Universidade de Aveiro
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YUCK! USANDO REALIDADE VIRTUAL PARA APOIAR A EXPLORAÇÃO DA MEMÓRIA PROSPECTIVA E CONTAMINAÇÃO

YUCK! USING VIRTUAL REALITY TO SUPPORT THE EXPLORATION OF PROSPECTIVE MEMORY AND CONTAMINATION

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em (Engenharia de Computadores e Telemática, realizada sob a orientação científica do Doutor Samuel de Sousa Silva, Professor auxiliar do Departamento de Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro e da Doutora Maria Beatriz Alves de Sousa Santos, Professora associada com agregação do Departamento Eletrónica, Telecomunicações e Informática da Universidade de Aveiro.

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palavras-chave

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

resumo

Ao longo da história, os seres humanos, de forma semelhante às adaptações físicas, desenvolveram-se de maneira a nos ajudar a sobreviver e evitar situações ameaçadoras à vida, como, por exemplo, os patógenos, que continuam a representar uma grande ameaça para a qual ainda devemos nos adaptar, como no recente surto de SARS-CoV-2. Nesse sentido, os seres humanos desenvolveram o que é conhecido como o Sistema Imunológico Biológico (BIS do Inglês *Biological Immune System*). Para aprofundar a compreensão do BIS, o campo da Psicologia Experimental realiza experiências que consistem em apresentar vários objetos descritos como estando em contato com uma pessoa contaminada ou com uma pessoa saudável. Tradicionalmente, este método baseia-se em fotografias acompanhadas de uma história relacionada com o objeto apresentado, o que exige um esforço imaginativo por parte dos participantes e tende a afetar a experiência, uma vez que não se trata de um cenário realista. O trabalho atual tem como objetivo apresentar uma solução que apoie o protocolo experimental em um ambiente virtual para transportar as experiências da abordagem tradicional para um ambiente mais realista e ecologicamente válido, utilizando vídeos em 360° como estímulos. Para atingir esse objetivo, foi desenvolvido um conjunto de módulos e melhorado para permitir que a equipe de investigadores configure, controle e supervisione as experiências em tempo real. O sistema foi desenvolvido em estreita colaboração com a equipe de investigação *Mnemonic Tuning for Contamination* (MTC) e, posteriormente, durante o desenvolvimento, foi parcialmente avaliado pela equipe, juntamente com seis estudantes de psicologia. O resultado dessa avaliação foi positivo e permitiu, após alguns ajustes, avançar para uma avaliação com 23 participantes, que também produziu bons resultados.

keywords

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

abstract

Throughout history, humans, similarly to physical adaptations, developed in a way that helped us survive and avoid life-threatening situations, as an example, pathogens are a major threat to which we must adapt even today with the recent SARS-CoV-2 outbreak. In that regard, humans have developed what is known as the Biological Immune System (BIS). To further the understanding of the BIS, the Experimental Psychology field conducts various experiments which consist of presenting various objects that are described as being in contact with either a contaminated person or a healthy person. This method traditionally relied on photographs accompanied with a backstory related to the object presented which requires an imaginative effort from the participants that tends to affect the experiment since it is not a realistic scenario. The current work presents a solution that supports the experimental protocol in a virtual environment to help move the experiments from the traditional approach to a more realistic and ecologically valid environment utilizing 360° videos as the stimuli during the experiments. To reach that goal, a set of modules were developed and expanded on to enable the researchers to set up, control and supervise the experiments in real time. The system was developed in a close collaborative effort with the Mnemonic Tuning for Contamination (MTC) team and later during development was partially evaluated by the team alongside six psychology students. The outcome of said evaluation was positive and enabled, after a few tweaks, to move on to an evaluation involving 23 participants which also yielded good results.

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1 Introduction

1.1 Motivation

Throughout history, humans, similarly to physical adaptations, developed in a way that helped us survive and avoid life-threatening situations, as an example, pathogens are a major threat to which we must adapt even today with the recent SARS-CoV-2 outbreak. In that regard, humans have developed what is known as the Behavioral Immune System (BIS) which consists of three components: emotional, cognitive, and behavioral.

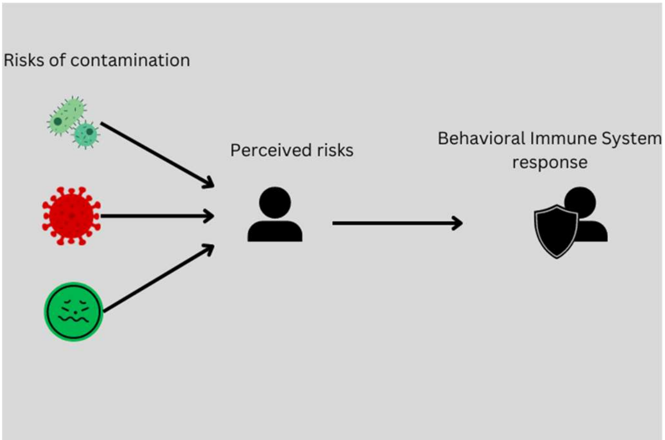


Figure 1.1: The Behavioral Immune System

Studies on the matter [1] have shown that memory plays a crucial role in the BIS. It has been found that participants remember better the objects that seem to have been subject to contamination (e.g.: been in contact with a sick person, dirt, feces) than objects associated with a healthy person. In this context, the typical experimental protocol consists of presenting a scenario to the participants alongside images that are presented on the computer screen and, later, ask to identify which objects were in contact with a possible contaminant.

1.2 Challenges

The use of visual stimuli in combination with a verbal scenario that provides a context to the stimulus is considered a reliable method in Experimental Psychology (EP) when it comes to memory. There is, however, an increased desire for a method that is more realistic and life-like since the current method relies heavily on the participant’s imagination, something that is not possible to control and, hence, may affect the experiment. To that end, real-life scenarios conducted with actors, in every experimental session, might be a good compromise, but the downside is that they cannot be replicated exactly (e.g., regarding the timings of the actions played) and the smallest changes could influence the results. In this regard, recording videos with actors could provide a more controllable setting and be richer in conveying the context than static images, but would still be short of the desired immersion. Following this line of thought, in recent years, Virtual Reality (VR) has become increasingly popular and is seeing wider use, specifically, in Experimental Psychology. VR solves the problem of replicability of experiments and potentially increases ecological validity compared to traditional methods. Some research to help transition to a VR environment has already been conducted mostly for exposure therapy but also memory-related studies. (e.g.: [2], [3]). However, the transition to a VR environment is not without its challenges. The implemented approach should help move closer to an ecologically valid setting than current practices and, thus, cannot be done by simply modelling an environment that looks artificial. Furthermore, to increase the potential ecological validity, the proposed approach should foster some sense of presence and immersion.

In recent work done at IEETA, Silva et al. [4] explored utilizing VR for studying memory and contamination. This work considered 360° videos of different recorded scenarios that could be played in a sequence. At the end of the sequence, a question would appear to the participants asking them if they remembered which item might have been contaminated. Nevertheless, although this initial proof-of-concept provided promising results for the selected approach, the work needs to evolve to be able to support the implementation of the whole experimental procedure. This should entail, for instance, providing the researchers with the current status and evolutions of the experiment, and be able to define the sequences of videos to play.

1.3 Objectives

This dissertation aims, in collaboration with the Psychology department of the University of Aveiro, to refine and evolve a framework for the creation and presentation of dynamic scenes to support experimental studies on prospective memory and contamination using virtual reality equipment. The accomplishment of this goal should entail:

- Acquisition of skills in virtual reality, 360° video, and the general technical and scientific aspects of Experimental Psychology, namely regarding prospective memory.
- Get acquainted with previous work on VR for studying memory and contamination performed at IEETA.
- Adopt a human-centered approach to understand existing challenges and needs and define a set of requirements for refining and evolving previous work.
- Iterative design and development of the identified features and their validation
- Writing: documentation, publications, and dissertation

1.4 Structure

This dissertation is divided into six chapters. Besides the current chapter, the other chapters are as follows:

Chapter 2 - Background: Explores VR's emergence and evolution throughout history to this day and its uses in experimental psychology as well as a brief account of the main concepts and research regarding the mnemonic tuning for contamination.

Chapter 3 - Requirements, Scenarios and Personas: Introduces the target users, their needs and motivations, identifies a set of scenarios that illustrate the actions and contexts that need to be supported by the novel solution to be proposed, and identifies the functional and non-functional requirements.

Chapter 4 – Development: Describes the methods adopted to address the list of requirements and provides a summary of the main aspects concerning the development of a framework used to support two important stages of the experimental procedures: the validation of the video dataset and the implementation of the experimental protocol.

Chapter 5 – **Evaluation**: Covers the evaluation of the developed system by a set of users that experienced the system while participating as evaluators of the video dataset.

Chapter 6 – **Conclusions**: Summarizes the work carried out, performs a brief critical analysis of its outcomes, and concludes identifying potential routes for future works.

2 Background

The Mnemonic Tuning for Contamination (MTC) refers to the study of human behavior and reactions in different situations to contamination in real life. The goal for MTC researchers is to attain a controlled, ecologically valid environment that allows them to conduct different types of experiments. As technology evolved, VR is a strong contender to achieve this goal. In this chapter, background research on Virtual reality, its uses in Psychology and the research addressing the MTC can be found to further explain the context of this work.

2.1 Mnemonic Tuning for contamination

2.1.1 The Behavioral Immune System

A critical aspect of human survival and evolution throughout history was the ability of humans to adapt and deal with various threats that threatened our survival. These threats could be either visible (e.g.: predators, natural disasters) or not visible to the naked (e.g.: viruses, bacteria). To avoid pathogens, humans developed what is called the Behavioral Immune System (BIS) [5]. The BIS refers to the psychological and behavioral responses that people have to potential sources of infection or contagion (e.g.: the feeling of disgust, avoiding spoilt food). When such stimuli are perceived, the BIS triggers a set of reactions involving: Emotional (e.g.: disgust), Behavioral (e.g.: avoidance), and cognitive (e.g.: memory) to avoid contamination [1].

To be effective, the BIS has evolved to be hypersensitive and tends to react to cues that may not present a danger (a false negative). But, arguably, avoiding a false negative is better in this case than potentially failing to identify a source of danger [6].

2.1.2 Emotion

Emotional responses are a crucial element in the human self-preservation process. Different emotions can be triggered in different situations (e.g., Fight or flight in front of immediate danger, anxiety in anticipation of the possibility of danger [7])

Among these emotions, disgust is one of the key components of the BIS [8] as it promotes avoidance of sources of potential diseases and contamination perceived by olfactive or sighting senses.

Objects or substances that are linked to known disgusting or vessels for contamination illicit a reaction of avoidance to minimize the risk of getting sick themselves and prevent contagion to other people.

This has been explored by Morales and Fitzsimons [9], in their experiments that consisted of presenting usual products that have been in contact with other objects that are considered disgusting or unhygienic to the participants. It has been found that participants were reluctant to interact with the “contaminated” objects. Furthermore, reluctance was also observed when even a sterilized object (in this case, a sterilized cockroach) was briefly introduced to a neutral object (water in this case). These results show that people are usually unable to state the reason behind this avoidance behavior towards an object or product they believe was contaminated, hence we tend to identify certain situations as false positives regardless of the facts presented. Which begs the question, how do humans learn and remember what is a risk and what is not? Does memory affect our judgment in these situations?

2.1.3 Memory

Memory plays a significant role in the avoidance of potential sources of contamination, as shown in studies by Fernandes et al. [11]. Their results indicated that participants tend to remember pictures of objects that have been in contact with a sick person more than objects that were not described as potentially contaminated. More recently, Thiebaut et al. [10] explored the effects of contamination on memory in relation to COVID-19. They found that, due to the high number of asymptomatic carriers during the pandemic, it is difficult for people to identify an infected person based on visual cues alone. They used a similar approach to Fernandes et al., by showing participants pictures of objects that were described as being handled by either a healthy person or an infected person, without any visual clues of contamination or sickness. As a result, the findings were similar to those of Fernandes et al., with participants recalling more of the objects that were described as in contact with a sick person than those that were described as in contact with a healthy person. This suggests that disgust was not a major factor in the process and that memory played a key role in the recall of potentially contaminated objects. This highlights the importance of memory in the avoidance of potential sources of contamination and the potential implications for the spread of infectious diseases such as COVID-19.

2.2 Current Approaches in Mnemonic Tuning for Contamination Research

The research on the Mnemonic Tuning for Contamination aims to analyze how people react to real-life contamination situations and how these situations affect them. In this section, the focus is on the current techniques used in experimental psychology to conduct experiments, namely considering line drawings and photographs, that explore these reactions and their limitations. However, it is important to note that these techniques often rely on people's memories, which can be unreliable. This highlights the need for careful consideration of the limitations of memory-based methods when studying contamination and its effects on individuals. Furthermore, this study suggests the need for further research to explore different techniques and methods that can be used to study contamination and people's reactions to it, in order to gain a more comprehensive understanding of this topic.

2.2.1 Line drawing

The Contamination Effect (CE) was explored by Fernandes et al. [1] using a set of line drawings provided by Snodgrass and Vanderwart that was made "according to a set of rules that provide consistency of pictorial representation" [11] (see Figure 2.1). The drawings were used in tandem with verbal clues that describe the characteristics of a person who has been in contact with the shown object (see Table 2-1). During the encoding phase, participants were asked to identify whether the object was in contact with a healthy or unhealthy person. The last phase was a surprise recall task in which participants had to remember as many objects as they could. It was found that the objects that were portrayed as being in contact with a person with signs of illness were remembered more than objects that were associated with signs of health (see Figure 2.2).

One limitation of this approach is that the stimuli presented lacked ecological validity, so it leaves room for interpretation and imagination on the participants' part.

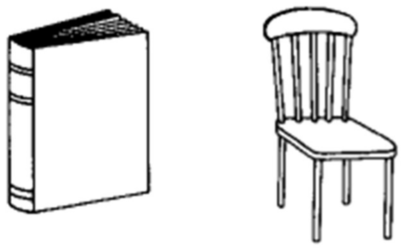


Figure 2.1: Examples of drawings from Snodgrass and Vanderwart [11]

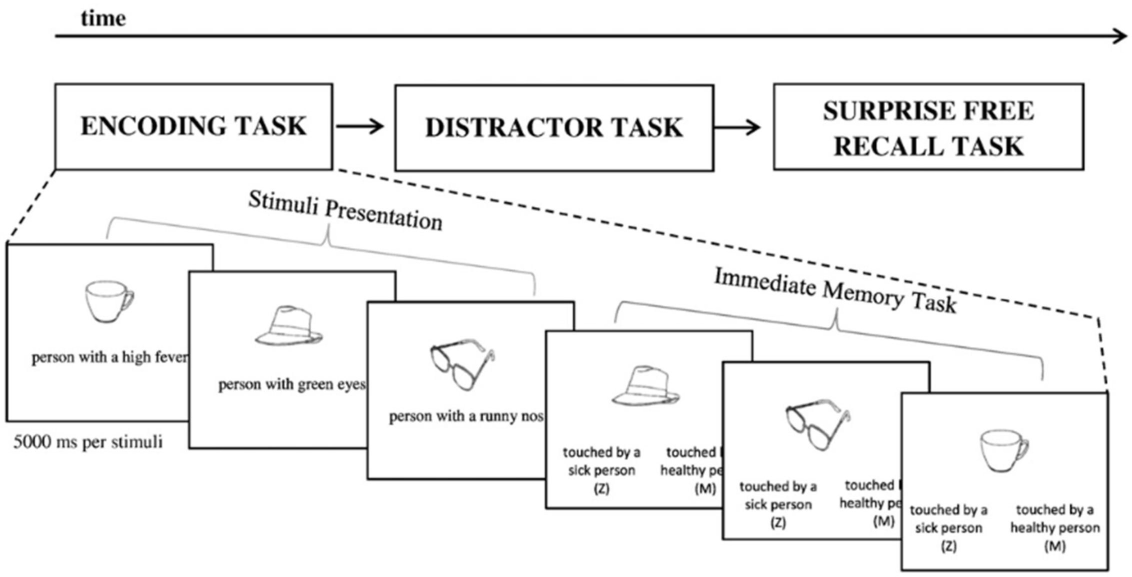


Figure 2.2: Representation of the experiment conducted by Fernandes et al. [1]

Sick person	Healthy person
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.

2.2.2 Photographs

Fernandes et al. recognized the importance of ecological validity in their experiments, and thus sought to increase it by using photographs rather than line drawings. They also included other indicators of contamination that may have occurred in conjunction with the object, as well as the faces of people who were in contact with it around the same time. This is a step forward towards achieving more valid results, as it allows for more comprehensive data collection due to increased realism. Such an approach is likely to be more effective than traditional methods such as line drawings, since including photographs of objects and people connected to it provides a more accurate depiction of reality and thus can lead to more meaningful conclusions. This type of experimentation therefore yields higher ecological validity, making it easier to draw reliable conclusions from the results.

In the experiments that were conducted with line drawings, as stated earlier, participants for all intents and purposes had to rely heavily on their imagination to envision the object and the contact that occurred given the verbal description of the person and the abstract drawings of the objects. For that reason, the experiment was replicated again this time with pictures that depict the object in direct contact with the contaminant [12] (Figure 2.3).

The results of the experiment indicated that when objects were presented to participants as being handled by hands covered in a substance that resembled a source of contamination (e.g.: chocolate mousse to emulate defecation), the memory of these objects was enhanced in comparison to the memory of objects that were presented as being held with clean hands. The presence of contamination influenced memory formation, indicating that participants are more likely to remember objects they perceive as contaminated than those they perceive as clean.

In Figure 2.3, photographs row (A) was used in Experiments 1a and 1b associated with cues (both in the immediate memory phase and item presentation phase), and in Experiments 2 and 3 as belonging to healthy people (presentation phase); (B) In Experiment 2, the items were described as contaminated (presentation phase); (C) In Experiment 3, during the presentation phase, the items were described as covered either in chocolate spread (for non-disease contexts) or in diarrhea (for disease contexts); (D) In Experiments 2 and 3, this was used as a part of the immediate memory test.

Figure 2.3 : Examples of images presented to the participants in different experiments, retrieved from [12]

The replication and extension of the studies conducted by Fernandes et al. [12] as denoted is a step towards making the experiments more ecologically valid and improve immersion. As discussed later in section 2.3, the main advantages of the technology are its immersion and high sense of presence in the environment presented which makes it a good contender to transition the current experiments to a virtual reality setting. Such attempts have been already made in the field of Experimental Psychology and we'll discuss them in the next section.

2.3 Virtual Reality in Psychology

The main advantages for the use of VR in Psychology is the ability for the technology to provide a controlled environment that allows the replication of experiments as they are intended, automated data collection (e.g.: head movement, what objects were interacted with) and a high degree of similarity to real world scenarios, either using 360° videos [4] or the design of a virtual environment with high fidelity graphics. In this section, we will explore how the field of both applied and experimental psychology utilized these advantages to enhance the experiment process.

2.3.1 Virtual reality

A definition of Virtual reality proposed by Jeralt in his book "The VR Book: Human-Centered Design for Virtual Reality" is *"virtual reality is defined to be a computer-generated digital environment that can be experienced and interacted with as if that environment were real."* [13]

Virtual reality, albeit with its recent notoriety, is not an emergent technology. The first efforts date back to the 1950s when "Sensorama" (see Figure 2.4) invented by Morton Heilig, was used as a simulator for the military. Later, Ivan Sutherland's vision described in his paper "the ultimate display" [14] the idea of a "kinesthetic" meaning it would allow the user to see through the mathematic process to have a better understanding of the phenomena and the idea that displays and computers should also be able to stimulate more human senses than just sight.

Figure 2.4: Virtual Reality Machine, Sensorama, created by Morton Heilig retrieved from [15]

Around 40 years later, in 1995 Nintendo Co., Ltd. released the “Virtual Boy” which was the first VR product aimed at the public. It was a console able to display stereoscopic 3D imagery. It consisted of a head-mounted display and a controller as an input device.

It is only just recently that VR equipment became more widespread for general consumers thanks to more reliable technologies that minimize motion sickness and other discomforts one might encounter, also the price steadily went down making them more affordable.

After the release of the HTC Vive and the Oculus Rift in the 2010s, the ecosystem around VR keeps on growing with video games, immersive videos, and so on. Mostly during the SARS-CoV-2 pandemic when VR systems were used as a substitute for work, socializing, and entertainment. [16]

Figure 2.5: Modern VR systems in use retrieved from [1]

Virtual reality has exploded in popularity in recent years due to its unique ability to fully immerse users in a digital environment. One of the key factors contributing to the effectiveness of VR is the

[1] https://www.polygon.com/2017/8/21/16177270/htc-vive-price-cut-599 (accessed 12/01, 2022)

advancement of computer and graphics technology, which has allowed for the creation of virtual worlds that are highly realistic and believable. When immersed in a VR environment, the human brain is tricked into thinking that it is interacting with the real world, resulting in cognitive responses that are similar to those experienced in real-life situations which makes it a great tool for multiple applications (e.g.: Cognitive Behavior Therapy [17]). This sense of immersion is what sets VR apart from other forms of media and makes it an incredibly powerful tool for a wide range of applications. The concept of "presence" in virtual reality refers to the feeling of being physically present in the virtual environment. This sense of presence is a key factor in determining the effectiveness of a VR experience and is often used as a measure of the immersion provided by a VR system [18].

Several factors contribute to the sense of presence in VR, including visual and auditory fidelity, haptic feedback, and the ability to interact with the virtual environment naturally and intuitively. Research has shown that a strong sense of presence can lead to an enhanced cognitive and behavioral response for adults aged 50 and older. [19], [20].

Overall, the sense of presence is a crucial element of virtual reality and is essential for creating immersive and engaging VR experiences.

2.3.2 Virtual Reality and Exposure Therapy

Exposure therapy (ET) is considered the treatment of choice for anxiety-related disorders, and in-vivo exposure has been shown to be the most effective form of ET [21], [22]. However, there have been efforts to transition towards virtual reality exposure therapy (VRET) as an alternative form of ET [17], [23], [24].

Studies have shown that VRET can be just as effective as in-vivo ET, if not more so. Bouchard et al. [17] found that a combination of cognitive behavior therapy (CBT) and VRET was more effective than CBT and in-vivo ET. Geraets et al. [25] also found that VRET was effective in treating generalized social anxiety disorder, with patients showing improvements in social anxiety and quality of life at post-treatment and depressive symptoms decreasing at follow-up.

One of the major benefits of VRET is that it can be used in situations where in-vivo ET is not possible, such as when a patient has a phobia that cannot be easily replicated in real life, or when there are restrictions such as during the COVID-19 pandemic [26]. VR technology is widely available and relatively low-cost, and it allows for the creation of virtual environments tailored to the needs of the patient. Additionally, it allows for more control over the severity of the scenarios, although it can be difficult to develop virtual environments that are highly realistic. Overall, VR exposure therapy can be a valuable alternative to in-vivo exposure therapy for the treatment of anxiety-related disorders, particularly when in-vivo exposure is not possible.

2.3.3 Virtual reality uses in Experimental Psychology

As explored in the previous section, VR is also being used in EP in regards to a wide variety of topics (e.g.: motor control for elderly people [27], episodic memory [21], emotional reactions [22])

Compared to the traditional methods explored in earlier sections, they rely on the participants' ability to imagine themselves in a hypothetical situation, which can vary greatly from person to person and is beyond the control of the researcher. This can make it difficult to accurately measure and compare participants' responses. VR offers a solution to this problem by facilitating participants' immersion in the situation of interest. Instead of asking participants to imagine the situation, VR recreates realistic-looking settings, enriched with multisensory information, that transport the participant to a more real-world-like immersive environment. This significantly enhances their sense of presence, making their experience more comparable to reality. This approach not only improves the realism of the experience but also makes it more consistent across participants, providing researchers with more accurate and reliable data. Overall, VR technology allows for more control over the research environment and offers a more immersive and realistic experience for participants, resulting in more accurate and reliable data for researchers.

One of the key benefits of using virtual reality (VR) in research is its ability to be combined with other devices and techniques to measure a wide range of human responses. For example, in a study by Bermo et al. [23], the researchers used Magnetic Resonance Imaging (MRI) to observe brain activity in people with painful injuries while they were using VR as an analgesic action. The VR experience allowed the patients to "get distracted" from their pain and the MRI results showed a significant suppression of pain-related brain activity in the insula, thalami, and secondary somatosensory cortex. This demonstrates how VR can be used in conjunction with other technologies to provide a more comprehensive understanding of human responses, in this case, pain management. This approach enables researchers to gain new insights into complex human behaviors and experience. Additionally, VR can also be combined with other physiological measures such as heart rate, skin conductance, and eye tracking to provide a more holistic view of the participant's experience. Overall, VR's ability to be combined with other devices and techniques allows researchers to gain a deeper understanding of human behavior and response in various contexts.

2.3.4 Virtual reality in the Mnemonic Tuning for Contamination

Regarding the Mnemonic Tuning for Contamination, VR seems to be an appropriate choice. For that matter, Silva et al.'s [4] work focused on building a framework supporting video acquisition and their presentation as stimuli that was validated by the research team. This approach allows for a higher degree of ecological validity compared to a lower fidelity 3D render.

To achieve this, Silva et al. developed a framework that consisted of a Unity based application running on an Oculus Quest 2. This application was responsible for displaying the 360° videos and enabling participants to answer a set of questions in the VR environment as well as a web application that serves as a medium to control the experiments (e.g.: choose what sequence of videos is to be played on the

VR headset) and allow the researchers to download the data that has been gathered from the experiments in the form of a CSV file.

A Samsung Gear 360 mounted on a tripod was used to capture the videos, the height and distance of the camera from the table was chosen according to literature review and validated after evaluating six different settings (two camera heights and three different distances from the table) all of which were recorded in the same room.

Results from the evaluation showed a preference for certain settings of video acquisition (55cm for the distance from the table, and a preference between 110cm and 115cm that might be due to the participants' height). Results also indicated a preference for the environment that was shown last and since the order of the different environments was random for each participant might point towards a positive effect of prolonged exposure in increasing the sense of presence in the virtual environment.

The videos were then played on the Oculus Quest 2 that is running the Unity application. To do this, the video was projected on a Sphere *GameObject* in tandem with a shader that would invert the image so that the video would be visible from inside the sphere where an *OVRCamera* was placed in the middle of it.

This approach allows such experiments to be replicated as they were intended thanks to the cataloging of the videos used on a database. After evaluating the results, the team found a high usability score, confirming the efficiency of the system and its user-friendliness. Feedback from the MTC research team was also conclusive, further supporting the effectiveness of this approach. Although some challenges remained, and were some of them were addressed in this work.

2.4 User centered design

The development of a VR system supporting Experimental Psychology poses many challenges, one of the most important being the focus on the user experience. This calls for an effort to gather feedback from real users consistently and at every stage of development in order to refine and evolve the system to provide the best experience possible to the end users. With that in mind, the adoption of a User-Centered Design (UCD) is crucial when undertaking a project such as this to be able to avoid design flaws that might impact the quality of the system [13].

User-Centered Design consists of a set of iterative processes in which the designers main focus is on the needs of the end users. UCD is usually split into four different phases [28] :

- **Understanding the context of use :** Consists of trying to understand the users themselves and in what context the system will be used.
- **Specify user requirements :** Identifying and specifying the requirements of the users.
- **Design solutions :** Developing solutions that fit the previously identified requirements.
- **Evaluate against requirements:** Evaluating the proposed solution against the requirements in order to verify if the solution meets the users' expectations.

Following the last phase of the UCD cycle, the team further improves the solution depending on the feedback gathered from the end users also further iterates the four different phases until the product fully meets the user expectations and requirements. This approach requires constant communication and close collaboration with the end user to better understand their needs, this might include brainstorming sessions, surveys as an example.

However, among the different techniques used, a common approach to understand the people who will use the system and how they will use it, is by creating personas, scenarios, defining requirements and finally evaluating the product which will be described in the following subsections.

2.4.1 Identifying the users and the contexts of use

One of the approaches utilized to ensure the good design of a system is the formulation of user's model. The model should focus on the users first and foremost, depicting in a simple form the relationship between them and the system being designed. Such a representation is called "Personas". Commonly used to visually represent and understand the user's interaction with the system, Personas should identify patterns in user behavior in a way that can be translated into prototypes. But preceding the creation of personas, some investigative work is required to identify potential users, and then behaviors and traits are identified. Additionally, when creating personas, there are crucial points that need to be identified, such as :

- **Name and age** which might influence the language and the scope of the product.
- **Level of education** which might influence the jargon used in the final product.
- **Motivation** impacts user behavior and interaction with the product.

Amongst the points that a Persona has, motivation is especially important to consider since motivations of the user help indicate how the user will interact with the product. As such, we can infer from their motivations usage patterns that then can be implemented to meet the users' expectations.

As simple and efficient of a tool Personas is, alone it might not paint the full picture to guide design choices. To that end, scenarios serve as a complementary tool to Personas to help paint a clearer picture of how actors, who are substitutes for users, perform tasks. Subsequently, these actors can be replaced by the Personas that have identified which in turn drives the focus on the specific users and how they interact with the product. Creating scenarios comes with its set of challenges however, as John Carroll [29] discusses in his book, a set of challenges has to be kept in mind when opting for a scenario based design approach. Additionally, a scenario should be able to answer these questions below while keeping the scenario understandable to people who do not have a technical background and keeping the user at the center of the scenario.

- Who is the target user ?
- What are their motivations ?
- When and where will they perform the desired tasks ?
- Why do they need to perform those tasks ?
- What are the challenges when performing the tasks ?

Thanks to their simplicity, scenarios act as a bridge facilitating the communication between the design team and the stakeholders making the following steps easier for both sides and more comprehensible.

2.4.2 Identifying the requirements

Preceding the development of a product, requirements need to be clearly defined in order to meet the final users' expectations. These requirements should derive from the Personas and the scenarios established in previous phases [30] as they should hold enough information for the design team to infer the characteristics of the product.

Requirements can be broken down to three main categories :

- **Functional requirements:** Specifying the functionalities of the system, what it allows the user to do when using and what actions it should not perform.
- **Non-functional requirements (Quality) :** Specifying the qualities of the system (e.g.: Safety, accessibility, scalability)
- **Usability :** Specifying the usability requirements of the system (e.g.: Intuitiveness of the user interface, Efficiency of use, user error prevention)

These three categories of requirements need to be clearly identified so that they can be reflected in the design and later in the development of prototypes and subsequently, the final product and be translated to features that will be implemented.

2.4.3 Designing solutions

For most products, the interaction of the users with the system will be primarily through a User-Interface (UI). The design of a UI should reflect the functionalities of the system clearly while also keeping the user experience in mind by promoting aesthetics and ease of access among other criteria. While designing a UI, in the initial phase of development, low fidelity representations or wireframes can be used to validate the initial concept and from there, move towards higher fidelity nonfunctional prototypes namely mockups that are higher fidelity than wireframes but still are nonfunctional prototypes and this is to showcase the overall aesthetic and look of the UI (e.g.: layout, colors, navigation) although static, it helps convey in a more realistic way what the product would look like. And finally, functional prototypes that act as a simulation of the end result and how the end user would interact with it. This is particularly informative since it is not static meaning that the users can interact with the prototype, express concerns, or small tweaks that they would like to see implemented and informs the designers further on how the user would interact with the interface.

2.4.4 Evaluate against requirements

Given that the main purpose of undertaking a UCD approach is to obtain a useful and usable application, the proposed solutions have to be evaluated. To that end, there are several methods that can be utilized, these methods should be applied over the life cycle of the product. Some techniques are more tailored for some products than others while others are more versatile and can be applied in virtually any use case.

In the case of evaluating usability, there are several methods that can be used, including questionnaires that help gauge the quality of a system. A non-exhaustive list of these questionnaires that are relevant to this work includes :

- **System Usability Scale (SUS) :** SUS is a simple ten item questionnaire with each item having a Likert-type scale from 1 (strongly disagree) to 5 (strongly agree) referring to the agreement or disagreement with the statement presented. The SUS is a highly reliable and widespread usability evaluation method that is known to be "quick and dirty" which means it's very time and cost efficient.

- **Post-Study System Usability Questionnaire (PSSUQ) :** The PSSUQ developed by James R. Lewis [31] consists of a series of 16 questions that users answer to provide feedback on their perceived satisfaction with a system with each item having a Likert-type scale ranging from 1 (strongly agree) to 7 (strongly disagree) and a N/A option. PSSUQ is used to gauge certain criteria like : System Usefulness (SYSUSE), Information quality (INFOQUAL) and Interface quality (INTERQUAL)

- **VRUSE :** VRUSE, developed by Roy S. Kalawsky [32] used to measure the usability of a VR system and acts as a tool to gather information about the interface from a user perspective. This questionnaire however is quite extensive, containing 100 questions evaluating different aspects (e.g.: Ease of use, Intuitiveness, Presence).

2.5 Discussion

With the aim of moving towards a more ecologically valid environments to study the role of the BIS, VR proved to be a solid solution. The use of 360° videos serves as an alternative for the traditional methods of experiments in the MTC research field. Although this approach yielded encouraging results, many challenges remain, this dissertation aims to address these challenges and address their validity to the field of research. The remaining challenges can be summarized as follows :

- **Providing live feedback of the experiment to researchers**. – By displaying a live feed of the participants point of view on the dashboard rather than a text message indicating the stage of the experiment.
- **Collect and display participant data.** – This includes both performance and behavior (e.g.: head movements, highlight potentially interesting behavior, participant task performance)

- **Support a larger number of videos and images.** – Since the current research used a set of three stimuli and three questions for the memory test, the application currently only allows a sequence of three images and videos to be displayed, to allow more flexible experiments to be ran, this limitation should be addressed.
- **Automatic sequence generation.** – Currently, the researchers must set up a sequence manually by selecting the appropriate videos and images from the list, to facilitate the process, the ability to generate a sequence automatically by just selecting the desired filters is one solution that can be explored.
- **More data collection during experiments**. – One of the limitations so far is the amount of data collected during experiments. More data other than participant performance might be relevant and provide more insight.

3 Requirements, Scenarios and Personas

Identifying the scenarios, requirements and the personas serves as a great tool to understand the users' needs and their motivation. These needs and motivations were identified via an iterative process in close collaboration with the domain experts through discussion of ideas, refinement, and validation of the proposed prototypes. The results of that process are presented and discussed in this chapter.

3.1 Personas

Identifying the user's motivation is important going forward with the development of a system. And to have a better understand of these motivations, three Personas were created as being representative of the type of users that will be interacting with the system. The creation of these Personas was a result of an iterative process of discussions and feedback regarding prototypes. Since this work is a continuation of what has been carried out by Silva et al. [4], the discussions and feedback were more focused around improvements and new needs past what has already been done, namely, a need for a validation system, since previous work aimed to serve as a proof of concept for the experimental protocol.

The goal of the validation process is to gage the impact of a stimulus, in this case a video representing the scenario, using different metrics (e.g.: Arousal, perceived sickness of the person holding the object) and better understand if the participants were able to process what is depicted.

Presented in this section, the previously created Personas that were adapted to the new identified motivations (highlighted in bold).

Filipa Marques, researcher in the field of Psychology.

Figure 3.1 Filipa Persona

Filipa Marques, a 35-year-old psychologist, works fulltime 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.

Motivation: Filipa wants to explore and implement more ecologically valid stimuli **and validate its applicability** in the 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 modern 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 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 livable 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 experiments and **help validate the catalog of stimuli**.

3.2 Scenarios

New scenarios to depict the validation process were established based on the motivations of the personas identified in the previous section. This section presents the scenarios related to the validation process listed first, followed by those pertaining to the experimental process.

Participation in the validation process

Preparation – Maria arrives at the Psychology department, where she will be participating in the validation process of the videos to be shown in the experimental process. Upon arriving, the team welcomes her and duly explain to her the possible side effects and what to expect during this task. She was then asked to sign a consent form and then asked to enter a room, where she would be seated and asked to wear the VR headset. To get Maria acquainted with the VR environment, a brief training period is played first where she would explore the environment and get familiar with the controls.

Presentation of stimuli – As the validation process starts, Maria is presented with a video serving as the stimulus, in this case representing a person entering the room, coughing on a cup, and placing that cup on the table. After the end of that stimuli, a set of questions appear in front of Maria, each question asking her to evaluate different feelings she might've had during the presentation of the stimuli. Maria then uses the joystick on the controller to select a value on a slider that matches her answers and submits that answer with a press of a button on the controller. At the end of the process, Lucas helps Maria to remove the headset and asks her about how the experiment went then leads her out of the room marking the end of the validation process.

Data collection – While the experiment is ongoing, Filipa looks at her dashboard to follow the state of the experiment. In that page, she can see some details like what video is currently playing, the status of the HMD (connected or disconnected) and real time data regarding the user answers.

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 chose Virtual Reality as a means to conduct more immersive experiments, 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 a 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 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. Maria uses the controllers to provide her answer. 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.

3.3 Requirements

The Personas' motivations and scenarios made identifying the requirements more intuitive. The requirements for the experimental process were already identified in Silva et al. [4] work, those requirements are listed below in addition to the requirements that arose for the validation process. Whereas Silva's requirements focused more on the usability of the system for the research team, it is important to keep in mind the intuitiveness and the affordance when it comes to the participants interaction with the virtual environment when it comes to answering questionnaires inside the virtual environment.

Experiment Configuration

- Set the order of videos as desired.
- Experiment preview.
- Saving experiment configuration.
- Configuring separate phases of the experiment, e.g., training period, experimental phase.
- Defining questionnaires and the moment of their application during the experiment.

Experiment Controller

- Introducing 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.
- 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.

Validation controller

- Provide feedback on the status of the process.
- Save relevant data from the experiment to file (e.g.: participant answers, randomized initial values, order of appearance of questions)

Validation Renderer

- Ability to use the controllers' joystick to answer the questions.
- Good affordance during the questionnaire answering phase.
- Randomize the order of appearance of questions and the initial answer value.
- Able to play multiple videos.

4 Development

Incorporating an iterative user-centered design approach is important throughout the development process. However, conducting frequent iterations can consume considerable time and resources when considering a short duration project such as a dissertation.

To address this challenge, a more informal approach was adopted by engaging in weekly discussions with the Psychology team. These discussions served as a platform to review the current stage of the prototype and provide grounds for further improvements. Whenever deemed appropriate, such as for a more stable prototype or the introduction of new features, a more formal evaluation was carried out, which will be described in detail later.

By employing this balanced approach, the project ensured both efficiency and meaningful engagement.

4.1 Overall conception

With all the requirements for the development of the system in mind, a diagram illustrating the high-level components of the system was created as seen in Figure 4.1 where the modules colored in yellow are modules that have been developed previously and the modules that are not colored are newly developed or overhauled modules. The flow of the system can be described as follows : Capturing 360° videos to act as stimuli for the experiments then saving those videos in the catalog using the video annotator in combination with additional information about the video (e.g.: title, tags, thumbnail). Next, to set up an experiment or start the validation process, the configurator allows the set-up of the process by, for example, defining the sequence of videos to be played and the images to be shown chosen from the catalog. Then, depending on the type of message, either validation or experiment, the controller, responsible for the communication between the configurator and the renderer, will send the appropriate instruction to the VR application to start the desired process. The application then displays the videos to the participants accordingly.

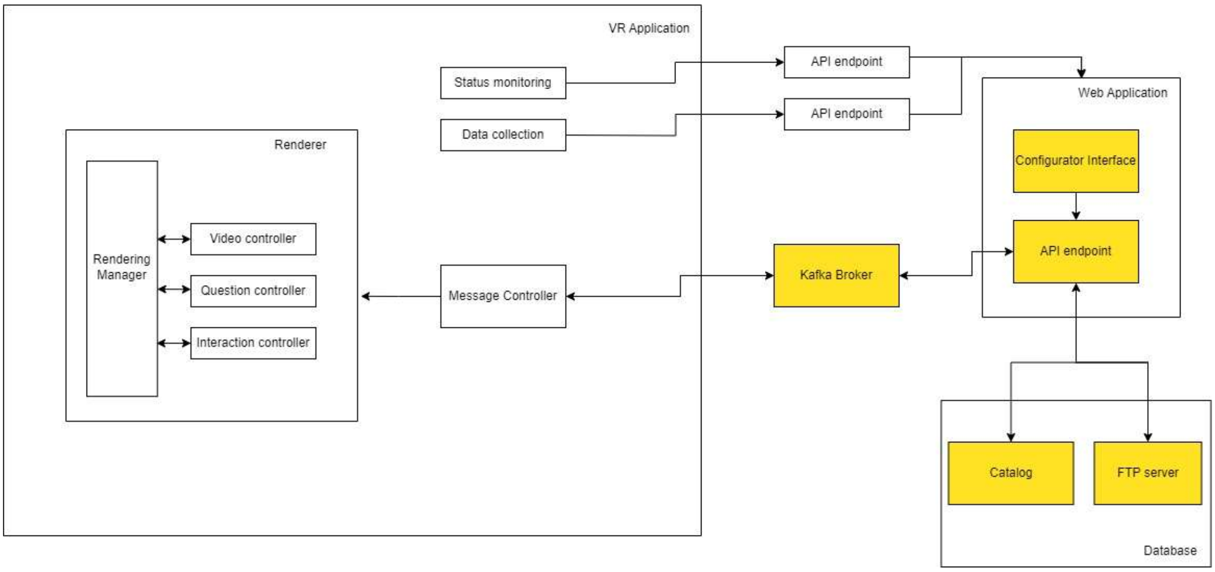


Figure 4.1: Overall system architecture depicting the three core components: a VR application, running on the HMD, a web application running on the experimenter's computer and a video database. The modules depicted in yellow correspond to the initial system considered at the onset of the work.

4.1.1 Renderer

The renderer module depicted in Figure 4.1 hosts all the logic pertaining to the experiment, divided into sub-modules that perform a specific task. But they also can have different behaviors depending on the type of message that has been received. The messages are sent to the message controller module that, depending on the type of message received from the web application (either "experiment" or "validation"), would configure the renderer accordingly as the renderer was designed to allow for different configurations.

In this section, the base logic of each sub-module will be explored, regardless of message type.

Later in this chapter, we will explore how each submodule is configured depending on the desired type of operation and the configurations provided by the experimenters.

4.1.1.1 Video controller

As depicted in Figure 4.1, one of the modules contained in the renderer is a video controller. Its main task is the ability to display a list of videos, irrespective of whether they are meant for validation purposes or experimental use. This sub-module serves as a foundation for both the validation and the experimental process. However, due to the differences between them, as will be discussed later in this chapter, each process requires specific settings to accommodate these differences.

Currently, the video controller operates by receiving a collection of video paths as input. It subsequently proceeds to render each video from the given list, employing a *VideoPlayer* object that is attached to a sphere. After the current video reaches the end, the next video will be loaded according to the type of experiment being run (i.e. : Experimental protocol or validation).

One of the requirements is the ability to play multiple videos in a row, but due to a technical limitation, mostly concerning memory, where the *VideoPlayer* object in Unity would not clear previously played videos from memory unless the object is either destroyed or the *Stop()* method is called. This results in a blank screen appearing between videos for approximately 2 seconds. This interruption breaks the immersion of the participant, which is not a desired outcome.

To remedy this issue, the first idea was to utilize an approach like the technique used in computer graphics, utilizing 2 buffers (front buffer and a back buffer). In this instance, 2 different *VideoPlayer* objects alternating the display of videos acting as different buffers. This approach still results in a small delay between videos as the next buffer still needs to load the video file before playing it. And this also meant that there was a need to destroy the non-used buffer when the current buffer is playing then re-create the object and attach it to the sphere that is displaying the videos to clear its memory usage which exhibited a notable allocation of system resources during this process.

Following another meeting with the research team, one of the suggestions was to have a transition or a stopping point between videos which is not too abrupt but still noticeable, it involved playing a bell ring to draw the participants attention before the stimuli is presented. For that, we agreed to use a static picture (see Figure 4.2) of the room the stimuli were recorded and applied as a material to another sphere. This spheres' renderer would be enabled whenever the *VideoPlayer* object is not currently playing a video and would be disabled when that object is playing. However, the sphere showing the picture had to be scaled down compared to the one that is displaying the videos, since having them at the same size made the two spheres intersect and cause a blinking effect of the triangles at the intersection points. This, in addition to editing done on the picture to align the door and the table depicted in it with the videos by cropping a portion of the picture, led to the picture appearing slightly zoomed in compared to the videos but after discussing this prototype with the team we concluded that the transition satisfies the need for it to be noticeable yet not too abrupt for the participants.

The video controller plays a vital role in presenting these videos to the participants seamlessly. As the video controller progresses through the list, and eventually reaches the conclusion of the list, a canvas is displayed to the participant, superimposed over a static image signaling the end of the list of videos.

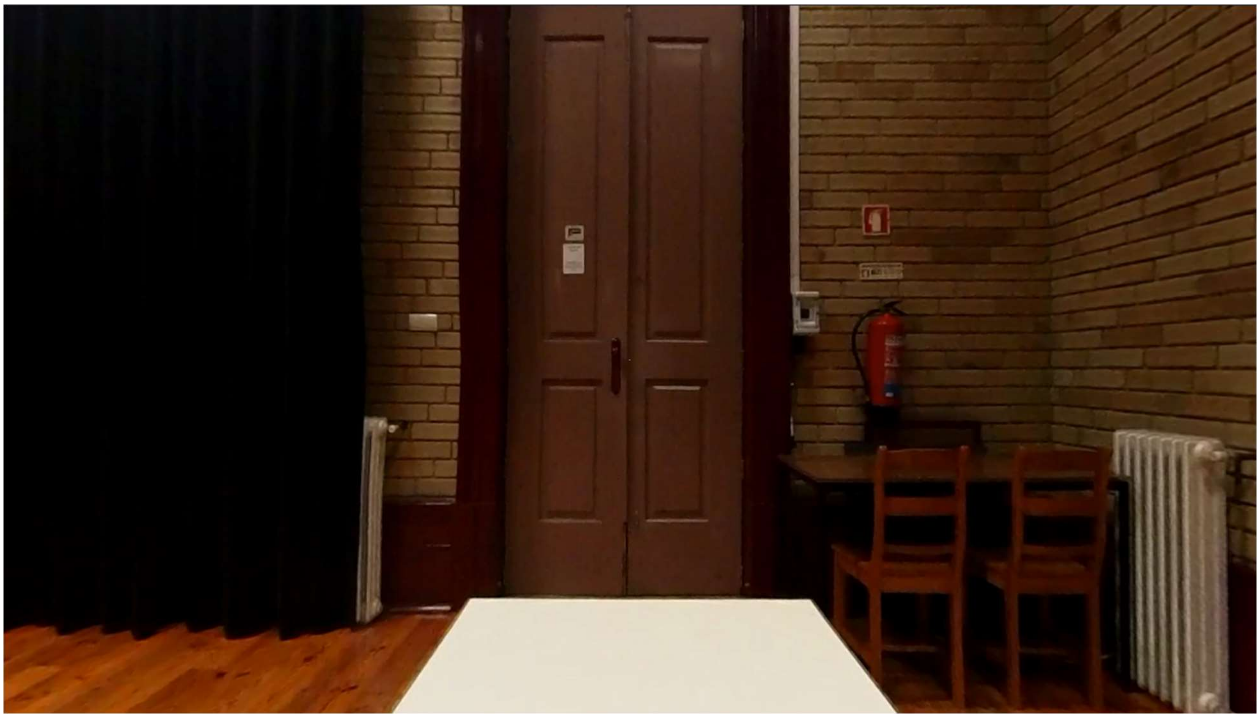


Figure 4.2: Centered view of the transition image showed between videos.

4.1.1.2 Question controller

Just like the video controller, the question controller acts as a base sub-module that solely handles how and when the appropriate questions will be displayed to the participant.

There are two types of canvases that can be displayed : one type for the validation process and another type for the experimental process. Differences between the two types will be explored in later sections of this chapter.

The controller at its base form will enable and disable the appropriate canvases when needed while also updating the question text appropriately. The questions are displayed either when a video reached its end or after the list of videos to be played is over.

To allow the participants to interact and answer the questions displayed, the question controller sub-module is also responsible for the handling of user input via the provided Oculus Quest 2 controllers.

For this sub-module, two different types of questions with different scales are considered, one type involves a Likert-like scale and the other a dichotomous scale (e.g.: yes or no).

We carefully selected scales for each question based on their suitability for the specific context. Additionally, we considered how best to present these questions to ensure clarity and user-friendliness.

Affordance refers to the potential or perceived interactions with an object, in other words, what the properties of a certain object suggest to the perceiver on how it can be interacted with. And in relation to VR environments, the way an object, or in this case, a question is presented, becomes relevant since the way the canvas that contains the question text and the tools to answer said question (e.g.: slider, buttons, checkbox) is conveying not only context about the question itself but also provides visual clues to help guide the participant on how to interact with it.

During the initial meetings with the researchers, a nonfunctional prototype was provided depicting their vision of how the questions should be presented shown in Figure 4.3. The figure shows a semi-transparent canvas that would display the question text alongside the different values representing a scale to help guide the participants answer the question appropriately.

Each value is a different button, and the idea is to have the participant use the controller ray casting to aim towards the desired button and use a button to select it.

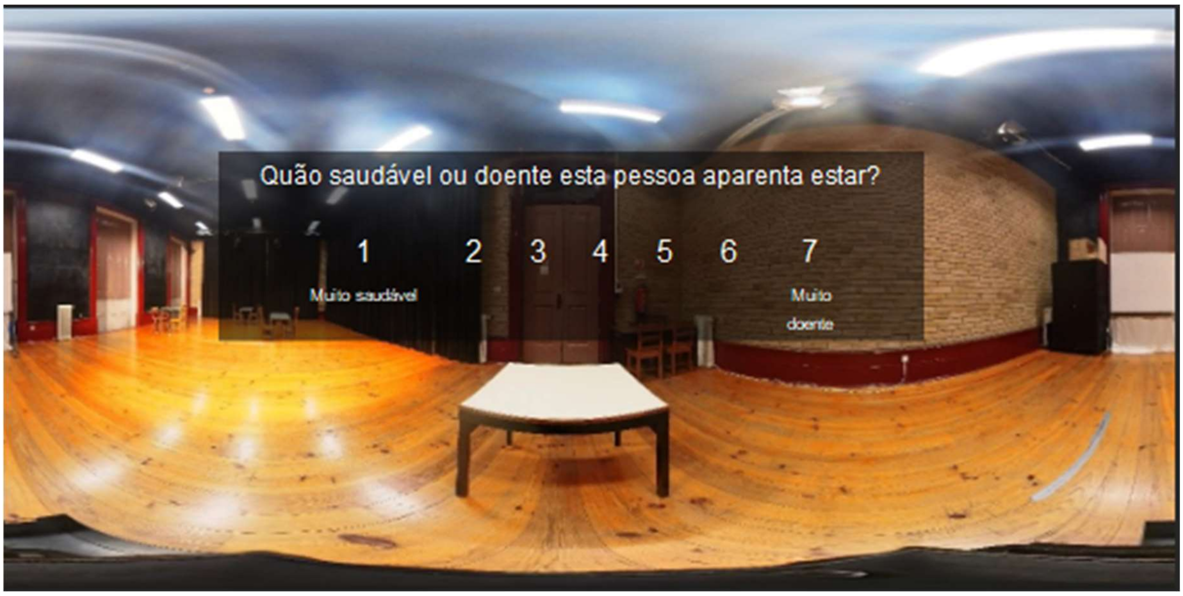


Figure 4.3: Nonfunctional prototype depicting the presentation of questions.

However, through later discussions, it was decided that we can substitute the buttons with a slider that allows the user to select only integers, ranging from 1 to 7 with a visual clue on what value is currently selected. This decision was preferred when the affordance of the canvas was considered. An alternative to utilizing a slider, is allowing the user to select their answer by pointing the controller towards the desired value and selecting it by pressing a button. This however was deemed as a non-practical solution when considering the overall duration of the validation process per participant that can reach up to an hour long with a 5 minute break every 30 minutes and the repetitive movements of the hand aiming towards this is really too long values might not only result in fatigue or discomfort especially for participants that might suffer from physical disabilities or injuries but also requires a certain level of precision that in turn, might increase the risk of user error when selecting answers.

In contrast, a slider strongly suggests that the joysticks of the controller can be used to alter its value left or right. The use of a slider over buttons allows for more precision if needed in the future, the range of the slider can be either integers or decimal values whereas a list of buttons is restricted to just discrete values. The proposed solution, depicted in Figure 4.4 replaces the list of buttons proposed for a slider with a range of 1 through 7 and only allows integer values to be selected in combination with a numeric value shown on top.

Figure 4.4: Questions canvas utilizing a slider for answers.

4.1.1.3 Data collection

The data collection module's primary role is to collect, format and send data back to the computer the experiment was started on.

The data is, during the experiment, held in memory and before the application signals the end of the experiment to the participant, the data is then formatted into a JSON format and send it to the API endpoint to be saved to a JSON file, then, the application would await for a response from the API that contains a hash of the data received, when the response is received, the VR application would compare the hash received against its local hash to ensure that the data is complete and not corrupted.

During the experiment, the data received by the API would only be displayed to the researchers and not saved, that way if messages are lost, it is not that impactful. And after the experiment ends, the data collection module would ensure that the data was properly sent to the PC by awaiting a confirmation message from the API that the data was saved to a file properly. If not, the module would keep trying until the confirmation response is received.

To ensure that the correct data was the one saved and no loss or corruption to the data happened, the API endpoint will calculate a hash (SHA256) of the object received, and in the response, would send that hash back to the VR application, then, the application would compare the hash received from the

API endpoint and the local hash. If the hashes are equal, then the correct data was received. If it is not the case, retry to send the data again and go through the process again.

To help the researchers further in the data processing process, a script was developed and integrated in the dashboard that, when invoked, will cycle through the folder where the JSON files were stored (one file per participant) and aggregate all of the files data into one CSV file that then can be exported to Microsoft Excel, making it easily readable and allows for more actions and processing to be performed on the dataset. The resultant CSV file shows, per line, the stimuli presented to a participant, followed by the answers and the time it took them to answer the set of 6 questions.

4.1.1.4 Rendering manager

As depicted in Figure 4.1, all the previous sub-modules are communicating directly with the rendering manager. The rendering manager sub-module acts as an orchestrator that coordinates when each sub-module would be invoked and how it is going to be configured as we will be exploring later in this dissertation.

The rendering manager constantly monitors the progress of the experiment and keeps track of the current stage or phase it is on and determines what task needs to be executed at that moment considering the type of experiment that need to be ran, as received from the message controller which allows it to also hold and communicate the appropriate configurations to the remaining sub-modules. For instance, when reaching the end of a video and want to display the questions canvas, the rendering manager is responsible for triggering that behavior.

4.1.1.5 Interaction controller

The interaction controller sub-module handles the interactions with the UI and the participant via the joysticks provided with the Oculus Quest 2 HMD. The interaction controller also allows the participants to use either the left or right controller for ease of access depending on their dominant hand or preference.

The interactions that this sub-module handles are :

- **Selecting answers :** Moving the joystick left or right would change the value of the slider in the case of the validation process or highlight either one of the choices in the case of the experimental protocol.

- **Submitting answers** : Pressing the select button (A for the right controller, X for the left controller) will lock in the selected value or choice and signals the rendering manager to move to the next step of the protocol.

4.2 Supporting Research in the Mnemonic Tuning for Contamination

For the research in MTC to happen, there needs to be two distinct steps it needs to undergo, the first step consists of the validation of the 360° videos that have been acquired in previous work, this is important to assess which videos are fit to be used in the experimental protocol and their validity in this context. The second step consists of applying the defined protocol regarding the Mnemonic Tuning for Contamination utilizing the videos that have been chosen from the validation process as stimuli to be presented in this step.

The developed modules described earlier in this dissertation were made with both the validation process and the experimental protocol in mind. This entails that they were designed to support the features that would serve the needs of both protocols, allowing the research team to reuse the modules by simply choosing the appropriate configuration depending on the desired protocol.

4.2.1 Video validation

During the regular discussion with the research team, we agreed that a validation component designed to assess the accuracy and reliability of videos should include a set of questions that evaluates how the participant processed the stimuli presented.

This involves showing two lists of videos, each list consisting of 16 videos that are displayed in a randomized order and at the end of each video, the participant is shown 6 questions, that also have a randomized order. At the end of the first list of videos, there is a five-minute pause for the participant to avoid ocular fatigue or any other signs of cybersickness.

The development process of the validation component was an iterative process informed by weekly discussions with two female researchers from the Department of Education and Psychology, one PhD student and one Post doctoral researcher. The weekly meetings involved the presentation of mockups, gathering feedback regarding functional prototypes of different functionalities and testing the overall validation workflow.

Later during development, the validation process was better defined, and is comprised of three phases:

- **Training period:** The participant is shown two sets of stimuli-questions to get familiar with the controls and the questions that will be asked during later periods.
- **Habituation:** The habituation period is a three-minute-long period with the main purpose of allowing the participants to explore the environment and get more at ease with it. This phase is shown before both lists of videos to be shown to the participant. No stimuli or questions are displayed during this period.
- **Validation period:** Shows two lists of videos to the participant. These lists are chosen in advance by the researchers on the dashboard. There is a pause of 5 minutes between each list.

The steps and their order during the process are shown in Figure 4.5. The habituation period is played twice during the process, once before every list of videos, the first time is to help the participants settle in the virtual environment and get familiar with it, the second time before the second list start playing to help re-habituate the participants again after the five-minute pause. The purpose of the pause is to avoid fatigue to the participants, each list of videos is around 25 minutes long, made to be just long enough so that participants do not experience visual fatigue [33]

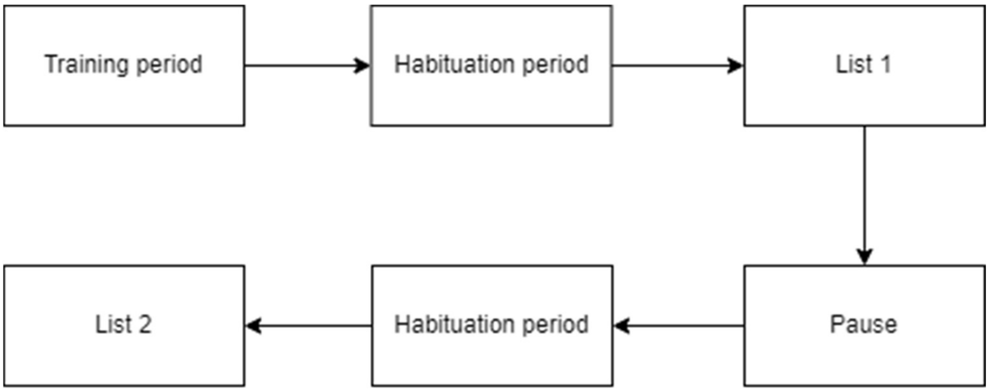


Figure 4.5: The steps of the validation process

4.2.1.1 Video rendering

As depicted in Figure 4.5, the validation process involves multiple different phases, each with their own set of videos to be rendered. As defined by the MTC research team, the training period and habituation period stimuli will always be the same for every participant which allows us to keep the configuration for those periods static although the possibility to change the videos to be played during that time can be changed. And regarding the lists, the videos to be played for each list is also static however, the order is important (e.g.: List A1 then List A2) and the order within each list also is randomized. This required that the video renderer module not only stays aware of what phase of the process is being currently ran to display the according videos at the proper time but also keep track of the randomized order of each list.

4.2.1.2 Questions rendering

Given the nature of the questions, a numeric value attached to the slider as was previously discussed (as seen in Figure 4.4), shown to the participant, was found to be confusing during a pilot study where the prototype was tested by 4 bachelor students and the MTC research team. For that reason, the numeric value that served as feedback, was dropped (see Figure 4.6). During that same meeting, the gathered feedback also addressed the randomization of the slider value for each question. The reasoning behind randomizing the slider value was initially decided with the numeric value shown in mind to avoid potential suggestion. However, now that the scale does not show a value, the students that tested the prototype felt like the randomization of the scale felt as if it was suggesting an answer and had them second guessing their answers. For that reason, the initial value of the slider will be in the middle of scale instead of randomized for each question.

Figure 4.6 : Updated canvas for rendering the questions.

Having a vision of how a question would be rendered to the participants, the order of presentation of the questions had to be addressed, which involved using the same canvas instead of individual canvases per question and dynamically change the text fields' value before enabling the canvas.

The questions text is stored in the questions renderer modules' memory in a list, that list then gets shuffled and would iterate through the shuffled list to display the questions in that order.

4.2.1.3 Data collection

In the validation phase, data collection pertaining to the stimuli to be validated is important to discern which stimuli are suitable for the experimental process and which ones should be disregarded. Consequently, comprehending the specific data that needs to be gathered during the validation is a crucial step towards this objective.

Regarding the types of data that are collected during the experiments, the most important ones were the user answers to the questions linked to the stimuli they relate to and the time in seconds it took the participant to answer the set of questions for one stimulus.

As mentioned in the previous section, the order of appearance of the questions to the participant is randomized. However, the collected data is always provided to the researcher in its original order to facilitate gathering the data for all participants and facilitate analysis.

To this effect, after recording the answers of the participants on the VR application side, the answers are rearranged back to their original order before getting sent back to the dashboard and written to a JSON file.

Throughout testing of the prototypes, we noticed that some messages were either lost or not being sent back properly. To remedy this issue, we decided to have two separate processes for displaying and saving the data.

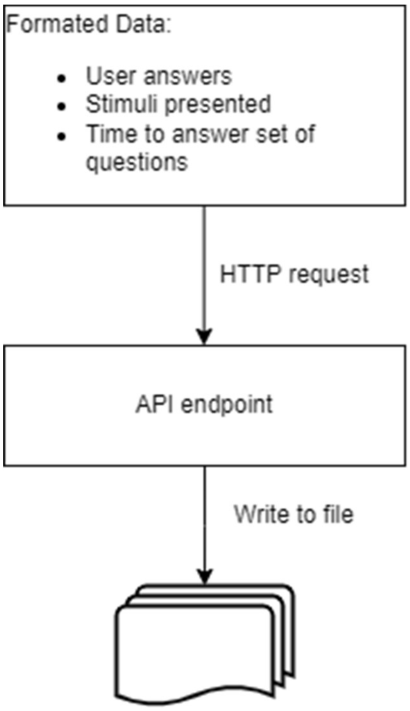


Figure 4.7: Data collection process

4.2.1.4 Experiment status

One of the challenges the research team expressed during the various meetings, is the lack of visibility regarding the current stage of the experiments. This new requirement was met by redirecting the users to a page after starting an experiment that would display various types of information regarding the experiment. This page would provide the researchers with the ability view in real time various types of data such as the currently playing video, a table containing the order of the played videos represented by the index, answers, the time in seconds it took answering the set of questions, and their corresponding stimuli, and the status of the app (connected / disconnected) as seen in Figure 4.8

The purpose of displaying the status of the connection in that page is to inform the experimenter(s) on the VR headsets' connection status to avoid possible situations where it gets disconnected and disrupt the flow of the experiment. This loss of connection was observed during the 5-minute break when the VR headset goes into standby mode leading to the data at the end of the experiment to not get sent and saved. This allows the researchers to manually reconnect the headset if needed during the break.

Index	Time	Video	Answers
0	23.133	/sdcard/Videos360/Training/O_scissors_A1.F_cough.mp4	2, 2, 1, 7, 5, 4
1	30.223	/sdcard/Videos360/Training/W_sunglasses_A4.M_whistle.mp4	2, 4, 5, 7, 5, 3
2	17.221	/sdcard/Videos360/A2/K_bowl_A26.F_yawn.mp4	3, 1, 2, 5, 5, 4
3	23.021	/sdcard/Videos360/A2/K_jar_A15.F_yawn.mp4	7, 2, 2, 1, 4, 7
4	19.321	/sdcard/Videos360/A2/K_spoon_A11.F_sneeze.mp4	1, 2, 4, 5, 6, 4
5	35.652	/sdcard/Videos360/A2/T_teddy bear_A14.F_yawn.mp4	4, 3, 2, 1, 1, 6
6	19.55	/sdcard/Videos360/A2/W_bracelet_A7.M_sneeze.mp4	4, 3, 1, 1, 5, 2
7	19.114	/sdcard/Videos360/A2/W_sunglasses_A4.M_yawn.mp4	1, 1, 3, 4, 6, 2
8	25.332	/sdcard/Videos360/A2/W_watch_A14.F_whistle.mp4	3, 4, 2, 1, 1, 2
9	28.456	/sdcard/Videos360/A2/W_fan_A21.M_yawn.mp4	4, 5, 2, 5, 7, 1

Figure 4.8:The page indicating the live status of the system including the video that is currently being played and a table containing participant performance data such as the answers and the time to provide the answers.

4.2.2 Experimental process

As discussed earlier in Figure 4.1 the experiment module and the validation module are part of the renderer module.
In the previous section, we introduced how this module is configured for the validation process, and in this section, we will introduce how the same module is configured for the experimental protocol.

The experimental protocol albeit different from the validation process, shares similarities functionally with said process. It consists of displaying lists of videos, referred to as sequences, each sequence contains a total of three videos and three pictures. The pictures depict objects that have been seen in the videos presented in addition of a question canvas asking the participant whether the object displayed has been in contact with a healthy or unhealthy person.

4.2.2.1 Video rendering

Regarding the experimental process, as defined by the research team, each participant will be presented a set number of sequences, each sequence containing 3 videos and 3 images.

Throughout testing, it was determined that the technical limitations faced during the validation process regarding the transition between videos were not an issue with a small number of videos as is in this case. This allows us to transition between videos in that sequence directly instead of utilizing a static image to serve as a transition point while the next video is loading although at the cost of utilizing more memory, but the smooth transition between stimuli helps upkeep the sense of presence and immersion for the participants. The combined memory of each sequence then can be cleared using the same technique utilized in the validation process.

The questions that would be presented to the participants are also shown later during the process and not in-between videos, so we could play the sequence of videos as is, without interruptions.

4.2.2.2 Question rendering

Following one of the various meetings with the research team, it was decided that the questions for the experimental protocol should have a dichotomous scale for answers, meaning that there is a need for a different approach from the validation process to display the questions as they are intended.

Given the nature of the scale and how the questions are formulated, we can utilize the two different text boxes that are managed by the question controller sub-module (see 4.1.1.2) indicating the possible choices, in this case, “Healthy” or “Unhealthy” and we can also utilize the slider to provide the visual feedback for the participants on what answer is currently selected. However, the slider for the experimental process has been modified to appear as an arrow below each option pointing out what is currently selected. This approach has two main advantages, firstly, we get to reuse the slider component made available in the question controller so that there is no need to create a new component to act as an indicator and secondly, this simplifies the way we get the answer selected by the participant as the logic is already implemented, in contrast to if we added a new component.

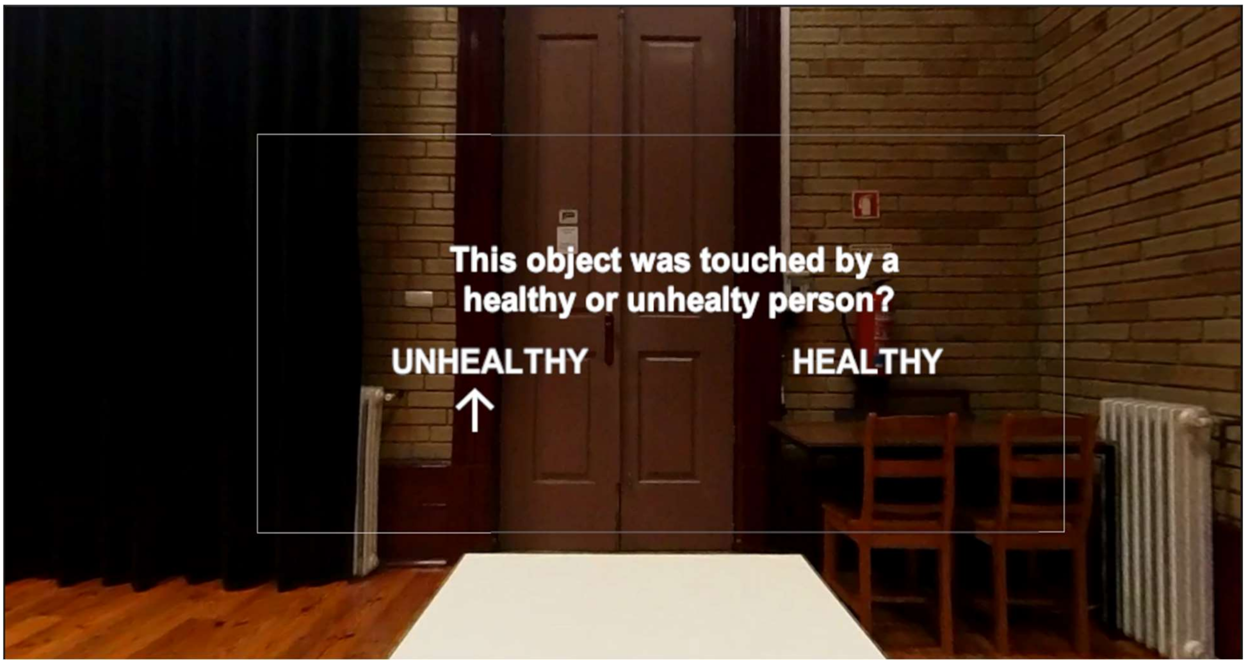


Figure 4.9: Example of the question presentation during the experimental protocol

4.2.2.3 Data collection

During the experimental process, two types of data are being collected regarding the experiment : Performance data (User answers) data and behavioral data (Head orientation). The user answers data is handled similarly to the user answers in the validation process as in it gets sent back to the dashboard as the answers are provided by the participant to be displayed for the research team and saved to file when the experiment concludes. The head orientation data on the other hand had to have its own logic. In fact, since the head orientation is a continuous type of data, we need to send back samples as they come. This could have been easily achieved by utilizing a broker (e.g.: Kafka) but given the technical limitations of the HMD used (Oculus Quest 2), Kafka was not supported, which led to experimenting with other solutions.

Sending the data using HTTP requests as they come proved to not only put a heavy strain on the HMD but also resulted in some data getting lost in the process. Trying to limit the number of samples to be sent helped alleviate that stress on the HMD but the data loss was still an issue. To remedy that issue, the current solution involves writing the data to a temporary file, locally on the HMD to ensure the data is not being lost in transmission, and towards the end of the experiment, send the contents of the file back to the dashboard, and similar to how it is done for the validation protocol, ensure that the hash of the data received by the dashboard, matches the hash generated by the Unity application.

4.2.2.4 Experiment status

The experiment status works similarly to the validation process in the experimental process, although the module had to be expanded to accommodate for communicating the information regarding which image is currently being displayed since during the experimental process, the questions are displayed over the images instead of in-between videos in the validation process. To achieve this, the experiment status controller no longer sends the *VideoPlayer* object's currently playing video name solely, but rather considers the current item in a list that stores all the files we need to display in order. Doing it this way allows to identify both the videos and the images that are currently being displayed on top of leaving room for gathering this information about any other type of files that potentially need to be played in the future (e.g.: audio file)

4.3 Discussion

In this chapter, we identified and presented the modules that satisfy the research teams' requirements for the system. We first started by going over the modules design choices and their barebones implementation. Later in this chapter, we explored how we can apply the modules at their general state to the specific scenarios that arise from the experimental protocol and have the modules support said scenarios.

After gathering the initial feedback from the research team regarding the system at its current state, the results suggest that the system is adequate to support both the experimental protocol and the validation protocol. However, a proper validation for the system is still required, as we move on to the next step, it is important to evaluate our implementation and design choices.

5 Evaluation

Considering the system is now able to support the experimental workflow, the next step was to evaluate it. To avoid interfering with the research team's data collection, we also deemed it appropriate to not impose tasks to the participants and consider the experiment as a task alongside answering the questions during the validation process.

This evaluation was twofold, on one hand, a Usability test utilizing a System Usability Scale (SUS)[34] that was presented to the participants after they had finished the experiment, and on the other hand, a custom questionnaire, also presented after the end of the experiment, regarding the overall experience of the participants when they were immersed in the virtual environment. Only one questionnaire was presented per participant however, since they reported fatigue following the process.

The companion application was not considered in this SUS, as it was already validated in previous work [4] and was not altered in a meaningful way. Yet it is equally important to evaluate the research teams experience using the system and the improvements that have been made to it. This chapter will illustrate the data gathered from both questionnaires.

5.1 System Usability Scale

SUS is a simple ten item questionnaire with each item having a Likert-like scale from 1 (strongly disagree) to 5 (strongly agree) referring to the agreement or disagreement with the statement presented. The scales of the questionnaire we used however have been reversed to scale position 1 being "totally agree" and scale position 5 being "totally disagree" (see Figure 5.1). This decision was solely for the sake of ease of readability and has no impact on the final score.

Post Task Questionnaire

Instructions: Thank you for your cooperation with this study, which aims to evaluate the User Interface of the application/system and, try to improve it following the Usability criteria.
Your collaboration is important for the success of this evaluation, so we ask you to complete this questionnaire, the data of which will be used in total anonymity for scientific purposes only.

1. Demographic data

User number:___________
(check the correct options)

Gender: ☐ Female ☐ Male **Age:**_________ **Profession:**_______________

Previous experience with this type of application/system: ☐ None ☐ Some ☐ A lot

Observations (fill in any relevant facts for this test, e.g., vision, handiness):

2. Overall opinion on the application/system (SUS)

After using the application/system and taking into account your final assessment, check the circle that best reflects your opinion regarding its usage. If you believe that these quantifications are not applicable, choose NA.

I think that I would like to use this system frequently.	Totally agree	○○○○○	Totally disagree	NA
I found the system unnecessarily complex.	Totally agree	○○○○○	Totally disagree	NA
I thought the system was easy to use.	Totally agree	○○○○○	Totally disagree	NA
I think that I would need the support of a technical person to be able to use this system.	Totally agree	○○○○○	Totally disagree	NA
I found the various functions in this system were well integrated.	Totally agree	○○○○○	Totally disagree	NA
I thought there was too much inconsistency in this system.	Totally agree	○○○○○	Totally disagree	NA
I would imagine that most people would learn to use this system very quickly.	Totally agree	○○○○○	Totally disagree	NA
I found the system very cumbersome to use.	Totally agree	○○○○○	Totally disagree	NA
I felt very confident using the system.	Totally agree	○○○○○	Totally disagree	NA
I needed to learn a lot of things before I could get going with this system.	Totally agree	○○○○○	Totally disagree	NA

Please leave any comments about the user experience provided by the application/system:

Thank you very much for your collaboration!

Figure 5.1: System Usability Scale

5.1.1 Results

For this evaluation, 12 participants (female = 7), ages ranging from 18 to 45 provided their answers. Out of the 12 questionnaires, 1 of them had "NA" as an answer for a question (question 5), for that reason, it was omitted from the score calculations. As seen in Table 5-1, the average SUS score out of the 11 questionnaires is 73.68 and the median is 75 with a minimum score of 65 and a maximum score of 82.5. Given that a score of 68 corresponds to a usable system, an average of 73.68 indicates a good system. After looking into the responses gathered (see Figure 5.2), we have noticed that the question 1, "*I think that I would like to use this system frequently*", received lower scores overall. This is not surprising given the nature of the system and its setting as part of a research experiment, i.e., not aiming for entertainment.

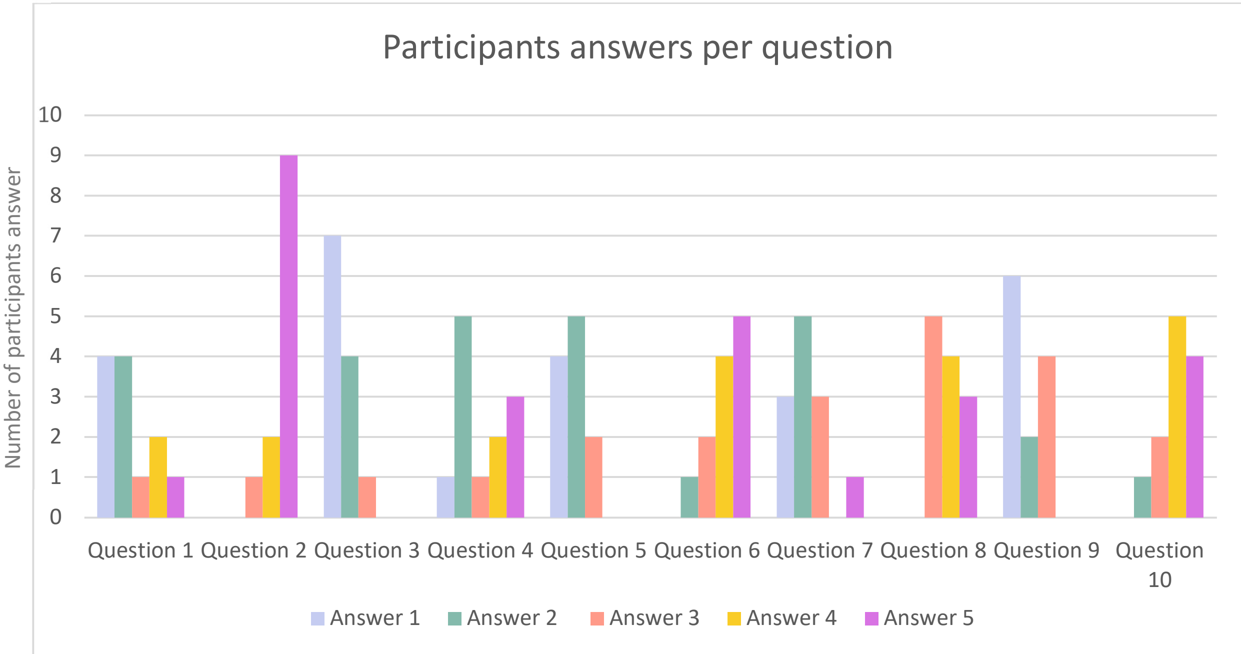


Figure 5.2 : Participant answer count per SUS question

Minimum	Maximum	Average	Median
65	82,5	73,68	75

Table 5-1 : Overall statistical SUS data

Additionally, the majority of SUS questionnaire scores fall in the “good” and “excellent” categories is 8 out of 11 as seen in Figure 5.3. This indicates a good overall perception of the system by the participants.

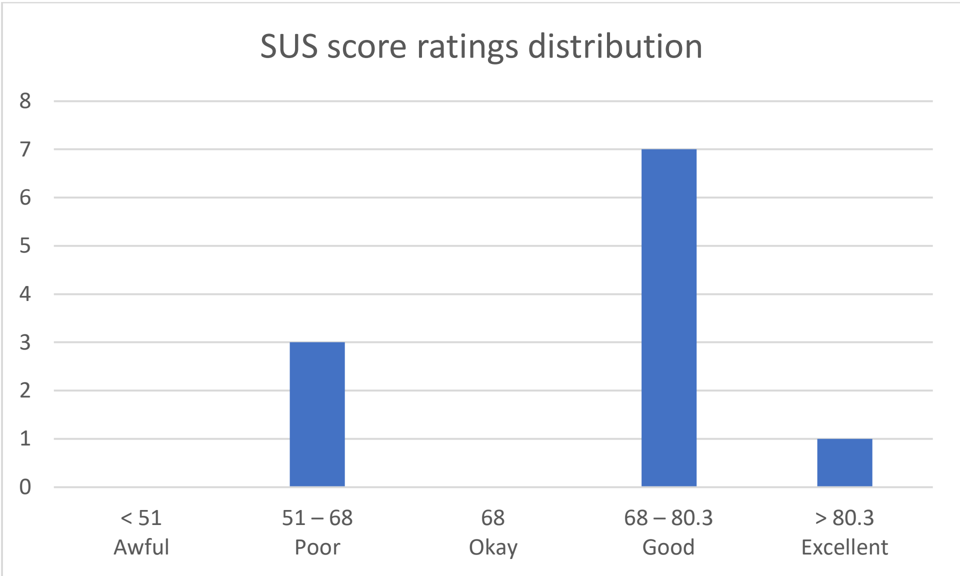


Figure 5.3: SUS scores distribution by their corresponding category

5.2 User experience questionnaire

In addition to the SUS, we also deemed appropriate to evaluate the participants experience during the experiments to gauge, if any, there was some discomfort or any signs of cybersickness given that they will be exposed to a VR environment for an extended period. Although cybersickness usually manifests itself when motion is simulated which is not the case for our application, or some pre-existing clinical factors [35] It is still important to make sure that the system does not create discomfort to the participants when used, which is one the goals of this questionnaire (see Figure 5.4). This questionnaire is presented to the participants after the end of the experiment and before a memory task where they were asked to remember as many objects as they could.

The second aspect of this questionnaire is to also evaluate the experience of the research team when interacting with the system and understanding whether their experience setting up the experiments went as intended or if they faced any problems. The questions presented to the researchers target specific aspects of the setup phase, while the experiment is running and after the session concluded (see Figure 5.5).

Post Task Questionnaire

Instructions: Thank you for your cooperation with this study, which aims to evaluate your perception about certain aspects of the system you just used. Your collaboration is important for the success of this evaluation, so we ask you to complete this questionnaire, the data of which will be used in total anonymity for scientific purposes only.

User number:____________

Gender: ☐ Female ☐ Male **Age:**____ **Profession:**__________________

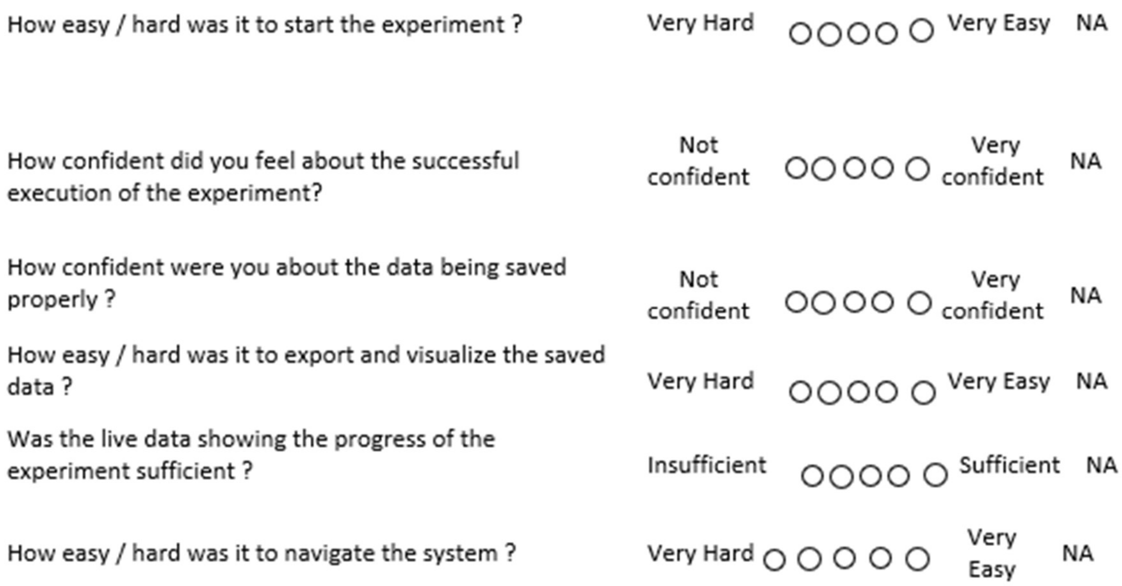
Previous experience with this type of application/system: ☐ None ☐ Some ☐ A lot

Observations (fill in any relevant facts for this test, e.g.: vision, handiness):

Considering your final assessment, fill the circle that best reflects your opinion about the system.

How immersed did you feel in the environment during the experiment ?	Not Immersed	○○○○○	Totally Immersed
How realistic did the environment look and feel?	Very unrealistic	○○○○○	Very realistic
Did you, at any point during the experiment, feel any dizziness ?	Very much	○○○○○	Not at all
Did you, at any point during the experiment, feel any sickness ?	Very much	○○○○○	Not at all
Did you, at any point during the experiment, feel any discomfort?	Very much	○○○○○	Not at all
Did you, at any point during the experiment, feel disorientated ?	Very much	○○○○○	Not at all
How was the transition between scenes? Were there strange pauses, black screens, or glitches?	Very glitchy	○○○○○	Very smooth
How easy was it to identify the objects placed on the table?	Very Hard	○○○○○	Very Easy
Were the questions presented during the experiment easy to read ?	Very Hard	○○○○○	Very Easy
How easy was it to understand what you needed to do to choose your answer (i.e., move left and right using the controller)	Very Hard	○○○○○	Very Easy
How easy was it to understand and remember how to validate your answer (i.e., press A button) ?	Very Hard	○○○○○	Very Easy
How intrusive was the way the questions were presented, i.e., did they break the illusion of being in the room or did they blend well with the scene?	Very Intrusive	○○○○○	Not Intrusive
How do you classify your overall experience with this experiment?	Very unpleasant	○○○○○	Very pleasant

Figure 5.4 : Questionnaire presented to the participants to evaluate their experience using the VR application.



How easy / hard was it to start the experiment ?	Very Hard	○○○○○	Very Easy	NA
How confident did you feel about the successful execution of the experiment?	Not confident	○○○○○	Very confident	NA
How confident were you about the data being saved properly ?	Not confident	○○○○○	Very confident	NA
How easy / hard was it to export and visualize the saved data ?	Very Hard	○○○○○	Very Easy	NA
Was the live data showing the progress of the experiment sufficient ?	Insufficient	○○○○○	Sufficient	NA
How easy / hard was it to navigate the system ?	Very Hard	○○○○○	Very Easy	NA

Figure 5.5: Questionnaire presented to the research team to evaluate their experience.

5.2.1 Results

Out of the 11 questionnaires gathered, 9 participants answered 4 or above for questions 3 and 4 and 8 participants for question 8. Considering 4 and 5 equate to mild symptoms and not at all respectively, these results indicate that the system did not induce cybersickness.

Regarding immersion related questions, 8 participants answered question 1 with a 4 or higher indicating a high level of immersion with 5 being "totally immersed" and 6 participants answered question 2 with a 4 or higher regarding the realism of the virtual environment.

The median answers per question depicted in Figure 5.6 however, indicate that 50% of participants experienced up to moderate levels of discomfort and glitches.

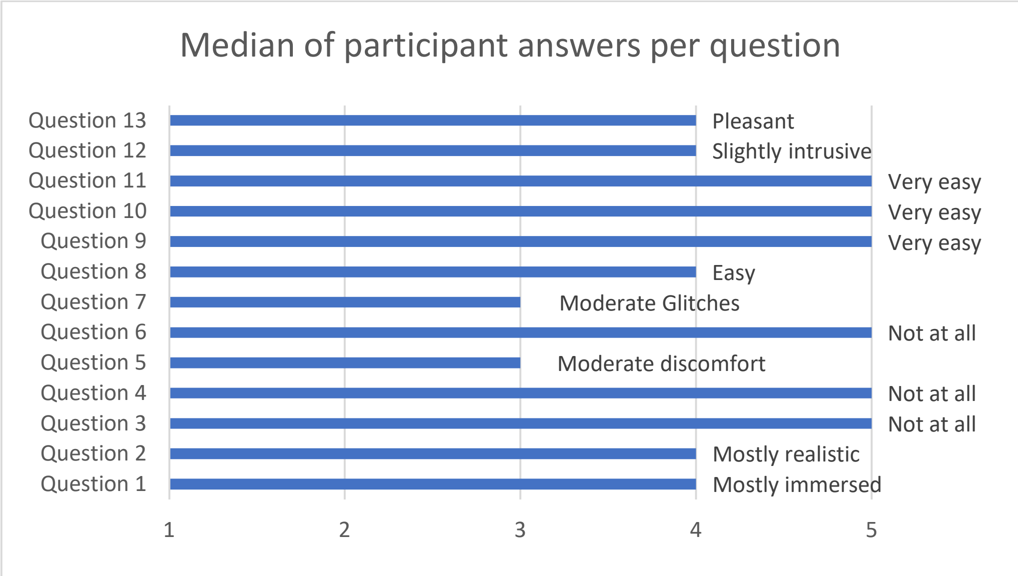


Figure 5.6 : Median of participant answers per question with their corresponding category

Among the observations that were gathered with the questionnaires, one participant reported that they were not wearing their contact lenses and another participant had myopia. Given the lengthy exposure to the VR system during the validation process, eyesight health seems to be a factor of perceived comfort when interacting with an HMD.

The results also show that participants experienced jagged transitions between scenes. This might be due to the fact that the picture that was used as a transition between scenes had to be edited, and in doing so, its resolution was lower than the videos' resolution which made it appear bigger and more pixelated.

As for the researchers' answers, 8 out of 11 of the answers provided for question 5 were rated 4 or higher showing a high level of confidence in the system's ability to save data properly. Question 6 had all the answers rated at 5 reflecting the ease of the data collection / visualization process. The medians of the answers per question can be seen in Figure 5.7.

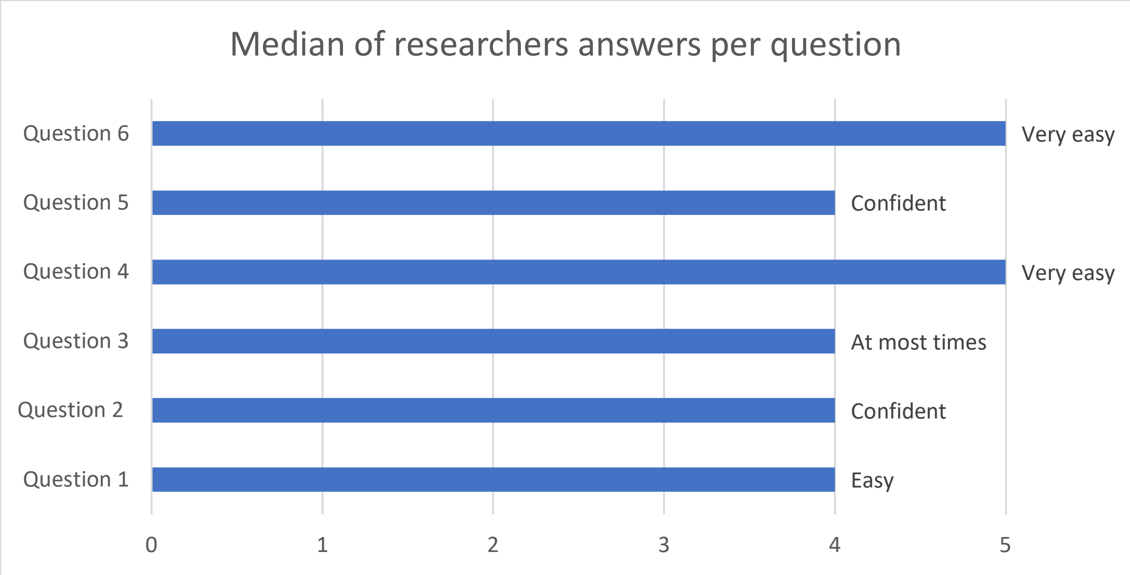


Figure 5.7: Median of researchers answers per question with their corresponding category

5.3 Discussion

Considering the aim of this dissertation is to develop a system that is able to support the experimental protocol of the MTC research team and allow for the validation of the stimuli, the results of the evaluation that were presented in this chapter indicate that the system not only satisfies the research teams requirements and demands but also provides good experience overall to the participants.

Although the results overall are good, they also highlight what aspects of the system can be improved, namely, the transition between scenes and increasing the comfort of participants that can be linked to many factors (e.g.: HMD overheating, wearing the HMD on top of glasses).

6 Conclusion

The aim of this dissertation was the development of a framework allowing the MTC research team to validate stimuli in the form of 360° videos and support the team's experimental protocol. This included the development of several features and the refinement of an existing framework aimed at increasing the ecological validity of the current Mnemonic Tunning for Contamination studies. This should be accomplished by transitioning from the traditional techniques to a more immersive environment to increase the sense of presence for participants while also giving more control over the experiments by allowing for a better reproducibility of the experiments and support the various experimental protocols used in these experiments. To achieve this goal, the work entailed closely working with the researchers from the Psychology and Education Department, and a system was developed that meets their requirements.

The goals and requirements of the project were identified through an initial brainstorming session and were later refined throughout the duration of the project during weekly meetings. After the requirements were clearly defined, and an architecture of the project was made, prototypes of the various modules identified in the architecture were developed and discussed to assess their validity and were refined according to the feedback gathered.

During the development phase, we faced many challenges, mainly pertaining to technical limitations such as memory management of the HMD in order to play multiple videos in a row which we solved utilizing a transition point between the videos to clear the memory of the previously played video, data collection and presentation which due to the HMD Oculus Quest 2 being incompatible with Kafka, had to be implemented differently.

Later during development, a pilot study was conducted that involved six students from the Department of Psychology and Education (DEP), this initial evaluation showed good results and that it is suitable to support the experimental protocol, namely the validation process.

Which led us to the validation phase of this project that involved 23 participants that provided their feedback after using the system; the feedback consisted of two different questionnaires : the SUS and a custom questionnaire that was made to discern if there are any cyber illness symptoms that were perceived by the participants and gauging their level of immersion on one hand and on the other, evaluating the experience of the MTC research team when using the dashboard.

Following the pilot study and the validation process, we can conclude that the objectives of this dissertation were matched and that it resulted in a system that fully supports both of the stages described by the MTC research team and yielded good feedback from both participants and the researchers.

6.1 Future works

Even though the system proved to be adequate for supporting both experimental stages, there are still ways to refine or expand the current solution. These aspects are either additional features or an optimization of currently existing features. Some of these improvements are listed below:

- **Real time video stream of the experiment:** Although the status page that provides the researchers with live data helps convey a rough idea of the current state of the experiment, a live video feed of experiment from the point of view of the participants would be a great addition. However, since we are using a private network, we have no access to the Internet on campus. To get around this limitation, there is the possibility to reconstitute the point of view of the participants as we are already gathering the head orientation data and the currently played video by displaying the currently playing video and applying the camera movements to it on the player since it is a 360° video.
- **Replay previous experiments:** The ability to replay past experiments would be an improvement to the system as it would help the research team better analyze participants' behavior during those experiments. This could be done similarly to the suggested solution for displaying a real time video feed, by having the head orientation data already saved for each participant, we can reconstruct the experiment using the stock videos used as stimuli instead of saving a recording for each participant which would take a considerable amount of disk space.
- **Additional participant data:** The benefit of utilizing a virtual environment for this approach is that it not only gives the research team control over the experiment but also the ability to collect a wide variety of data. In this dissertation we were able to collect head orientation data, but there is more that can be done. As an example, eye movements on HMD that support that feature or other types of biometric data such as skin temperature and heart rate. This would improve the system and would provide the researchers with more information.
- **Customizable questions and answers:** In the current state of the system, the questions, and the answers for both the memory test and the validation protocol are static. However, an improvement to this approach is to allow the configuration of the different aspects of how the questions are presented via the dashboard (question text, the answers, or the scale). This would improve the system by making it more versatile and able to fit the specific needs of the researchers.

Overall, these improvements, which can now be explored profiting from the work carried out, would further expand how research on the MTC is performed and pave the way for its advance in a potentially more ecologically valid setting. The scientific outcomes of these endeavors can also inform the potential relevance of future approaches, e.g., entailing modelling a realistic environment, to attain a configurable VR environment to serve as grounds for the experiments.

7 References

[1] N. L. Fernandes, J. N. S. Pandeirada, S. C. Soares, and J. S. Nairne, “Adaptive memory: The mnemonic value of contamination,” *Evol. Hum. Behav.*, vol. 38, no. 4, pp. 451–460, Jul. 2017, doi: 10.1016/j.evolhumbehav.2017.04.003.

[2] D. Peeters, “A standardized set of 3-D objects for virtual reality research and applications,” *Behav. Res. Methods*, vol. 50, no. 3, pp. 1047–1054, Jun. 2018, doi: 10.3758/s13428-017-0925-3.

[3] P. M. G. Emmelkamp and K. Meyerbröker, “Virtual Reality Therapy in Mental Health,” *Annu. Rev. Clin. Psychol.*, vol. 17, no. 1, pp. 495–519, 2021, doi: 10.1146/annurev-clinpsy-081219-115923.

[4] S. Diana, “Supporting Research in Memory and Contamination through a Virtual Reality Approach,” International Conference on Graphics and Interaction – ICGI’2022, Aveiro, 2022.

[5] M. Schaller, “The behavioural immune system and the psychology of human sociality,” *Philos. Trans. R. Soc. B Biol. Sci.*, vol. 366, no. 1583, pp. 3418–3426, Dec. 2011, doi: 10.1098/rstb.2011.0029.

[6] R. Carlos and V. Machado, “Exploring the behavioral component of the behavioral immune system through the cyberball game,” University of Aveiro, 2021.

[7] T. Steimer, “The biology of fear- and anxiety-related behaviors,” *Dialogues Clin. Neurosci.*, vol. 4, no. 3, pp. 231–249, Sep. 2002.

[8] S. L. Neuberg, D. T. Kenrick, and M. Schaller, “Human threat management systems: Self-protection and disease avoidance,” *Neurosci. Biobehav. Rev.*, vol. 35, no. 4, pp. 1042–1051, Mar. 2011, doi: 10.1016/j.neubiorev.2010.08.011.

[9] A. C. Morales and G. J. Fitzsimons, “Product Contagion: Changing Consumer Evaluations through Physical Contact with ‘Disgusting’ Products,” *J. Mark. Res.*, vol. 44, no. 2, pp. 272–283, May 2007, doi: 10.1509/jmkr.44.2.272.

[10] G. Thiebaut, A. Méot, A. Witt, P. Prokop, and P. Bonin, “COVID-19 and Memory: A Novel Contamination Effect in Memory,” *Evol. Psychol.*, vol. 20, no. 2, Apr. 2022, doi: 10.1177/14747049221108929.

[11] J. G. Snodgrass and M. Vanderwart, “A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity,” *J. Exp. Psychol. [Hum. Learn.]*, vol. 6, no. 2, pp. 174–215, Mar. 1980, doi: 10.1037//0278-7393.6.2.174.

[12] N. L. Fernandes, J. N. S. Pandeirada, and J. S. Nairne, “The Mnemonic Tuning for Contamination: A Replication and Extension Study Using More Ecologically Valid Stimuli,” *Evol. Psychol.*, vol. 19, no. 1, p. 1474704920946234, Jan. 2021, doi: 10.1177/1474704920946234.

[13] J. Jerald, *The VR Book: Human-Centered Design for Virtual Reality*. Association for Computing Machinery and Morgan & Claypool, 2015.

[14] I. Sutherland, “The Ultimate Display,” presented at the IFIP Congress, Jan. 1965, pp. 506–508. Accessed: Jan. 02, 2023. [Online]. Available: https://typeset.io/papers/the-ultimate-display-35zd3b9ucp

[15] W. Alharthi, “Investigation into the Impact of Using Virtual Heritage to Depict the Historical City of Al Madinah,” University of Kent, 2015. doi: 10.13140/RG.2.2.20206.74564.

[16] C. Ball, K.-T. Huang, and J. Francis, “Virtual reality adoption during the COVID-19 pandemic: A uses and gratifications perspective,” *Telemat. Inform.*, vol. 65, p. 101728, Dec. 2021, doi: 10.1016/j.tele.2021.101728.

[17] S. Bouchard *et al.*, “Virtual reality compared with in vivo exposure in the treatment of social anxiety disorder: A three-arm randomised controlled trial,” *Br. J. Psychiatry*, vol. 210, no. 4, pp. 276–283, Apr. 2017, doi: 10.1192/bjp.bp.116.184234.

[18] S. Nichols, C. Haldane, and J. R. Wilson, “Measurement of presence and its consequences in virtual environments,” *Int. J. Hum.-Comput. Stud.*, vol. 52, no. 3, pp. 471–491, Mar. 2000, doi: 10.1006/ijhc.1999.0343.
[19] F. Chaze *et al.*, “Virtual reality and well-being in older adults: Results from a pilot implementation of virtual reality in long-term care,” *J. Rehabil. Assist. Technol. Eng.*, vol. 9, p. 205566832110723, Feb. 2022, doi: 10.1177/20556683211072384.
[20] K.-T. Huang, “Exergaming Executive Functions: An Immersive Virtual Reality-Based Cognitive Training for Adults Aged 50 and Older,” *Cyberpsychology Behav. Soc. Netw.*, vol. 23, no. 3, pp. 143–149, Mar. 2020, doi: 10.1089/cyber.2019.0269.
[21] S. A. Smith, “Virtual reality in episodic memory research: A review,” *Psychon. Bull. Rev.*, vol. 26, no. 4, pp. 1213–1237, Aug. 2019, doi: 10.3758/s13423-019-01605-w.
[22] J. Diemer, G. W. Alpers, H. M. Peperkorn, Y. Shiban, and A. Mühlberger, “The impact of perception and presence on emotional reactions: a review of research in virtual reality,” *Front. Psychol.*, vol. 6, 2015, doi: 10.3389/fpsyg.2015.00026.
[23] M. S. Bermo, D. Patterson, S. R. Sharar, H. Hoffman, and D. H. Lewis, “Virtual Reality to Relieve Pain in Burn Patients Undergoing Imaging and Treatment,” *Top. Magn. Reson. Imaging*, vol. 29, no. 4, p. 203, Aug. 2020, doi: 10.1097/RMR.0000000000000248.
[24] R. Mclay *et al.*, “A Randomized, Controlled Trial of Virtual Reality-Graded Exposure Therapy for Post-Traumatic Stress Disorder in Active Duty Service Members with Combat-Related Post-Traumatic Stress Disorder,” *Cyberpsychology Behav. Soc. Netw.*, vol. 14, pp. 223–9, Feb. 2011, doi: 10.1089/cyber.2011.0003.
[25] C. N. W. Geraets, W. Veling, M. Witlox, A. B. P. Staring, S. J. M. A. Matthijssen, and D. Cath, “Virtual reality-based cognitive behavioural therapy for patients with generalized social anxiety disorder: a pilot study,” *Behav. Cogn. Psychother.*, vol. 47, no. 6, pp. 745–750, Nov. 2019, doi: 10.1017/S1352465819000225.
[26] B. A. Fina *et al.*, “Conducting Prolonged Exposure for PTSD During the COVID-19 Pandemic: Considerations for Treatment,” *Cogn. Behav. Pract.*, vol. 28, no. 4, pp. 532–542, Nov. 2021, doi: 10.1016/j.cbpra.2020.09.003.
[27] E. D. de Bruin, D. Schoene, G. Pichierri, and S. T. Smith, “Use of virtual reality technique for the training of motor control in the elderly,” *Z. Für Gerontol. Geriatr.*, vol. 43, no. 4, pp. 229–234, Aug. 2010, doi: 10.1007/s00391-010-0124-7.
[28] “What is User Centered Design?,” The Interaction Design Foundation. Accessed: Sep. 28, 2023. [Online]. Available: https://www.interaction-design.org/literature/topics/user-centered-design
[29] J. M. Carroll, “Five reasons for scenario-based design,” *Interact. Comput.*, vol. 13, no. 1, pp. 43–60, Sep. 2000, doi: 10.1016/S0953-5438(00)00023-0.
[30] J. D. McCabe, “2 - Requirements Analysis: Concepts,” in *Network Analysis, Architecture, and Design (Third Edition)*, J. D. McCabe, Ed., in The Morgan Kaufmann Series in Networking. , Burlington: Morgan Kaufmann, 2007, pp. 57–97. doi: 10.1016/B978-012370480-1/50003-7.
[31] J. R. Lewis, “Psychometric Evaluation of the Post-Study System Usability Questionnaire: The PSSUQ,” *Proc. Hum. Factors Soc. Annu. Meet.*, vol. 36, no. 16, pp. 1259–1260, Oct. 1992, doi: 10.1177/154193129203601617.
[32] R. S. Kalawsky, “VRUSE—a computerised diagnostic tool: for usability evaluation of virtual/synthetic environment systems,” *Appl. Ergon.*, vol. 30, no. 1, pp. 11–25, Feb. 1999, doi: 10.1016/S0003-6870(98)00047-7.
[33] B. J. Li, J. N. Bailenson, A. Pines, W. J. Greenleaf, and L. M. Williams, “A Public Database of Immersive VR Videos with Corresponding Ratings of Arousal, Valence, and Correlations between Head Movements and Self Report Measures,” *Front. Psychol.*, vol. 8, 2017, Accessed: Jun. 16, 2023. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fpsyg.2017.02116
[34] J. Brooke, “SUS: A quick and dirty usability scale,” *Usability Eval Ind*, vol. 189, Nov. 1995.
[35] H. Kim *et al.*, “Clinical predictors of cybersickness in virtual reality (VR) among highly stressed people,” *Sci. Rep.*, vol. 11, p. 12139, Jun. 2021, doi: 10.1038/s41598-021-91573-w.