"/> No	—:—	<input type="checkbox"/> None <input type="checkbox"/> Some <input type="checkbox"/> Many	<input type="checkbox"/> Yes <input type="checkbox"/> No Where?	<input type="checkbox"/> Yes <input type="checkbox"/> No What?	1 2 3 4 5

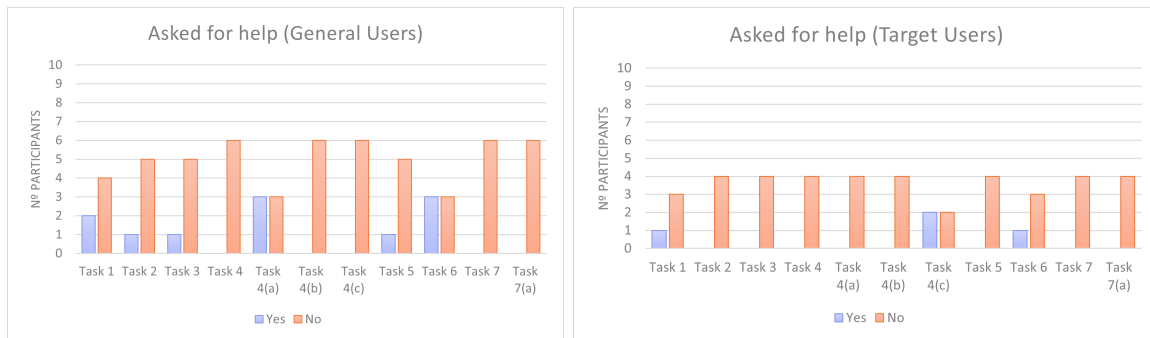
**Figure B.4:** Table used to take notes about the interaction between the users and the system.

## Results

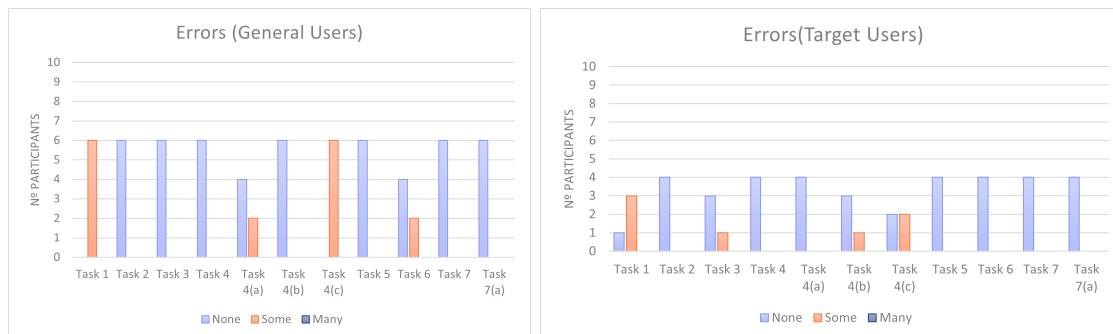
The results of this usability test can be seen resumed in the graphs presented below:



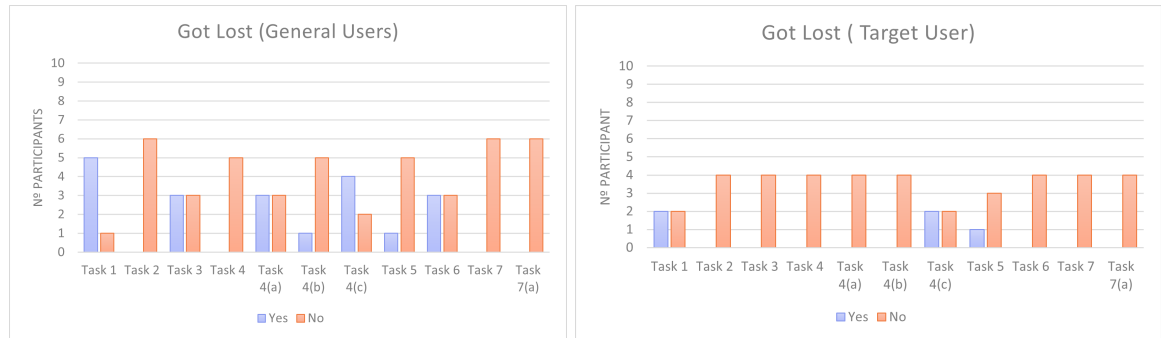
**Figure B.5:** Graph indicating the time spent on each task.



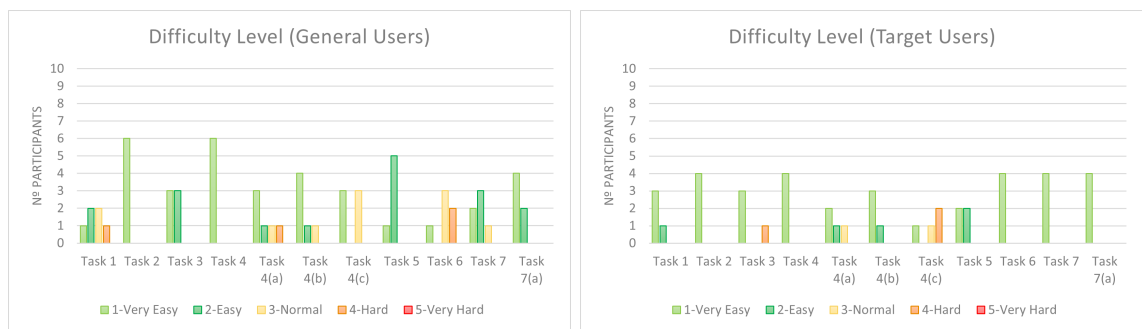
**Figure B.6:** Graph indicating if the participants asked for help during each task for general users, on left, and for target users, on right.



**Figure B.7:** Graph indicating the number of errors - None, Some, Many - made by the participants for each task on the companion tool (web application) for general users, on left, and for target users, on right.



**Figure B.8:** Graph indicating if the participants got lost while completing each task for general users, on left, and for target users, on right.



**Figure B.9:** Graph indicating the difficulty level of the companion tool (web application) for general users, on left, and for target users, on right.

### B.2.1 Questionnaires

To evaluate this system, given the fact that there was two applications, web and VR applications, two questionnaires were made: (a) one for the web application, where the Table B.3 shows the questionnaire taken after all the tasks were made, were used the typical questions used for a System Usability Scale (SUS) questionnaire; (b) other one for the VR application were the questions were choosed based on what are the needs to conduct a better experiment, shown on Table B.4.

SUS questionnaire
1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

**Table B.3:** System Usability Scale questionnaire used to evaluate the Web App.

#### *The System Usability Scale (SUS)*

How to calculate results for the SUS:

- For each of the odd numbered questions, subtract 1 from the score.
- For each of the even numbered questions, subtract their value from 5.
- Take these new values which you have found, and add up the total score. Then multiply this by 2.5.

The average System Usability Scale score is 68. Here's an overview of how your scores should measure:

- 80.3 or higher is an A. People love your site and will recommend it to their friends
- 68 or thereabouts gets you a C. You are doing OK but could improve
- 51 or under gets you a big fat F. Make usability your priority now and fix this fast.

Results of the SUS questionnaire show a score of 80,5, detailed scores of each participant can be seen on Figure B.10.

		Participant									
		1	2	3	4	5	6	7	8	9	10
SUS Questions	1	1	1	1	1	3	3	4	5	5	3
	2	2	1	1	2	1	4	1	1	1	1
	3	4	3	4	4	2	3	4	5	5	5
	4	2	1	3	1	3	3	1	1	2	1
	5	5	5	5	4	4	3	5	5	5	4
	6	1	1	1	1	1	2	1	1	1	1
	7	5	5	5	5	5	2	4	5	4	5
	8	1	2	1	1	1	2	1	1	1	1
	9	4	4	4	4	4	3	4	5	4	4
	10	1	4	1	3	1	3	1	1	1	3
TOTAL		80	72.5	80	75	75	50	90	100	92.5	87.5

**Figure B.10:** SUS questionnaire score and rating of the companion tool.

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Questionnaire for the Virtual Reality application

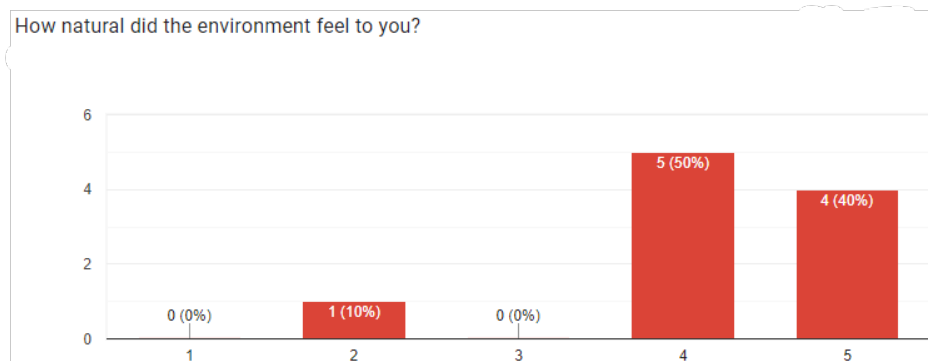
---

1. How natural did the environment feel to you?
  2. How similar did the experience in the virtual environment seem to you compared to the real-world experience?
  3. How well were you able to examine the objects?
  4. How well were you able to examine people?
  5. How present did you feel in the virtual environment (i.e., feeling of being there)?
  6. To what extent did you feel unbalanced, dizzy or sick during your experience in the virtual environment?
  7. The same environment recorded with different cameras was shown:
    - How was the quality of the first set of videos(Samsung gear)?
    - How was the quality of the second set of videos(Insta360)?
  8. Do you remember how many questions you answered? If you do , how many?
  9. Did you find the way to answer the questions intuitive?
  10. It was easy to read the questions?
- 

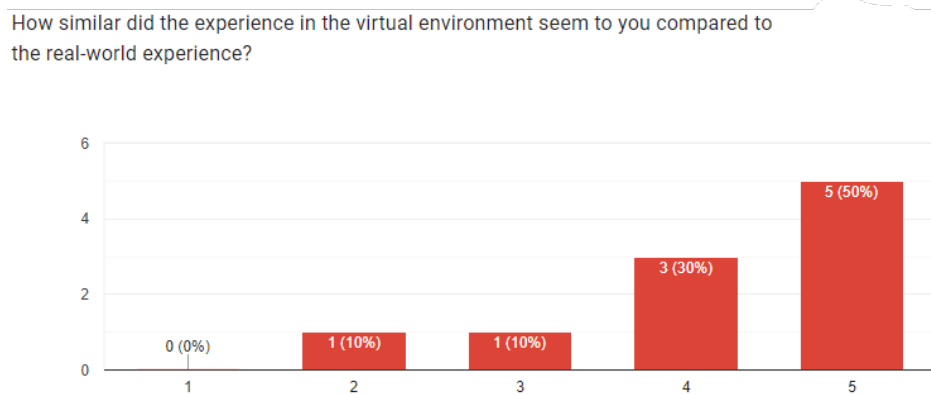
**Table B.4:** Questionnaire used to evaluate the VR application.

### Results

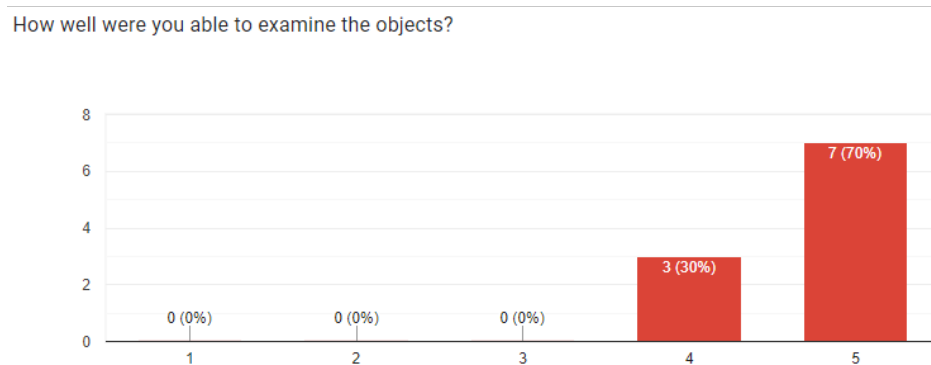
The results of the Virtual Reality Questionnaire can be seen resumed in the graphs presented below:



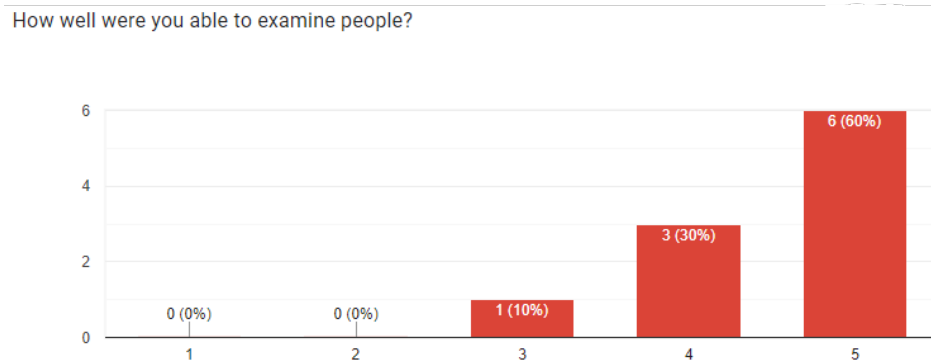
**Figure B.11:** VR questionnaire: Graph indicating the answers for the question "How natural did the environment feel to you?"



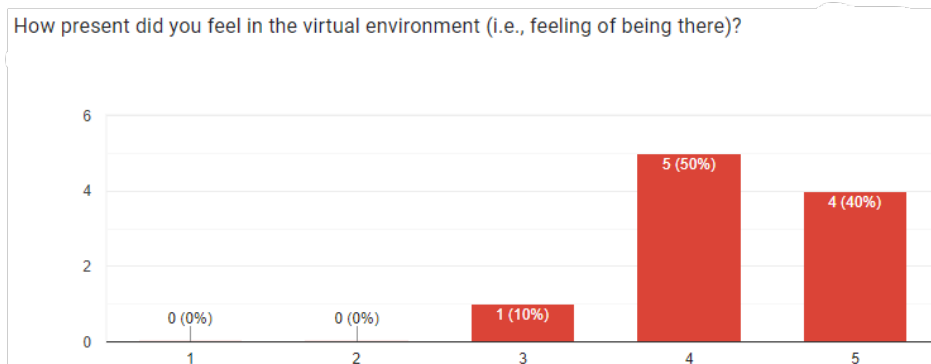
**Figure B.12:** VR questionnaire: Graph indicating the answers for the question "How similar did the experience in the virtual environment seem to you compared to the real-world experience?".



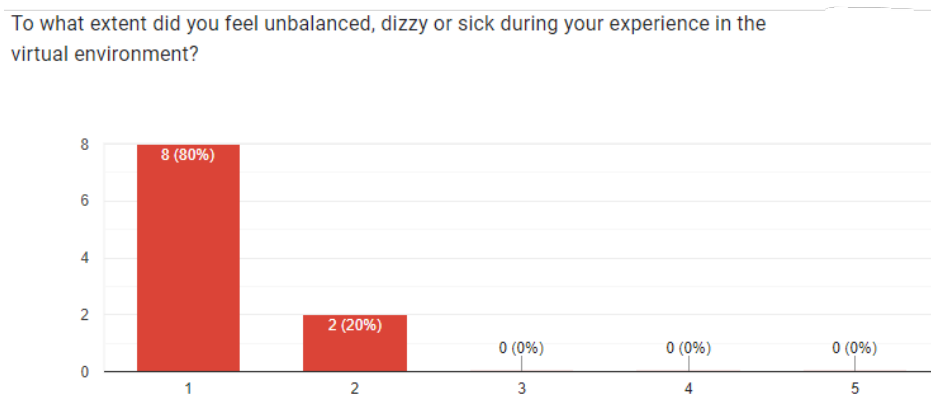
**Figure B.13:** VR questionnaire: Graph indicating the answers for the question "How well were you able to examine the objects?".



**Figure B.14:** VR questionnaire: Graph indicating the answers for the question "How well were you able to examine people?".

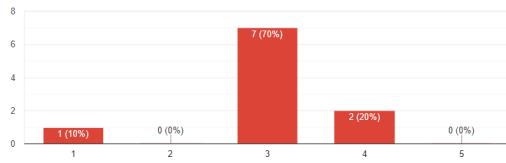


**Figure B.15:** VR questionnaire: Graph indicating the answers for the question "How present did you feel in the virtual environment (i.e., feeling of being there)?".

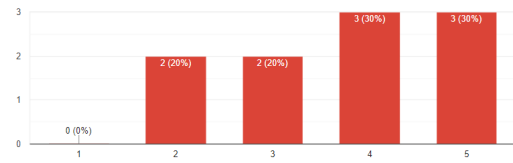


**Figure B.16:** VR questionnaire: Graph indicating the answers for the question "To what extent did you feel unbalanced, dizzy or sick during your experience in the virtual environment?".

Was the quality of the first and third videos good(samsung)?

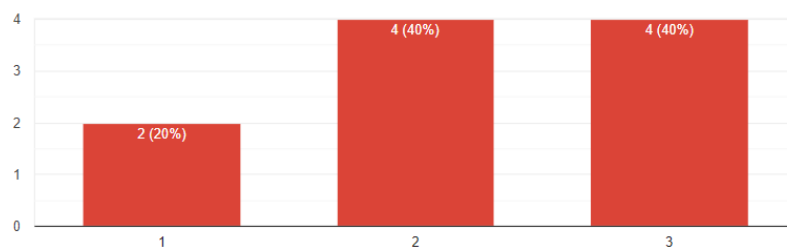


Was the quality of the second video good(insta)?



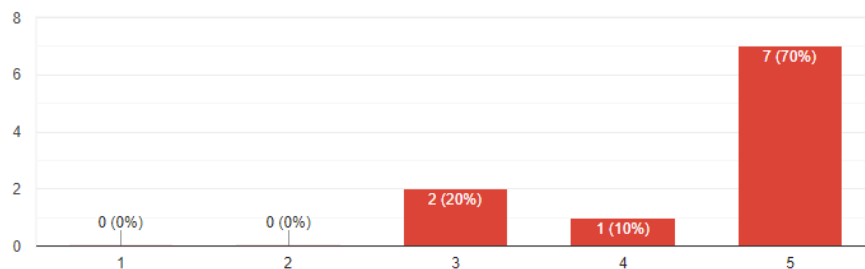
**Figure B.17:** VR questionnaire: Preference between videos filmed with Samsung Gear360 camera, on the left, and filmed with Insta360 One X2 camera, on the right .

Do you remember how many questions you answered? If you do , how many?



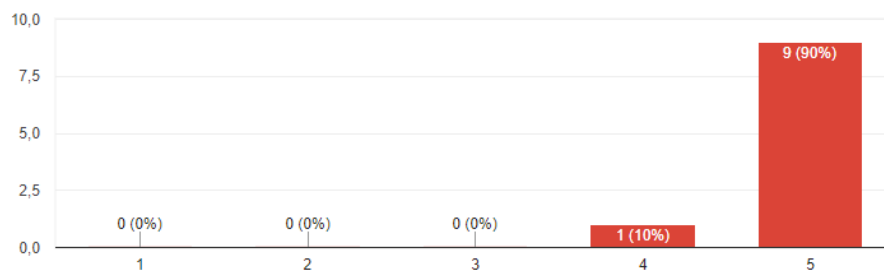
**Figure B.18:** VR questionnaire: How many questions the participants thought they answered.

Did you find the way to answer the questions intuitive?



**Figure B.19:** VR questionnaire: Graph indicating the answers for the question "Did you find the way to answer the questions intuitive?".

It was easy to read the questions?



**Figure B.20:** VR questionnaire: Graph indicating the answers for the question "It was easy to read the questions?".

# Extensive Tables

## C.1 TABLE - COMPANION TOOL CONSIDERED FRAMEWORKS





Framework	Advantages	Disadvantages	Conclusion
Angular <sup>1</sup>  Language: <ul style="list-style-type: none"> <li>HTML</li> <li>CSS</li> <li>TypeScript</li> <li>JavaScript</li> </ul>	MVC (Model-View-Controller) Architecture implementation, great for <b>client-side apps</b> . Supported by Google. Enhanced Design Architecture, easy to locate and develop. Modular, has its own modularity NgModules that are containers for cohesive block of code. Services and Dependency Injection (DI). Custom directives are suitable for dynamic client-side applications. TypeScript: better tooling, cleaner code, and higher scalability.	Limited SEO(Search Engine Optimization) options. Verbose and Complex. Steep learning curve, CLI (Command Line Interface) documentation is lacking details.	Great for front-end developers since its a framework turned more for the client-side apps. Not as good for back-end developers. Rendering is on the Client-Side. Can be quite difficult to learn compared to other frameworks like React or Vue. <u>Best for:</u> It is best for single page applications that update a single view at a time. Angular is a <b>cross-platform framework</b> , the only requirement is a JavaScript Engine.
React <sup>2</sup>  Language: <ul style="list-style-type: none"> <li>HTML</li> <li>CSS</li> <li>JavaScript</li> </ul>	Easy to Learn and Use, with multiple documentation, tutorials and training resources. Use JSX(JavaScript extension), that makes the creation of Dynamic Web Apps easier with less coding and more functionality. Reusable Components. Performance Enhancement. Uses virtual DOM (Document Object Model) based mechanism to fill data in HTML DOM. The virtual DOM works fast as it only changes individual DOM elements instead of reloading complete DOM every time. Known to be SEO Friendly.	Poor Documentation since technologies are developing so fast that also causes a neverending relearning of ways to do things. JSX as a barrier, developers complain about its complexity in the learning curve.	React is good for both client-side apps and server-side apps. Is good for full stack, front-end and back-end developers. More simple compared to Angular. More stable compared to Flutter. Rendering is on the Server-Side. <u>Best For:</u> It is best for single page applications that update multiple views at a time. React is a <b>cross-platform framework</b> .
Flutter <sup>3</sup>  Language: <ul style="list-style-type: none"> <li>Dart</li> </ul>	Relatively fast development. Full customisation & fast rendering thanks to Flutter's layered architecture. Offers proper documentation.It separates UI from native controls. Mid Learning Curve, availability of detailed documentation and a large number of examples.	Flutter is a new technology and because of it, it's still not entirely stable. A limited set of tools and libraries. Flutter apps are quite large and "heavy". The framework, as well as Dart language, are changing rapidly at times, which can make maintaining the code difficult in the long run. Not SEO friendly.	Faster to develop. Better for developing for different platforms and operating systems. Load size is much larger than other popular web frameworks. Web developers will not have the ability to modify generated HTML, CSS, and JS code. <u>Best for:</u> is ideal for single page interactive apps with animations and heavy UI elements. Flutter is a <b>cross-platform framework</b> .
Vue.js <sup>4</sup>  Language: <ul style="list-style-type: none"> <li>HTML</li> <li>TypeScript</li> <li>JavaScript</li> </ul>	Small Size. High performance since it uses virtual DOM. Integration capabilities and flexibility because it relies only on JavaScript and doesn't require any other tools to work. Solid tooling ecosystem. Easy to learn. Concise documentation.	Language barrier, part of its content and discussion is in Chinese. Reactivity complexity, the reactivity system renders only those chunks of data that were triggered. Lack of support for large-scale projects. Limited resources. Lack of plugins. Difficulties with mobile support.	Easy to learn, easy to start with only the basic HTML, CSS and JavaScript. <u>Best for:</u> it is perfect for creating single-page applications and user interfaces. Vue.js is a <b>cross-platform framework</b> .

Table C.1: Frameworks discussed for web application.

## C.2 TABLE - VIRTUAL REALITY IN PSYCHOLOGY

Mental Health Problem	Sample & conditions	Equipment Used	Virtual Environments
PTSD (Post-Traumatic Stress Disorder) [69]	A Veteran who have returned from Iraq with PTSD receive treatment using virtual reality exposure (VRE) therapy .	<ul style="list-style-type: none"> <li>• “eMagin Z800” HMD (with head-tracking and stereo earphone)</li> </ul>	<p>The participant was presented with a computer-generated view of a Virtual Iraq environment that changed in a natural way with head and body motion. It was used a scent palette in an airtight chamber filled with compressed air included such scents as burning rubber,diesel fuel, weapons fire, and spices</p>
FOF (Fear of Flying) [70]	Eighty-three participants with FOF and were randomly assigned to VRE, SE (standard (in vivo) exposure therapy), or WL (wait list control).	<ul style="list-style-type: none"> <li>• HMD “IISVR-VFX3D” (stereo earphones, and a head-tracking device within)</li> </ul>	<p>The participant was at the window seat inside the passenger compartment of an airplane. The session included:</p> <ul style="list-style-type: none"> <li>• The engines starting</li> <li>• Announcements made by flight attendants/pilot</li> <li>• The plane taxis on the runway</li> <li>• The plane taking off</li> <li>• The plane flying in good and bad weather</li> <li>• The plane landing</li> </ul>
Dental Phobia [71]	Thirty participants with Dental Phobia were randomly assigned to either VRE or informational pamphlet (IP) condition.	<ul style="list-style-type: none"> <li>• Oculus development kit 2 HMD</li> <li>• HR wristband “Mio Link” to record the physiologic response.</li> </ul>	<p>The participant was seated in a dental chair (to create a typical dental operatory related odour, a cotton wool soaked in clove oil around dental chair) and exposed to a dental operatory room, with 5 different situations encountered in a dental procedure.</p>
PSA (Public Speaking Anxiety) [72]	Fifty-one participants with high PSA were randomly allocated to: 360° video VRE incorporating stimuli of audiences (360° Audience), 360° video VRE incorporating stimuli of empty rooms (360° Empty) and no treatment control.	<ul style="list-style-type: none"> <li>• “Samsung Gear VR” headset</li> <li>• “Samsung Galaxy S7” smartphone.</li> <li>• “Samsung Gear 360° (2017) camera”</li> </ul>	<p>The stimuli utilized in the 360° Audience condition were designed to elicit anxiety through exposing participants to fearful stimuli (audiences). At each exposure session, room and audience size increased. Audience members were briefed to act as they naturally would when listening to a speech.</p>
PDA (Panic Disorder with Agoraphobia) [73]	Twelve participants with PDA were exposed to a 360° videos VRE.	<ul style="list-style-type: none"> <li>• “ HTC Vive” head-mounted display (HDM).</li> <li>• “Samsung 360 camera”</li> </ul>	<p>The virtual environments used were typical situations feared and avoided by people with PDA. There were 360° videos of inside a subway carriage, a walking tunnel, a busy train station, an elevator, an auditorium, and a tall bridge which they called scenarios, and each scenario consisted of different videos of different situations in that scenario.</p>
Speech Accommodation Without Priming [74]	Seventy-two male participants between were tested in the immersive VR lab	<ul style="list-style-type: none"> <li>• NVIS nVisor SX60</li> <li>• DTrack 2 motion tracking system</li> <li>• WorldViz Ambisonic Auralizer System</li> </ul>	<p>It used pre-recorded voices in a virtual environment that was an aisle of a supermarket with products for the voice pre-recorded talk about.</p>

**Table C.2:** Examples of the use of VR in Experiments and Treatments in Psychology.

<sup>1</sup>Angular, <https://angular.io/>.

<sup>2</sup>React, <https://reactjs.org/>.

<sup>3</sup>Flutter, <https://flutter.dev/>.

<sup>4</sup>Vue.js, <https://vuejs.org/>.

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