UNLOCKING THE VIRTUAL WORLD: A STUDY ON THE INFLUENCE OF MULTISENSORY STIMULI ON USERS' EMOTIONAL RESPONSES AND VIVIDNESS OF MENTAL IMAGERY IN THE CONTEXT OF VIRTUAL TOURISM

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If I have seen further, it is by standing on the shoulders of giants.

- Isaac Newton

Abstract

This thesis aims to explore how multisensory experiences in virtual reality influence users' emotional responses and the vividness of their mental imagery, focusing on the impact of the demographics of gender and age.

This thesis is driven by the recent rapid development of virtual reality in tourism, characterized by increasingly immersive multisensory experiences. It addresses the knowledge gap related to the limited understanding of how multisensory stimuli impact users' emotional responses and their mental imagery ability, considering the particular case of virtual tourism.

Two immersive virtual experiences were developed for this purpose. Multisensory combinations of visual, auditory, haptic, olfactory, and taste stimuli were strategically integrated at specific stages of the two experiments, after being previously validated in a focus group session. One of these virtual experiences included a scenario intended to elicit positive emotions in the user by resorting to a selection of pleasant multisensory stimuli, designated as the "positive IVE" (positive Immersive Virtual Environment). The other experience sought the contrary: to induce negative emotions in the user through a combination of unpleasant multisensory stimuli, which was labeled as the "negative IVE” (negative Immersive Virtual Environment). The basic combination of visual and auditory stimuli was consistently used during the entire experiment. Additional stimuli – taste, haptic, and smell – were introduced one by one, sequentially. Finally, all these stimuli were combined for a comprehensive experience.

A between-subjects experimental design was developed to explore and compare the users' emotional responses and vividness of visual imagery after each stimuli combination in the two virtual experiences, resorting to in-VR questionnaires for data collection. Key findings include the impact of different positive and negative multisensory stimuli combinations on the users' emotional responses, and how they, in turn, influence mental imagery. This research further suggests an inverse relationship between the intensity of the user's emotions and their mental imagery ability. Nevertheless, neither age nor gender was found to influence this relationship in either the positive or negative scenarios. Additionally, this investigation provides insights into the specific emotions triggered by the used multisensory stimuli combinations, addressing a need long identified by various researchers in the field.

This thesis contributes to understanding multisensory stimuli in virtual reality, highlighting its potential for application in various fields. It provides insights for future research in creating user-centered virtual reality tourism applications and understanding individual differences.

Keywords: Multisensory Virtual Reality, Virtual Reality, Emotional Responses, Vividness of Mental Imagery, Virtual Tourism.

Resumo

Esta tese visa explorar em que medida experiências multissensoriais em realidade virtual afetam as respostas emocionais e a capacidade de visualização mental dos utilizadores, tendo em atenção o impacto das variáveis demográficas género e idade.

Motivada pelo desenvolvimento acelerado e recente da realidade virtual no setor do turismo, caracterizado por experiências multissensoriais cada vez mais envolventes, esta tese aborda a lacuna no conhecimento sobre o modo como os estímulos multissensoriais influenciam as respostas emocionais dos utilizadores e a sua capacidade de visualização mental, focando-se no caso particular do turismo virtual.

Para o efeito, duas experiências virtuais imersivas turísticas foram criadas. Combinações multissensoriais de estímulos visuais, auditivos, hápticos, olfativos e gustativos foram estrategicamente integradas em momentos específicos das duas experiências, depois de previamente validados através de uma sessão de *focus group*. Uma dessas experiências virtuais incluía um cenário com vista a suscitar emoções positivas no utilizador, recorrendo para isso a uma seleção de estímulos multissensoriais agradáveis, tendo-se designado como "IVE positivo" (*Immersive Virtual Environment* positivo). O outro visava o oposto: induzir emoções negativas no utilizador, através de uma combinação de estímulos multissensoriais mais desagradáveis, tendo-se denominado "IVE negativo" (*Immersive Virtual Environment* negativo). Durante as experiências, a combinação básica de estímulos visuais e auditivos manteve-se presente. Estímulos adicionais - paladar, háptica e olfato – foram introduzidos um após o outro, sequencialmente. Por fim, todos estes estímulos foram combinados para uma experiência mais abrangente.

Foi desenvolvido um desenho experimental entre sujeitos para explorar e comparar as respostas emocionais e a nitidez da visualização mental dos utilizadores, após cada combinação de estímulos, tendo sido aplicados questionários respondidos em plena experiência virtual. Entre os resultados alcançados, inclui-se o impacto de diferentes combinações de estímulos multissensoriais positivos e negativos nas respostas emocionais dos utilizadores, bem como estas, por sua vez, influenciam a capacidade de visualização mental. Esta investigação indica também um resultado inversamente proporcional entre a intensidade das emoções do utilizador e a sua capacidade de visualização mental. Contudo, não se constatou que a idade ou o género influenciassem esta relação em nenhum dos cenários positivo ou negativo. Adicionalmente, este estudo desvenda algumas pistas sobre as emoções específicas que são desencadeadas pela combinação de estímulos multissensoriais usada, o que responde a uma necessidade previamente identificada por diversos investigadores da área.

Esta tese contribui para o esclarecimento do papel dos estímulos multissensoriais em realidade virtual, realçando o seu potencial de aplicação em diversas áreas. Fornece ainda algumas linhas de orientação para futuras investigações no desenvolvimento de aplicações turísticas de realidade virtual centradas no utilizador, e para a compreensão do impacto das diferenças individuais.

Palavras-chave: Realidade Virtual Multissensorial, Realidade Virtual, Respostas Emocionais, Nitidez da Visualização Mental, Turismo Virtual.

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Acronyms and Symbols

ASQ	After-Scenario Questionnaire
BIP	Break-In-Presence
CC	Capacity of Control of Mental Imagery
EDA	Electrodermal Activity
FEUP	Faculty of Engineering of the University of Porto
GIG	Graphics, Interaction, and Gaming
HMD(s)	Head-Mounted Display(s)
HR	Heart Rate
ICTs	Information and Communication Technologies
IPQ	Igroup Presence Questionnaire
IVE(s)	Immersive Virtual Environment(s)
M	Mean
MI	Mental Imagery
MR	Mixed Reality
NA	Negative Affects
PA	Positive Affects
PANAS-PT	PANAS Portuguese version
PANAS-PTsv	PANAS Portuguese short version
R.O(s).	Research Objective(s)

R.Q(s).	Research Question(s)
SD	Standard Deviation
SUS	Slater-Usoh-Steed Questionnaire
TVIC	Test of Visual Imagery Control
V+A	Visual and Auditory combination
V+A+H	Visual, Auditory, and Haptics combination
V+A+S	Visual, Auditory, and Smell combination
V+A+T	Visual, Auditory, and Taste combination
V+A+T+H+S	Visual, Auditory, Taste, Haptics, and Smell combination
VR	Virtual Reality
VT	Virtual Tourism
VIV	Vividness of Mental Imagery
VVIQ	Vividness of Visual Imagery Questionnaire
WS	Witmer and Singer Questionnaire

1. Introduction

1.1. Motivation

This thesis is motivated by the need to intertwine and explore the intricate relationships between four key topics: (1) Multisensory virtual reality, (2) Virtual Tourism (VT), (3) Emotions in virtual reality, and (4) Mental Imagery (MI) in terms of vividness (VIV). It integrates a variety of research areas, including tourism, psychology, marketing, and primarily, technology, aiming to contribute to a more holistic understanding of how we interact with and are affected by VR.

The advent of Virtual Reality (VR) has led to a new era of digital interaction, characterized by its ability to create immersive multisensory experiences. This thesis is driven by the interesting result of integrating visual, auditory, haptic, olfactory, and taste stimuli in VR to create compelling experiences. The goal lies in how these multisensory VR experiences can enhance users' VIV ability and elicit intense emotional responses.

Multisensory stimulation in VR is essential in generating intense and diverse emotions in the user [1-4]. However, its relationship with MI has been subjected to little research, given the novelty of their connection in the context of VR [5, 6], with most research focusing on audiovisual stimulation only [7-9].

VT offers an innovative application of VR, providing immersive experiences beyond physical [10-12], time [13], and economic limitations [11, 14, 15]. It combines the two concepts of "tourism" and "virtual reality", resulting in the overlapping of natural environments with artificial environments [16] to enhance the tourism experience [17]. Delving into VT within this thesis stems from its potential to revolutionize the tourism sector. VR no longer contributes merely to a new type of entertainment, as one might have confidently stated a few years back. Nowadays, it represents a significant shift towards sustainable and accessible content. In tourism, it can provide not only immersive and realistic, but also emotionally meaningful experiences [18], offering a new lens through which one can experience and understand the world. Although the connection between emotions and tourism is quite trendy [3], this topic has been poorly explored [1, 19], especially in tourism [20] and much more in VT research. Nonetheless, curiously, VT presents the advantage of assisting the scientific study of human behavioral responses, enhancing the validation of experimental designs in VR [21].

So, understanding how VR, particularly VT, can evoke and modulate emotions is a central theme of this thesis. Emotions are fundamental to human experience, and their exploration in VR is crucial for creating emotionally engaging and impactful experiences. Its importance is enhanced if considering the technological development and the increasing number of studies exploring multisensory information [6]. Moreover, emotions have demonstrated a substantial impact on memory. Nonetheless, most of the studies achieving this conclusion employed non-immersive VR methods, as recently attested by Mancuso, et al. [18], or just audiovisual cues [7-9], which highlights this thesis's potential.

This investigation also seeks to examine individual differences, namely the demographic variables age and gender, in emotional responses and VIV, which is crucial for developing efficient virtual environments adapted to the end users [6]. Although it is essential in the context of VR, as suggested by Iachini, et al. [5], the impact of these demographic variables on the relationship between users' emotions and VIV ability still faces a lack of consensus in the literature, as further explored.

1.2. Problem statement and research objectives

In the rapidly evolving field of VR, the interplay between multisensory stimuli, emotions, and MI presents a complex and underexplored area of study. Despite significant advancements in VR technology, there is a limited understanding of how different combinations of multisensory stimuli within VR environments impact the users' emotional responses and MI ability, as attested by several authors [22-26]. So, the primary problem it is aimed to address is the lack of comprehensive understanding regarding the relationship between multisensory stimuli in VR and their effects on users' emotions and MI ability. Specifically, it is intended to explore how varying combinations of visual, auditory, haptic, olfactory, and taste stimuli in VR can elicit different emotional responses and how these emotions, in turn, have the power to enhance the users' ability to generate vivid mental images. VIV is one of the fundamental key aspects of MI [5], which is related to the clarity, brightness, or intensity of the mental representations [27], fundamental to explore in VT contexts, as discussed by several authors [17, 28, 29]. Additionally, considering the controversy regarding the impact of some individual differences in these variables, as discussed later, the potential impact of age and gender (control variables) on this relationship is taken into consideration.

This research addresses a critical gap in the field of VR, where most studies have predominantly focused on visual and auditory stimuli, often neglecting the potential impact of more comprehensive multisensory experiences [30-32]. Furthermore, while the connection between emotions and MI *per se* is well-established in the literature [33], its dynamics within VR remain poorly understood. Understanding these relationships is crucial for the development of more effective and user-centered VR applications [6]. This includes potential implications for tourism, therapeutic purposes, education, entertainment, and other sectors where VR can be used for emotional regulation and cognitive training, and where user-oriented multisensory environments can enhance engagement and learning outcomes [7].

Bearing this in mind, a crucial initial step was to address how to elicit a range of emotional states in users, specifically differentiating between positive and negative emotions. To do that, two immersive virtual environments (IVEs) were developed. One of them was designed specifically to induce positive emotions (termed the "positive IVE", representing the positive scenario), while the other was developed to evoke negative emotions (referred to as the "negative IVE", representing the negative scenario). Based on the addressed problem statement, this thesis' research objectives (R.Os.) are as follows:

R.O. 1 To understand the effect of different combinations of multisensory stimuli to elicit intense emotional responses in a VT experience;

R.O. 2 To investigate the effect of different combinations of multisensory stimuli to enhance the users' VIV in a VT experience;

R.O. 3 To conclude the relationship between the users' emotional responses and the VIV ability in a VT experience, considering users' age and gender.

1.3. Research questions, variables, and hypothesis

According to the previously enumerated R.Os., the research questions (R.Qs.) that are intended to answer at the end of this thesis are as follows:

R.Q. 1 Do different multisensory stimuli combinations in a VT experience elicit variations in the user's emotional responses?

- **R.Q. 1.1** What is the effect of positive multisensory stimuli combinations?
- **R.Q. 1.2** What is the effect of negative multisensory stimuli combinations?

R.Q. 2 How does the users' VIV ability change in response to different combinations of multisensory stimuli in a VT experience?

- **R.Q. 2.1** What is the effect of positive multisensory stimuli combinations?
- **R.Q. 2.2** What is the effect of negative multisensory stimuli combinations?

R.Q. 3 What is the relationship between the users' emotional responses and VIV in a VT experience?

R.Q. 3.1 What's the impact of gender on that relationship?

R.Q. 3.2 What's the impact of age on that relationship?

In summary, while R.Q. 1 and R.Q. 2 aim to explore the impact of different multisensory stimuli combinations (independent variable) on the users' emotional responses and on the users' VIV (dependent variables), respectively, R.Q. 3

intends to determine the effect of the users' emotional responses (now, as independent variable) on their VIV ability (dependent variable). Considering the existent controversy regarding the effect of age and gender on the users' emotions and VIV, these demographic variables will be considered as control variables in R.Q. 3. So, this research's dependent and independent variables vary according to the R.Qs., as illustrated in Table 1.

Table 1 Independent and dependent variables according to the specific research questions

Research Questions		**Independent Variables**		**Dependent Variables**	**Control Variables**
		Stimuli Combination	IVEs	Emotional Responses and VIV	Demographics
R.Q.1	R.Q. 1.1	V+A V+A+T V+A+H V+A+S V+A+T+H+S	Positive IVE	Users' emotional responses	-
	R.Q. 1.2		Negative IVE		
R.Q.2	R.Q. 2.1	V+A V+A+T V+A+H V+A+S V+A+T+H+S	Positive IVE	Users' VIV	-
	R.Q. 2.2		Negative IVE		
R.Q.3	R.Q. 3.1	Users' positive emotional responses		Users' VIV	Age and gender
	R.Q. 3.2	Users' negative emotional responses			

Caption:

V+A: Visual + Auditory
V+A+T: Visual + Auditory + Taste
V+A+H: Visual + Auditory + Haptics
V+A+S: Visual + Auditory + Smell
V+A+T+H+S: Visual + Auditory + Taste + Haptics + Smell

The independent variables for R.Q. 1 are the five stimuli combination and the two IVEs. The dependent variables are the users' emotional responses, which might vary between negative and positive. For R.Q. 2, the independent variables are the same, and the dependent variable is the users' VIV. Finally, for R.Q. 3, the independent variables are the users' obtained emotional responses, and the dependent variable is their VIV. Users' demographics (age and gender) assume the role of control variables, considering their potential effect on the relationship between the dependent and the independent variables, as it will be further explored.

Based on the insights from the literature, several hypotheses can be formulated to address the proposed R.Qs. In general, it is expected that:

H 1. Different combinations of multisensory stimuli in a VT experience will differently impact the user's emotional responses:

- **H 1.1.** with positive multisensory stimuli from the positive IVE leading to more intense positive emotions, particularly accentuated when using V+A+T+H+S; and
- **H 1.2.** with negative multisensory stimuli from the negative IVE leading to more intense negative emotions, also particularly accentuated when using V+A+T+H+S.

These first hypotheses are supported by findings that multisensory VR systems have great potential to elicit different emotional responses, which tend to be more varied and intense when multiple human senses are engaged in the virtual experience [1-4, 34, 35]. Consequently, the full stimuli combination V+A+T+H+S is expected to contribute to intense levels of emotional responses, compared to any other stimuli combinations. On the one hand, the positive IVE, as it uses positive multisensory stimuli, is expected to lead to more intense positive emotions, compared to the negative ones. On the other hand, as the negative IVE resorted to negative multisensory stimuli, it is expected to trigger more intense negative emotions, compared to the positive ones.

Regarding the second hypothesis, it is expected that:

H 2. The users' VIV ability will vary in response to different combinations of multisensory stimuli in a VT experience:

- **H 2.1.** with positive stimuli enhancing VIV, particularly accentuated when using V+A+T+H+S; and
- **H 2.2.** with negative stimuli impacting VIV in the same way, particularly accentuated when using V+A+T+H+S.

It is hypothesized that the full combination of multisensory stimuli will make the mental representation of a specific scenario more similar to the reality and, thus, more realistic and vivid. Consequently, based on the observation that the more vivid and realistic an event is perceived in VR, the more intense and diverse the emotions reported [36, 37], it is advanced that V+A+T+H+S will enhance VIV in both positive and negative IVEs. Furthermore, given that extreme scenarios, arising either from intense positive or negative emotions, are associated with improved VIV abilities [38], it is expected that in both positive and negative IVEs, highly intense emotions will correlate with a heightened VIV ability.

For the third hypothesis, it is anticipated that:

H 3. There will be a statistically significant relationship between the users' emotional responses and VIV:

- **H 3.1.** with gender interfering in this relationship; and
- **H 3.2.** noting a significant age effect.

This third hypothesis is generically based on the observation that emotions leave traces in memory [36]. Particularly, considering that multisensory stimuli are anticipated to trigger both positive and negative emotional responses, it is predicted that participants will exhibit varying levels of VIV ability. When a user feels more positive emotions, they are likely to remember visual details better, as these details probably sparked their interest and had a positive impact on memory. Conversely, it is anticipated that when a user feels more negative emotions, they will have greater difficulty in memorizing visual details, possibly due to their interest not being as effectively captured.

Concerning the impact of users' demographic factors, such as age and gender, on this relationship, there is no consistent evidence available. Nevertheless, based on the idea that women tend to express more freely than men when self-reporting their emotions [39], it is expected that women will report higher intensity of emotional responses than men. Consequently, women will also register higher VIV ability in general.

Regarding the impact of age, some studies suggest age-related differences in information processing, due to cognitive changes, which affect the way people emotionally react [40]. Thus, it is expected that younger individuals report higher VIV ability in general.

1.4. Methodology of investigation

Considering the R.Qs. outlined, this section provides a general explanation of the methodology of investigation used.

A between-subjects experimental study was conducted involving the development of two distinct IVEs, referred to in this thesis as the positive and the negative IVEs. The need to develop two IVEs is tied to the goal of exploring a broad spectrum of emotions. Mixing the elicitation of positive and negative emotions within a single IVE would be practically unfeasible and highly prone to yielding biased results, a viewpoint also endorsed by Kuang, et al. [41], especially considering tourism purposes. Moreover, this method of using distinct positive and negative IVEs to examine participants' emotional responses is a recurrent practice in academic research [34, 41, 42].

The primary distinction between the developed IVEs lies in the level of stimuli pleasantness, designed to be higher in the positive IVE and lower in the negative IVE so that they could elicit more intense positive or negative emotional responses, correspondingly. The positive IVE, representing a daytime visit to a nature tourist spot, corresponds to a touristic scenario embraced by the sunlight, a warm breeze, the sound of birds chirping, the scent of pine from the surroundings, and the aroma of cinnamon from tea. In this scenario, participants were also invited to taste some sips of Port wine, as well as cinnamon tea. In contrast, the negative IVE is based on the same location but set during a dark, rainy night. It features a cool breeze, the sound of rain hitting the ground, the smell of smoke from typical forest fires, and an unpleasant fish odor, accompanied by the taste of acidic (vinegar-based) and salty water samples. Both IVEs were developed and validated on a process composed of:

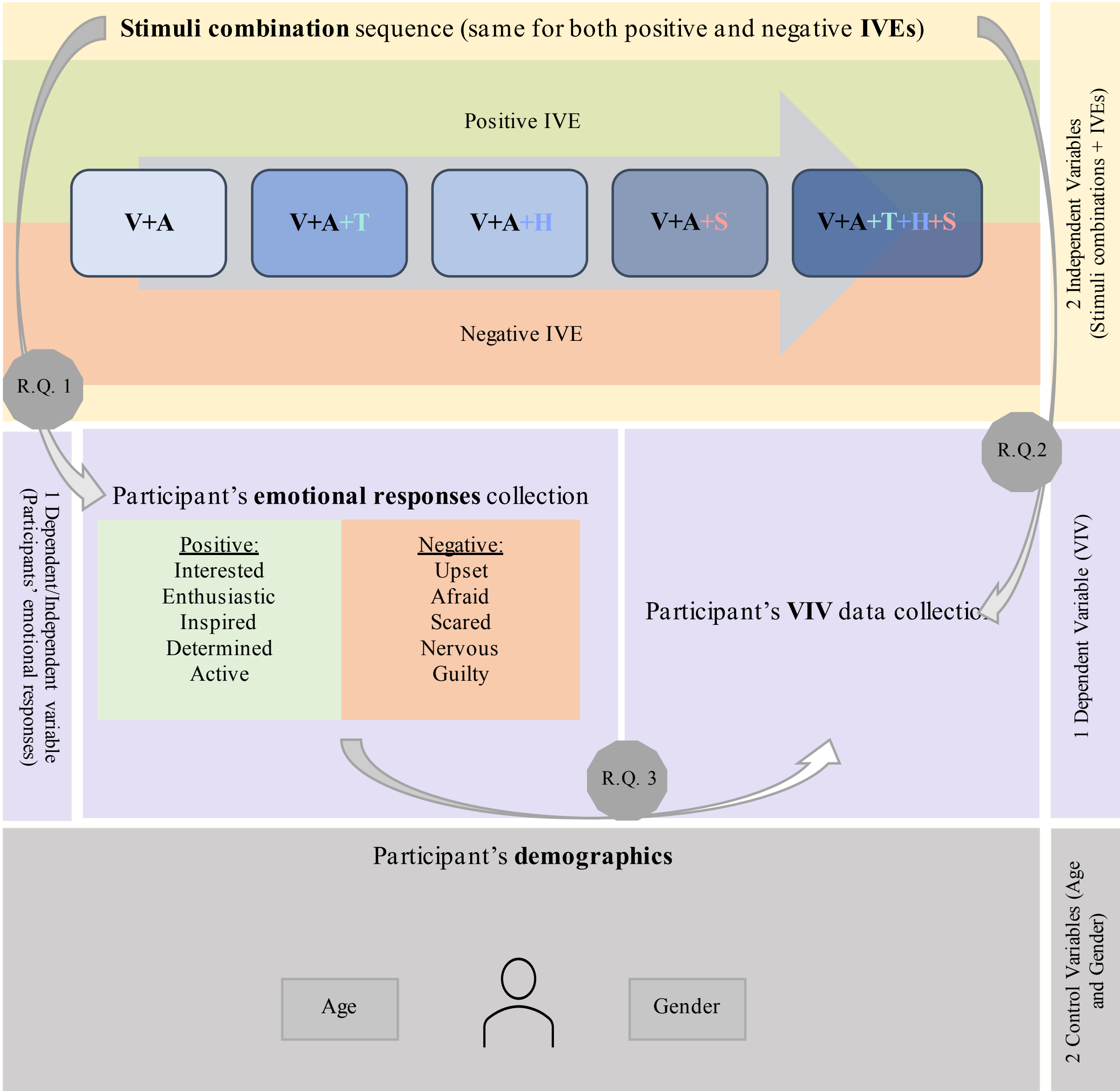
Steps	Phase	Timing
1. a review of the multisensory cues affecting users' emotions (section 3.2.1); 2. a systematic literature review regarding the assessment of the users' emotional responses in multisensory VR, written and published by this thesis' author [22]. It also analyzed all the investigations triggering at least three stimuli to conclude the relationship between the stimulus provided and the users' emotional responses. The main findings regarding this work are discussed also in section 3.2.1;	**Development**	**Before the VR experiment**
3. a focus group session to assess the pleasantness of the multisensory stimuli to be used, as detailed in section 4.3.1;	**Validation**	
4. the analysis of the users' pre- and post- emotional responses (collected before and after the VR experiment), to ensure that the positive and negative IVEs met the expectation of eliciting more intense positive emotions in the first case, and more intense negative emotions in the second, as detailed in section 4.3.2.		**After the VR experiment**

The IVEs were developed to be interactive walkthroughs, aiming to elicit different and intense emotional responses. Walkthrough scenarios are highly recommended for VR purposes, specifically in the case of tourism [43], as they contribute to increasing users' enjoyment and the recognition of the location [44]. Furthermore, considering that physical movements are frequently identified as a limitation in VR, especially when simultaneously aiming to collect users' emotional responses [22], the development of the IVEs incorporated the use of a teleport function. Thus, users could utilize the trackpad on the VR controller to teleport to their chosen location. Simultaneously, the function of room-scale locomotion (walk-in-place) was available. The combination of these functionalities offers a more versatile and immersive experience, that leverages the advantages of both locomotion methods, resulting in a natural, intuitive, and immersive form of virtual moving, which reduces the levels of simulation sickness. Also, it promotes spatial awareness and realistic interactions, as the user's body movements can be mapped more accurately to their in-game avatar's [45].

A multisensory treasure hunt was integrated into each IVE. During that task, the user had to find five objects randomly scattered throughout the virtual scenario. When the user found each one, a stimuli combination was triggered, aiming to provide multisensory hints about that object. In both IVEs, the multisensory combinations followed a consistent manner, i.e., the treasure hunt of the positive and negative IVEs was divided into the same five sections, according to the introduction of the new stimulus/stimuli, as shown in Diagram 1. The flow of the VR experiment is explained in video (available here).

As Diagram 1 shows, visual and auditory elements were consistently present during the whole IVE, as they are the basis of VR in general, and the two naturally expected elements in a VR experience [46]. Respectively, they corresponded to the visual representation of the tourism spot and its features, and to the sound of birds chirping in the positive IVE, or the rain sounds in the negative IVE. This approach enabled a comparison of the impact of visual and auditory stimuli combination (V+A) with the addition of taste, haptics, and smell, both individually and combined, on the users' emotional responses and VIV ability. The results obtained for each IVE regarding users' emotional responses could answer R.Q. 1, and results about users' VIV ability could provide a response to R.Q. 2. Finally, to answer R.Q. 3, regarding the effects of gender (R.Q. 3.1) and age (R.Q. 3.2) on the relationship between emotional responses and VIV, correlations between these two variables were performed. Data collection was made through an experimental VR-based study, in which in-VR questionnaires were administered with scale responses.

Diagram 1 Flow of the investigation, research questions and variables



Findings from this research are expected to contribute to a better comprehension of the role of multisensory stimuli in VT, considering how individuals feel and mentally represent visual details when facing specific stimuli combinations. It will help create more appealing and intensive emotional tourism experiences, oriented to a specific target (based on age and gender differences). With these thesis' outcomes, we believe that VR developers, the tourism sector and consumers will benefit from this more efficient, engaging, and oriented communication.

1.5. Thesis structure

This thesis is divided into ten sections. It begins with the Introduction (this first section), which likely sets the stage for the entire research. This part introduces the core aspects of the study, including the motivation, problem statement, and research objectives. It also outlines the research questions and hypotheses, providing a preliminary overview of the methodology to be employed in the study.

After the introduction, there is a comprehensive Literature Review (section 2). It covers a range of topics such as the foundational concepts and recent advancements in multisensory VR, the emotional engagement in VR and in VT in particular, and the role of MI and VIV.

The Research Methodology (section 3) details the methods used in this investigation. This section presents how data was collected and the subsequent analysis methodologies.

Next, section 4 includes the sample information, the data preparation process, and the validation of the experimental design, which, in turn, encompasses a focus group session and the analysis of the users' pre- and post-emotional responses.

Section 5, 6, and 7 present, respectively, a comprehensive analysis and discussion of R.Q. 1, R.Q. 2, and R.Q. 3. These sections explore the participants' emotional responses and VIV according to different multisensory stimuli combinations. Additionally, the impact of demographic factors of gender and age is examined.

Toward the end, section 8 delves into the conclusions of this investigation. Specifically, it features a dedicated segment aiming to direct and concisely answer the proposed R.Qs. Additionally, this section addresses the limitations of the investigation and provides recommendations for future work.

Finally, sections 9 and 10 refer, respectively, to the References and the Appendix sections.

2. Literature Review

The realm of VR has transcended the boundaries of science fiction and has become firmly entrenched in our contemporary digital landscape. Over the past few decades, VR technology has evolved at an unprecedented pace, offering immersive experiences that engage not only visual senses but also a multitude of other sensory modalities. In this dynamic and ever-evolving landscape, the convergence of multisensory VR, users' emotions within virtual environments, and the enhancement of MI have emerged as a nexus of profound significance.

As LaValle [46] recently wrote, when considering a VR system, it might be tempting to primarily emphasize the conventional technical elements, such as hardware and software. Nonetheless, it is of equal, if not greater, significance to grasp and make use of the intricacies of human physiology and sensory perception. These domains can be thought of as "reverse engineering". They intricately interconnect to constitute the discipline of "perception engineering" (Figure 1[1]).

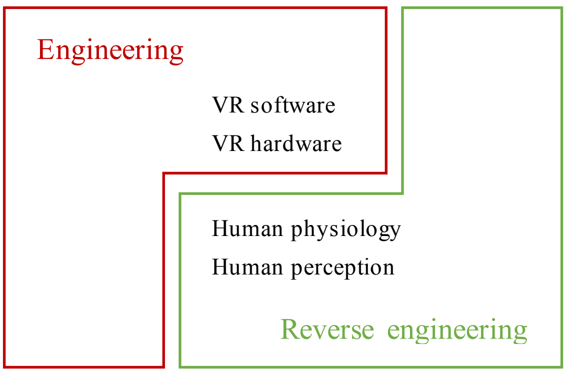


Figure 1 The complement of human physiology and perception on a VR system

[1] Adapted from [46] S. M. LaValle, *Virtual reality*. Cambridge University Press, 2020.

Emotions have long been a subject of fascination in psychology, and the advent of VR has provided a unique opportunity to investigate the interplay between technology and human emotions [26]. The immersive nature of VR has the power to elicit a wide spectrum of emotional responses. However, the emotional aspects of a VR experience are frequently neglected [47]. VIV, the ability to generate vivid mental representations of objects, scenes, or experiences [27], plays a pivotal role in how we perceive and interact with VR. In its context, the mind's eye takes on new dimensions as users navigate and interpret synthetic worlds.

As we embark on the exploration of multisensory VR, users' emotions, and VIV, it is intended to assess the state of the art in these interdisciplinary areas and to illuminate the future possibilities and challenges that lie ahead in harnessing the full potential of multisensory VR as a tool for transforming the digital experiences.

2.1. Foundations of virtual reality

VR has a rich history that spans several decades. Its development results from technological innovations and the convergence of various disciplines [48]. Below is an overview of the history of VR, touching on the most significant inventions since the concept of virtual environments first emerged.

Some researchers defend that the beginning of VR goes back to 1931 with the introduction of the concept of "feelies" in a movie theater by Aldous Huxley entitled "Brave New World". In this movie, instead of just watching a screen, viewers could experience physical sensations corresponding to what was happening in the film [49]. The haptic sensation was transmitted via two metal knobs on the armrests. In this sensory cinema, the goal was to not only make an object appear real but also feel real, offering some sense of presence, as argued by Paterson [50].

In 1935, Stanley Weinbaum took it a step further and offered an elaborate concept of VR in his work "Pygmalion's Spectacles" (Figure 2):

> *But listen—a movie that gives one sight and sound. Suppose now I add taste, smell, even touch, if your interest is taken by the story. Suppose I make it so that you are in the story, you speak to the shadows, and the shadows reply, and instead of being on a screen, the story is all about you, and you are in it. Would that be to make real a dream?* (as cited in Mihelj, et al. [49])

The subsequent noteworthy step in the history of VR, was the development of the first Head-Mounted Display (HMD) model, known as the Philco HMD, in 1961 (Figure 3). Instead of offering a portal into a virtual world, this prototype helmet featured a small screen for each eye, creating a stereoscopic view. It allowed users to watch a video from an actual, remote location. It can be regarded as an early instance of telepresence [49].

Figure 2 Pygmalion's Spectacles
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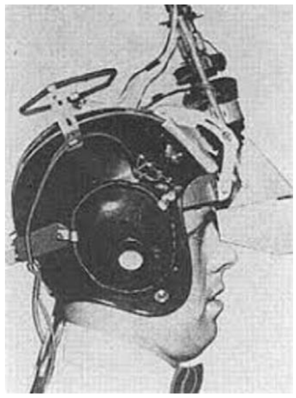

Figure 3 Philco HMD
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Despite these primary attempts to develop a VR system, it is more common to find in the literature the invention of Sensorama as the prominent starting point of VR. It was first unveiled in 1962, by Morton Heilig, and stands as an early example of a multisensory VR simulator. A 1964 review in Popular Photography offered the following description:

> *Watch out for a remarkable new process called Sensorama! It attempts to engulf the viewer in the stimuli of reality. Viewing of the colour stereo film is replete with binaural sound, scents, winds, vibration. The original scene is recreated with remarkable fidelity. At this time, the system comes closer to duplicating reality than any other system we have seen.* (as cited in Gigante [51])

In Sensorama (Figure 4), users could embark on a motorcycle journey through New York City, complete with artificially generated wind, noise, and the odors of the city [52]. Heilig's system possessed all the essential attributes of a VR system, although it lacked interactivity, as the route was predetermined and prerecorded [51]. Although it was never commercialized, Heilig's work opened new horizons in the worlds of cinema and VR, so he is referred to by many as the father of VR [49].

Three years passed until the emergence of "the ultimate display" (Figure 5), in 1965 [53]. The emergence of VR is closely tied to this pioneering work of Ivan Sutherland, who is often referred to as the "father of computer graphics". Sutherland made significant contributions to the development of VR, particularly through his invention of the first head-mounted display system, known as the "Sword of Damocles". This device featured eyeglasses with two small screens (one for each eye), to create a stereoscopic vision effect. This setup presented a virtual environment consisting of rooms depicted with basic wireframe models [49]. Later, in 1968, Sutherland described it as an HMD that could meticulously track the viewer's movements and continuously update a graphical display to accurately reflect the viewer's changing perspective. Sutherland stands as a pioneer in the field of computer graphics [51], and his work set the stage for advancements in immersive technologies and laid the theoretical foundation for VR as we know it today [54].

Figure 4 Sensorama

(retrieved from this link)

Figure 5 The Ultimate Display

(retrieved from this link)

All these inventions enabled users to experience the concept of virtual environments but lacked the capability for user interaction with them. The first responsive environment to user actions was developed around 1970 by Myron Krueger. Using an array of sensors, ranging from video cameras to pressure sensors embedded in the floor, Krueger's VR system could identify users' actions and manipulate objects within the virtual environment accordingly. This means that virtual objects behaved much like their real-world counterparts. Moreover, as multiple users could engage with the virtual environment simultaneously, this marked the pioneering instance of multi-user environments. One of Krueger's most renowned creations was the "Videoplace" environment, which featured artistic activities such as drawing on virtual objects. Additionally, Krueger introduced the term "artificial reality," referring to the recognition of user actions and the generation of feedback that reinforced the illusion of these activities occurring within a virtual environment [49].

Finally, the term "virtual reality" was coined in 1989 by Jaron Lanier, to describe a computer-generated environment in which people could interact [55]. VR has rapidly transformed from a science fiction dream into a tangible technological reality, reshaping how people interact with digital information and the world. Its primary usage started to be general entertainment, but it rapidly became more comprehensive, by opening its way to science, education, medical applications, industry, and so on. VR still lacks a universally agreed-upon definition, although it is generally agreed that it is characterized by the illusion of being in a place where one is not actually [51], often referred to as the "feeling of being there" [52, 56]. Nonetheless, thirty years ago, Latta and Oberg [57] had already advanced a definition of VR, focusing on its essence, purpose, implementation, and effects. The authors defended that VR served as a computerized interface for human perceptual and muscular systems, immersing the user in artificial environments, such as flight simulators. It leveraged technology to craft a realistic setting, producing effects that are either experiential or operational. This means it could either provide a significant personal experience or facilitate specific actions within the virtual environment. Even though it is an older definition, it has remained remarkably relevant over time. Currently, alongside technological evolution, VR can be seen as an interactive computer-generated simulation that monitors the user's actions and conditions, subsequently adjusting or amplifying sensory input to one or multiple user senses. This manipulation creates a feeling of complete immersion within the simulated environment. In this way, the user is more than just an external observer of the synthetic environment [51].

Mihelj, et al. [49] identify four fundamental components of VR: the virtual environment itself, virtual presence, the sensory feedback triggered by the user's interactions, and interactivity. As the authors explain, a virtual environment is defined by its contents, encompassing objects and characters. These elements are presented through multiple sensory modalities, including, for instance, visual, auditory, and haptic cues, and the user apprehends them through their faculties of sight, hearing, and touch. Like in the real world, objects within a virtual environment possess distinct attributes such as shape, weight, color, texture, density, and temperature. These attributes can be discerned using various sensory channels. For instance, an object's color is exclusively perceived through the visual sense, whereas its texture can be apprehended through both visual and haptic sensations.

Virtual presence (or just presence) can be categorized into two main types: physical (sensory) presence and mental presence. It involves the sensation of truly "being" in a virtual environment, which can either be purely psychological or facilitateoculuf riftd through a physical medium. Physical presence is fundamental in VR, where the user's body becomes immersed in the medium through synthetic stimuli, although not necessarily engaging all senses or encompassing the entire body. Mental virtual presence, on the other hand, resembles a state of absorption, with the user feeling connected to and engaged in the virtual world.

Sensory feedback plays a vital role in the context of VR. VR systems provide users with immediate sensory responses based on their physical positions. Typically, these responses predominantly consist of visual cues [22]. Naturally, accurate tracking of the user's location is imperative to deliver relevant feedback.

To achieve high levels of realism, VR systems must be interactive, meaning they should respond to the user's actions. Interaction in VR can take various forms: one involves allowing users to influence computer-generated environments; another is related to enabling users to change their perspective by altering their location and viewing angles within the virtual environment. Additionally, there is the concept of a multi-user environment. When collaborating with others in the same virtual environment, tracking and responding to their activities, including their posture, gestures, actions, gaze direction, and speech becomes essential. The term "avatar" is commonly used to describe a virtual representation of a user or a real-world object within the virtual environment, commonly used in interactive VR experiences [49].

As further detailed in the next section, presence and immersion are considered two of the main characteristics of VR [58], mainly distinguishable by their subjective or objective nature, respectively [59-61]. Understanding these key aspects of VR provides a solid foundation for exploring this dynamic field.

2.1.1. Presence and immersion

It is typical to find VR grounded in the concepts of the sense of presence and immersion. Indeed, these key features are fundamental to creating a convincing and engaging virtual experience for users. They act together to make VR scenarios more realistic, attractive, and effective [62]. As briefly explained before, the sense of presence creates a strong illusion of "being there" [52, 63, 64] in a virtual place where people can realistically interact with the virtual simulation. The "being there" dimension, initially coined by Minsky [65] and expanded by Steuer [52], defines presence as the feeling of existing in a mediated environment. To describe it, some authors focus on the spatial aspect, relating presence to the sensation of physically being in a mediated environment [52]. Others emphasize the psychological aspect, referring to it as the illusion of being part of an alternate world, such as Slater [64], who calls the mediated environment the "place of illusion". Presence describes the subjective quality of a virtual environment [5], also known as a *qualia* experience, i.e., the raw, individual, and intrinsic qualities that make our perception of the world [64]. For example, the *qualia* of experiencing the color red includes the way red appears to that person, the emotional or aesthetic response it elicits, and any associated thoughts or memories. So, in other words, the same virtual experience might evoke a stronger sense of presence in one individual compared to another due to their unique perceptual sensitivities.

As clarified by Gutiérrez, et al. [62], presence occurs when the brain processes multimodal simulations (including images, sound, haptic feedback, etc.) and interprets them as a coherent environment where activities and interactions can occur. It is the awareness, whether intentional or not, of being within a virtual environment. For instance, when someone plays a video game, they are aware that the game's world is not real, yet they choose to act as though it were a genuine situation. An indicator of presence is when individuals in a virtual environment exhibit behavior closely aligned with how they would act in a similar real-life scenario.

The experience of presence emerges from the combination of three interwoven features, the so-called "three "Is": Immersion, Interaction, and Imagination. Starting from the end, imagination refers to mental imagery. It consists of the individual aptitude to voluntarily recall details of certain events [5]. Interaction relates to the natural capacity of exploring the virtual environment. Finally, immersion refers to the isolation from the real world. It is an objectively quantifiable concept, mainly associated with technological features, such as the display resolution, field of view, the matching between visual aspects and the user movements, among others) [60]. It can be regarded as the technological means to immerse the user in the virtual world [59]. As defined by Slater, et al. [60], it is "an objective description of what any particular system does provide", i.e., immersion serves as a means to assess the VR experience's quality. So, immersion is closely linked to the physical setup of the user interface in a VR application [62]. For that reason, Cummings and Bailenson [66] consider essential to maximize the levels of immersion by using technologically advanced immersive systems with faster refresh rates, light finely-tuned motion tracking detectors, devices with broader stereoscopic field of view, and more realistic virtual entities.

As evident, the concept of presence is subject to various definitions and perspectives. In turn, presence and immersion are frequently used controversially, due to their close association and relation with VR [67]. In short, they can be easily distinguished mainly by the subjective/objective nature: immersion can be objectively quantified, unlike presence, which can only be measured by the user experiencing it, thus, subjectively quantifiable [61]. Consequently, the methods used to measure presence also vary, a topic that is addressed in the next section.

2.1.1.1. Measuring user's sense of presence in VR experiences

Presence evaluation is a common practice in assessing VR applications, and it is fundamental to evaluate the effectiveness of VR applications. However, due to the subjective nature of presence, determining "how present" a user is entails several inherent limitations [67]. Distinct approaches for attempting to quantify the concept of presence can be found in the literature, categorized into two groups: objective measures and subjective measures. On the one hand, objective measures assess the impact of a virtual environment on automatic, less consciously controlled reactions. It includes behavioral measures, which examine the actions shown by the user in reaction to objects or events within the virtual environment, and physiological measures, aiming to assess presence by monitoring variations in biometric data. This information can be retrieved by resorting to physiological indicators, like pulse and respiration rate, heart rate (HR), and skin conductance, to name a few, which offer more objective and continuous data. The evaluation of posture, responses to stress stimuli, and conflict response tests, are some examples of behavioral measures [68].

As stated by Slater and Steed [69], one of the main criticisms objective measures face is related to the fact that some feature or task has to be added to the environment (to elicit an immediate response, for example), which may not have anything to do with the application. Additionally, it has been demonstrated that using extra equipment to record physiological responses can significantly enhance the "Break-in-Presence" (BiP) [70].

On the other hand, subjective measures involve directly or indirectly inquiring about individuals' feelings and experiences within the virtual environment [47]. They are the most common, easy to apply, and offer better adaptability to different contexts [71]. Nevertheless, interpreting raw presence scores can be challenging [67]. Currently, validated questionnaires are the predominant method for assessing presence, and they have proven to be adequately sensitive in detecting variations in presence, as attested by Insko (2003) in [72].

There are several approaches to subjectively measure the users' sense of presence. The most frequently referenced instruments for measuring it in VR [68] include the Witmer and Singer (WS) questionnaire, also called "Presence Questionnaire" (PQ) [73], the Slater-Usoh-Steed Questionnaire ("SUS Questionnaire") [69], and the Igroup Presence Questionnaire (IPQ) [61].

Barfield and Weghorst [74] proposed one of the most earlier approaches to measuring presence. The authors intended to explore how the update rate of a computer-simulated environment influenced the feeling of presence in stereoscopic virtual environments. To do so, they used 6-item for assessing presence, and 7-item for interaction fidelity in an integrated questionnaire. However, some questions were too specific to their experiment, thus, its use became limited and obsolete [72].

Drawing from prior research and inspired on the theoretical framework developed by Sheridan [75], which identified the fundamental elements of presence (sensory information, sensor control, motor control), Witmer and Singer [73] created a 32-item questionnaire to assess presence. They categorized this into three distinct subscales: involvement/control, naturalness, and interface quality. Nonetheless, it faced criticism for its subjectively determined factors and the limited number of items that directly evaluated presence [61, 76].

Another attempt to measure presence was the Slater-Usoh-Steed (SUS) questionnaire [77-79]. This questionnaire centers around questions that vary around three key themes: (1) the sense of being in the virtual environment, (2) the extent to which the virtual environment becomes the dominant reality, and (3) the extent to which the virtual environment is remembered as a "place". Although it is the second most cited presence questionnaire in VR investigations, according to Schwind, et al. [72], research conducted by Usoh, et al. [79] demonstrated that both the WS and SUS questionnaires are unable to distinguish between presence and immersion, one of the main criticisms of the WS, pointed by Schwind, et al. [72].

Numerous researchers have developed their questionnaires by drawing on the frameworks established by Slater and Wilbur [59] and Witmer and Singer [73]. They often blend or individually adapt these models, merging existing questions with new ones specifically designed for their research [71]. A notable example in this context is the iGroup Presence Questionnaire (IPQ) [61]. It is a 14-item questionnaire, also offering a Likert scale to register the answers, aiming to assess the fundamental concepts of presence and immersion within four subscales:

- Overall sense of presence;
- Spatial Presence: the sense of feeling physically present in the virtual environment;
- Involvement: the awareness of being in a virtual environment;
- Experienced Realism: the sensation of reality conveyed by the virtual environment.

Indeed, by inspecting SUS and IPQ, it is possible to conclude some similarities between them:

- SUS item 1 aligns with IPQ item 1 (G1) and is essentially equivalent;
- SUS item 2 addresses the perception of experienced realism, which corresponds to the IPQ subscale of "experienced realism" (REAL);
- SUS item 3 mirrors IPQ item 3 (SP2);
- SUS item 4 corresponds to IPQ item 4 (SP3);
- SUS item 6 is related to IPQ item 6 (SP5).

However, there is no equivalent in the IPQ for SUS item 5, which assesses the subject's spatial memory and the duration of spatial perception. Conversely, the 6-item SUS does not provide any insights into experienced involvement (INV1-INV4), which is represented by the subject's attention to the virtual environment.

Additional questionnaires to measure presence have been created, each targeting particular applications, for instance, the ITC-Sense of Presence Inventory (ITC-SOPI) [80] and the Temple Presence Inventory (TPI) [71], both designed for non-interactive media.

Although, in general, they have faced significant criticism, questionnaires remain the most commonly used tool for assessing users' sense of presence [71, 81]. One argument to justify it is that the subjective nature of presence calls for a subjective measurement approach, as claimed by Sheridan [75]. Its widespread use is also attributed to the ability to gather broader and more detailed results, and to the ease of application in various contexts. In contrast, objective measures of presence offer less comprehensive insights and are more restricted in their application [71].

Regardless of the specific questionnaire chosen, the most endorsed approach for subjectively measuring presence in VR is through a post-test questionnaire. In this context, the IPQ, although not being the most cited presence questionnaire on Google Scholar according to Schwind, et al. [72], is often recommended due to its high validty and reliability.

2.1.2. Virtual reality systems classification

There are many classifications for VR systems, which can be regarded in terms of immersion, interaction, or the tracking features available. The most common is the first classification, related to the distinction between non-immersive, semi-immersive, and fully-immersive, initially proposed by Costello [56] and currently defended [18, 62, 82] and adopted [2, 18, 22, 83-85] by several authors. In a non-immersive system, also known as desktop-based VR, the user engages with the virtual environment using conventional graphic workstations like a PC monitor, keyboard, and mouse. Typically, static or 360º videos and images can be seen in such systems [26]. A semi-immersive VR system typically features more advanced graphics. It employs larger flat surface displays to present the virtual environment, e.g., the CAVE system, a multiuser workplace equipped with screens that project a virtual world, developed in 1992 by Cruz-Neira, et al. [86]). Finally, a fully-immersive virtual environment encompasses huge surrounding projection surfaces or, preferably, HMDs, that can be differentiated as follows: wired, such as Oculus Rift, or HTC Vive; wireless, such as the Samsung Gear VR and Oculus Quest 2; or low-immersion HMDs, such as the Google Cardboard [83]. With highlights on the wired and wireless, HMDs effectively position the patient within the virtual environment, offering the highest degree of immersion [56, 82]. The combination with other multisensory devices such as headphones, haptic devices, and smell and taste interfaces contribute to isolating the user from the real world, contributing, in turn, to increasing the levels of immersion [62]. So, VR systems are more immersive the less the user can perceive (see, hear, touch) the outside world [62-64, 73]. Consequently, it fosters increased user interaction with the virtual environment, while also amplifying its ability to elicit emotions, in contrast to non-immersive and semi-immersive systems [26].

Lately, most of the VR experiences developed are fully-immersive and predominantly relied on HMDs. The primary objective is to completely isolate users from their actual surroundings, in order to enhance the realism and effectiveness of their virtual experience. Fully-immersive systems successfully achieve the illusion of an alternate reality, resorting to more advanced technology. However, what may be perceived as a positive point often carries a downside and a challenge, namely the motion sickness-related problems that result from the use of such modern and immersive technology [62]. This phenomenon is called cybersickness and can occur during and after a VR experience [87].

Although less prevalent, the degree of user interaction is also a possible classification for VR systems. The extent to which users interact with the virtual experience can range from passive to active and interactive. Passive interaction occurs when users receive sensory experiences without actively initiating specific actions, such as gestures or movements. The user is mainly an observer. On the other hand, active interaction involves users generating sensory responses through actions like shouting or jumping. So, the user can actively engage with and manipulate the virtual environment. Lastly, interactive interaction refers to the dynamic exchange of sensory activities between multiple users and the virtual environment [88].

VR systems can also be distinguished according to the tracking features, i.e., the body parts whose movements are monitored. According to LaValle [46], the basic level is the tracking of the user's sense organs, such as the eyes and ears. The next level is the tracking of the user's other body parts, like limbs. Finally, tracking the rest of the environment relates to monitoring physical objects in the real world surrounding the user. This tracking can serve various purposes, from safety alerts (e.g., preventing collisions with obstacles), or to providing touch feedback when interacting with physical objects in the virtual world, for instance.

2.1.3. Multisensory experiences in virtual reality

As explained before, VR requires the brain to assimilate multimodal information and to perceive it as a coherent environment, where one can perform some activities and interact. Once this information is processed, various reactions can arise. A thoughtfully designed virtual world has the potential to influence our emotional state, eliciting feelings such as anxiety, happiness, or sadness. This phenomenon has driven many researchers to explore the use of VR as a therapeutic tool for addressing conditions like arachnophobia or social phobia, as attested by Sanchez-Vives and Slater [63].

Depending on the specific situation, certain senses may hold greater importance than others. For instance, when simulating surgical procedures for training medical professionals, having precise tactile haptic feedback takes precedence over the visual quality of the simulation [62]. Guttentag [14] illustrates this theory with the "Gardens of Versailles" example, in which, although visual and auditory aspects are very important, the addition of appropriate olfactory stimulus is crucial to let the user perceive the smell of nature.

Humans perceive their surroundings through a multitude of sensory pathways. It stands to the reason that VR should be explored in the same manner, where the users are effectively transported to an alternate environment through sensory cues. These sensory cues align with the five primary human senses, and can be found isolated or combined [89]. The role of multisensory stimuli in VR is to create a holistic and immersive experience for users by engaging multiple senses, including vision, hearing, touch, smell, and taste (when appropriate). Moreover, multisensory VR has great potential to evoke users' different emotional states [1-4] and to alleviate potential gender disparities in passive VR, namely regarding the sense of presence [90].

Vision is recognized as "the primary source of information about the outside world" [62], namely regarding light, color, and depth, and it is the most studied element in VR [49]. It acts as a double-check to recognize other senses, such as unexpected sounds [62, 91]. To visually explore a virtual environment, VR displays range from fully-immersive systems, like HMDs that entirely disconnect the user's field of vision from the physical world, to non-immersive systems, which commonly display static or 360º videos and images through standard graphic workstations such as a PC monitor, keyboard, and mouse [26].

HMDs typically consist of small displays with lenses, often incorporated into a headset. These displays can employ various technologies like LCDs, or OLED. Many HMDs also feature integrated speakers or headphones to provide both video and audio output, and include tracking devices to adjust the displayed perspective as the user moves their head [62]. The rising success of VR can be significantly attributed to the growing affordability of the HMDs [92]. Some recent examples include the Meta Quest 3 (Figure 6), released in 2023, priced at $499, and the PlayStation VR 2 (Figure 7), launched in 2022, with a retail price of $550, as specified by the companies responsible for developing each respective headset.

Figure 6 Meta Quest 3

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Figure 7 Play Station VR 2

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Unlike our visual system, which has high spatial resolution but limited field of view, the **auditory** system provides spatial cues from the entire surrounding environment simultaneously, allowing us to both locate objects and feel immersed in a spatial scene through sound reflections and reverberation. Audio has the potential to evoke both the feeling of an object's presence and the sensation of being inside or surrounded by a specific space. Furthermore, while visual scenes can be static, sound is inherently dynamic and continuous, conveying the sense that something is happening. This temporal aspect of sound is crucial for both object presence and spatial presence, as direct sound constantly reminds us of an object's presence, which influences our perception of space [93]. Sound is part of our real-life experience, considered the humans' secondary sense, which gives essential information about everyday life [62, 91]. Although not mandatory, auditory information is an expected element in a virtual experience [62]. It has the power to provide the user with more immersion [3], to enhance the sense of presence [43, 91, 93-95] and spatial presence, which is better the greatest the audio quality [95]. Also, it enhances the scene's realism and has the ability to awaken multiple emotional states [96], ranging from anxiety [94] to calm [97], depending on the audio technique and the sound/music that is being used. Furthermore, when synchronous, it helps the user create associations between visual stimuli and real scenarios. For instance, the sound of traffic and cars will remind a person of a big city. As explained by Larsson, et al. [91], as ears are always open and, consequently, always susceptible to stimuli, in contrast to eyes, it should be undoubted that hearing provides the sense of being there, no matter if "there" is a real or a virtual place.

Just as in real life, where vision and audio are the primary sources of information, the same holds true in VR, as seen in tourism [98] and gaming [99], for example. In fact, most VR applications heavily depend on visual and auditory stimulation [31, 84, 93]. Nevertheless, it can impose limitations on the overall quality of the user experience, since one's perception about the real world inherently involves multiple senses [84]. Multisensory stimulation (other than just audiovisual) plays an essential role in evoking human emotion [100] and enhancing the user experience [101], especially regarding the perception of realism [62, 85, 96], sense of presence [2, 62, 96, 102, 103], and participant performance [104]. In turn, these benefits help overcome one of the main challenges faced by VR, which is the interaction between the user and the virtual environment [4], very encouraged in the literature [49, 105].

Despite the benefits of incorporating other cues in addition to audiovisual, haptics, smell and taste have been receiving significantly less attention within the VR industry [84, 103], mainly due to the challenges that researchers face in implementing it [46, 85], as further discussed at the end of this section. Despite becoming increasingly prominent and often used in VR research, haptics is an example of it [50].

The term "**haptic**" is derived from the Greek word "haptesthai", denoting the human body's tactile perception of objects and space. Human touch is a crucial sense, encompassing cutaneous, kinesthetic, mid-air, and haptic systems. The cutaneous system, involving skin-embedded mechanoreceptors, processes surface stimulation [50, 62]. These devices provide tactile feedback by stimulating the skin directly with miniature electromechanical actuators. They modulate contact pressure against the skin, typically at the finger pad, using techniques like pin arrays, small mobile platforms, or lateral skin stretch mechanisms. In this approach, users wear haptic devices like gloves that provide tactile and force feedback to the entire hand [106]. These gloves, in turn, can be traditional (e.g., the Gloveone™ [107] - Figure 8), thimbles (e.g., VRtouch™ - Figure 9 - by Go TouchVR [108]), or exoskeletons (e.g., the CyberGrasp™ - Figure 10 [109]) [110]. These devices allow for a more immersive experience by simulating the manipulation of virtual objects with diverse gestures, such as grasping and pinching. Wearable haptics can simulate up to 22 Degrees of Freedom (DoF) of human hands, dynamically adjusting the force feedback based on the interaction between the virtual hand and the objects [106].

Figure 8 The Gloveone

(Retrieved from this link)

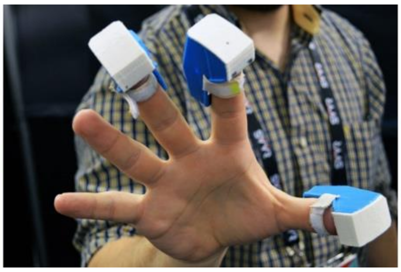


Figure 9 The VRtouch

(Retrieved from this link)

Figure 10 The CyberGrasp

(Retrieved from this link)

The kinesthetic system, located in muscles, tendons, and joints, provides awareness of limb positions and movements, often referred to as proprioception. It involves simulating hand-object contacts and providing feedback by computing coupling forces between the hand avatar and the kinesthetic haptic device. It requires a high update rate to simulate high contact stiffness stably and involves complex computational processes for collision detection, collision response, and force computation. This involves the use of devices like multi-joint robotic arms fixed on a desktop. Users interact with virtual environments through a stylus or handle (for instance, the PHANToM OMNI® haptic device - Figure 11 [111]), receiving force feedback that simulates the motion and contact with virtual objects. This method supports 6 DoF for motion and force feedback, providing a high level of control for precision tasks like surgical simulations or mechanical assembly [106].

Mid-air haptic interfaces enable both direct touch and mid-air interaction without the need to hold or wear any device. Common techniques include using air jets or ultrasound modulation to create tactile sensations in mid-air [112], like the HaptiGlow - Figure 12, a technique that integrates ultrasound haptics with peripheral visual feedback to assist users in accurately positioning their hands for enhanced mid-air interaction [113]. Finally, the haptic system combines aspects of both cutaneous and kinesthetic systems. In VR, haptic interfaces produce mechanical signals that activate the kinesthetic and tactile sensory channels in humans [50, 62], which can be provided through vibration, pressure, or changes in temperature, typically applied to the hands [46]. Haptics has been demonstrated to enhance interaction, the detection, and discrimination of stimuli, facilitate self-regulation of psychological states, trigger the sympathetic nervous system, and improve spatial awareness within VR environments, as concluded in a systematic literature review conducted by Apostolou and Liarokapis [84]. However, considering the challenges involved in designing haptic displays, an alternative approach is to use physical objects within the interaction zone to convey feedback to the somatosensory system [46]. For instance, a fan can simulate the sensation of a thermal warm environment [114], wind [25, 99, 114], fire, or even a ghostly breeze [32]. Such methods are commonly categorized as haptic feedback [115, 116], which can be classified into two groups: "active haptic feedback," involving computer-controlled actuators applying forces to the user, and "passive haptic feedback," related to interactions with tangible objects [117]. Collectively, active and passive haptic feedback contribute to what is known as "Smart Substitutional Reality" (SSR) [32].

Figure 11 The PHANToM OMNI® haptic device (Retrieved from this link)

Figure 12 The HaptiGlow (retrieved from [113])

The **smell** is the most ancient sense, and it is directly connected with the brain's emotional areas [118]. This explains why researchers frequently focus on the emotional potentials of scent as part of notification systems, instead of considering it as a powerful sensory dimension that highly contributes to increasing the sense of presence, as part of the whole multimedia experience [119]. Moreover, the smell tends to be more prevalent in particular domains, notably in wellness applications, such as stress reduction [120], therapy from post-traumatic stress disorder exposure [121], and training simulations related to firefighting and fire detection [122]. Recently, COVID-19 has increased awareness of the significant role of olfaction in life quality, appetite, health, and safety, considering the sudden loss of smell (known as anosmia) as a common symptom [123], which has contributed to increased research on it. However, there are still many obstacles in reproducing smell in VR, mainly related to the intrusiveness it causes, due to the requirement of wearing “anything” in the face [124], which, in turn, hampers the investigator to understanding participants’ behavior [125]. These challenges include the complexity of blending scents, which resultant smells can vary from person to person [103], and may be unpleasant for some users [62].

Moreover, occasionally, the odorants emitted by the device do not even reach the nose [126]. Finally, the timing of odor delivery and dissipation also represents an arduous task [127, 128].

Despite the constraints, several olfactory displays have been developed to present smell cues to the user in VR experiences. They can be distinguished according to their physical location, which can be fixed (in the environment), or wearable (located near the nose, like HMDs, or around the neck, as scent collars) [129]. The "Pump unit BB-200" (@aroma GmbH, Berlin, Germany), the *Hajukone* [130], or the unnamed device developed by Herrera and McMahan [131] are examples of it. However, although highly innovative, they still cannot fill all the mentioned gaps. For instance, the olfactory display - Figure 13 -, created by Kato and Nakamoto [126] promises to direct the smell to the nostril, assuring that the user will correctly feel the smell, but, still, it is a large and intrusive apparatus.

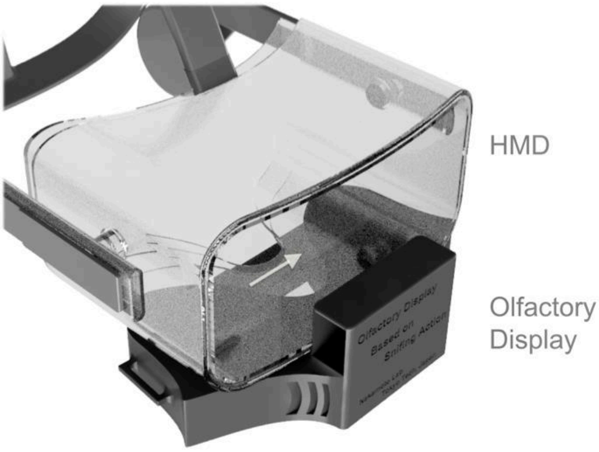


Figure 13 The olfactory display

(retrieved from [126])

Furthermore, the authors assumed that the odor molecules dispersed into the surrounding air could potentially cause confusion for the user regarding the specific scent being presented at a given moment [132]. Recently, a novel way of delivering scents that can combat intrusiveness was presented by Niedenthal, et al. [119]. The so-called "Olfactometer", a device that fits the central opening of the hand controller of HTC Vive, was developed to integrate physical smells within the synthetic VR environments. It allows the users to manipulate virtual objects and sniff them by making the natural gesture of elevating the hand close to the nose. Furthermore, it enables the presentation of just one scent or a mix of various, blended through stepless valves. As a compact, low-cost device, intuitive to use, and stable enough for long-term sessions, it can be a promise for recreational, educational, therapeutic, and scientific domains [119]. Lately, it has been proved that the introduction of odors enriches the virtual experience, as it significantly enhances the users' immersion, particularly the experience realism. Surprisingly, not even the introduction of unpleasant odors demonstrated additional side effects, i.e., cybersickness. Instead, they tend to increase the users' sense of presence (e.g., maggots in a casserole dish, smoke, and a rotting head) [128].

Finally, the sense of **taste** results from a complex interaction between multiple sensory mechanisms since the food is placed in the mouth and the taste receptors are stimulated. So, taste derives from the gustatory system and refers to five basic classes – sweet, sour, bitter, salty, and umami – which are perceived differently by each individual [62], i.e., is a *qualia* experience. The taste perception derives not only from the gustation sensations and the characteristics of the food itself [133], but also from the environmental aspects unrelated to the food, such as the texture or the color of the food container [134], and the location where the food is being tasted [135]. For example, two edible samples, one with a rounded shape and another with a spiky shape, may influence one's perception of food sweetness [136]. It also corresponds to a wide experience composed of taste, odor, and chemical sensations. In fact, smell is responsible for 80% of taste, as mentioned in [137].

The most common techniques to simulate taste in VR are chemical, using the retargeting technique, electrical stimulation, or using real stimuli. When using chemical modulators, the goal is to change how specific taste receptors respond to foods, allowing a single food item to simulate multiple tastes. The taste retargeting technique involves delivering droplets of modulators to the mouth before eating. This allows a single food prop to represent various virtual foods by modifying tastes such as sweetness, sourness, and bitterness. Finally, electrical stimulation refers to the application of electrical currents to the tongue to evoke taste sensations. It works while in contact with the tongue and often affects the entire flavor profile rather than specific tastes [138]. Due to technology limitations, the taste is considered the most sophisticated sense to simulate in a virtual experience [139], which explains why so few devices are found in the literature for stimulating taste in VR. As mentioned by Martins, et al. [139], the most recognized work in this field is the "food simulator" - Figure 14, proposed by Iwata, et al. [140]. These authors have first developed a haptic interface that presents taste, sound, and the feeling of chewing real food. Later, the system allowed the user to suck virtual food, getting the corresponding sound and vibrations of chewing it [141].

The Virtual Cocktail Device (the Vocktail - Figure 15) [142] is another example developed to simulate the sensation of taste by combining digital taste, smell, and color sensations. It can simulate a few flavors using electrical and thermal stimulation of the tongue.

Figure 14 The food simulator

(retrieved from [140])

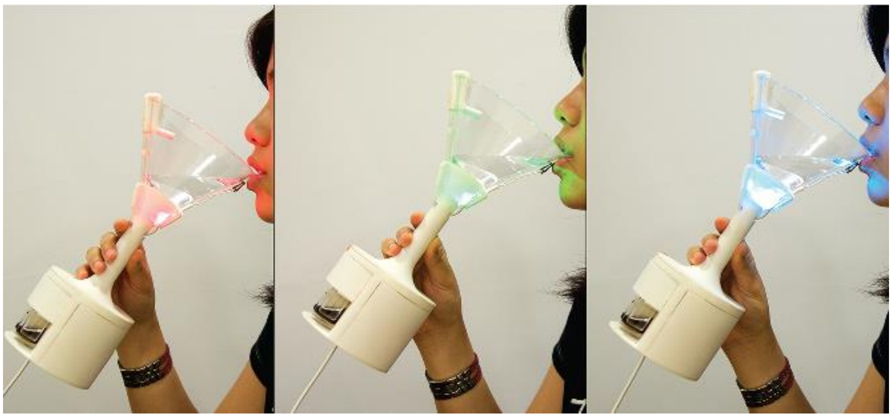


Figure 15 The Vocktail

(retrieved from [142])

More recently, Chalmers, et al. [143] presented the FlavoSim – Figure 16. It is a high-fidelity system that includes nine cartridges containing food-safe chemicals for basic tastes (sweet, sour, bitter, salty, umami) and mouthfeel components (oiliness, astringency, capsaicin). It also has six aroma cartridges and three-color cartridges. This device can warm or cool the virtual flavor and is digitally controlled via USB or Bluetooth.

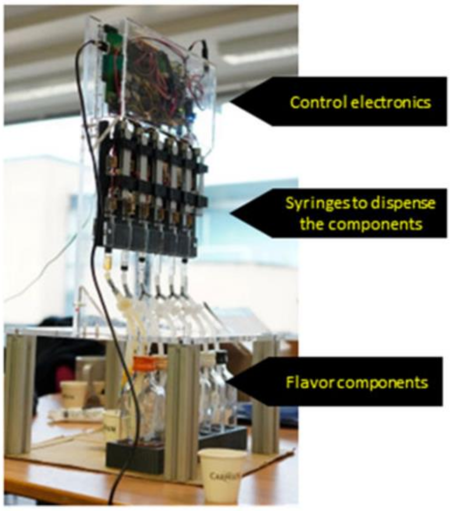


Figure 16 The FlavoSim
(retrieved from [143])

Several studies have explored the correlation between multisensory stimulation and immersion. It is clear that the more human senses are stimulated: 1) the higher the users' sense of presence [3], 2) the better users perceive the virtual environment [96], 3) the better they perform on it [59, 102], and 4) the more detailed and authentic the virtual environment is perceived [144]. So, more than the multisensory stimulation *per se*, their mixture and complexity are crucial factors in creating positive virtual experiences. The interplay of these sensory elements produces a synergistic impact that notably originates VR experiences more akin to the real world [84, 145].

Lately, more research regarding other than just visual-auditory stimuli is increasing [146], considering the emergence of creating more compelling experiences [99, 147]. For a long time, the costs associated with implementing haptic, smell, or taste interfaces were very high. Nowadays, it is possible to create more affordable multisensory installations by connecting prototyping platforms such as Arduino or Phidgets to a low-cost ventilator or simple smell interfaces. There is also an increasing appearance of less expensive HMDs, such as the Oculus Rift or PlayStation VR [32, 99, 148]. Furthermore, various engineers have been working on the development of new technologies capable of offering the user more immersive VR experiences, with low-cost devices and installation [25, 149], such as the FeelReal Mask [150] and the Vocktail [142]. Nevertheless, the integration of additional stimuli other than audiovisual is still scarce in VR [30-32], especially in emotions-based studies, as further addressed.

2.2. Virtual reality in tourism – Virtual tourism

The tourism industry has undergone significant transformations over the decades, evolving from traditional forms to more innovative and technology-driven approaches. This journey from conventional tourism to virtual tourism marks a pivotal shift in how travel experiences are conceived, marketed, and consumed. Technological tools such as Augmented Reality (AR), Mixed Reality (MR), and VR have emerged with considerable potential to significantly impact various fields. Tourism is one notable example where these technologies have driven substantial changes [83]. So, in this section, the journey from traditional tourism to virtual tourism will be outlined, to understand the potential of this topic in exploring the interplay between multisensory VR, MI, and users' emotional responses.

The word "tourism" was registered in the Oxford Dictionary back in 1811 [151]. At that time, tourism was primarily an activity for the wealthy elite. This era saw the rise of the Grand Tour, a traditional trip undertaken by young aristocrats and wealthy individuals across Europe. The Grand Tour aimed to educate and cultivate cultural knowledge through visits to major cities, historical sites, and centers of art and culture such as Paris, Rome, and Florence [152].

Still in the early 19th century, significant shifts in the tourism sector began to appear, marking the emergence of modern tourism. This transformation was influenced by the social, cultural, and economic changes of the period. This form of tourism heavily relied on physical presence, sensory engagement with the surroundings, and direct interaction with local communities [153]. Since then, tourism has played a significant role in the global economy, contributing to the gross domestic product, and employment [151].

From the 1980s onwards, with the intersection of tourism with the Information and Communication Technologies (ICTs), the concept of eTourism emerged. It refers to the digitalization of tourism services and processes through ICTs. It encompasses the electronic management and distribution of tourism information, marketing, and sales of travel products and services. The primary goal of eTourism is to enhance the efficiency, convenience, and reach of tourism services, providing consumers with accessible and comprehensive tools to plan and book their travel experiences online [154]. This revolution gave rise to a profound impact on consumer behavior [155, 156], which in turn contributed to the rise of a new type of tourist, more knowledgeable and demanding. These tourists were weary of conventional tourism and aspire to transition from being passive to becoming more engaged and active participants [156]. In fact, more recently, it was found that the average age of international tourists is decreasing, indicating a growing number of younger travelers seeking new adventures. Emerging trends in tourism include long-haul travel, wellness and health holidays, sports, cultural tourism, ecotourism, beach, and more [157].

Inserted in eTourism, VT, often referred to as virtual travel [83], emerged with the alliance of VR in tourism, around 2004, breaking with the basic premises of traditional tourism (physical relocation and a minimum 24-hour stay away from home) [16]. It is, therefore, a fusion concept that combines the realms of VR and the tourism experience [157]. It could finally meet the needs of these new tourism consumers and trends, offering a captivating preview of real destinations and attractions. VT transforms the way travelers engage with destinations, marking it as the future of the industry and reshaping the consumer experience at an accessible cost [158].

Initially, VT was predominantly based on non-immersive virtual environments, with a monoscopic view, where users could basically view and hear a video of the tourist destination [157]. The subsequent significant advancements involved the integration of stereoscopic 360º videos to create VR content and experiences, still distributed via non-immersive systems [46]. Nowadays, not only is the content projected with significantly higher resolution in advanced HMDs, offering a fully-immersive experience, but also the interaction with the environment and the user's free movements have also contributed to a significant transformation in VT [159]. VT became captivating as people could explore any location in real-time, from anywhere in the world, simply using their smartphones [157].

The literature has outlined the potential of VR technologies in the tourism and hospitality sectors, elucidating their capacity to convincingly replicate real-life scenarios and environments, and emphasizing the sensory and emotional impact [158]. The recognition of VR's potential to revolutionize and reshape the tourism sector has been established for quite some time. For instance, Hobson and Williams [10], early acknowledged the transformative potential of VR, characterizing it as "possibly one of the most significant technological advancements of the late 20th century", particularly, in the tourism sector. Given its intangible nature, i.e., something that cannot be tested before the decision to buy is made, the introduction of tools that enhance user engagement with the virtual environment can be a significant asset for the tourism industry [160-162]. Indeed, a successful VR experience can evoke a positive destination image, given its well-recognized power to enhance market effectiveness [161]. Moreover, VR enables access to in-depth information about the destination image, aiding in the formation of realistic expectations about the chosen place [162]. Destination image has an important connotation in the context of VT. It can be defined as the collective impressions encompassing a destination, comprising both knowledge and emotions [163]. The mental representation of a destination aids consumers in anticipating their tourism experiences, which justifies the importance of a high degree of similarity between consumers' mental perception of a destination and the actual place [162]. It contributes to tourist satisfaction and their willingness to recommend the destination to others, such as friends and family, as underscored by several authors [160, 163-165]. Therefore, engaging in proactive and dynamic consumer-centered communication efforts becomes imperative to optimize destination images, enhance consumers' expectations, and consequently increase their satisfaction [164, 165].

The positive arguments regarding the benefits of VT conduct to the widely-discussed topic of whether VT might one day be able to substitute traditional tourism [10-12, 14, 62, 166]. Besides being easily attainable and low-cost [14, 15], VT offers several notable advantages when it comes to sustainability, addressing some of the critical environmental and social challenges posed by traditional tourism. These benefits include:

- The environmental protection, by helping to protect natural and cultural heritage sites from the wear and tear caused by mass tourism. By providing virtual access to these sites, the physical impact on fragile ecosystems and historical monuments can be significantly reduced, helping to preserve them for future generations [14];
- The reduction in carbon emissions associated with travel. By allowing people to experience destinations without physically traveling, it cuts down on the greenhouse gas emissions produced by air travel, car rentals, and other forms of transportation [167];
- A decreased overcrowding and preservation of natural sites, which often lead to environmental degradation and resource depletion. By providing an alternative way to experience these sites, VT can help preserve their natural and cultural integrity [168];
- Enhanced accessibility to those who may not be able to travel due to physical, financial, or logistical constraints. This inclusivity ensures that more people can enjoy and learn about various destinations, fostering a broader appreciation for global cultural and natural heritage without the need for physical travel [169]. The same can be observed for those sites that do not exist anymore, or to visit protected, inaccessible, or dangerous places [10, 11]. Additionally, it eliminates accessibility obstacles for the elderly or travelers with disabilities [10];
- Providing developing countries, with limited opportunities for self-promotion, the ability to showcase themselves without costly marketing techniques, as pointed out by Bauer and Jacobson (1994) in [11].

Using VT as a planning tool allows the consumers exploring the destination before making a purchase, which, in turn, results in avoiding disappointments, as noted by Leston in Sussmann and Vanhegan [11]. Furthermore, considering that a lack of time is a limitation to travel, as mentioned by Leston (1996) in [13], VT overcomes this obstacle by eliminating this need, both to the destination and during a potential stay. Based on these advantages, and considering the rapid growth of VR, occasionally, some authors argue that VT will substitute traditional tourism. In contrast, several others believe that it will just act as a complementary tool to promote tourism. For instance, Cheong [12], who defends that VR serves as a means to ease entry into distinct dimensions from our own, argues that it has the potential to offer an alternative to traditional travel and tourism experiences. Additionally, Jung, et al. [166] delve into the ways in which fully-immersive VR can replace in-person tourism experiences, and also contribute to enriching the traveler's overall experience. More recently, mainly due to the COVID-19 pandemic, which caused widespread panic, public health crises, economic disruptions, and changes in consumer behavior, this debate has gained exceptional prominence [10, 11, 14, 17, 83, 139, 158, 170]. Consumers are increasingly satisfied with substitute travel experiences, with many visiting simulated environments like theme parks in large numbers [170]. Disney World, as the fourth most popular destination, is a notable example of this trend. According to Caproni [15], people tend to embrace such tourism experiences because they are convenient, cost-effective, predictable, and ensure enjoyment for the entire family. Especially in the post-COVID era, these experiences, capable of generating interest and fostering positive emotions, have been revealed to be crucial for destination recovery [35].

Despite its potential, as attested, for instance, by Martins, et al. [139] in the successful case of wine virtual tourism, the substitution of VT by the traditional is contradicted by many researchers who defend that VT will just complement traditional tourism [10, 11, 14, 17, 83, 139, 158, 170]. In this regard, Ye, et al. [170] clearly declare that "there is no substitute for offline travel that brings tourists a natural feeling". Ultimately, whether VR is accepted as a substitute for traditional tourism remains an open question, as it largely depends on each traveler's openness to it, as defended by Guttentag [14].

In summary, VR is rapidly becoming a key element in creating new tourism experiences, serving various purposes such as information, entertainment, education, accessibility, and heritage preservation. The technological advancements in VR offer opportunities for destinations, hospitality, and attractions across the entire customer journey.

2.3. Emotions in virtual reality

Given this thesis' interest in the impact of multisensory VR on users' emotions, it becomes imperative to understand its effects on our daily lives. There is currently a growing tendency to accept that emotions exert a significant influence on human life. Nearly all human decisions and actions are shaped by emotional factors. These emotions impact our behavior and decision-making processes, which can yield either positive or negative outcomes for ourselves, others, and society at large. Computer graphics and interactive technologies have significantly expanded this potential, broadening, and enhancing the scope of emotional design. Specifically, VR has the capacity to offer immersive elements, enabling users to inhabit different personas and living entities while encountering a diverse array of situations that can range from calming to exhilarating [171].

Emotional elicitation in VR can be passive or active. Passive elicitation entails the subject taking on the role of an observer during an emotional event, such as watching movies. Conversely, in an active scenario, the subject actively engages in the emotional experience. Active methods primarily involve avatar mediation, and interactive VR, promoting higher interaction between the user and the virtual environment. In contrast to passive elicitation, these active methods offer a more realistic and compelling level of participant involvement and emotional engagement [26]. The influence of films, TV shows, imagery techniques, and various interactive media in evoking emotional responses is evident. Nevertheless, immersive VR remains incomparable in this regard [55]. In a study conducted in 2022, virtual environments represented 32,84% of the studies investigating emotions among various media types. Nevertheless, there is a notable trend indicating that this percentage is likely to rise [26].

The term "emotional experience" fundamentally relies on a physiological reaction, fulfilling personalized needs, and evoking a positive sensation that emerges within an individual's awareness when they attain a specific level of emotional, physical, intellectual, or even spiritual contentment [172]. Although emotions are present in everyday life, they are probably one of the least understood aspects of human experience. They are "transient states of feeling, of relatively short duration (…) caused by specific events" [173], and are a result of the combination of valence and arousal [18, 174]. Emotions are related to the human five senses, which are awake by eating, touching, smelling, listening, or looking [3]. So, it is comprehensible why multisensory VR systems have great potential to elicit different human emotional responses [175]. Moreover, emotional reactions tend to be more varied and intense when multiple human senses are engaged in the virtual experience, resulting in increased levels of the sense of presence [1-4, 34, 35]. Nevertheless, it is important to retain that eliciting emotions in VR, while generally feasible, can be a complex task for researchers. Some emotions, such as sadness, disgust, and happiness, are relatively easier to evoke in VR due to their strong connections with visual and auditory stimuli, requiring less user involvement and storytelling. Conversely, triggering negative emotions like anger and surprise can be more challenging, as they often demand a higher level of immersion in the narrative to elicit the intended reactions. To address this challenge, some authors recommend inducing similar emotions, for instance, using frustration instead of anger [171].

Much like presence, as previously discussed, emotions are in a constant state of flux and dynamism, shaped by physiological self-perceptions, cognitive self-descriptions, and the ongoing interactions of these factors with the environment [47]. By representing "natural conditions", comparable to real-life in terms of stimulation [4, 171], intensity, and impact [171], VR currently has gained high importance in emotional research. Furthermore, the increasing interest in emotional VR is expected to become a key influencer in the coming years, to enhance human behavior and life quality [171]. Some examples are combating autism or the psychotherapy of phobias (e.g., arachnophobia or fear of heights), thanks to the "manipulation" feature of the users' psycho-emotional states and consciousness [4]. The immersion provided in a VR application has the ability to evoke a wide range of emotions in users [19, 174, 176], either positive or negative, with different levels of intensity [1, 2, 177], as further discussed in this section.

2.3.1. Users' emotions in the context of virtual tourism

As discussed, VR has the power to evoke a wide range of emotions, from positive, like joy and excitement, to negative, such as fear and sadness. It gives the user the feeling of being in a place one is physically not [175, 178], which offers a notable advantage for the tourism industry by enabling the users to experience the illusion of traveling to remote destinations without leaving the current location.

In the tourism context, emotions play a critical role, especially in the pre-travel phase, when consumers explore and seek inspiration and motivation [179]. Its relevance has been established across a great variety of tourism subtopics, such as festivals, shopping, theme parks, holidays, heritage sites, scenic tourist attractions, and adventure tourism, as attested by Hosany, et al. [20]. For instance, the investigation of the potential of VR virtual parks as an emotional medium taken by Riva, et al. [55], identified positive associations between the sense of presence and negative emotions in parks designed to induce anxiety. Conversely, they found positive correlations between the sense of presence and positive emotions in parks designed to promote relaxation.

Emotional engagement is a crucial component of tourism itself [20], as well as for VT. Accordingly, VR developers, marketeers and researchers are consistently exploring new multisensorial strategies to make the intangible aspects of the tourism experience more tangible [157], by visually representing the real world [180] and increasing the feelings of presence [181]. The challenge lies in the fact that emotions are affected by behaviors and cognitions, which, in turn, are unstable and different from one person to another [19]. Furthermore, consumer decisions are often influenced by their momentary emotional state or mood [182]. So, exploring human emotions can be a hard task, especially in tourism research, explaining the scarce studies addressing this topic. By exploring tourists' emotional responses, researchers are more capable of predicting travelers' enjoyment with tourism services, leisure, and destinations [3] and, subsequently, to better understand their decision-making [174], satisfaction, loyalty [165] and the overall image evaluation [183]. Therefore, it becomes understandable that tourism and psychology represent closely interconnected research domains [20] and, given this perspective, an increasing number of authors are acknowledging the growing significance of "emotional tourism". It arises after several studies establishing VR as an "affective medium" capable of eliciting various emotional responses through the interaction with its contents [55], that can be similar to those experienced in the corresponding real-life scenario [145]. This concept underscores the importance of recognizing the role of emotions and affects on tourism research [3, 184]. One of the greatest findings regarding emotions in VT is that the combination of interaction, presence, and VIV culminates in an extraordinary emotional VT experience, the noteworthy key principles to developing emotional VT experiences [105]. Nonetheless, the absence of studies that merge presence and emotion within the realm of tourism becomes particularly conspicuous when contrasted with the increasing significance of those topics [185]. This becomes particularly evident when it comes to studies resorting to fully-immersive virtual environments, using HMDs [174], although they are more capable of elevating positive emotions and reducing negative emotions, along with a strong sense of presence and satisfaction [34]. In addition to the limited availability of research regarding this topic, evidence is frequently characterized by contradictions and significant fragmentation. For instance, some authors exclusively delve into the topic of arousal, while others solely refer to valence, some others explore it in a categorical manner. The fragmented nature of this information makes it even harder to study emotions in general, and, particularly within the context of tourism [22].

2.3.2. Models for assessing emotions

Emotions are the basis for understanding the human mind in terms of progress and evolution. Since they are involuntary expressions [3], they offer valuable insights into one's unconscious state [25, 186]. However, the comprehension and exploration of emotions present a challenging endeavor due to their inherently abstract and subjective nature, as acknowledged in the literature, which, in turn, complicates their measurement [186].

To understand the complexity of emotions, it is important to address its classification. Various frameworks have been established for the study of emotions, utilizing both data-driven and theory-driven methodologies [26]. Psychology literature proposes three main theoretical models to describe emotions: dimensional, categorical (also called discrete), and cognitive (also known as appraisal).

As the name indicates, the dimensional model theorizes emotions in a multidimensional space, where they are represented according to their dimension, e.g., valence/arousal. One the most well-known dimensional model is the “Circumplex Model of Affect” [187] - Figure 17, which considers two dimensions, valence and arousal, respectively “the degree to which an emotion is perceived as positive or negative”, and “how strongly the emotion is felt” [175]. An additional scale, dominance, was introduced to this model to represent control. However, the consensus among psychologists leans more towards interpreting emotion dimensions as just valence and arousal. Despite its initial proposal having occurred several years ago, the Circumplex Model of Affect is currently still accepted and remains one of the most commonly used [26]. One of the main criticisms pointed to it is that this dimensional approach does not clarify if distinct emotions of the same valence, such as sadness, anger, and fear, or elation and contentment, lead to different action tendencies [188].

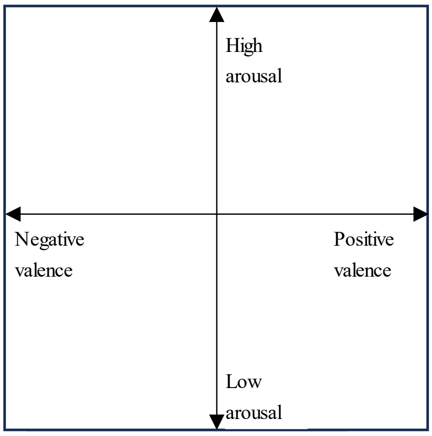


Figure 17 Graphical representation of the two dimensional-model of valence/arousal

The categorical approach suggests that core emotions, which are essential for evolutionary needs, trigger specific responses. These emotions are linked to changes in facial expressions, physiology, and functionality [26]. For instance, "the big six" basic emotions of Ekman [189] is an example of the categorical approach. It indicates that anger, surprise, disgust, happiness, fear, and sadness are the six basic emotions, which are cross-cultural and innate systemic responses [190]. Ekman's research on these universal facial expressions of emotion has had a significant impact on psychology, as it provides insight into the nonverbal cues that people use to communicate their emotional states. His work has applications in various fields, including psychology, criminology, and even artificial intelligence, where researchers have developed technology to detect and interpret these facial expressions in computer systems for a range of applications. Nevertheless, it is important to note that, while these expressions are considered universal, individual differences and cultural nuances can still influence how emotions are expressed and perceived in specific contexts [20].

Finally, the appraisal theories conceptualize emotions as processes comprising several components [191]. These include an appraisal component for evaluating events, a motivation component determining action tendencies, a physiology component reflecting changes in bodily functions, an expression component involving motor expression, and a feeling component representing the emotional experience. In short, the appraisal theory was developed by Richard Lazarus, a psychologist, in the 1960s [192], and focuses on how individuals evaluate and interpret events to determine their emotional responses. This theory suggests that emotions are not solely a result of external events but are also heavily influenced by the way individuals appraise or evaluate those events [193]. The Component Process Model, a variant of appraisal theories, further breaks down the appraisal component into four major evaluations: relevance, implications, coping potential, and normative significance of an event. Despite their comprehensive approach to describing emotional experiences, appraisal theories are not extensively studied in the literature, often overshadowed by models focusing on singular aspects like feelings [194]. Cognitive theory also suggests that the emotional responses an individual experiences is a result of the combination of primary and secondary appraisals. This means that two people facing the same situation may experience emotions differently based on their assessment of an event [193] (e.g., the personal evaluation of an event may elicit joy to one individual and surprise to another [20]).

In the case of VR-related emotional research, it is common to see the use of dimensional models for studying the emotions of users [22] (e.g., [18, 195]), although they also often focus on the evaluation of discrete and, more rarely, in appraisal models [191]. Nevertheless, it is worth noting that the selection of an emotional model, whether being dimensional (grouping emotions as pleasant or unpleasant, for instance), categorical (identifying discrete emotions like "joy" or "guilt"), or cognitive appraisal, should be guided by the specific objectives of the study, as recommended by Hosany, et al. [20]. For instance, research in which the primary focus is not on individual emotions, the dimensional approach is adequate. In contrast, studies aiming at understanding specific emotions (like joy, awe, delight) or emotions sharing the same valence (such as regret and disappointment) are better served by a categorical approach. Cognitive appraisal methods are most effective for exploring the precursors of specific emotions.

2.3.2.1. Objective and subjective methods and instruments

Many methods exist in human-computer interaction, to acquire information about users' emotional responses [196]. The assessment of emotions can take place deliberately, resorting to subjective methods and instruments [24], or unconsciously through the utilization of objective methods and instruments. Furthermore, a mixed approach, also known in the literature as "complementary metrics" (e.g., [67]), can be used, allowing the recognition of an individual's emotional state by combining the two methods [186].

The majority of emotional VR studies involve the use of subjective methodologies [20, 22, 67, 197]. Subjective measures are more adequate when the aim is to evaluate an individual's emotional experience from their personal perspective. These measures typically include the use of standard questionnaires [22, 197], as well as specifically designed questionnaires and interviews [22]. Questionnaires can be constructed as lists of a limited number of adjectives, requiring respondents to convey their emotional state at a given moment through a predefined scale. Examples of such questionnaires include the PANAS ("Positive and Negative Affect Schedule"), consisting of twenty adjectives (ten positive and ten negative), with a response scale from 0 to 5 [198]; STAI ("State-Trait Anxiety Inventory"), which assesses the level of anxiety on a 0-3 response scale [199]; VAS ("Visual Analogue Scale"), initially designed to gauge patient pain in clinical research around 1921 by Hayes and Patterson, and now widely used to measure agreement on a continuous scale; and CATA ("Check-All-that-Apply") questionnaires, employed to comprehensively investigate user perceptions concerning various attributes [200]. More than just verbal, these scales may also involve pictorial elements, such as the SAM, originally devised by Bradley and Lang [201], featuring a figurative representation to aid respondents in expressing their emotions.

Regarding interviews, they can be structured, semi-structured, or unstructured, depending on the level of predefined questions or the flexibility allowed for the interviewer to adapt the conversation based on participants' responses. Focus groups, a type of interview method, enable the collection of subjective reports through facilitated group discussions involving a moderator and typically 6 to 12 participants. This dynamic fosters interaction and the exchange of ideas, as Williamson [202] described.

When using subjective methods and instruments, like the previously mentioned, researchers rate emotional responses according to the interviewee's report, which is the easiest and primary way to obtain such information [20]. However, although being, in general, time and effort-consuming, they present a high risk of human bias [203]. When participants attempt to self-report their actual feelings, sometimes they are unable to accurately distinguish and report different emotions and feelings [204]. Despite the potential for biases and measurement challenges, subjective measures and instruments are frequently employed, especially due to their application's low complexity [20, 67]. However, it is essential to consider potential interference from individual and sociodemographic factors, as mentioned by Prescott [205], including age, education, culture, socio-economic status, and personality, which may influence the results. For instance, there is a tendency for women to self-report their emotions "more freely" than men [39]. Another con of the use of subjective measures involves self-reporting, which is inherently a limitation, as one's own perception of emotional responses can be challenging and, consequently, influenced by personal bias [206, 207].

On the other hand, when the objective is to assess the most unconscious aspects of an individual, psychophysiological measures result more adequate. Involuntary adjustments in the Autonomic Nervous System regulate an individual's physiological processes. The results obtained from measuring physiological responses can serve as indicators of emotional variations [186, 208]. These measurements encompass monitoring metrics such as HR, respiration rate, finger pulse volume, blood pressure, and electrodermal activity (EDA), also known as galvanic skin response, which measures the skin conductance level), to name a few. Emotional responses can also be expressed through various forms of behavior, including the observation of one's facial expression, body behavior, verbal communication, and voice intonations [186, 209]. These measures facilitate the collection of physiological and biometric data, offering crucial insights into an individual's emotional state, even when they are not consciously aware of it, as highlighted by Ferreira and Saraiva [186]. It is worth noting that objective methods also present limitations. They are highly susceptible to bias caused by external factors (e.g., room temperature [125], the sensitivity of some technological materials, such as those to measure the HR and EDA [206], which can be further impacted by the users' movements [210]). Moreover, objective methods are frequently reported as intrusive [22], especially due to its uncomfortable design and heavy-weight [207].

Alternatively, an approach corresponding to a combination of subjective and objective measures can be used. Its use is frequently recommended in VR studies [25, 31, 32, 99, 206, 211-214], with the argument that the combination of two distinct approaches is more reliable. Johnson and Onwuegbuzie [215] have also endorsed this idea, suggesting that employing a mixed approach can lead to enhanced validity and more resilient conclusions. Nevertheless, mixed approaches also present contraindications. The systematic literature review conducted by Magalhães, et al. [22] suggests that, despite while several authors recommending using a mixed approach to assess users' emotional responses in multisensory immersive VR experiences, there is no clear advantage in doing so. The authors argue that using a mixed approach can enhance result robustness only if the data from both methods show similar outcomes. Otherwise, it becomes less advantageous and confusing if there is a significant disparity between objective and subjective data. In such cases, opting for either an objective or subjective measure may be more favorable. The conclusion is that a balanced evaluation of the pros and cons of each approach (subjective, objective, or mixed) should be made in each study, rather than assuming that a mixed approach is always more reliable.

Regardless of the method (subjective, objective, or mixed approach), the use of pre-tests (prior to the experience), and post-tests (after the experience) is typically recommended, as the pre-existing individual mood may influence the intensity of subsequently elicited emotional responses. Furthermore, it helps detecting mood transitions [216], and to check if the system has elicited the affective states for which it had been designed to [175].

2.3.3. Individual differences in emotional responses

Although formal technological and design elements like sounds and lighting are crucial for eliciting particular emotions in the users in VR experiences, various individual factors can also interfere with one's emotional responses [217], which explains, for example, why a particular movie scene might move one viewer to tears while not affecting another at all [218]. This emotional resilience indicates that some individuals may exhibit greater emotional resilience, allowing them to remain calm and composed in various VR experiences, while others might become more emotionally reactive to the same stimuli.

Emotions in VR can vary due to a complex interplay of individual factors, including demographics, past experiences, emotional resilience, personal preferences, and physical well-being. Understanding individual differences is essential for designing VR experiences that cater to a wide range of emotional responses. In general emotion-based studies, evidence suggests many individual differences interfere with the VR experience. On the one hand, a consensus in the literature seems to exist regarding the interference of personality [145, 218], dispositional affect [218], prior experiences [219, 220], and technology usage [220, 221]. The last two are related to the perceived novelty caused by the immersion, which, in turn, might interfere with the users' emotional responses and satisfaction [220]. All these differences can exert an influence on emotional reactions, emotional memory, and emotional perception. Just as emotional reactions to stimuli can significantly vary from one person to another, a similar pattern of individual factors comes into VR, affecting users' emotions, much like in real life [218]. On the other hand, while sociodemographic differences such as age and gender have also been extensively investigated, their impact on users' emotional responses in VR is not unanimous [222], as discussed below.

Age is frequently explored to examine emotional variations in VR. Nonetheless, the primary focus of these studies is on young healthy adults, as administering these tests to the elderly and children involves special ethical considerations, which differ among different age groups. For instance, ensuring that the levels of immersion provided are adequate is fundamental for older people, as they prefer lower levels such as those provided by smartphones, in contrast with young adults who rather prefer highly-immersive HMDs, as concluded by Pavic, et al. [223].

There are scarce comparative studies on age differences in emotional VR. Still, considering the occasional ones, it is possible to rapidly conclude that there is no consensus regarding the impact of it on users within different age groups facing the same stimuli [101]. It was reported by Williams and Drolet [40] that older adults are less reactive than younger individuals when exposed to the same emotional stimuli [224]. This might be explained by the inherent differences in information processing caused by cognitive changes, which affect the way people emotionally react. Nevertheless, this information is contradicted, for instance, by Rivu, et al. [145], who found no differences in emotional self-reports regarding participants' prior experience with VR, gender, and personality, for the elicited emotions when different-aged individuals faced the same stimuli. Also Baños, et al. [225] found no age impact regarding the differences between VR stereoscopic and monoscopic presentations on emotional responses, using subjective measures.

Similar to age differences, regarding gender, there is also a lack of agreement on its impact on the reported emotional responses. First, to explain this gender disparity, it is important to understand a significant interference contributing to it: social desirability. It is a phenomenon defined by Paulhus [226] as "(…) the tendency to give overly positive self-descriptions". It is mainly caused by transient motivation or situational pressure, mainly observed within men [227]. Another phenomenon contributing to the gender disparity in emotions is the general perception that women tend to be more emotional and sensitive. This can be attributed to the fact that they easily express their emotions, in a more freely way than men [39]. Additionally, it has been demonstrated that they exhibit heightened sensitivity and susceptibility to adverse or stressful situations [228]. *Per se*, these two phenomena shed light on why gender can influence the emotional experience in VR. Supporting this idea, findings from Dirin, et al. [229] revealed gender differences using self-reports, concluding that women tended to report more intense emotions than men. Yet, the extent of this impact remains somewhat ambiguous, as some other findings reveal no gender impact when using either objective measures (e.g., through cardiac reactivity data [224] or via electrodermal activity [230]), or subjective (e.g., SAM [145] or via a specifically designed questionnaire [90]).

2.4. Foundations of mental imagery

Another fundamental topic for this thesis is the concept of Mental Imagery. This section will explore the main theories that have shaped its current understanding.

Remembering a past event frequently makes one feel in that place and time, reviving that specific situation in a certain way [231]. This process of voluntarily recalling any type of information stored in memory is a capacity generically defined as "mental imagery" [5, 232, 233]. It is related to an individual's clarity, vividness, and robustness of an object, place, or event [234], in the absence of sensory input [235], thus, a *qualia* subjective experience. MI is considered a multisensory phenomenon [236, 237]. For instance, when someone is asked whether the word "bad" appears in the first verse of the iconic Beatles song "Hey Jude," one can audibly hear Paul McCartney's voice singing the opening line, "Hey Jude, don't make it bad" in mind to confirm, as exemplified by Berger [238]. Also, imagining the tactile sensation of being kissed on the cheek is an ability of MI [239]. So, MI refers to the process of memory accessing perceptual information of any type [237, 240], "giving rise to the experience of 'seeing with the mind's eye', 'hearing with the mind's ear' and so on" [237]. It results either from recalling previous objects or events, or combining or modifying stored perceptual information [237]. MI is an essential brain function for daily life, for instance, orientation, navigation [9] and sociability. It is a reflection of reality, which can originate visual (visual imagery), auditory (auditory imagery), smell (olfactory imagery), taste (gustatory imagery) and tactile images (motor imagery) [237, 241].

VIV (also known as "image ability" [242] or just "vivacity" [243]), and capacity of control (alias "image/imagery control" [242] or "controllability" [244]) are the two most important features of MI found in the literature, related to this human imaginative ability [5]. As the name suggests, VIV refers to a mental visualization's degree of clarity and detail, similar to the actual image. It relates to how vivid or lifelike the mental representation is in the person's mind. In turn, the CC denotes an individual's ability to mentally transform or manipulate an image. It involves the degree to which a person can modify or change the details, perspectives, or content of their mental images [5, 245].

Although it is vital to understanding the individuals' mental function, MI remains a difficult concept to explore, as it is related to the human mind [237]. One of the earliest studies in this field dates back to 1910 [246]. Even though that investigation did not explicitly mention the concept of MI, it marked a significant milestone by providing strong empirical evidence for the striking similarity between MI and perception. In that innovative experiment, Perky [246] asked participants to focus on a screen and to imagine seeing specific items (a tomato, a book, a banana, an orange, a leaf, and a lemon). Discreetly, her team projected colored shapes onto the screen, matching the size and form of these imagined objects, while the participants were absorbed in visualizing them. Surprisingly, almost none realized that the objects Perky was projecting onto the screen in front of them were actual, not just in their imagination. According to Berger [239], this experiment was the first to offer substantial empirical support for the idea that MI and perception are remarkably alike. Nevertheless, it is maintained many years after this experiment [247].

A little later, in 1913, the founder of "Behaviorism", John B. Watson, used to discredit the existence of mental images. The author suggested that thinking was dependent on the movements of the vocal apparatus [248]. Similarly, shortly after, Jean Piaget worked on the theory of cognitive development, arguing that young children's cognitive development progresses through various stages, each characterized by distinct ways of thinking. He suggested that early on, children think primarily in sensory-motor terms, meaning they rely on their sensory perceptions and motor actions to understand the world [249]. Sixty years later, in 1973, Pylyshyn [250] defended that mental images are not just "images" but, rather, they are mental descriptions, similar to those that underlie the language. Finally, still in the same year, the experiments made by Marks [27] allowed him to conclude the vital function imagery has on memory and VIV in particular. These findings have contributed to the term "eidetic imagery", coined by Ahsen [251], who considered imagery as a structure, rather than factual information. MI's definition was later expanded by Kosslyn, et al. [252], who described it as the primary mode of cognitive functioning, a mental phenomenon related to memory, learning, information processing, and reasoning. Cognitive neuroscience was vital to understanding the basis of visual perception, memory, and emotions, which, in turn, were fundamental concepts to start exploring the role of MI.

For nearly half a century, the field of psychology has been engaged in a lively debate regarding the role of MI. The central issue revolves around whether the internally generated mental images are "picture-like" analog copies of sensory experiences that faithfully retain crucial features of the physical world or if they are the product of more fundamental propositional thought representations, involving the combination of discrete symbols, forming an abstract, rather than analog, impression of the concept in question [238]. On one side, there were proponents of the idea that no fundamental distinction exists between what we envision in our minds and what we perceive [252, 253]. On the opposite side of the argument, there were those who contended that there is an underlying mental process at work, which is inherently distinct from perception [250]. Considering the increasing credibility in the neurosciences, greater attention has been paid to MI, especially regarding the development of clinical psychology, e.g., anxiety, or emotionally disturbing images experienced in post-traumatic disorders [33].

Currently, much evidence has proven that MI engages the visual cortex areas 17 and 18, and that it can control physiological processes (HR, breathing rate, and skin conductance, for instance) [237]. The relationship between MI and cognition unfurls into our days as an established scientific theory [254]. To bolster the claims regarding the functional role of imagery in human behavior and overall well-being, the intensity of VIV has been linked to the strength of motivation [255], personality characteristics [256], motor skills [257], emotional states [33, 258, 259], and physiological reactions [260].

Despite encompassing all five senses, visual imagery research has dominated the field of MI. The focus on vision stems from the dominance of visual processing in the human brain and the richness of visual information. However, this emphasis on vision can limit the understanding of MI's broader aspects [8].

2.4.1. Vividness and capacity of control

VIV and the CC have emerged as two fundamental elements in the literature for assessing MI [5]. Each one is related to different imaginative individuals' abilities, as referred to in the previous section. VIV, on the one hand, refers to "the extent to which imagination feels lifelike and forceful" [243]. That refers to the clarity, brightness, or intensity of the mental representation [27]. Higher levels of VIV are considered an important source of inspiration in creative production [261]. Vivid imagery is frequently associated with better memory recall, as more detailed mental images are easier to remember. However, as recently clarified by Cooper, et al. [262], the number of details remembered is not necessarily correlated to their VIV, i.e., one individual can report a high degree of VIV and low recall ability.

The CC, on the other hand, is related to an individual's ability to manipulate and alter their mental images intentionally. It includes the ability to change the content, perspective, or details of the mental image at will. People with a high CC can modify their mental images in various ways, such as rotating objects, changing colors, or altering the scene in their minds [5, 245]. The CC can be influenced by factors such as an individual's imagination, cognitive skills, and specific tasks. For example, some people may find it easy to manipulate mental images when solving spatial puzzles, while others may struggle with this task. So, it is crucial in tasks like mental rotation, where individuals need to manipulate images mentally to solve problems [245]. It is important to note that VIV and CC are independent variables, which means that the fact that one reports very vivid mental images does not imply better performance in the manipulation of such images [263].

Despite the inexistent consensus regarding what being vivid exactly amounts to, it is known that not all memories can be recalled so easily or vividly. VIV ability can vary from person to person. On the one hand, some individuals have a natural ability to create highly vivid mental images, that can be, sometimes, too vivid, interfering with one's attention and engagement with the real world [243]. On the other hand, others may struggle to create clear and detailed images. These VIV differences are even more prominent if considering the impact of the negative events. This is explained by the "NEVER" model ("Negative Emotional Valence Enhances Recapitulation"), developed by Bowen, et al. [231], which, among other objectives, emphasizes the role of negative events, compared to positive, to increase recollection, vividness, and the ability to store sensory details. This was later studied and corroborated by Cooper, et al. [262], who, additionally, found a "novel memory-fading effect", whereas negative emotions increase vividness and the precision of the visual features. One example of it, is how a specific color can be remembered years after a negative event has occurred [264]). Controversially, despite contributing to memory vividness, in some cases, the negative emotional content can also contribute to memory fading, as concluded by the same authors [262].

Over time, many cognitive diseases related to deficits in imagery and perception started to be reported and taken seriously. For instance, aphantasia – the life-long incapacity of "create a quasi-perceptual visual picture in the mind's eye" [234] –, although early recognized in 1880 by Galton [265], remained obscure in scientific literature until being formally recognized by Zeman, et al. [266], in 2015. Aphantasia affects short-term memory, daydreaming, and creativity [266].

Aphantasics have serious difficulties in remembering details of autobiographical memories, or details of a recently told story [234]. Wicken, et al. [259] conducted an experiment that revealed a flat line in physiological responses according to skin conductance levels when aphantasic individuals were told frightening stories or exposed to fearful images. These results prove that the lack of physiological responses is more related to the inability to mentally visualize specific scenarios than to general emotional or physiological dampening. Aphantasia is experienced by the general population, affecting women and men equally. For instance, results from Dance, et al. [234] pointed to a prevalence of 3,9% of aphantasia (based on a study's population of 502 individuals), revealing a complete absence of visual imagery in 0,8% of this population.

2.4.2. Assessing users' mental imagery

As research into the context of MI continues to evolve, the significance of identifying suitable measures for assessing imagery processing becomes increasingly pronounced [267]. MI is typically assessed through subjective methods, specifically using questionnaires, although, sometimes, interviews, or focus groups are also used. When using interviews, researchers ask the participants about a specific scenario they had been shown before to force them to recall that image, which is similar to the practice when using questionnaires, in this case, done individually, without the presence of an interviewer [245].

Due to the inherent individual's introspection it requires, and its subjectivity, measuring MI remains a challenge [243]. Nevertheless, the first attempt to subjectively measure MI is ancient. It dates back to 1883, and was pioneered by Galton [268], underpinned in three dimensions of imagery experiences: the illumination ("Is the image dim or fairly clear?"), definition ("Are all objects pretty well defined?"), and coloring ("Are the colors of all the objects quite distinct and natural?"). The author developed his questionnaire based on a breakfast table, to assess the participants' performance when recalling specific objects. A more refined questionnaire was created a few years later, by Betts [269], the "Questionnaire upon Mental Imagery" (QMI), in which participants had to assign a numerical value (from 1 to 7), to assess the degree of VIV of evoked images. This questionnaire considers seven multimodal images: visual, olfactory, auditory, cutaneous (e.g., the touch of fur), gustatory (e.g., the taste of salt), kinesthetic (e.g., the muscular feeling when running), and organic (e.g., the sensation of hunger) [267]. However, its 150 items make it prohibitively long to apply, as explained by Andrade, et al. [240], which led to the development of a shortener and modified version with 35 items, proposed by Sheehan [270], in 1967. While this author's new questionnaire marks a significant advancement in MI, it has faced criticism for its limited number of items per sensory modality and the incorporation of items that are deemed unclear or outdated, such as the request to imagine "the whistle of a locomotive", as explained in Dance, et al. [234].

Similar to the QMI, attempting to measure other than just visual images, further questionnaires have been developed. For instance, Gilbert, et al. [271] developed the "Vividness of Olfactory Imagery Questionnaire", focusing on the perception of the clarity, vividness, and sensory richness of one's mental olfactory experiences. Regarding the introduction of the domain of movement imagery, the "Vividness of Movement Imagery Questionnaire" (VMIQ) [272], the "Haptic Movement Imagery Questionnaire" (HMIQ) [273], and the "Revised Vividness of Movement Imagery Questionnaire" (VMIQ-2) [274] were developed, among others. Recently, Croijmans, et al. [275] developed the "Vividness of Wine Imagery Questionnaire" to measure the wine's visual, olfactory and taste modalities. In the same work, the authors criticized the fact that investigations frequently focus on one modality only (vision), which remains a problem in the present, as defended by other authors [239, 240].

It is scarce to find MI assessed as a whole. Instead, MI research focuses just on one of its two fundamental aspects, tending to the degree of vividness rather than to the CC, as seen in multiple works [27, 240, 271-273, 275]. This is even more perceptible when analyzing the questionnaires' designations, as they all announce the construct measured, for instance, the "Vividness of Visual Imagery Questionnaire" (VVIQ) [27], the "Vividness of Wine Imagery Questionnaire" (VWIQ) [275], or the "Vividness of Olfactory Imagery Questionnaire" (VOIQ) [271].

A significant attempt to measure VIV was made by Marks [27] in 1973, who developed the VVIQ, in 1973. Originally, the author proposed the following four scenarios: a dear person, the rising sun, a country scene, and the front of a shop. For each of the images, participants were required to assess the level of vividness of their mental representations, considering four specific aspects, as outlined in Table 2. VVIQ is composed of 16 items and relies on a 5-point Likert scale, as follows: (5) "perfectly clear and as vivid as normal vision", (4) "clear and reasonably vivid", (3) "moderately clear and vivid", (2) "vague and dim", or (1) "no image at all, you only 'know' that you are thinking of the object". The score consists of the sum of all the responses, which means that considering a 5-point Likert scale, the final result varies between 16 and 80 [27]. When compared to its primary and longstanding competitor (Betts' QMI), the VVIQ garnered significant acclaim for its development process. For instance, some authors suggested that the process of filling out this scale holds greater appeal compared to the QMI. Additionally, the questions in this questionnaire may elicit more vivid mental images than those in the Betts scale since they revolve around familiar, and therefore highly visualizable, scenarios. VVIQ's questions also offer respondents a more abundant array of cues, potentially enhancing the concreteness and VIV [276]. Moreover, despite being subjective, VVIQ was validated by correlating its results with the activity of the early visual cortex via Functional Magnetic Resonance Imaging, which potentially fills the gap between the subjective and the objective tools to assess MI [277].

One of the most significant advantages of using the VVIQ lies in the fact that it is a highly versatile questionnaire, as it is adaptable in many aspects to the researcher's objectives, for instance, item modification (e.g., adding, removing, or adjusting VVIQ items according with the particular aspects of visual imagery the researcher intends to achieve), scoring changes, cultural adaptation, and age group modifications. Moreover, VVIQ is suitable for situations in which the researcher aims to evaluate the VIV of a scene, location, or object, under the assumption that they have previously encountered it and stored the information in their memory for later recall [9]. For instance, Dance, et al. [278] considered a beach scenario and its aspects (e.g., "the appearance and the colour of the water") to evaluate the link between VIV and sensory sensitivity, not addressing the original objects, events, or places proposed by Marks [27]. Simplício [279] used eight scenarios (instead of the originally proposed four) to explore the relations between hypnotic suggestibility and VIV. Inevitably, the scoring system will suffer alterations in these situations, although the most common procedure is to keep the sum of all the responses given in a Likert scale to achieve the total score of VVIQ.

Table 2 VVIQ (original version)

SCENARIO	BRIEFING	DETAILS
A dear person	Think of some relative or friend whom you frequently see (but who is not with you at present) and consider carefully the picture that comes before your mind's eye.	The exact contour of face, head, shoulders, and body. Characteristic poses of head, attitudes of body, etc. The precise carriage, length of step, etc. in walking. The different colors worn in some familiar clothes.
The rising sun	Visualize a rising sun. Consider carefully the picture that comes before your mind's eye.	The sun is rising above the horizon into a hazy sky. The sky clears and surrounds the sun with blueness. Clouds. A storm blows up, with flashes of lightning. A rainbow appears.
A country scene	Think of the front of a shop which you often go to. Consider the picture that comes before your mind's eye.	The overall appearance of the shop from the opposite side of the road. A window display including colours, shapes and details of individual items for sale. You are near the entrance. The colour, shape and details of the door. You enter the shop and go to the counter. The counter assistant serves you. Money changes hand.
The front of a shop	Finally, think of a country scene which involves trees, mountains and a lake. Consider the picture that comes before your mind's eye.	The contours of the landscape. The colour and shape of the trees. The colour and shape of the lake. A strong wind blows on the trees and on the lake causing waves.

VVIQ is a long-established metric in the field [235, 244], and a highly trustworthy and robust tool to measure visual imagery [234, 244]. According to a systematic literature review conducted by Suica, et al. [244], aiming to evaluate all the available subjective methods to measure MI, the authors concluded regarding VIV, that only VVIQ and the Sport Imagery Ability Questionnaire (SIAQ) [280] showed sufficient psychometric properties. Apart from these advantages, VVIQ is a common method to recognize aphantasic patients. Typically, considering the original version, which is composed of 16 items, a total score under 32 (40% of the maximum score) is associated with aphantasia [234, 259].

As discussed at the beginning of this section, it is common to find the concept of MI being assessed according to its constructs individually. Similarly to the earlier examples that measured VIV, other instruments have been developed with the goal of assessing the capacity to control, yet, in a significantly smaller number [244]. The greatest attempt to subjectively measure imagery control was done in 1949, by Gordon [281], who developed the "Test of Visual Imagery Control" (TVIC), (also known as the Gordon's Test of Visual Imagery Control (VIC) [267]). It is a 12-item questionnaire to assess the ability to intentionally modify or manipulate a mental image (e.g., after visualizing a car, the inquiries can be asked: "Can you now see it in a different color?"). However, due to the criticism faced for its lack of specificity in measuring the construct, this questionnaire was later modified by Richardson [282], in 1969. The adaptations included shifting the response format from a two-point to a three-point scale and reducing the scale from 12 to 11 items. This new version resulted in higher internal consistency and reliability, as explained by MacInnis [267].

Besides the TVIC, no other questionnaires exist to evaluate the CC. This construct is more frequently assessed through specific tasks like the "Card Rotation Test", the "Cube-cutting Task", the "Mental Paper Folding", the "Measure of the Ability to Rotate Mental Images", or the "Spatial Orientation Skills Test", as attested by Suica, et al. [244].

Recently, considering the rapid technological evolution, efforts to objectively measure MI have also been developed, although still scarce. Kato, et al. [283] were the first to attempt using a 3D eye tracker for visual imagery measurements. This technique, although demonstrating good results, presents a hard calibration routine, which is especially accentuated if considering the use of an HMD to test it in VR. Some other attempts resorting to psychophysiological responses have been made, mainly to assess VIV [263]. To the best of our knowledge, only functional magnetic resonance imaging was used. Furthermore, only a few examples can be seen in the literature [277, 284]. Despite these few attempts made in the past, the idea of objectively measuring MI did not prevail. Such tests often fail to return precise and reliable results, in general, and the efforts to establish connections between objective and subjective measures have not yielded significant results.

It is clear in the literature that, whether in older or more recent studies, subjective measures remain predominant to measuring MI [263], with highlights for the VVIQ [244]. One of its main advantages, as indicated by prior studies, is that visual imagery questionnaires, like the VVIQ, are not significantly affected by social desirability biases [285]. Although so many years have passed, and despite all the subjective and the few attempts to measure MI, VVIQ has been the most widely and extensively used self-report to assess VIV [7, 244, 283].

2.4.3. Individual differences in mental imagery

The influence of individual differences on MI is an intricate area of study within the fields of psychology and cognitive science. As MI is the internal representation of sensory experiences in the absence of external stimuli [235], it varies significantly among individuals due to a wide range of factors. These individual differences can profoundly affect how people create, use, and experience MI. In this section, it will be explored the key factors and implications of individual differences in MI.

The VIV relies on the sensory and emotional qualities of the concept or stimulus being envisioned, as well as the availability and functionality of cognitive processes and emotional states, as confirmed by several studies [8, 38, 246, 247, 286, 287]. Additionally, it can also be influenced by demographic features like age [288-290] and gender, as identified by several authors [5, 27, 227, 270, 291-295]. Regarding cognitive abilities, while many people can consciously create mental images, some individuals, known as aphantasics, lack this ability, as previously discussed.

Recently, it has been proven that the strength of the connection from the Occipital Place Area to the Parahippocampal Place Area, particularly in the left hemisphere, is crucial in MI, as this connection positively correlates with the ability to create vivid mental images [9]. Additionally, it is known that temporary states of cognitive functioning disabilities, caused, for instance, by alcohol or drugs, may also interfere with cognitive performance and, consequently, with MI, as proven in [287]. These cognitive dysfunctionalities are also related to the emotional influence, that can derive from traumatic experiences or highly emotional memories that contribute to more powerful mental imagery in terms of vividness and intensity. In fact, MI is so closely linked to emotions, that it can elicit comparable emotional responses to directly witnessing an object or event. It can even be confused with reality [247]. Furthermore, MI has been observed to produce analogous physiological effects on the body as the actual observation of the subject in question. This includes heightened skin conductance, increased HR, and accelerated breathing rate when visualizing threatening objects, as early demonstrated by Lang, et al. [286].

Cultural and societal aspects may also influence MI. Social desirability, for instance, is one example. Similar to the influence on the users' emotions, social desirability also acts as a cultural feature capable of interfering with MI [7, 20, 80, 234, 263]. Another factor to consider is the concept of "stereotype threat", which arises when individuals belonging to a specific social group face the risk of validating stereotypes associated with their group, particularly in terms of their performance. For instance, if women are made aware of the stereotype that they tend to perform less effectively than men in tasks like mental rotation or navigation skills, this awareness alone can have a detrimental effect on their performance, resulting in underperformance compared to both men and a control group that has not been exposed to such stereotypes, as clarified by Aydin [296].

In this regard, Moè and Pazzaglia [297] demonstrated that when individuals were exposed to stereotype threat, female participants were less influenced by the task's level of difficulty compared to their male counterparts in a mental rotation task. Moreover, when the instructions suggested that females generally outperformed males in these tasks, female participants exhibited an improvement in their performance levels.

The literature also addresses the impact of individual demographics like age, gender, and academic background on MI. Early, Ernest and Paivio [291], observed that women use "imaginal processes" to facilitate information recalling, which men cannot do so easily. A little later, two experiments developed by Marks [27] confirmed this idea, by demonstrating a strong relationship between accuracy and VIV regarding visual information (pictures). In particular, females revealed higher VIV ratings, which means that they recalled more accurately pictorial information, than men. This contributed to the classification of the so-called "poor" and "good" visualizers (men and women, respectively, in this case) [27]. Consistent results were achieved in the subsequent years [5, 227, 292-294, 298], with the exception of research made by McKelvie [295], who found no substantial gender differences regarding VIV. Regarding the CC, results show the opposite. Findings from Ruggiero, et al. [290] reported that men showed higher performance in spatial tasks and mental rotation. These results were recently confirmed by Aydin [296], who found gender differences in tasks related to object mental rotation and spatial imagery performance: men showed higher mental rotation performance and spatial imagery, whereas women reported higher object imagery. Significant gender differences were also found in the transformation process, with men outperforming women in a study conducted by Palermo, et al. [299]. Conversely, Iachini, et al. [5] found no gender differences in the CC.

Considering the effect of age, as MI involves the ability to create, manipulate, and visualize mental representations of objects, events, or scenarios without their physical presence, it seems clear that increasing age implies a decrease in all of these abilities. However, limited literature regarding the impact of age on VIV exists, and no consensus can be found regarding CC. For instance, Kosslyn, et al. [289] found that VIV increased with complexity for older groups but not for the youngest. The same study reported that image maintenance ability was found to be similar across ages. In image scanning tasks, younger groups generally scanned more slowly than older groups. Finally, in image rotation tasks, the study observed linear increases in response times with strong disparities detected between the age groups. Also some age discrepancies were found by Palladino and De Beni [300], who concluded that older adults reported a greater quantity of irrelevant detail in their mental images, and recall a lower number of items compared to younger individuals. Later, in accordance with prior research [288], results from Ruggiero, et al. [290] demonstrated a negative impact of age on some CC tasks like spatial inference, mental rotation, and sequential spatial memory. Age was found to reduce visuospatial memory, which inevitably interferes with imagery control. These findings support the idea that as individuals age, their performance in tasks requiring significant working memory and attentional resources tends to decline [301]. This was also corroborated by Palermo, et al. [299], who found that aging might particularly affect the objects' mental transformation. Recently, this has also been confirmed by Rubin [302], who found a small correlation between scene recall and increasing age.

In terms of educational background, the literature reveals a pattern wherein engineers and scientists tend to perform better in spatial imagery, while visual artists demonstrate greater proficiency in object imagery. These trends were recently confirmed by Kibar and Akkoyunlu [303], in a comprehensive study involving 448 university students. Their findings indicated that students pursuing science-related fields exhibited higher spatial skills and preferences. Interestingly, object imagery scores were not significantly higher among visual arts undergraduates. Aydin [296] has also investigated the influence of academic training by comparing three distinct academic divisions: Engineering, Social Sciences, and Management. The study revealed that there were no notable variations among these academic areas in terms of VIV.

2.4.4. The interplay of emotions and mental imagery in virtual tourism

VT, propelled by advancements in technology, has revolutionized the way individuals experience and engage with travel destinations [83, 155, 156]. Considering the intangible nature of tourism, which is related to the inexistence of a "try before you buy" experience [304], it is important for the tourist to create a mental representation of the product/service before purchasing it. Mental representation, in the tourism context, can be described as the set of feelings, knowledge, and global impressions about a destination, which is the result of perceptual and affective evaluations [163].

There is much evidence that tourists' mental representation is essential to predicting consumer behavior, especially the decision-making process [163, 305, 306], and consumers' satisfaction [165, 306, 307]. In fact, a pre-conceived image of a place can contribute to generating a positive effect on the tourists' beliefs of a future tourism experience [165]. In addition, positive images contribute to a destination more likely to be considered and chosen [308-310].

Different emotions occur when mentally representing an image. This association between emotions and MI can be neurologically explained by the fact that it activates the autonomic nervous system and the amygdala, which, in turn, plays a significant role in regulating human emotions [237]. Additionally, given that human experiences imprint affective traces in memory, it is clear that upon recalling particular mental representations, all associated emotional information is simultaneously evoked. Nevertheless, not all memories are recalled with the same intensity. Mundane memories, such as what we ate a couple of days ago or what we read in the news recently, tend to fade quickly from our recollection. Conversely, emotionally impactful experiences – like the day of our graduation or wedding – are more likely to remain in our memory store [18].

VR stimulates MI to create tourism experiences that resemble the real world [105]. The more vivid/realistic one perceives an event, the more intense and diverse emotions [36], and the more emotionally engaged they will feel [37]. This idea can be transposed to the context of VT. Emotions play a pivotal role in shaping our experiences, and the immersive nature of VT has the capacity to evoke a wide array of emotions, considering VR as an "emotional medium" [18]. For example, the sense of awe and wonder while virtually exploring majestic landscapes or historical sites can evoke feelings of excitement, curiosity, or even a sense of adventure. On the other hand, visiting serene and tranquil locations may evoke emotions of relaxation and peace. The emotional impact on users can be profound, influencing their perceptions, memories, details, and their VIV [18]. Moreover, when individuals engage in a VT experience, the emotional responses triggered by the simulated environments can greatly influence their overall experience [35].

MI and emotions are undissociated concepts, as highlighted by the significant correlations established between these two elements (e.g., [311]). This consequential relationship has prompted certain authors to suggest that the effectiveness of a marketing tourism campaign relies on the VIV human ability [309]. Nevertheless, scarce literature can be found regarding its dynamics within the field of VR, and even more in VT.

3. Research Methodology

This section outlines the methodological process conducted in this research. It details the experimental design (section 3.1), followed by the positive and the negative IVEs development (section 3.2.1). After this, the multisensory treasure hunt and all the stimuli used are presented (section 3.2.2). Finally, the procedure for conducting the virtual experiment is described in section 3.3, along with a description of all the in-VR (section 3.4) and out-VR (section 3.5) questionnaires used.

3.1. Experimental design

This research aims to understand the role of multisensory stimuli on users' emotional responses and VIV, and the impact of these obtained emotions' results on VIV. To investigate it, a between-subjects experimental study was conducted, creating two distinct IVEs termed "positive" and "negative", with the primary difference between the two being the pleasantness of the stimuli, as further described in section 3.2.1.

The virtual experiment was developed to present an interactive walkthrough scenario, designed for VT, where users were encouraged to engage in a multisensory treasure hunt involving five objects representative of traditional Portuguese culture (as detailed in section 3.2.2). When each object was found, the user could inspect them (which, *per* se, served as a visual clue), an audio narrative was presented (auditory clue) – V+A –, and a specific combination of stimuli was triggered accordingly:

1. Visual + Auditory combination (**V+A**)
2. Visual + Auditory + Taste combination (V+A+**T**)
3. Visual + Auditory + Haptics combination (V+A+**H**)
4. Visual + Auditory + Smell combination (V+A+**S**)
5. Visual, Auditory, Taste, Haptics, and Smell combination (V+A+**T**+**H**+**S**).

After each object had been successfully inspected, two in-VR questionnaires appeared, both resulting in quantitative data: first, the PANAS, about the emotions felt at that moment, and second, the VVIQ, about the VIV of that object in the user's memory. The experimental design in Figure 18 illustrates this process.

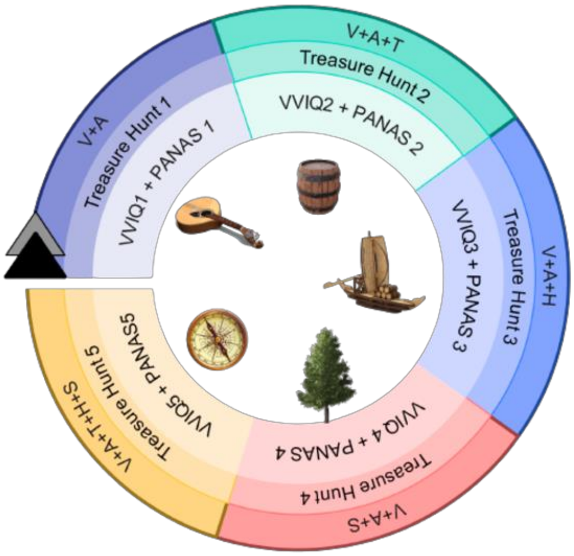


Figure 18 Experimental design illustrated (own elaboration)

Finally, after completing the treasure hunt and all related questionnaires (PANAS and VVIQ), users were asked to fill out a final in-VR questionnaire about their sense of presence in the IVE.

Science is abundant with outstanding academic research on the impact of presence in virtual experiences, as attested by Yung, et al. [35], the reason why our primary focus was not on this aspect. Instead, IPQ was used to measure the overall degree reported by the users. The ultimate objective of resorting to it was as a component to evaluate how effective the developed virtual experience had been for the users, a vital process according to several authors [67, 75, 312, 313]. This information will be crucial for contrasting the positive and negative IVE in terms of their effectiveness in producing high levels of presence, which will be further explored in section 4.3. In general, high levels of overall presence would indicate an effective virtual experience, whereas low levels of presence would indicate a less effective virtual experience [67].

3.2. IVEs development

A focus group session was performed to validate the multisensory stimuli proposed in this methodology, focusing on the stimuli to be used, as described later in section 4.3.1. After this process, 94 participants were recruited to participate in the virtual experiment, which took place in a lab (GIG Lab) of the Faculty of Engineering of the University of Porto (FEUP), between the 8th of

March and the 21st of April 2023. Considering that the study was conducted in Portugal, to accommodate participants who might be more comfortable with Portuguese than English, all aspects of the experiences, including the questionnaires, were carried out in Portuguese.

The proposed methodology involves developing two distinct IVEs: one positive, providing the user with positive multisensory stimuli, and one negative, presenting negative multisensory to the user. The virtual environment and the task that forms the core of this methodology (the multisensory treasure hunt) were pre-developed by some research colleagues at the *Massive* lab, located at the University of Trás-os-Montes and Alto Douro. They developed a virtual experience where one could explore a tourism spot, the viewpoint of São Leonardo da Galafura (Figure 19), in the Alto Douro Wine Region of Northern Portugal, a UNESCO World Heritage Site [314]. Virtually there, the users had the opportunity to engage in some activities, including a treasure hunt. These IVEs were developed to create a realistic experience, resorting to photogrammetry techniques to create a three-dimensional replica of the actual location, as claimed by some of the authors behind the virtual environment's basis development in Melo, et al. [90].

Figure 19 São Leonardo da Galafura (photo captured by the author)

The virtual environment intended to reproduce the existing chapel (Capela de São Leonardo), and all the environmental details that comprise this place, such as the wide view from the top to Rio Douro, the trees, the shrubs, the sandy soil, and the pebbles. Figure 20 and Figure 21 represent two virtual replicas of the positive and the negative IVEs, respectively. Despite these details having been reproduced carefully, it was also taken into consideration that minimalism in the VR applications development is sufficiently effective for memory recall [315], and, consequently, to assess imagery VIV which is one of our main goals to explore.

Figure 20 Virtual replica of the real location (positive IVE)

Figure 21 Virtual replica of the real location (negative IVE)

The IVE pre-developed served as the basis and acted as inspiration for the construction of the methodology's virtual experiment. Nevertheless, it was redeveloped and redesigned using the Unity game engine, to align with the aims of this thesis. This involved adding the specific objects to be located during the treasure hunt, inserting the instructions for the user, implementing in-VR questionnaires, and introducing multisensory stimuli such as the narratives (audio) and the thermal sensations induced by a fan (as explained in section 3.2.2.2), which were not features of the initial version.

The initial phase of the IVE development involved a comprehensive conceptualization process. Detailed mockups were developed using *Balsamiq*, a wireframing tool, to visually represent the main modifications and the new features. The primary objective was to create an immersive and interactive experience that allowed users to virtually explore the viewpoint of *São Leonardo da Galafura*. The target audience include both individuals who have previously visited the viewpoint and those who have not, but wish to experience it anew, virtually.

Special attention was given to the visual presentation to ensure high-quality graphics and realistic representations of destinations. The IVEs were developed using Unity version 2020.3.30f1. C# was the primary programming language used, enabling the creation of more complex interactive elements, namely regarding the interaction with the objects during the treasure hunt. The assets corresponding to the five objects were retrieved from the Unity asset store, and readjusted using *CAD 3D Solidworks* software, to improve the materials and textures.

As seen in the literature review section, interaction, vividness, and presence are considered key principles when developing emotional VT experiences [105]. Accordingly, the virtual experiments were carefully developed, prioritizing these topics. A visually appealing and realistic space was intended to be created, to enhance the fidelity of the virtual environment [25], with distinctive elements carefully planned, as detailed in the next section (3.2.1), to enhance users' ability to perceive the virtual environment [96]. For this purpose, the positive and the negative IVEs were centered around the accomplishment of an active task: the multisensory treasure hunt. Both positive and negative IVEs, including the treasure hunt, had the same objects to be located. The primary distinction between the two was in the pleasantness of the multisensory stimuli used: the positive IVE employed pleasant stimuli aiming to evoke intense positive emotions, while the negative IVE included unpleasant stimuli, intended to induce intense negative emotions more effectively.

The resort to a multisensory treasure hunt task in the virtual experiment had five motivations:

1. Treasure hunts have been revealed as a common recent task within various immersive experiences for tourism purposes, namely in VR (e.g., [316, 317]) and AR (e.g., [318, 319]). Moreover, it has been proven to be an effective instrument to enrich a visitor's experience and learning during the exploration of a touristic place in virtual environments [318];
2. The treasure hunt enhances the interaction between the user and the system, since the user has to inevitably navigate through the virtual space, utilizing the controllers for teleportation to find and examine the objects. As previously observed (section 2.1.3), the user-system interaction is a crucial component in VR [49, 105], although challenging [4], which gains particular significance in the development of emotional tourist experiences [105]. The higher interaction between the user and the virtual environment contributes, in turn, to other advantages, which are the enhancement of the user performance on it [59, 102], and the generation of more emotionally intense experiences [320], fundamental for VIV data collection.
3. The third motivation refers to the benefit of the treasure hunt to make the users become familiar with the appearance of the objects during the search. The fact that the users have to accomplish a treasure hunt task acts as an "excuse" for them to involuntarily recall that object later. Furthermore, upon locating each of the five items, users were required to examine it for a maximum of 20 seconds, accompanied by the corresponding narrative as

an audio clue. Recommendations from Tullo, et al. [9] indicate that when assessing VIV via VVIQ, the mental images asked to recall belong to well-known scenes/objects, to ensure that they had been "previously recognized, elaborated, and stored in memory". The selection of renowned Portuguese icons as the objects of the treasure hunt was deliberately chosen to achieve that effect, simultaneously reinforcing the tourism context of this thesis. Nevertheless, in the uncommon instance where the user might be unfamiliar with the object (which could occur, for instance, with non-native Portuguese speakers), the treasure hunt ensured that the user had at least one prior viewing of it. Additionally, it could guarantee that all users had an equal understanding of the object's visual aspects. Regardless of prior knowledge, each participant had the chance to inspect those specific objects, with their unique colors and textures, which would be subsequently recalled in the VIV task.

4. The fourth motivation was to address the gap in the literature regarding the lack of studies exploring VIV resorting to active tasks in VR, as pointed out by Tullo, et al. [9].
5. Last, it was related to the need to stimulate all the human senses. The fact that the user had to sequentially locate the objects (one at a time) allowed the isolation of different multisensory combinations for each object. As a result, data concerning emotional responses and VIV could also be isolated for analysis, enabling clearer outcomes and comparisons between isolated (V+A) and combined stimuli (V+A+T, V+A+H+, and V+A+S), based on the perceptual information the users stored about what they just saw (visual imagery), heard (auditory imagery), smelled (olfactory imagery), felt (haptic imagery) and tasted (gustatory imagery).

3.2.1. The positive and the negative IVEs

The need to develop two IVEs is linked to the objective of investigating a wide range of emotions (positive and negative), a goal that would be more complex to achieve within a single IVE, an argument also supported by Kuang, et al. [41]. Inducing positive and negative emotions concurrently using different combinations of multisensory stimuli within the same IVE, while maintaining a coherent pathway would be practically unfeasible. Additionally, the mix of feelings likely experienced by the users could lead to skewed results and imprecise conclusions. Furthermore, this approach based on positive and negative scenarios to explore the participants' emotional reactions is a common practice among academics (e.g. [34, 41, 42]).

To develop the positive and negative IVEs we considered the existent literature on the sensory and semantic elements that can elicit specific emotional responses to the users. Table 3 was inspired by the systematic literature review conducted by Magalhães, et al. [22], whose first author corresponds to this thesis' author, who reviewed all the investigations triggering at least three stimuli to conclude the relationship between the stimulus provided and the users' emotional responses. Such results revealed fundamental to developing this thesis' positive and the negative IVEs.

Table 3 Review of the multisensory cues affecting users' emotions

<table>
<tr><th rowspan="2">Type</th><th rowspan="2">Stimulus</th><th colspan="2">Triggered emotional responses</th><th rowspan="2">Author</th></tr>
<tr><th>Positive</th><th>Negative</th></tr>
<tr><td rowspan="6">Visual</td><td>Bright</td><td>Free, glad, and enthusiastic</td><td>Aggressive</td><td rowspan="2">[321]</td></tr>
<tr><td>Dark</td><td>Daring</td><td>Nostalgic,</td></tr>
<tr><td>Blue lightning</td><td colspan="2" rowspan="2">Lower valence and dominance</td><td rowspan="2">[322]</td></tr>
<tr><td>Red Lightning</td></tr>
<tr><td>Representation of manipulated HR feedback</td><td>Interest and excitement</td><td>Scariness, nervousness, and fear</td><td>[24]</td></tr>
<tr><td>Dark</td><td rowspan="2">Empathy and self-awareness</td><td rowspan="2">Pity, sadness, nervousness, dear, and horror</td><td rowspan="2">[323]</td></tr>
<tr><td rowspan="4">Auditory</td><td>Instrumental</td></tr>
<tr><td>Bee swarm</td><td>Happiness</td><td>-</td><td rowspan="4">[25]</td></tr>
<tr><td>Bad weather (low-frequency sound)</td><td colspan="2" rowspan="2">Surprise</td></tr>
<tr><td>Zombie swarm</td></tr>
<tr><td rowspan="2">Olfactory</td><td>(Not specified)</td><td>Happiness</td><td>-</td></tr>
<tr><td>Unpleasant and intense odor</td><td>-</td><td>Stress and anxiety</td><td rowspan="7">[324]</td></tr>
<tr><td rowspan="6">Taste</td><td>Milk chocolate in a positive IVE</td><td rowspan="2">Peaceful, pleasant, good, satisfied, glad, pleased, and polite.</td><td rowspan="2">-</td></tr>
<tr><td>White chocolate in a positive IVE</td></tr>
<tr><td>White chocolate in a negative IVE</td><td rowspan="2">Affectionate, interested, happy, loving, joyful, and friendly.</td><td rowspan="2">-</td></tr>
<tr><td>Milk chocolate in a negative IVE</td></tr>
<tr><td>Dark chocolate in the positive IVE</td><td>-</td><td>Bored, worried, disgusted, and aggressive</td></tr>
<tr><td>Dark chocolate in the negative IVE</td><td>Adventurous, energetic, wild, active, and enthusiastic</td><td>-</td></tr>
<tr><td rowspan="4">Haptics</td><td>Back vibration simulating a spider behind the back</td><td colspan="2">Surprise</td><td>[25]</td></tr>
<tr><td>Haptic feedback from EMS or Solenoid</td><td>-</td><td>Fear and pain</td><td>[147]</td></tr>
<tr><td>Cold</td><td colspan="2">More relaxation and less arousal (than warm)</td><td rowspan="2">[323]</td></tr>
<tr><td>Warm</td><td colspan="2">More arousal and valence (than cold)</td></tr>
</table>

Beyond this research, other academics have sought to establish a link between specific stimuli and emotional responses yet disregarding the exclusion criterion of engaging at least three human senses. For instance, low valence was associated with dark colors, mysterious voices and sounds, children singing, monsters, and clowns by Dozio, et al. [325]. Another example is the visual appearance of spiders, that has been associated with negative emotions, while butterflies and birds to positive emotions [326]. In general, these emotion-based studies rely on inducing joy, fear, relief, anxiety, amusement, stress, sadness, interest, anger, pleasure, and disgust, which partially corroborates previous findings from Diniz Bernardo, et al. [222]. On the opposite, scarce or none explore more complex (and typically non-positive) emotions like disgust [222], shame, disappointment, neutrality, distress, depression, admiration, compassion, regret, contempt, confusion, unconfident, and hate, as concluded by Somarathna, et al. [26], and corroborated by the findings here exposed. As explained by the same authors, this could arise from the intricate nature of these emotions, which adds complexity to VR design and, consequently, to their analysis. In the tourism context, these cues become even more critical, as VT requires a heightened level of sensory fidelity and presence, as defended by Yung, et al. [35].

While there are numerous cues available to create emotional virtual environments, including those mentioned earlier, the majority of them are primarily visual and often lack a context or a structured framework (in this case, for the context of tourism). Moreover, there remains a lack of comprehensive and patronized data concerning precise stimuli that evoke particular emotional responses in users, as highlighted in several works [22-26] and supported in this section. Therefore, to ensure the robustness of this thesis' experimental design, namely the combination of multisensory stimuli used in both positive and negative IVEs, a focus group was conducted for prior validation. Additionally, an examination of users' pre- and post-emotional responses was carried out to confirm that the positive and negative IVEs aligned with the expectation of intensely eliciting more positive emotions in the first case, and more intensely negative emotions in the latter, as discussed in section 4.3.

So, in line with the key points recommended by previous research, the following topics were taken into consideration for the virtual experiment's design:

1. the immersion levels (by providing a fully immersive and totally multisensory VR experience);
2. the interaction between the user and the system (by offering a treasure hunt task);
3. the content (the IVEs were developed with a logical sequence involving five distinct audio narratives, told at specific intervals, about typical Portuguese objects) Pavic, et al. [223];
4. the incorporation of multisensory features, as highly recommended by Sui, et al. [172] for designing emotional VT experiences. Additional visual cues, such as shadows, textures,

and spatial depth were taken into consideration, as fundamental according to other authors, to visually mimic the real world [180] and increase the feelings of presence [181]; and

5. the emotional feature of the IVE, that was transmitted, for instance, by the light conditions, sound, motion, and colors, as suggested by the framework proposed by Kuang, et al. [41]. Moreover, as mentioned by the same authors, the inclusion of these elements for designing affective VR systems is considered a good practice. This was also corroborated by Pinilla, et al. [327], who found that dynamics, motion, and animations provide an IVE with emotional meaning. These authors published an innovative work regarding the relationship between media and concrete stimuli, which concluded that bright and saturated colors are linked to emotions characterized by a positive valence and high arousal (e.g., excitement). A similar idea was defended by Baños, et al. [34], who argued that warm tones with low brightness and saturation evoke joy and relaxation. On the other hand, dark and unsaturated colors were found to be associated with low arousal and negative valence emotions (e.g., depression).

Based on the above argumentation, the basis of the positive and the negative IVE were developed as follows:

- **Basis of the positive IVE:** An outside sunlit touristic place, where one could hear the birds chirping, while listening to positive stories about the five described objects, told by the first narrator.
- **Basis of the negative IVE:** The same outside scenario, where one could see and hear the rain dropping, and watch the wind shaking the trees, while listening to negative stories about the same objects, told by the second narrator.

This basis of the IVEs refers to the scenario that welcomed the user at the start of the virtual experience, remaining constant throughout. That is, although new stimuli were intentionally introduced during the multisensory treasure hunt task – taste, haptics, and smell (the "controllable stimuli", as designated from now on), the core environment of the virtual experiment always remained the same.

3.2.1.1. Selection process of the positive and negative IVEs

The selection of the IVE (positive or negative) took into consideration two main variables, concerning the food samples, due to their eventual risk to human health:

1. Food intolerances and
2. Personal Tastes

To do that, the participants were invited to complete a pre-questionnaire regarding their personal preferences and food intolerances (Q2 questionnaire, appendix section 10.4), before starting the VR experiment. These results were immediately pre-analyzed, with their consent, while the participants answered the remaining questions (Q3, appendix section 10.4). This procedure was explained to the participants as something normal just to assess whether they had any food intolerance/allergy or refused to try any of the food samples. This clarification was given in such a way that they would not realize what type of stimuli they were going to receive (positive or negative).

To the IVE process selection, the main goal was to make sure that the participant experiencing the positive IVE effectively enjoyed the positive stimuli used (to contribute to generating positive emotions), whereas the participant experiencing the negative IVE disliked the negative stimuli used (to contribute to generating negative emotions). In the case there were reported any regarding food intolerances, allergies, or refusal to try the samples, three scenarios were considered:

1. If there was any intolerance, allergy, or refusal to try any of the positive edible samples, but **none towards the negative** edible samples, the participant would take the negative IVE;
2. If there was any intolerance, allergy, or refusal to try any of the negative edible samples, but **none towards the positive** edible samples, the participant would take the positive IVE;
3. If there was any intolerance, allergy, or refusal to try **simultaneously at least one of both the positive and negative** edible samples, the participant would be unable to participate in the experience. It should be noted that this scenario never occurred.

On the other hand, if the participant had reported no food intolerances, allergies, or refusal to try, four scenarios were considered regarding their **personal tastes**:

1. Dislikes two negative stimuli and likes two positive stimuli (R1);
2. Dislikes two negative stimuli and likes at least one positive stimulus (R5 and R9);
3. Likes everything (R16);
4. All other possibilities. In this case, the selection of the IVE was indifferent and, consequently, left to my judgment, guided by the need to meet the statistical objectives (e.g., more male participants experiencing the positive IVE or more female participants experiencing the negative IVE).

The combined analysis of Diagram 2 and the truth table (Table 4) illustrate this selection process and allow concluding which IVE was selected for each participant.

Diagram 2 Positive and negative IVE selection process

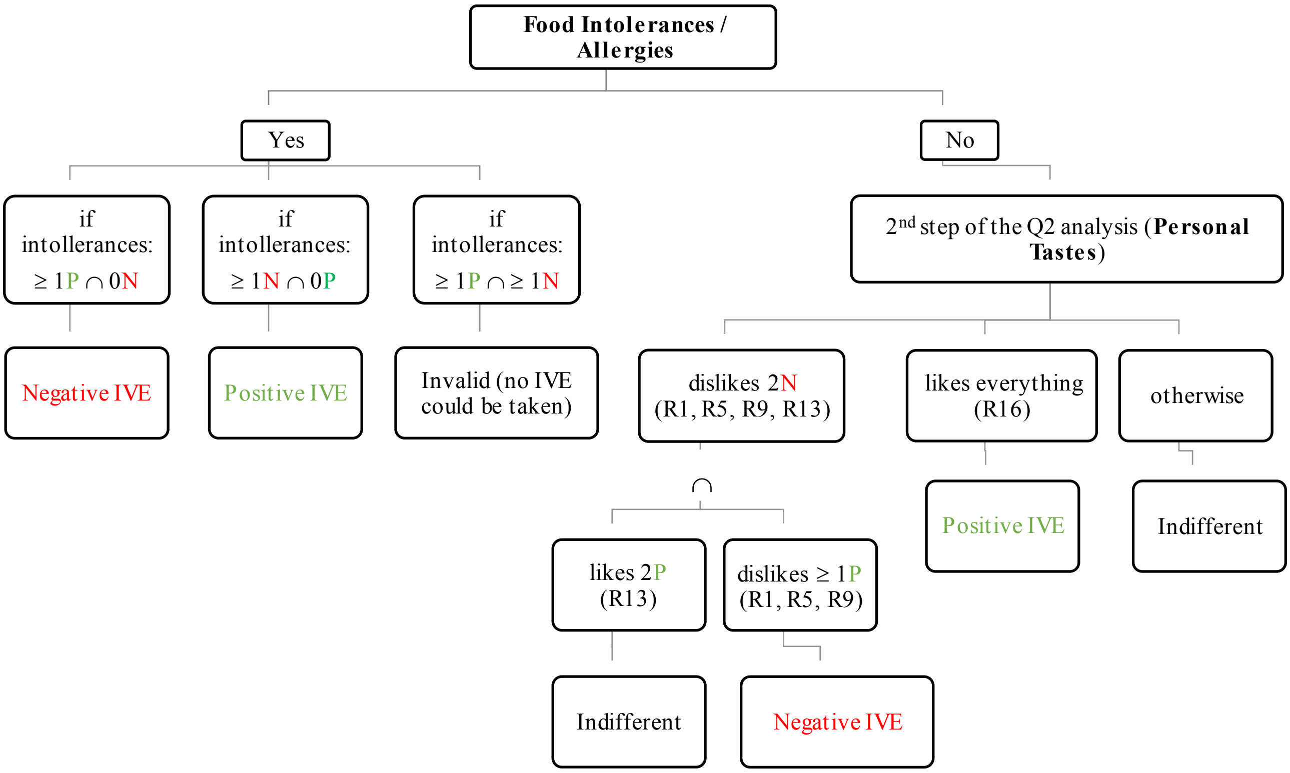


Table 4 Truth table regarding the IVE selection process

Stimuli					Result (R) - positive, negative or indifferent IVE	
P1	**P2**	**N1**	**N2**			
0	0	0	0		R1	Negative IVE
0	0	0	1		R2	Indifferent
0	0	1	0		R3	Indifferent
0	0	1	1		R4	Indifferent
0	1	0	0		R5	Negative IVE
0	1	0	1		R6	Indifferent
0	1	1	0		R7	Indifferent
0	1	1	1		R8	Indifferent
1	0	0	0		R9	Negative IVE
1	0	0	1		R10	Indifferent
1	0	1	0		R11	Indifferent
1	0	1	1		R12	Indifferent
1	1	0	0		R13	Indifferent
1	1	0	1		R14	Indifferent
1	1	1	0		R15	Indifferent
1	1	1	1		R16	Positive IVE

Caption:
P1 Positive Stimulus 1
P2 Positive Stimulus 2
N1 Negative Stimulus 1
N2 Negative Stimulus 2

Subsequently, it was important to validate each participation by crosschecking whether a participant who took the negative IVE, in fact, felt and disliked the multisensory stimuli used, and if a participant who took the positive IVE, in fact, felt and enjoyed the multisensory stimuli used. So, the aim of this selection process was to increase the chances of this happening. This validation process will be further addressed in section 4.1.1.

3.2.2. The multisensory treasure hunt

The mechanics of the virtual treasure hunt involved the exploration of the viewpoint of the São Leonardo da Galafura, as previously commented. The user began the experience at this location, just a few meters away from the Chapel of Santa Bárbara and São Leonardo (right picture from Figure 22), from where they could glimpse the landscape over the Douro River (left photo from Figure 22). An interactive kiosk was also within sight (Figure 23), serving as the spot where users received all the necessary instructions for the treasure hunt and filled out the in-VR questionnaires.

Figure 22 São Leonardo da Galafura scenes

(on the left, photo captured by the author; on the right picture retrieved from this link)

Figure 23 Virtual representation of the interactive kiosk

(on the left in the sunny positive IVE; on the right in the rainy and dark negative IVE)

The task started there: the user was briefed on their current location and the task they needed to complete. They were also advised that the task was not timed, encouraging the user to take in the scenery and enjoy the virtual tour at their leisure. Timing came into play only when an object was located. Objects appeared one at a time, in open boxes on the ground within the virtual space, as Figure 24 shows.

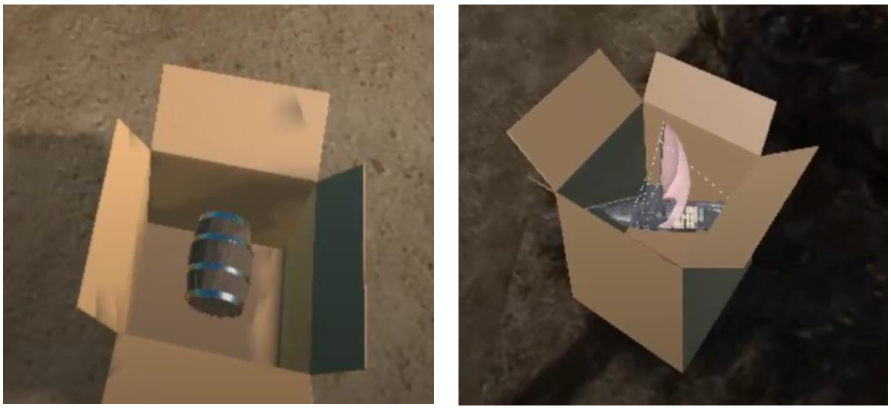


Figure 24 Example of a box appearing with the object to be located inside (on the left in the sunny positive IVE; on the right in the rainy and dark negative IVE)

To collect an object, the user was required to bend slightly, mimicking the action they would take to pick up an item in the physical world. When the headset's controller tracked the user's virtual hand contacting the object, it automatically attached to the user's virtual hand (Figure 25).

Figure 25 Example of the interaction between the user's virtual hand and the object (on the left in the sunny positive IVE; on the right in the rainy and dark negative IVE)

It is worth noting that the objects were resized to similar scales to fit within the user's virtual hand, facilitating a throughout and swift examination. This hands-free attachment feature was intentionally created to eliminate the need for button pressing, thereby simplifying the experience, and making it more accessible, particularly for users who might not be as familiar with VR technology and the controllers' operation.

At this point, the relevant combination of stimuli (V+A for the first object, V+A+T, V+A+H or V+A+S for the subsequent ones, or V+A+T+H+S for the last object) was initiated. The object was programmed to stay affixed to the user's virtual hand for 20 seconds, allowing them to freely inspect it, rotating and observing it from all angles during that time. It could be zoomed in for a closer inspection or out for a wider perspective just by moving it closer to or further from their face, mimicking the natural movements one would make in the real world. During these 20 seconds, the corresponding narrative (audio) for the object being presented was also triggered. After this period, the object and all the stimuli introduced in that stage would disappear automatically.

To find the objects, the user was encouraged to freely navigate the IVE, where they randomly appeared one after another, in a specific order (Portuguese guitar, wine barrel, Rabelo boat, pine tree, and compass). Navigation within the virtual landscape could be accomplished by physically walking (walk in place) within the limits of the VR setup's 3m × 3.5m tracking space, or by using the VR controller's trackpad to teleport to the desired location. Given that the virtual environment extends beyond the tracking area, and to ensure user safety, a blue fence would appear when users neared the boundary of the tracking space, prompting them to turn back or to teleport to continue exploring.

After locating each object, the user should return to the interactive kiosk to complete the in-VR questionnaires about that particular object, following the PANAS and VVIQ sequence. This step was repeated after finding each of the five objects. Following the fifth and last object's questionnaires, one final (the IPQ) was presented to measure the user's subjective sense of presence. The virtual experiences finished after all the questionnaires had been filled out. On the interactive kiosk, a message thanking the participant appeared, signaling the end of the experience, although they could keep navigating the virtual space at their discretion.

The main challenge when developing the treasure hunt task was ensuring congruence between the stimuli provided, i.e., that there was a match between all the presented stimuli for each object, so that all the multisensory information could equitably contribute to trigger the participant's memory of that specific object. A lack of consistency in multisensory stimuli is a topic explored by several authors [328, 329], which can potentially have a detrimental effect on the user experience, leading to rapid cognitive overload and distraction from the VR experience's intended purpose. Then, the following procedure was taken into consideration:

1. In the case of the first object (when V+A occurred), it was necessary for there to be a match between the visual stimulus (a Portuguese guitar) and the corresponding audio-narrative;

2. In the case of the second object (when V+A+T occurred), a match between the visual stimulus (a barrel of Port wine), the corresponding audio-narrative and taste stimuli was necessary;
3. In the case of the third object (when V+A+H occurred), a match between the visual stimulus (a *Rabelo* boat) and the corresponding audio-narrative and haptic stimuli was necessary;
4. In the case of the fourth object (when V+A+S occurred), a match between the visual stimulus (a pine tree) and the corresponding audio-narrative and smell stimuli was necessary;
5. Finally, for the fifth and last object (where V+A+T+H+S occurred), a match between all the multisensory stimuli was necessary, i.e., there should be ensured a connection between the visual stimulus (a compass) and the corresponding audio-narrative, taste, haptic, and olfactory stimuli.

Table 5 details this congruence process, revealing the multisensory stimuli used in both positive and negative IVEs and the material needed to provide it to the user during the IVEs.

Table 5 Stimuli combinations for positive and negative IVEs during the treasure hunt

STIMULI COMBINA-TIONS		POSITIVE IVE (During a sunny day)		NEGATIVE IVE (During a rainy and dark day)	
		Multisensory Stimuli	**Hardware/ Material needed**	**Multisensory Stimuli**	**Hardware/ Material needed**
1	**Portuguese guitar**				
1	Visual	A Portuguese Guitar	Headset	A Portuguese Guitar	Headset
1	+ Audio	A positive story about Fado culture	Headset	A sad/negative story about Fado culture	Headset
2	**Port Wine barrel**				
2	Visual	A wine barrel	Headset	A wine barrel	Headset
2	+ Audio	A positive story about Port wine	Headset	A sad/negative story about the negative impact of wine	Headset
2	**+ Taste**	Port wine	Port Wine	A sip of diluted vinegar (to represent acid wine)	Vinegar diluted in water
3	***Rabelo* boat**				
3	Visual	*Rabelo* boat	Headset	*Rabelo* boat	Headset
3	+ Audio	A positive story about *Rabelo* boats	Headset	A sad/negative story about *Rabelo* boats	Headset
3	**+ Haptic**	Heat	Ventilator fan (set to heat)	Wind	Ventilator fan (set to cold)

	Pine tree				
4	Visual	A pine tree	Headset	A pine tree	Headset
	+ Audio	A positive story about the positive effects of reforestation		A sad/negative story about the tragic fires in Portugal	
	+ **Smell**	Pine odor	Spray with pine fragrance	Smoke odor	Spray with liquid smoke
	Compass				
5	Visual	A wooden compass	Headset	A wooden compass	Headset
	+ Audio	A positive story about the relationship between Portuguese maritime exploration and tea		A negative story about the Portuguese maritime exploration	
	+ **Taste**	Cinnamon tea	Warm tea	A sip of salty water	Water with vinegar
	+ **Haptic**	Heat	Ventilator fan (set to heat)	Wind	Ventilator fan (set to cold)
	+ **Smell**	Concentrated fragrance of cinnamon	Spray with cinnamon scent	Concentrated fragrance of seaweed/fish	Spray with salmon-oil

3.2.2.1. Visual and auditory stimuli: objects and narratives

An important design aspect of this methodology is the narratives, i.e., the stories that were told during the object's inspection. The inclusion of narratives in a virtual experiment helps to engage the participant in the story and to perceive it as reality [330], and consequently to increase the sense of presence, by maintaining the subject's focus of attention in the VE [331]. The narratives were developed according to the positive and negative IVEs, resulting in an optimistic/positive or sad/negative story, correspondingly, to evoke positive or negative feelings in accordance with the IVE. Furthermore, considering the context of Portuguese tourism, the narratives highlighted brief historical-cultural episodes from Portugal, relevant to the object displayed in the treasure hunt. For each object, a 20-second narrative was provided through audio, serving as the auditory stimulus for all five objects in both the positive and negative IVEs. This duration was strictly maintained to avoid potential bias due to differences in the amount of inspection time available to each participant.

Below, in Table 6, we present a translation of the Portuguese originally written narratives (appendix section 10.1, Table 59) according to the IVE (positive/negative) and the object (Portuguese guitar, wine barrel, *Rabelo* boat, pine tree, and compass).

Table 6 Narratives (free English translation)

	Narratives	
Object	**Positive IVE**	**Negative IVE**
PORTUGUESE GUITAR	It is estimated that the origin of fado dates back to the beginning of the 1800s. Today, it occupies a central position in Portuguese musical culture, which has been particularly accentuated since the April 25th Revolution, that is, after the censorship experienced up to that point. The presence of the Portuguese Guitar in the melodies of fado means that there are no language barriers to understanding the emotion it aims to convey, thus becoming a universal language. Fado was declared an intangible cultural heritage by UNESCO in November 2011 [332].	The origins of the Portuguese guitar are not well-documented, but its connection to fado is well-established. Although fado is now acclaimed worldwide, it was initially received with strong rejection by groups considered to be intellectually superior. As it began to find its place in Portuguese culture, through theater and music festivals, for instance, the severe censorship in Portugal during the *Estado Novo* regime led to difficult times for this musical genre, which was significantly impacted [332].
WINE BARREL	Port wine barrels carry a strong cultural heritage from the city of Porto. Even today, the tradition of grape harvesting and artisanal grape treading is maintained, making this process unique and distinct from that of other wines [333]. The Alto Douro wine region, where Port wine is produced, established in 1756 by the Marquis of Pombal, is the oldest in the world and is currently a UNESCO World Heritage site [334].	Port wine is acclaimed for its unmistakable flavor. However, its fame and strong legacy have led to significant frauds, such as its illegal reproduction at lower prices, which greatly contributed to a severe crisis in the agricultural sector, the *Lavoura* crisis, in the 19th century. At that time, the Douro was seen as a portrait of misery, a label that lasted for many years [334]!
***RABELO* BOAT**	The Rabelo Boat was originally designed for the transportation of goods, particularly for the transport of Port wine. It sailed along the Douro River, heading to Vila Nova de Gaia, where the wine would be aged and develop its distinctive flavor. Although the Rabelo Boat is no longer used for this purpose today, some can still be seen adorning the Douro River as a tourist attraction. Each boat measures between 19 and 23 meters in length and can carry an average of up to 100 barrels [335].	The Rabelo boat was designed for the transportation of goods, especially for carrying Port wine. Its architecture enables it to withstand the strong currents of the Douro River. However, many lives have been lost aboard a Rabelo. One of the most well-known is related to the death of Baron Forrester in 1861, who is said to have drowned due to the bulky and heavy belt of money and gold he wore around his waist [335].

PINE TREE	The pine tree is one of the most dominant trees in Portugal. It adapts very well to different types of soil and high temperatures [336]. For this reason, after the fires of 2017 that devastated large forested areas, the *Pinheiro-manso*, in particular, has been essential for the reforestation of the Leiria district [337]!	Approximately half of the area burned in Portugal during the terrible fires of 2017 consisted of pine trees. Their conical shape, and the structure of their leaves and branches, facilitate the rapid spread of fire [336], and a high intensity of the flames. Despite the well-known danger of this species, forest management procedures continue to be improperly implemented [338].
COMPASS	Originating from China, tea was introduced to Europe by the Portuguese in the 16th century. Via Macau, which served as a port for the maritime trade of various spices, tea became one of the most popular in the West. For instance, the custom of “afternoon tea”, one of the most typical British traditions, was introduced by the Portuguese princess, *Catarina de Bragança*, upon her marriage to Charles II of England [339].	The compass was one of the most important navigation instruments for the Portuguese maritime expansion. Maritime journeys were extremely uncomfortable and dangerous adventures. It is estimated that one in every three ships that left Portugal in the 16th and 17th centuries sank, and that about 40% of the ship's population died during the journey, victims of hunger, pirate attacks, or diseases [340].

Visual and auditory cues were delivered via a VR headset. The virtual experiment was developed to run on the HTC Vive Pro 2 - Figure 26), not only due to logistics (as it was the available equipment in the lab), but mainly due to its high resolution and other features. This headset includes integrated headphones and a display composed of dual low-persistence LCD panels with a resolution of 2448 x 2448 per eye, a refresh rate of up to 120Hz, and a field of view of approximately 120 degrees. It uses SteamVR Tracking 2.0, which provides sub-millimeter accuracy for head and hand movements within a play area [341]. The Vive controllers were used for moving (via teleport) and interacting within the virtual environment.

Figure 26 HTC Vive Pro 2

Following each session, the VR headset and controllers were thoroughly sanitized with the Kabetec© Cleanbox (Figure 27). This sanitation device touts a 99.999% effectiveness against viruses and bacteria and employs UVC light for disinfection. The sanitization and preparation of the VR equipment for use is completed in just 60 seconds [342].

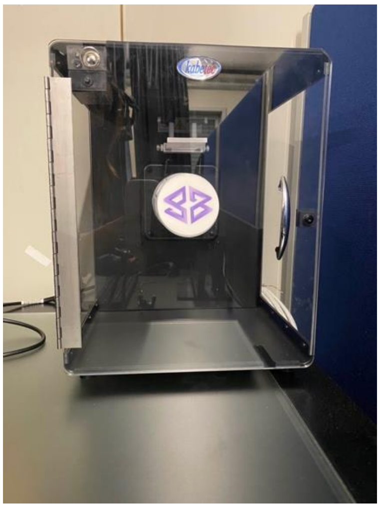


Figure 27 Kabetec© Cleanbox

3.2.2.2. The haptic stimulus

By means of a ventilator fan, the thermal sensation of heat and cold was created. This is a way of providing thermal stimuli in VR, well-recognized in the literature, and frequently used as active haptic feedback in VR scientific VR experiments (e.g., [32, 89, 206]).

For the execution of the thermal sensations of heat and cool, correspondingly to the positive and the negative IVEs, it was necessary to develop a system using an Arduino to automatically activate the fan when the user found the object linked to the haptic stimulus (the third and the fifth) and to switch it off once the designated time for the object had finished. The setup developed to control the fan required the following materials:

1. One Arduino
2. One 15v relay module
3. One electrical extension
4. Three jumper wires
5. One waterproof box (just for protection and esthetics)
6. One USB-B to USB-A cable
7. A laptop

The assembly began by opening the electrical extension and cutting the phase wire to pass it through the relay module's terminals. Subsequently, one end of the phase wire was connected to the relay's NO (Normally Open) terminal and the opposite end to the C (Common) terminal. Once this was accomplished, the relay module was linked to the Arduino with jumper wires in the following configuration:

- A yellow wire connected the SIG pin of the relay module to the Arduino's Digital 8 pin.
- A green wire bridged the 5V pin of the relay module to the Arduino's 5V pin.
- A blue wire joined the GND pin of the relay module to the Arduino's GND pin.

The Arduino was then connected to an Asus VR Ready laptop, which supplied power and allowed for the code to be uploaded via a USB-B to USB-A cable. The fan was plugged into the electrical extension, whose other end was connected to a standard 220V wall socket. This setup is demonstrated in Figure 28.

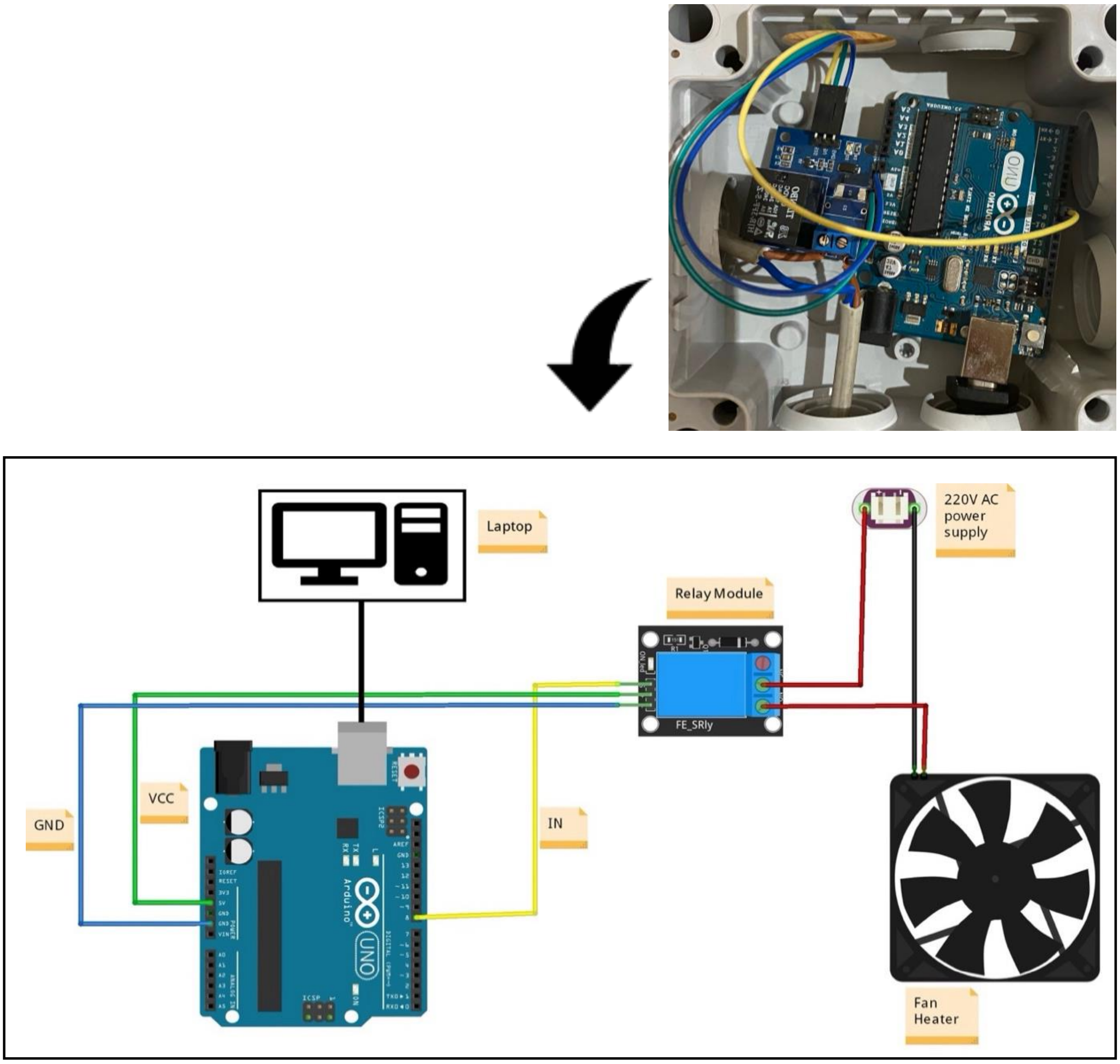


Figure 28 Arduino configuration

The final assembly of the ventilator fan connection to the Arduino can be seen in Figure 29.

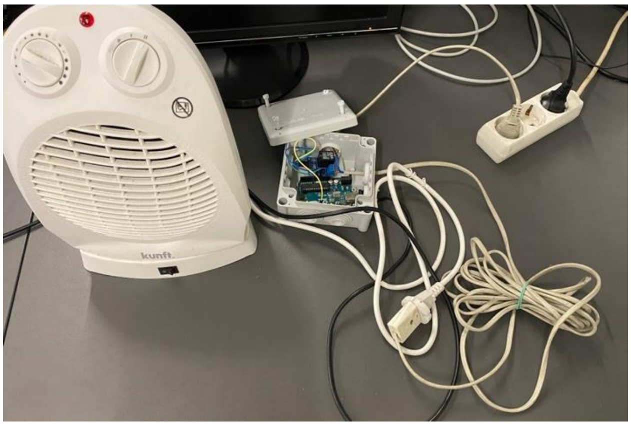


Figure 29 Ventilator fan and Arduino connected

The adjustment for heating or cooling was manually controlled due to the ventilator fan's physical toggle. Hence, based on whether the IVE experienced by the user was positive or negative, I would manually direct the switch toward either the heat or the cold setting accordingly. The ventilator fan was positioned approximately 50-60 cm away from the user's face, as shown in Figure 30. Although the user did not feel the cold/warm air in the eye area due to the headset covering, they could feel it from the lower part of the face (from the nose) down to the neck. The intention was to simulate the sensation of wind or sunlight at a distance that allowed the user to experience thermal stimuli while ensuring the safety and health conditions of the participants.

Figure 30 Researcher's position relative to the user for delivering the thermal stimulus

3.2.2.3. The smell stimulus

The incorporation of scents into VR significantly enhances the virtual experience, as discussed before. However, as explored by Archer, et al. [128], the impact of scents can often be attributed to their novelty, indicating that the initial exposure to a specific scent may be the most impactful. Therefore, given that the experimental setup had to include two different scents per session (for objects 4 and 5 – V+A+S and V+A+T+H+S), it was crucial to ensure that these scents were distinct from one another to preserve the element of novelty.

Timing, amount and authenticity were the major concerns related to the olfactory sensorial cues during the virtual experiments, as they have a great impact on the subject's immersion and emotional engagement [331]. First, authentic odors were selected to represent the object being inspected by the user. Next, sensory cues were introduced in small quantities at a specific moment so that the congruence was maintained, as previously explained.

The olfactory samples used (pine and cinnamon in the positive IVE, and smoke and fish in the negative IVE) were manually delivered to the user, through spray samples, as demonstrated in Figure 31. The negative strong-smelling odors were deliberately chosen, as they maximize the likelihood of increasing participants' sense of presence [128].

Figure 31 Example of an olfactory sample

Just like the delivery of haptic stimuli, scents, which were liquid-base, were manually administered to users by positioning the spray about 40cm away from the participant. The spray was pointed above the participant's head to prevent any droplets from directly hitting their skin - Figure 32. This method allowed the droplets to naturally fall and the scent to disperse around the user, ensuring the safety and health of the participants. The exact timing for introducing the olfactory stimulus was monitored via the laptop, which mirrored the ongoing experience.

Despite being difficult to definitely eliminate a smell before introducing another (resetting the nose), in the study of Niedenthal, et al. [119], participants reported good results in olfactory adaption (the state of no longer perceiving a scent after prolonged exposure to it), by using two common wine-tasting techniques to resetting the nose: (1) by just breathing fresh air or (2) sniffing skin at the crook of the elbow, both while moving away the olfactory display. With this in mind, the olfactory stimuli, which were introduced twice (object 4 and object 5) during each IVE, were scheduled to have at least a one-minute interval between them. This gap ensured that users could inhale fresh air and also allowed ample time for the prior scent to fade away. In the days the VR experiences occurred, the lab registered a temperature between 20ºC to 22ºC. However, it was constantly airy through the windows, which were always opened to ventilate the room, contributing to avoiding the mixture of scents. The results regarding the application of this technique in this research will be elaborated in section 4.1.1.

Figure 32 Researcher's position relative to the user for delivering the olfactory stimulus

3.2.2.4. The taste stimulus

The sense of taste is probably the most difficult to simulate in VR. To be fully virtually delivered, the process involves, in general, the use of a chemical substance that activates the receptors located in the subject's tongue, which are responsible for providing different taste sensations. In this case, at least one chemical soluble substance must be given to the subject, which will be dissolved in saliva. This process demands great accuracy and complexity to achieve. Sophisticated mechanisms are necessary and, moreover, taste mixtures are very difficult to achieve [343]. As an alternative to such complex methods, the exploration of MR has been explored for AR and VR purposes. MR involves the blend of virtual and physical world elements [344], generating something also known as "phygital" [220]. This method to reproduce the taste stimuli is increasingly being adopted by researchers, especially in food research, as attested by the review conducted by Chai, et al. [345]. Its main advantages include the ease of use and the fact that it does not make the virtual experience unpleasing and uncomfortable, especially when compared to electrical stimulation of taste. Moreover, recently Low, et al. [346] used MR to assess the influence of different contexts on consumer emotional response to food products. The study found that MR could induce the same level of emotional responses as in real-life settings, suggesting its usefulness for assessing ecologically valid consumer responses.

In this research, an MR approach was adopted to introduce the taste samples (Port wine and cinnamon tea, in the positive IVE, and acid wine and salty water in the negative IVE). So, at the same time the participant was using the VR headset, they were also equipped with two cross-body bottle bags that were placed around the neck (one ending at the left and one at the right of the waist, as Figure 33 shows), each holding a cup with a straw through which the liquid samples corresponding to the taste stimulus could be consumed. This approach allowed for the liquid samples' stimuli, to be tasted autonomously, along with all other types of stimuli (in the case of V+A+T and V+A+T+H+S), and without having to take off the VR headset, avoiding potential breaks in presence.

Similarly to the materials selected for the focus group and respecting environmental ethics, everything used for the virtual experiences was either recyclable or biodegradable.

Figure 33 Bottle bags (on the left). Two equipped participants performing the virtual experiences (on the center and on right)

3.3. Procedure

The virtual experiment occurred following a sequence of 12 steps, divided according to three main moments: 1) before, 2) during, and 3) after the VR experiment, as clarified in Table 7 and summarized in video (available here). The first moment (expected to occur in approximately 10 minutes) corresponds to the welcoming of the participant, during which the entire process was thoroughly explained, and when they were asked to fill out the preliminary questionnaires. After addressing any potential questions, the participant was required to sign the consent form. Then, participant filled out the pre-questionnaire regarding their current emotions, followed by the VR equipment fit and all the other necessary accessories for the sensory stimulation.

Table 7 Procedure: experiment stages, tasks, and timings

BEFORE THE VR EXPERIMENT				
	STAGES	TASKS/QUESTIONS		TIMING
1	General Instructions and explanation of the flow of experiment			≈ 10 Minutes
2	Demographic questionnaire	Age, gender, nationality, academic qualifications	Appendix section 10.4	
3	Initial personal questionnaire	Food intolerance/allergy and personal taste		
		Experience with VR		
		Normal or corrected-to-normal vision, smell, and taste		
		Medical conditions impeding the experience of VR		
4	Declaration of Consent			
5	Emotions pre-questionnaire	PANAS (1)		
(VR equipment initial setup and placement on the user)				
DURING THE VR EXPERIMENT				
	STAGES	DATA COLLECTION		≈ 12 Minutes
6	V+A	PANAS (2)		
		VVIQ (1)		
7	V+A+T	PANAS (3)		
		VVIQ (2)		
8	V+A+H	PANAS (4)		
		VVIQ (3)		
9	V+A+S	PANAS (5)		
		VVIQ (4)		
10	V+A+T+H+S	PANAS (6)		
		VVIQ (5)		
11	Presence Questionnaire (IPQ)		Appendix section 10.5	
(VR equipment removal)				
AFTER THE VR EXPERIMENT				
	STAGES	TASKS/QUESTIONS		≈ 3 Minutes
12	Final Questionnaire	After-Scenario Questionnaire (ASQ)	Appendix section 10.4	
		Rating of stimuli pleasantness		

During the VR experiment, when the treasure hunt task took place, with each object's location, different multisensory combinations were activated (from stage 6 to 10) – positive or negative, according to the positive or negative IVE that the participant was experiencing. After finding each object, the PANAS and VVIQ questionnaires were introduced to gather the user's emotional responses and VIV data. Once all five combinations had been experienced, the IPQ was presented to collect data about the user's sense of presence generated by the IVE. The VR experiment itself was developed to take about 12 minutes to complete.

After the VR experience, the participant was asked to fill out a final questionnaire about their perception of the entire experience – the after-scenario questionnaire (ASQ), and the pleasure provided by the stimulus. This final moment was expected to last approximately 3 minutes. Such data was essential to validate the positive and the negative IVEs: it was expected that those who experienced the positive IVE felt the stimuli as positive and those who experienced the negative IVE felt the stimuli as negative, as the participation's validation process further explains (section 4.1.1).

3.4. In-VR questionnaires

The most traditional and simplest way to present questionnaires in VR context is paper-based or computer-based [197, 347], also known as "out-VR" [58]. However, transitioning from the virtual world to the real space to self-report the VR experience involves a great loss of presence [73, 197, 348]. This interruption inevitably causes BiP [349], which is particularly undesired if presence is the construct under measurement. Moreover, taking the subjects out of the VR world (by removing the HMD) to fill out a questionnaire may introduce bias in the subjective responses, again, due to the BiP [72, 348]. "In-VR" questionnaires – the integration of questionnaires into VR experiences [58, 72, 350] – is a method that can avoid such inconveniences. One of the benefits it presents is the capacity to alleviate the transition from VR to reality, which, in turn, contributes to maintaining the user's immersion and presence [58, 347], while removing disorientation symptoms caused by cybersickness [72]. Moreover, it seems that completing questionnaires in VR does not significantly change the levels of presence felt during the virtual experience [72]. Also, as its application is immediate, the user can provide instant feedback, which contributes not only to reducing time and costs [197], but also to avoiding unprecise, inconsistent and incomplete subjects' memory details [38, 72]. When a participant is required to respond to multiple questionnaires, in-VR questionnaires offer significant advantages over traditional methods, such as paper or computer-based formats. They are more convenient, save time, and minimize distractions, as the user does not have to repeatedly remove and wear the HMD each time they need to answer a questionnaire [72]. Recently, Alexandrovsky, et al. [351] found that users typically prefer to fill out the questionnaires within the VE. They reported that such experience decreases their physical and mental demands. In another study, participants reported being more focused on in-VR questionnaires than in the traditional way (computer-based), in which they demonstrated signs of distraction [350], also corroborated by Schwind, et al. [72]. All these benefits contribute to more reliable results [197, 350].

Although its implementation has clear benefits, the use of in-VR questionnaires remains relatively unexplored. To our knowledge, the pioneering work in integrating in-VR questionnaires was done by Schwind, et al. [352], who, in 2017, carried out a study to explore user perceptions of different hand styles in VR. Schwind, et al. [353] further applied in-VR questionnaires to investigate the impact of having a reduced number of fingers in VR. However, as early as 2015, Frommel, et al. [354] had already discussed the potential of using in-VR questionnaires for assessing presence and immersion while playing a PC game. This approach continues to be discussed and recommended in contemporary literature by numerous authors [72, 197, 348, 350, 351].

Most of the research found in the literature that incorporates in-VR questionnaires focuses on the sense of presence [58, 72, 347, 350, 352-354]. For instance, Tamaki and Nakajima [347] have integrated the IPQ into their research to explore whether in-VR questionnaires can maintain the user's sense of presence. Their results show, overall, the maintenance of presence, although the participants reported a loss of the sense of "I am in the VR space" and "I am involved in Virtual Environment" when transitioning from the game to the questionnaire. Recently, Feick, et al. [197] proposed a "VR Questionnaire Toolkit", which allows researchers to easily collect subjective measures within VR using a Likert scale. The open-source toolkit includes a pre-installed selection of standard questionnaires (e.g., the IPQ), but it also allows researchers to create and integrate their custom questionnaires into an existing VR project. Its foundation is rooted in robust academic principles, incorporating numerous design recommendations, which bolsters its reliability.

3.4.1. PANAS short-version for emotional responses collection

As previously discussed, measuring emotions is a complex endeavor, yet it is identified as crucial, particularly in tourism research. This significance is underscored by the limited number of studies addressing this topic, as Hosany, et al. [20] concluded.

To gather the user's emotional responses within VR, and considering the limitations of both subjective and objective methods as outlined in section 2.3.2.1, this thesis employed a subjective approach, utilizing pre- and post-tests. This decision was influenced by various factors, especially due to the fact that this research involves a certain level of users' physical movement. Consequently, numerous challenges would arise in implementing an objective or a mixed approach, including:

- The eventual bias caused by external factors, including the intrusiveness [125] and the sensitivity of the hardware, such as the devices that measure HR and EDA [22, 206], as previously addressed. Moreover, the precision of these instruments might be influenced by the specific conditions of the test environment, like room temperature [125], which could be exacerbated by bodily movements. Although there were efforts to maintain a consistent climate during the VR experiments, the fact that the windows were always open could intensify the limitations of any objective instruments;

- The above limitation could be even worse considering that participants would need to use a wired headset (HTC Vive Pro 2) and two bags to taste the liquid samples;
- The eventual mismatch between the objective and subjective or behavioral data, which is an obstacle reported by many authors [22, 206, 355]; and
- The experiment already had a lengthy duration, and incorporating objective methods would further extend this, due to the necessary time to calibrate the instruments. This additional time could lead to increased frustration or boredom among participants, considering the low or inexistent workload required from the participant, as supported by Holzwarth, et al. [356].

Following the recommendation of Hosany, et al. [20], who defend that the selection of the subjective model to assess emotions must be dependent on the study's purpose, as detailed in section 2.3.2, this study resorts to a categorical approach. The categorical model of positive and negative emotions was used resorting to PANAS [198]. The choice of this model was driven by the necessity to associate specific multisensory stimuli with the specific triggered emotional reaction, to fill a gap in the literature pointed out by several authors [22-26]. PANAS allows the distinction between positive (PANAS-PA) and negative (PANAS-NA) affects, each composed of discrete emotions. It is one of the most used scales within emotional research [42], including in the VR context [22]. Specifically, a Portuguese short-version of the PANAS (PANAS-PTsv), developed and validated by Galinha, et al. [357] was used. This version was underpinned by a prior study from the same authors [358], in which they translated (and subsequently, validated) the original 20-item PANAS from English to Portuguese. PANAS-PTsv is a 10-item survey comprising 5 positive and 5 negative affect items, as opposed to the original version, which consists of 20 items, encompassing 10 positive and 10 negative affect items. Table 8 presents a comparison that includes all 20 originally written positive and negative affect items. The items in bold represent those retained for the shortened version, with the English version on the left column and the corresponding Portuguese translation on the right column.

Table 8 20-item PANAS version (original and Portuguese translated versions)

Original version by Watson, et al. [198]	Translated version by Galinha and Pais-Ribeiro [358]
PANAS – 10 Positive Affects (PA)	
Interested	***Interessado***
Enthusiastic	***Entusiasmado***
Excited	*Excitado*
Inspired	***Inspirado***
Determined	***Determinado***
Proud	*Orgulhoso*
Active	***Activo***
Alert	*Encantado*
Attentive	*Caloroso*
Strong	*Agradavelmente surpreendido*
PANAS – 10 Negative Affects (NA)	
Distressed	*Perturbado*
Upset	***Atormentado***
Afraid	***Amedrontado***
Scared	***Assustado***
Nervous	***Nervoso***
Jittery	*Trémulo*
Ashamed	*Remorsos*
Guilty	***Culpado***
Irritable	*Irritado*
Hostile	*Repulsa*

3.4.2. VVIQ adaptation for MI data collection

Two important features define MI, VIV and the CC, as detailed in section 2.4.1, both related to the human imaginative ability. As the name suggests, VIV refers to the capability of recalling vivid images, whereas the CC denotes the ability to mentally transform or manipulate an image [5, 245].

This thesis aims to understand the participants' aptitude to vividly recall specific details regarding the objects presented in the virtual multisensory treasure hunt, rather than if they can mentally manipulate them. Thus, the CC would not add any relevant information about it. So, we focus on VIV, thus, applying the VVIQ. This questionnaire's main advantages, as discussed before, lie in its high versatility [9], including the suitability for specific research goals (e.g., [278, 279]), as well as high reliability [244, 276, 277] and robustness [234, 244]. For this thesis context, a Portuguese adaptation of the VVIQ was conceived (Table 9) to serve this investigation's goals (assessing VIV according to the used objects and multisensory combinations). The originally written Portuguese version can be consulted in the appendix section 10.2 (Table 60).

Table 9 Adaptation of VVIQ (English translation from Portuguese)

Object	Briefing	Details
PORTUGUESE GUITAR	Think of a **Portuguese Guitar** and carefully consider the picture that comes before your mind's eye.	1. Can you visualize the overall appearance of that Portuguese Guitar? 2. Can you visualize the colors of that Portuguese Guitar? 3. Can you visualize the shapes of that Portuguese Guitar? 4. Can you visualize that Portuguese Guitar hanging on the wall?
BARREL OF PORT WINE	Think of a **barrel of Port wine** and carefully consider the picture that comes before your mind's eye.	1. Can you visualize the overall appearance of that barrel of Port wine? 2. Can you visualize the colors of that barrel of Port wine? 3. Can you visualize the shapes of that barrel of Port wine? 4. Can you visualize that Barrel of Port Wine in the middle of others?
RABELO BOAT	Think of a **Rabelo boat** and carefully consider the picture that comes before your mind's eye.	1. Can you visualize the overall appearance of that Rabelo boat? 2. Can you visualize the colors of that Rabelo boat? 3. Can you visualize the shapes of that Rabelo boat? 4. Can you visualize that Rabelo boat sailing on the river?
PINE TREE	Think of a **pine tree** and carefully consider the picture that comes before your mind's eye.	1. Can you visualize the overall appearance of that pine tree? 2. Can you visualize the colors of that pine tree? 3. Can you visualize the shapes of that pine tree? 4. Can you visualize that pine tree in a forest, amidst hundreds of others?
COMPASS	Think of a **compass** and carefully consider the picture that comes before your mind's eye.	1. Can you visualize the overall appearance of that compass? 2. Can you visualize the colors of that compass? 3. Can you visualize the shapes of that compass? 4. Can you visualize that compass pointing south in your own hand?

For the development of this VVIQ adaptation, four questions were developed. The originally proposed 5 points Likert scale was maintained as the answering scale.

The internal consistency of this adapted questionnaire was made, resulting in high levels of consistency, as Table 10 shows. All questionnaires show Cronbach's alpha values higher than 0,7, in accordance with recommendations from DeVellis [359] and Kline [360].

Table 10 Reliability statistics to assess the internal consistency of VVIQ's adaptation

	Cronbach's Alpha	Number of Items
VVIQ's 1st object questionnaire	,885	4
VVIQ's 2nd object questionnaire	,901	4
VVIQ's 3rd object questionnaire	,887	4
VVIQ's 4th object questionnaire	,914	4
VVIQ's 5th object questionnaire	,821	4

3.4.3. The Igroup Presence Questionnaire

Addressing topics like MI, multisensory stimulation in VR, and conducting emotion-based research without considering the sense of presence of users is practically unfeasible, as they are almost indissociable topics. As previously discussed, data from the user's sense of presence revealed to be essential in VR, namely to understand the impact of multisensory stimulation [43, 91, 95, 128], to explore the users' emotions [217], and the concept of MI [5].

Based on the literature review on presence assessment in VR (section 2.1.1.1), the IPQ was selected for gathering data on users' sense of presence. This choice was primarily influenced by the IPQ's high reliability and the subscales it measures [72]. It has been widely utilized to explore the elements influencing presence within virtual environments and their impact on users' overall experiences [361]. Moreover, when compared to other scales, the IPQ incorporates the notion of "being there" through the standalone item G1, and it encompasses five items to evaluate spatial presence, four for involvement, and it assesses the perception of experienced realism through four items. Below, we present the IPQ's 14 items divided by its subscales (Table 11). The full Portuguese version of the IPQ, which was used in the virtual experiments, can be consulted in Appendix section 10.5. It corresponds to the Portuguese version of the IPQ, validated by Vasconcelos-Raposo, et al. [362], which maintains the authenticity of the questions originally developed by [61].

Table 11 IPQ items divided by its subscales

Subscale	**Item ID**	**Item**
Presence	G1	In the computer-generated world I had a sense of "being there".
Spatial Presence	SP1	Somehow I felt that the virtual world surrounded me.
	SP2[1]	I felt like I was just perceiving pictures.
	SP3	I did not feel present in the virtual space.

	SP4	I had a sense of acting in the virtual space, rather than operating something from outside.
	SP5	I felt present in the virtual space.
Involvement	INV1	How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?
	INV2	I was not aware of my real environment.
	INV3[1]	I still paid attention to the real environment.
	INV4	I was completely captivated by the virtual world.
Experienced Realism	REAL1[1]	How real did the virtual world seem to you?
	REAL2	How much did your experience in the virtual environment seem consistent with your real world experience?
	REAL3	How real did the virtual world seem to you?
	REAL4	The virtual world seemed more realistic than the real world.

[1] Item is reverse-coded due to their Likert polarity, as defined by the author [61]

3.5. Post-VR: the After-Scenario Questionnaire

A post-experiment questionnaire was used to measure participants' satisfaction after the virtual experiment. The ASQ was chosen to evaluate the VR experiment, due to its low complexity (brief and easy to answer), and high reliability and sensitivity. Moreover, it is suitable for formal usability studies [363, 364]. The ASQ is a 3-item questionnaire with a 7-point Likert scale from "Strongly disagree" to "Strongly agree". It was presented in 1991, by Lewis [364], but it is still one of the most popular psychometric methods to currently evaluate studies in the field of Human-Computer Interaction [363]. It facilitates a comprehensive assessment of user's satisfaction in terms of easiness, time required, and information provided to complete a certain task. Originally written in English, the ASQ is as follows:

1. Overall, I am satisfied with the ease of completing the tasks in this scenario.
2. Overall, I am satisfied with the amount of time it took to complete the tasks in this scenario.
3. Overall, I am satisfied with the support information (online help, messages, documentation) when completing the tasks.

As no validated translation of the ASQ into Portuguese could be found, items were presented according to the translation developed and used by Moniz [365] (appendix section 10.4).

4. Experimental design validation and users' tests

This section starts by describing the sample of participants recruited for the virtual experiment in the research (section 4.1), followed by the data preparation process (section 4.2). Then, the validation of the experimental design is presented (section 4.3), which encompasses a focus group session (section 4.3.1) and the analysis of the users' pre- and post-emotional responses (4.3.2). Lastly, the results regarding the IPQ and the ASQ are revealed, respectively in sections 4.4 and 4.5.

4.1. Sample

To answer the proposed R.Qs., a between-subjects experimental study consisting of an immersive VT experience was developed. This means that each participant only experienced one of the IVEs, either positive or negative, resulting in two groups of participants. This methodology was implemented with great concern for the sample, as demographics might have a significant influence on users' emotions and VIV, as discussed. Also, as previously denoted, since the research took place in Portugal, all elements of the experiment, including the out-VR questionnaires and all the features of the IVE (the initial instructions, the audios, and the in-VR questionnaires) were developed in Portuguese. This decision is linked to the participants' greater comfort with their native language, Portuguese, as compared to English.

In the first questionnaire (Q1), all participants were asked if they had normal vision, good hearing (either naturally or with correction), and the ability to smell and taste food. They were also inquired about any physical or cognitive conditions that might prevent them from fully experiencing VR, such as epilepsy, frequent migraines, or eye diseases. These responses were analyzed beforehand to ensure that there would be no medical complications during the virtual experiment, thereby protecting the health and safety of the participants.

The decision regarding the number of participants in this study was guided by the recommendations of Macefield [366], who suggests that, in comparative studies, a sample size ranging from 8 to 25 participants per group is typically sufficient to yield statistically significant results. The author also advises that an increase in the group size intensifies the study's reliability, which is recommended for complex studies, although it also raises the experiment duration and the eventual inherent costs. Nonetheless, it is important to note that even in more complex studies, the number of participants should be calculated based on the effect size intended to be measured. Attention should be given to the test's power, and the sample size (N) should not be increased indiscriminately.

To enhance participation in the virtual experiment, the strategy involved a widespread promotion through FEUP. The result was a non-probabilistic convenience sample. A total of 94 volunteer participants (47 male and 47 female), between 18 and 66 years of age (M = 34,99; SD = 12,138)[2] completed the experiment (Table 12).

Table 12 Sample Descriptive Statistics (gender and age groups crosstabulation)

		Age Groups					Total
		18 ≥ 24	25 ≥ 34	35 ≥ 44	45 ≥ 54	≥ 55	
Gender	Male	20	8	6	8	5	47
	Female	7	14	14	11	1	47
Total		27	22	20	19	6	94

The academic qualifications of the participants ranged from high school to Ph.D. levels, as shown in Table 13. The majority were individuals with an academic degree, accounting for 76 participants (80.85%), which is likely attributable to the extensive dissemination conducted at FEUP.

[2] In order to simplify the age descriptive statistics, five age groups were created (18≥24, 25≥34, 35≥44, 45≥54, and ≥55). For this subdivision, consideration was given to evenly distributing age ranges across each group.

Table 13 Sample Descriptive Statistics (gender and academic qualifications crosstabulation)

		Academic Qualifications				Total
		High School	Graduation	Master's Degree	Ph.D.	
Gender	Male	8	16	17	6	47
	Female	10	16	20	1	47
Total		18	32	37	7	94

4.1.1. User's participation validation process

Following the completion of the three-question ASQ, participants responded to the final six questions about the pleasantness of the controllable stimuli (taste and smell, and haptics), i.e., those not included in the basis of the VR experience (V+A). These questions can be found in the Appendix section 10.4. The information obtained contributed as the basis of the user's participation validation process, which consisted of two stages:

1. Verification of the pleasantness of controllable stimuli in the experienced IVE, detailed below;
2. Detection of aphantasic participants, which might potentially lead to biased results.

For the first stage, data were organized using a conditional filter to select the cases that fulfilled the following requirements:

- For the positive IVE:
    1. The participant reported **being able** to discern two distinct smells and two different flavors, and also felt some heat directed towards their face during the experience;
    2. The participant reported that the taste stimuli (wine and cinnamon), the olfactory stimuli (pine and cinnamon), and the haptic stimuli (heat) had been **pleasant**.
- For the negative IVE:
    1. The participant reported **not being able** to discern two distinct smells and two different flavors, and also did not feel any heat directed towards their face during the experience;
    2. The participant reported that the taste stimuli (vinegar and salt), the olfactory stimuli (liquid smoke and fish-oil), and the haptic stimuli (cool) had been **unpleasant**.

The following matrix (Table 14) represents the validation process using this conditional filter, according to the IVE (positive or negative), leading to the exclusion of 14 participants, as they did not simultaneously meet both criteria set for the selected IVE.

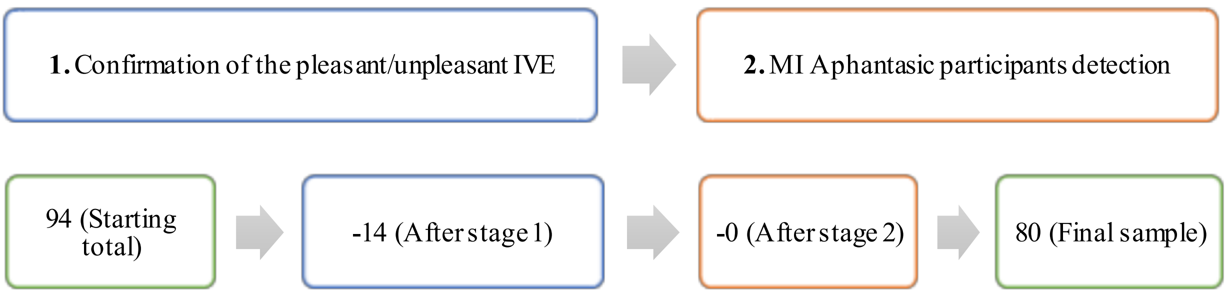
Table 14 User's participation validation process

	Positive IVE		Negative IVE	
Stimuli	Distinguished and reported as pleasant	Distinguished and reported as unpleasant	Distinguished and reported as pleasant	Distinguished and reported as unpleasant
Taste	✓	✗	✗	✓
Smell	✓	✗	✗	✓
Haptics	✓	✗	✗	✓

The second and last stage of the user's participation validation process was the detection of aphantasic participants, i.e., those who scored under 40% of the maximum total score in the VVIQ for any of the five objects. So, considering a maximum score of 20 points for each object, a minimum of 8 points per object must have been achieved to be considered a valid participation. This validation stage was inspired by the conclusions of some authors [234, 259], who argued, as previously addressed, that results including responses from aphantasic are likely to bias the conclusions. It is worth noting that, after a rigorous analysis of the VVIQ's individual score for each of the objects, no aphantasics were detected.

The two stages of the validation process and the number of participants removed accordingly are illustrated in Diagram 3.

Diagram 3 Validation process and adjustment of the number of participations



After the participation validation process, data could be tested to analyze the outliers and normal distribution according to each R.Q.' dependent and independent variables.

Despite investigation on the impact of outliers in ordinal data being scarce, as attested by Zijlstra, et al. [367], there is no evidence to suggest that retaining outliers in studies using ordinal scales, such as Likert scales, could be detrimental to the research. The authors defend that outliers detected in data resulting from Likert scales may just reflect extreme responses, although they do not necessarily indicate outliers. Instead, they might reflect strong attitudes or opinions of the measured construct and may be interpreted in the specific context of the study. Furthermore, as stated by the same authors, an outlier in a Likert scale questionnaire is an unusual observation. So, a particular and careful observation of each outlier must be done to conclude whether it should be discarded.

Following this recommendation, in this thesis, a search by outliers was performed, and 26 cases were detected by exploring the variables' boxplots. Each case was analyzed individually, leading to the conclusion that these outliers simply represented strong yet consistent responses aligned with each participant's overall results.

While an equal gender distribution across the negative and positive IVEs was initially achieved with 47 men and 47 women completing the experiences, the validation process reduced the sample size from 94 to 80 participants, resulting in an inability to maintain the initial precise distribution. Thus, the final sample was composed of 80 individuals, with 18 men and 17 women experiencing the negative IVE, and 23 males and 22 females experiencing the positive IVE (Table 15).

Table 15 Sample descriptive statistics (gender and IVE crosstabulation)

		IVE		**Total**
		Negative	Positive	
Gender	Male	18	23	41
	Female	17	22	39
Total		35	45	**80**

Lastly, in terms of the sample's normal distribution, the data were not normally distributed as expected, mainly due to the acceptance of outliers. This was evidenced by the combined results of the Kolmogorov-Smirnov and Shapiro-Wilk tests, both showing p < 0,001, indicating that employing non-parametric tests would be more suitable. Moreover, considering the unequal group sample sizes, these tests are even more recommended [368].

4.2. Data preparation

After validating the users' participation, the next step was to prepare the data to conduct the tests needed to address the proposed R.Qs. This involved processing the outcomes from:

- The presence scores derived from the IPQ scores analysis;
- The emotional outcomes from the pre- and post-tests, based on the PANAS scores comparison between the first and the last obtained responses;
- The positive and negative emotional responses obtained after the treasure hunt task, based on the PANAS scores;

- The VIV results obtained after the treasure hunt task, based on the VVIQ scores;
- The overall satisfaction with the virtual experiment, determined through the ASQ scores.

The scoring approach adopted was the original recommended by the authors of each respective questionnaire. For the IPQ, the average scores of the four subscales were computed for each of the IVEs (for further comparison), accounting for the reverse items, as suggested by the authors [61]. Higher IPQ scores indicate greater effectiveness of the IVEs in terms of presence, while lower scores suggest the opposite [67].

Regarding PANAS, two different results were generated: Positive Affects (PA) and Negative Affects (NA). PANAS-PA and PANAS-NA correspond to the average score of the positive and the negative emotional responses, respectively [198]. As the short version was used, to obtain the final scores of PANAS-PA and PANAS-NA, the sum of the five PANAS-PA and the five PANAS-NA was calculated [357]. A Likert scale composed of 5 points was used, as originally proposed. Therefore, results could range between 5 and 25 for each scale (PANAS-PA and PANAS-NA).

Regarding VVIQ, the final score involved summing up each participant's responses to all items. Considering a Likert scale of 5 points, and a total of four questions per object, as originally proposed, total scores vary between 4 and 20 per object. Higher scores are related to more vivid and clear VIV, and vice-versa [27].

Finally, ASQ results were obtained by calculating the mean of the three questions composing this questionnaire. Higher scores are related to an overall higher satisfaction with the virtual experiment, and vice-versa [364].

It is worth noting that all the quantitative statistical analysis was performed resorting to the IBM® Statistical Package for the Social Sciences (SPSS®) Statistics software, version 28.

4.3. Validation of the experimental design

To validate the experimental design, a focus group session was conducted prior to the users' tests (section 4.3.1). The primary goal was to validate the multisensory cues to be used in the VR experiments. This ensured that the multisensory stimuli combinations developed to serve in the IVEs as negative were indeed perceived as such, and similarly, those identified as positive were actually considered as positive by the participants. This focus group session also intended to understand the participants' perspectives regarding the two developed IVEs as a whole, i.e., regarding the congruency between all the stimuli and the VR scenario.

After the VR experiments, an analysis of the users' pre- and post-emotional responses was conducted (section 4.3.2). The aim was to confirm that they had indeed reported more intensively positive emotions when exposed to combinations of positive multisensory stimuli. Conversely, it was also intended that they had reported more intensively negative emotions when exposed to combinations of negative multisensory stimuli. This second step aimed to reaffirm the results obtained in the focus group, which ultimately led to the validation of the positive and negative IVEs.

4.3.1. Focus group

Focus groups are, in general, essential to debate and generate solutions based on a discussion between participants [369]. As one of this thesis' main goals is to explore the role of multisensory stimuli on the users' emotional responses and VIV in VR, it was crucial to validate the sensorial cues to be used in the VR experiments as well as the congruence between them, and its ability to trigger positive and negative emotions. Thus, a focus group was performed. This session was carefully planned, organized, and consequently analyzed to comply with the recommendations of experts on qualitative research. Typically, a well-designed focus group consists of 6 to 12 participants to ensure enough participants to yield adequate diversity in the information provided, and usually takes between 1 and 2 hours. Participants can be formed by preexisting groups, like colleagues from the same place of work. The data gathered from focus group sessions can be diverse [370], encompassing individual data, group data, and data from group interactions, as highlighted in [369].

For the focus group, a mixed population, varied in age and background, was recruited to collect more diversified points of view. A focus group session (Figure 34) was performed on the 3rd of March 2023, composed of seven participants, 3 men and 4 women (excluding the moderator – this thesis' author), with a duration of 1 hour and 20 minutes.

A convenience sample composed of Portuguese students, investigators, and professors from FEUP was recruited. Participants' ages ranged between 25 and 51 years of age (M = 40,71). The descriptive information of this sample is represented in Table 16.

The main goal of this focus group was to test and validate the developed positive and negative IVEs and the corresponding stimuli that would be used in the IVEs. To do that, ordinal data from questionnaires, and qualitative data from the discussion were collected. Regarding the ordinal data, participants were asked to explicitly report whether they considered each of the presented stimuli as pleasant/positive or unpleasant/negative. For the qualitative data, a discussion between the participants was recorded (voice only, previously authorized by each of the participants), and moderated by this thesis' author. All data was collected in the same focus group session, with the same participants.

Figure 34 Focus group session

Table 16 Focus group descriptive statistics

		Minimum	Maximum	Mean	Valid N (listwise)
Age		25	51	40,71	
Gender	Men				3
	Women				4
Total					7

The session was divided into four main stages, as follows:

1. **Introduction**: session presentation, sociodemographic questionnaire (Q1), a questionnaire regarding food intolerances and personal tastes (Q2), and signing the Informed Consent Statement[3];
2. **Individual tasks**, when participants were presented with the different multisensory stimuli, regarding each of the following subjects:
   2.1. Narratives: five positive (to be confirmed) and five negative (to be confirmed) stories about each of the five objects that would be used in the VR experiment;

[3] The sociodemographic questionnaire, the personal questionnaire, and the Informed Consent Statement can be found in the Appendix section 10.3.1.

2.2. Narrator voice test: one female positive (to be confirmed) and one female negative (to be confirmed) voice tones;
2.3. Climate test: one positive (to be confirmed) and one negative (to be confirmed) weather situation;
2.4. Olfactory test: two positive (to be confirmed) and two negative (to be confirmed) odors;
2.5. Taste test: two positive (to be confirmed) and two negative (to be confirmed) flavors;
2.6. Ambient sound test: one positive (to be confirmed) and one negative (to be confirmed) environment background noises);

3. **Discussion**; and
4. **Focus group experience review**.

In the first stage (1), all participants completed a sociodemographic questionnaire (Q1) and, subsequently, a personal questionnaire (Q2). In Q2, they could report any food intolerances, and their personal food tastes (like/tolerate; don't like/don't tolerate; refuse to try) on a table listing all the ingredients, among some decoys, they would be asked to taste. Participants were informed about the existence of a few decoys in this table, to prevent them from immediately guessing what they were going be invited to taste. As decoys, peanuts and shellfish were used. This questionnaire was subject to an initial rapid analysis to ensure that none of the participants were allergic or refused to try any of the foods (naturally, excluding the decoys). In the event of any participant indicating allergy or refusal to try (again, excepting decoys), they would not participate in that specific food test. It is worth noting that it did not occur.

After completing Q1, Q2, and signing the informed consent statement, participants were presented with the different multisensory stimuli. Initially, participants were instructed to register their assessment of each stimulus as positive/pleasant or negative/unpleasant. They were also encouraged to take some personal to facilitate the recollection of those stimuli's information later. Participants were told that their notes would be disregarded and disposed of after the session, and therefore, not analyzed. This procedure was done to ensure that they felt free to write down anything that came into mind for easier recall later, without any concern of being judged due to their thoughts.

Regarding the narratives exercise (stage 2.1), participants were invited to read the five narratives developed with the purpose of triggering positive emotions, and the other five developed to trigger negative emotions. As described in section 3.2.2.1, to trigger positive emotions, memorable and honored events were portrayed, whereas to trigger negative emotions, desolate and tragic events were described.

Considering the narrators' voices (stage 2.2), two voice tones were presented: the first one was intended to trigger positive emotions, considering being a more enthusiastic and cheerful voice tone, compared to the second one, which was supposed to trigger negative emotions, as it was a monotonous and melancholic voice tone. Additionally, participants were asked: 1) if they could recognize two different voice tones, and 2) which were the main differences between the two voice tones.

The following proposed exercise was related to the introduction of the climate situations – heat and cool (stage 2.3). A discussion was encouraged to: 1) understand the participants' preferences regarding heat and cool, in general; 2) understand the participants' preferences regarding heat and cool, considering a specific scenario (an outside situation with around 15ºC, where one feels thermally comfortable); 3) try to establish an association between heat, cool, sun, rain, the night's darkness and the day's light with positive and negative emotions.

Then, four odors (stage 2.4) – two to be confirmed as positive (coffee and pine) and two to be confirmed as negative (liquid smoke and fish oil) were presented to test their ability to awaken positive and negative emotions.

After, with the same purpose, four liquid food samples (stage 2.5) – two to be confirmed as positive (coffee and Port wine) and two to be confirmed as negative (salted water and water with vinegar) were introduced to the participants. For reasons of hygiene, and considering possible contagions by COVID-19, all the materials used in the olfactory and taste tests were for single and disposable use (cups, cup lids, straws, and paper for spraying the odor). Nevertheless, considering environmental ethics, special attention was taken to ensure that all the used materials were recyclable and/or biodegradable.

Finally, two ambient sounds – birds chirping and rain dropping (stage 2.6) were presented to contextualize the positive and the negative IVEs, respectively, to the participants.

All the previous stages' information was registered by the participants on a designated sheet. During the discussion (stage 3), a debate (without any further written registers) was promoted to:

1. gather feedback about the stimuli they have experienced in the previous stage;
2. explore their acceptance regarding the introduction of negative/unpleasant olfactory and taste stimuli and, specifically, the introduction of alcohol from Port wine (in minimal quantity) in a VR experience;
3. understand their opinion regarding the two developed IVEs, which were intended to be presented in the VR experiences. During this step, participants were introduced to a description of the to-be-confirmed-positive and negative IVEs, which would be composed of some of the stimuli that they had just been presented. So, they were informed that the positive IVE would be an outside sunlit touristic place, where one could hear the birds chirping, and feeling the heat, while listening to positive stories about the five described

objects, told by the first narrator. The negative IVE would be the same outside IVE, where one could see and hear the rain dropping, feel the wind and watch it shaking the trees, while listening to negative stories about the same objects, told by the second narrator.

Finally, in the focus group experience review (stage 4), participants were asked to evaluate the focus group, regarding the complexity of the tasks, the enjoyment, and final comments or suggestions. It was unanimous that it was a funny session, well-developed and organized. No further comments or suggestions were added.

This focus group session's qualitative data was analyzed resorting to the classical content analysis model, organized according to the following points, as described by Onwuegbuzie, et al. [370]:

1. Transcription of the focus group audio record;
2. Codification of small chunks of data;
3. Group similar contents;
4. Count the chunks within each of the created codes (frequency), resulting in quantitative information.
5. If possible, supplement this quantitative data with a description of each code (qualitative data), originating a mixed method of content analysis, which will enrich the results and conclusions.

4.3.1.1. Focus group's outcomes

Regarding this focus group's results, first, it is important to mention that no allergies or refusal to try any listed foods (including decoys, just out of curiosity) were registered.

A combined analysis of the quantitative and qualitative data was performed (mixed method of content analysis), as recommended by Onwuegbuzie, et al. [370]. First, a transcription of the focus group discussion was made, which can be found in the appendix section 10.3.2 (Table 61). The data were then submitted to rigorous analysis, supported by the software webQDA® (Qualitative Data Analysis), conducted by this thesis author and followed by the validation of a specialized investigator to crosscheck the work, resulting in minor improvements. To analyze the qualitative data, a codebook was developed (appendix section 10.3.3) based on the validation criteria (Table 17). After these steps, the frequency of each code (quantitative data) was obtained, also represented in appendix section 10.3.3, complying with the classical method of content analysis.

Table 17 Criteria to validate qualitative data regarding the positive and negative stimuli

STIMULI			SCENARIOS	
			To be considered as positive	**To be considered as negative**
		Object		
READING	Narratives	Portuguese Guitar Wine Barrel *Rabelo* Boat Pine Tree Compass	• Recalled good memories or feelings • Participants associated the object with positive emotions, according to PANAS-PTsv	• Recalled bad memories or feelings • Participants associated the object with negative emotions, according to PANAS-PTsv
AUDITORY	Voice Tones	Narrator 1 Narrator 2	• Recalled good memories or feelings • Participants associated that voice tone with positive emotions, according to PANAS-PTsv	• Recalled bad memories or feelings • Participants associated that voice tone with negative emotions, according to PANAS-PTsv
AUDITORY	Ambient Sounds	Birds Chirping Rain	• Recalled good memories or feelings • Participants associated birds chirping/rain sounds to positive emotions, according to PANAS-PTsv	• Recalled bad memories or feelings • Participants associated birds chirping/rain sounds to negative emotions, according to PANAS-PTsv
HAPTICS	Climate situations	Heat	• Recalled good memories or feelings • Participants associated heat with positive emotions, according to PANAS-PTsv • Whenever it was mentioned that it was dependent on the context and that it was consistent with the VR experiment (Spring/Summer)	• Recalled bad memories or feelings • Participants associated heat with negative emotions, according to PANAS-PTsv • Whenever it was mentioned that it was dependent on the context and that it was not consistent with the VR experiment date (Spring/Summer)
HAPTICS	Climate situations	Cold	• Recalled good memories or feelings • Participants associate cold with positive emotions, according to PANAS-PTsv • Whenever it was mentioned that it was dependent on the context and that it was consistent with the VR experiment (Spring/Summer)	• Recalled bad memories or feelings • Participants associated cold with negative emotions, according to PANAS-PTsv • Whenever it was mentioned that it was dependent on the context and that it was not consistent with the VR experiment date (Spring/Summer)
OLFACTORY	Liquid Smoke Fish-oil Coffee Pine		• Recalled good or neutral-to-good memories or feelings • Participants associated it with positive emotions, according to PANAS-PTsv • Whenever the reported smell was correct or very close to the real one	• Recalled bad or neutral-to-bad memories or feelings • Participants associated it with negative emotions, according to PANAS-PTsv • Whenever the reported smell was correct or very close to the real one
TASTE	Salted water Water with vinegar Coffee Port Wine		• Recalled good or neutral-to-good memories or feelings • Participants associated it with positive emotions, according to PANAS-PTsv • Whenever the reported taste was correct or very close to the real one	• Recalled bad or neutral-to-bad memories or feelings • Participants associated it with negative emotions, according to PANAS-PTsv • Whenever the reported taste was correct or very close to the real one

Conclusions originated by the combined analysis of the quantitative and qualitative data are presented next, to conclude whether a story (Table 18), a voice tone (Table 19), a climate situation (Table 20), an odor (Table 21), a taste (Table 22), and an ambient sound (Table 23) could be considered as positive (green highlighted) or as negative (orange highlighted). Yellow highlighted are the problematic stimuli, which will be addressed throughout this section.

Regarding the narratives (Table 18 and grey part of the codebook - Table 62), stories 1, 5, 7, 8, and 9 could be considered as positive, and stories 2, 3, 4, 6, and 10 as negative, as projected. However, story 1, regarding the *Rabelo* boat, according to the participants' recommendations (qualitative data), presented two inaccurate terms: "inutilizados" ("unused") and "margens do rio" ("riverbanks"). Thus, these terms have passed through a revision. The other nine stories remained the same for the VR experiences, as no unfavorable aspects were reported to consider stories 5, 7, 8, and 9 as positive, and more favorable aspects could be found to consider stories 2, 3, 4, 6, and 10 as negative, according to both quantitative and qualitative results.

Table 18 Narratives descriptive analysis

	Positive	**Percent**	**Negative**	**Percent**	**Total**
Story 1	**6**	85,7%	1	14,29%	N = 7 / 100%
Story 2	2	28,57%	**5**	71,43%	N = 7 / 100%
Story 3	1	14,29%	**6**	85,71%	N = 7 / 100%
Story 4	1	14,29%	**6**	85,71%	N = 7 / 100%
Story 5	**7**	100%	0	0%	N = 7 / 100%
Story 6	1	14,29%	**6**	85,71%	N = 7 / 100%
Story 7	**6**	85,71%	1	14,29%	N = 7 / 100%
Story 8	**7**	100%	0	0%	N = 7 / 100%
Story 9	**7**	100%	0	0%	N = 7 / 100%
Story 10	0	0%	**7**	100%	N = 7 / 100%

For the narrators' voice test, quantitative data (Table 19 and blue part of the codebook - Table 62) left no doubt that narrator 1 could be considered as positive and narrator 2 as negative. Qualitative data also confirmed such results, as more favorable arguments could be found to consider voice tone 1 as positive and voice tone 2 as negative.

Table 19 Voice tones descriptive analysis

	Positive	Percent	Negative	Percent	Total
Narrator 1	**7**	100%	0	0%	N = 7 / 100%
Narrator 2	0	0%	**7**	100%	N = 7 / 100%

Results regarding climate situations (Table 20 and pink part of the codebook - Table 62) could validate heat as positive and cold as negative, according to both quantitative and qualitative data.

Table 20 Climate situations descriptive analysis

	Positive	Percent	Negative	Percent	Total
Heat	**5**	71,43%	2	28,57%	N = 7 / 100%
Cold	0	0%	**7**	100%	N = 7 / 100%

Regarding odors (Table 21 and yellow part of the codebook - Table 62), liquid smoke and fish oil could be validated by both qualitative and quantitative data as negative olfactory stimuli. Pine was also validated as a positive stimulus. However, coffee odor, although initially projected to be a positive stimulus, could not be confirmed as such, considering the quantitative data. Moreover, qualitative data revealed just one favorable aspect to consider it as positive. Implications for it will be later discussed at the end of this section.

Table 21 Fragrances descriptive analysis

	Positive	Percent	Negative	Percent	Total
Pine	**7**	100%	0	0%	N = 7 / 100%
Liquid Smoke	1	14,29%	**6**	85,71%	N = 7 / 100%
Coffee	1	14,29%	**6**	85,71%	N = 7 / 100%
Fish oil	2	28,57%	**5**	71,43%	N = 7 / 100%

Qualitative and quantitative data were congruent regarding taste stimuli (Table 22 and green part of the codebook - Table 62): water with vinegar and salted water were revealed to be negative taste stimuli, whereas Port Wine was undoubtedly considered a positive stimulus. However, similar to the olfactory test, coffee has not been revealed to be a strong positive taste stimulus, especially considering the qualitative data. The implications of this will also be addressed at the end of this section.

Table 22 Tastes descriptive analysis

	Positive	Percent	Negative	Percent	Total
Salted water	2	28,57%	**5**	71,43%	N = 7 / 100%
Port Wine	**7**	100%	0	0%	N = 7 / 100%
Water with vinegar	1	14,29%	**6**	85,71%	N = 7 / 100%
Coffee	**4**	57,14%	3	42,86%	N = 7 / 100%

Finally, regarding the ambient sounds (Table 23 and orange part of the codebook - Table 62), birds chirping and rain have been revealed to be a positive and a negative stimuli, respectively.

Table 23 Ambient sounds descriptive analysis

	Positive	Percent	Negative	Percent	Total
Birds chirping	**7**	100%	0	0%	N = 7 / 100%
Rain	1	14,29%	**6**	85,71%	N = 7 / 100%

As already mentioned, yellow highlights in Table 18, Table 21, and Table 22 show the concluded most problematic stimuli: story 1 as a positive auditory stimulus, and coffee as both positive taste and olfactory stimuli. Regarding story 1, as briefly commented, "inutilizados" (unused) was seen as a negatively strong word to define the *Rabelo* boats. Also, it was suggested to change that the *Rabelo* boats used to sail "along the riverbanks" ("margens do rio") for "along the river" (not the riverbanks), as it is not a precise fact. So, story 1 has been reviewed and rewritten accordingly.

Regarding coffee, it was found to be a questionable cue to use in the IVEs, especially as taste stimulus, due to the inexact serving temperature, due to the caffeine's undesirable effects reported by some individuals (or to the unpleasant of decaffeinate reported by others), and also due to missing sugar (which is not unanimous, as some participants would prefer it with no sugar). One participant considered coffee as a "dangerous" ("perigoso") stimulus, based on these arguments. Pondering these opinions, and also the weak quantitative supporting coffee as a positive olfactory cue, it was considered to change coffee as both olfactory and taste stimuli. It was suggested by the moderator, and highly supported by the participants' opinion, that cinnamon tea could be a great substitute for it, with the arguments that it has a great flavor, its taste tends to be consensually pleasant, and there are many options to introduce it in the VR experiment (e.g., bags or tea leaves). Additionally, cinnamon tea provides a consistent link between the object and its associated multisensory stimuli, similar to coffee. It also connects to the "Age of Discoveries," represented by the compass, just as coffee was intended to. So, in short, to substitute coffee as an olfactory stimulus, cinnamon was elected, and to substitute it as a taste stimulus, cinnamon tea was chosen.

Based on this focus group, some improvements have been made to the originally proposed experimental design, which differences are clarified in Table 24:

Table 24 Stimuli changes based on the focus group

Stimuli	Initial	Final
Auditory stimuli (Story 1)	O Barco Rabelo foi idealizado para o transporte de mercadorias, nomeadamente para o transporte de vinho do Porto. Circulava pelas margens do Rio Douro, por onde seguia até chegar a Vila Nova de Gaia, para envelhecer até ganhar o seu sabor caraterístico. Apesar de atualmente inutilizados, ainda é possível ver alguns exemplares a embelezar o rio Douro. Cada barco mede entre 19 e 23 metros de comprimento, e pode transportar, em média, até 100 barris!	O Barco Rabelo foi idealizado para o transporte de mercadorias, nomeadamente para o transporte de vinho do Porto. Circulava pelo Rio Douro, por onde seguia até chegar a Vila Nova de Gaia, para envelhecer e ganhar o seu sabor caraterístico. Apesar de atualmente o Barco Rabelo já não servir para o mesmo propósito, ainda é possível ver alguns exemplares a embelezar o rio Douro como atração turística. Cada barco mede entre 19 e 23 metros de comprimentos, e pode transportar, em média, até 100 barris
Olfactory Stimuli	Coffee	Cinnamon aroma
Taste Stimuli	Coffee	Cinnamon tea

4.3.2. Emotions pre and post-tests

To ensure that the designed IVE would not bias the subsequent results, an initial test was performed to ensure that the positive and negative IVEs met the expectation of eliciting intensely more positive emotions in the first case, and intensely more negative emotions in the second. To do this, a comparative analysis of emotions before and after the virtual experiment, obtained with PANAS, was conducted (emotional responses pre and post-tests).

Prior to analyzing the differences in the users' emotional responses before and after the VR experiment, a test to assess normality was performed, by exploring the skewness and kurtosis values of each variable, which varied between -2 and 2. According to George and Mallery [371], these values are within the acceptable range for confirming a normal distribution. Therefore, the parametric paired-sample t-test was used. This test allows to determine whether there is a statistically significant difference in the mean score of positive and negative emotions before and after the exposure [371].

The analysis of Table 25, related to the positive IVE, allows concluding statistically significant lower levels of all the PANAS-PA before than after the virtual experiment, specifically for “interest” (t(44) = -4,249, p < ,001), “enthusiasm” (t(44) = -4,180, p < ,001), “inspiration” (t(44) = -7,416, p < ,001), “determination” (t(44) = -3,292, p < ,05), and “activeness” (t(44) = -2,874, p < ,05). For the PANAS-NA, only “nervousness” was found statistically higher before than after the VR exposure (t(44) = 2,028, p < ,05).

Table 25 Paired Samples T-test for the positive IVE

			Paired Differences							Significance
			Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Two-Sided p
						Lower	Upper			
PANAS-PA	Pair 1	Interested_Pre – Interested_Pos	-,533	,842	,126	-,786	-,280	-4,249	44	**< ,001**
	Pair 2	Enthusiastic_Pre – Enthusiastic_Pos	-,600	,963	,144	-,889	-,311	-4,180	44	**< ,001**
	Pair 3	Inspired_Pre – Inspired_Pos	-1,333	1,206	,180	-1,696	-,971	-7,416	44	**< ,001**
	Pair 4	Determined_Pre – Determined_Pos	-,578	1,177	,175	-,931	-,224	-3,292	44	**,002**
	Pair 5	Active_Pre – Active_Pos	-,356	,830	,124	-,605	-,106	-2,874	44	**,006**
PANAS-NA	Pair 6	Upset_Pre – Upset_Pos	-,022	,499	,074	-,172	,128	-,298	44	,767
	Pair 7	Afraid_Pre – Afraid_Pos	,089	,596	,089	-,090	,268	1,000	44	,323
	Pair 8	Scared_Pre – Scared_Pos	,156	,520	,078	-,001	,312	2,006	44	,051
	Pair 9	Nervous_Pre – Nervous_Pos	,222	,735	,110	,001	,443	2,028	44	**,049**
	Pair 10	Guilty_Pre – Guilty_Pos	-,022	,260	,039	-,100	,056	-,573	44	,570

Despite not demonstrating statistical significance, by observing the t-values, there is a notable tendency for higher levels of PANAS-PA after than before the exposure. The opposite can be noted regarding the PANAS-NA of “afraidness”, “scariness”, and “nervousness”, i.e., they decreased after the exposure. In summary, they show that the positive IVE was effective in accentuating all the users' positive emotions while reducing the negative ones, as intended. Overall, the combination of high levels of PANAS-PA and low levels of PANAS-NA after the VR exposure on the positive IVE means that it has pleased the users, as projected. The circumstances surrounding the location where the experience occurred might have contributed to this result: the majority of the participants entered that lab for the first time, they were not acquainted with the people there, and had only a rough idea of what their role would be in the virtual experiences. This situation could have influenced the overall PANAS outcomes: as the virtual experiment progressed, PANAS-NA decreased and PANAS-PA increased, coinciding with the participants becoming increasingly comfortable with the situation.

Regarding the negative IVE, by analyzing Table 26, it is possible to conclude, for a sample of 35 users, that statistically lower levels of inspiration (PANAS-PA) were found before than after the VR exposure ($t(34) = -2{,}836$, $p < ,05$), as attested by the negative t-value, meaning that the first condition had a smaller mean than the second [372]. Also, statistically lower levels of PANAS-NA "upset", ($t(34) = -4{,}552$, $p < ,001$)), "scariness" ($t(34) = -2{,}451$, $p < ,05$), and "guiltiness" ($t(34) = -2{,}503$, $p < ,05$) were found before than after the VR exposure. No other statistically significant results could be observed (as $p > ,05$).

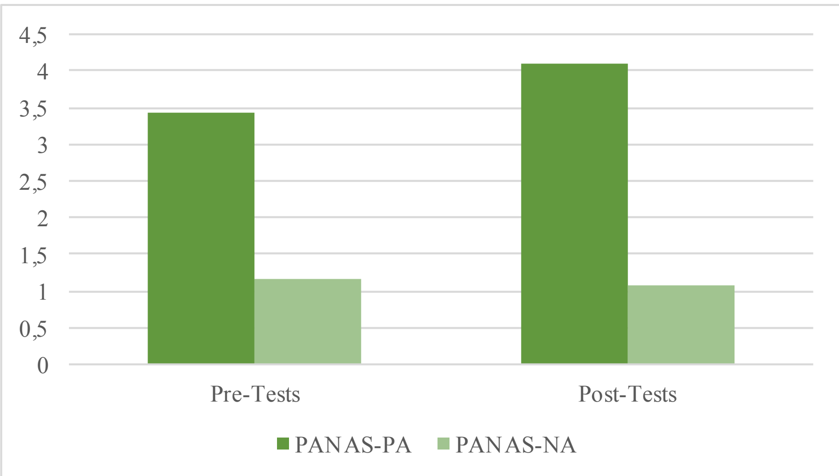
Table 26 Paired Samples T-test for the negative IVE

			Paired Differences							Significance
			Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Two-Sided p
						Lower	Upper			
PANAS-PA	Pair 1	Interested_Pre – Interested_Pos	-,057	1,083	,183	-,429	,315	-,312	34	,757
	Pair 2	Enthusiastic_Pre – Enthusiastic_Pos	-,171	1,224	,207	-,592	,249	-,828	34	,413
	Pair 3	Inspired_Pre – Inspired_Pos	-,657	1,371	,232	-1,128	-,186	**-2,836**	34	**,008**
	Pair 4	Determined_Pre – Determined_Pos	,143	1,240	,210	-,283	,569	,682	34	,500
	Pair 5	Active_Pre – Active_Pos	-,171	1,043	,176	-,530	,187	-,973	34	,338
PANAS-NA	Pair 6	Upset_Pre – Upset_Pos	-,771	1,003	,169	-1,116	-,427	**-4,552**	34	**< ,001**
	Pair 7	Afraid_Pre – Afraid_Pos	-,143	1,004	,170	-,488	,202	-,842	34	,406
	Pair 8	Scared_Pre – Scared_Pos	-,486	1,173	,198	-,888	-,083	**-2,451**	34	**,020**
	Pair 9	Nervous_Pre – Nervous_Pos	,171	1,014	,171	-,177	,520	1,000	34	,324
	Pair 10	Guilty_Pre – Guilty_Pos	-,200	,473	,080	-,362	-,038	**-2,503**	34	**,017**

Despite not showing statistical significance, by observing the t-values, there is a notable tendency for higher levels of PANAS-PA after than before the exposure (excepting "determination"). The same can be noted regarding the PANAS-NA (with the exception of "nervousness"). Nevertheless, a notably higher intensity in PANAS-NA compared to PANAS-PA was registered in the negative IVE, reinforcing the validation of the stimuli used in this IVE as negative. In summary, these results indicate that, despite amplifying the intensity of users' negative emotions, as intended, it also heightened the overall positive emotions. This result was somehow expected, considering the immersive nature of VR, which intensifies emotional responses irrespective of whether the stimuli are more positive or negative. This result is consistent with prior studies, which highlight the capacity of immersion to evoke a wide range of emotional responses [19, 174, 176], with different intensity levels [1, 2, 177], as previously discussed.

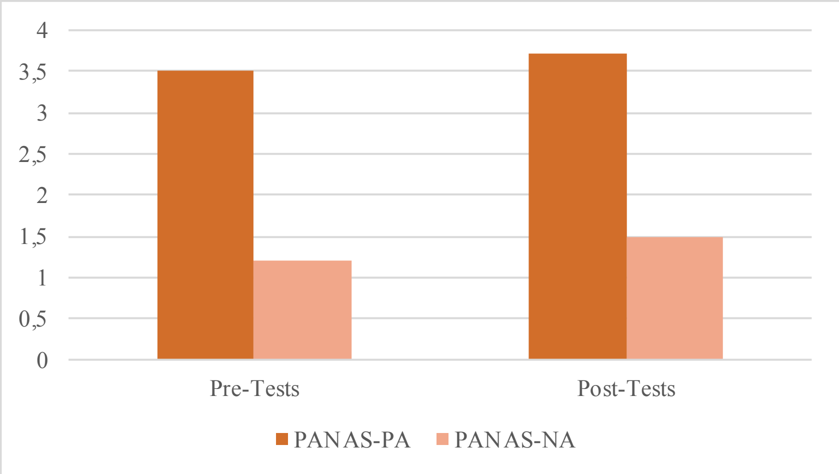
Still regarding the negative IVE, only the levels of the PANAS-PA "inspiration" registered statistically high levels after than before the VR exposure. Nevertheless, an increase in the overall users' positive emotions was noted. This outcome could be due to the perception of VR as a novel experience by some users, resulting in their satisfaction regardless of the specific stimuli applied, as Talukdar and Yu [220] explained, and supported by Archer, et al. [128]. Furthermore, if we correlate these findings with the sense of presence, an alternative explanation for these results emerges: the presence scores in the negative IVE were significantly high (and higher than those in the positive IVE). Given that presence is linked to higher levels of immersion [43, 91, 93-95], engagement [62], virtual environment's effectiveness [67], and higher levels of users' overall satisfaction [34], this may have contributed to a general increase in the user's positive emotions.

The joint analysis of Graph 1 and Graph 2 allows for a wide perspective of these results. On the one hand, we can conclude that the positive IVE fulfilled the task of accentuating the users' PANAS-PA while mitigating the negatives. As Graph 1 illustrates, there is an increase in PANAS-PA from the pre- to the post-test results, while PANAS-NA shows a decrease.



Graph 1 Results of the pre- and post-tests from the positive IVE

On the other hand, the negative IVE was powerful enough to increase users' overall emotions. As shown in Graph 2, there was a tendency for both PANAS-PA and PANAS-NA to increase from the pre- to the post-tests.



Graph 2 Results of the pre- and post-tests from the negative IVE

These key observations, drawn from comparing emotional responses before and after the experiments, indicate that the subsequent analysis was not impacted by any potential drawbacks in the virtual experiment development. The successful elicitation of the targeted emotions supports this, pointing to potentially reliable outcomes. Furthermore, this likely indicates that the preliminary exploration into multisensory stimuli carried out for developing the IVEs (section 3.2.1), and the conducted focus group proved to be advantageous and valuable for the research.

4.4. IPQ results

To ensure VR applications deliver a good user experience and fulfill their intended goals, it is vital to evaluate their effectiveness, and presence is a key factor in assessing it [67]. High presence scores are crucial in many areas, for instance in terms of engagement, as discussed previously, revealing particularly valuable in VT, to enhancing the tourism experience [17]. Presence scores are crucial not just for assessing the effectiveness of a VR application, but also for determining if the subsequent results could have been influenced by any reported low levels of presence.

The analysis of the IPQ was conducted to assess each subscale, regarding the positive and the negative IVEs. After this, the differences between the two groups could be explored.

By the combined analysis of Table 27 and Table 28, it is possible to conclude that, in general, similar high scores were obtained for the four subscales of IPQ, for both IVEs. In light of the innovative research conducted by Melo, et al. [67], which offers significant insights into interpreting and evaluating the effectiveness of VR applications in terms of presence (also utilizing the IPQ), it is noticeable that both IVEs scored above average. The authors reported an average overall presence score of 3.40 in their analyzed studies. They found averages of 3.99 for spatial presence, 3.33 for involvement, and 2.65 for experienced realism. Our results exceed these benchmarks, as demonstrated in the subsequent tables. Therefore, following their qualitative grading description for presence, the VR environments used in this thesis can be classified as "Very Good" (Grade B).

Table 27 IPQ Score for the positive IVE

IPQ Subscale	Total Score	SD
Overall presence	4,3778	,11141
Spatial presence	4,2267	,05915
Involvement	4,1444	,06430
Experienced realism	3,9000	,07470

Table 28 IPQ Score for the negative IVE

IPQ Subscale	Total Score	SD
Overall presence	4,4571	,11841
Spatial presence	4,2857	,06874
Involvement	4,2143	,08645
Experienced realism	3,9357	,07344

Next, to determine the most accurate test to assess the differences between the two groups, first, IPQ data was checked for normal distribution. The joint analysis of Kolmogorov-Smirnov and the Shapiro-Wilk test (both presenting $p < 0{,}001$ for all the IPQ items) – Table 29 – demonstrated that the data were not normally distributed, meaning that the use of non-parametric tests is advisable. Given the unequal sizes of the sample groups, the use of these tests is even more strongly recommended [368]. Consequently, the Kruskal-Wallis Test, an alternative to the parametric test one-way ANOVA, was performed to test if there are significant differences in the central tendencies (medians) of these two groups, as recommended [371, 372]. All the three basic assumptions this test requires were valid, which are as follows [373]:

1. The dependent variable that is being tested (presence) is continuous or ordinal;
2. There should have independence of observation, indicating that there is no relationship or dependency among the observations within each group of the independent variable or among the groups themselves;

3. Each group should consist of at least 5 observations. This threshold ensures that the chi-square distribution is a good approximation for the H statistic when the sample size falls within this range or above.

Table 29 Tests of normality

Scale	Item ID	IVE	Kolmogorov-Smirnov			Shapiro-Wilk		
			Statistic	df	Sig.	Statistic	df	Sig.
Presence	G1	Negative	,324	35	<,001	,706	35	<,001
		Positive	,309	45	<,001	,757	45	<,001
Spatial Presence	SP1	Negative	,245	35	<,001	,838	35	<,001
		Positive	,236	45	<,001	,834	45	<,001
	SP2[1]	Negative	,312	35	<,001	,739	35	<,001
		Positive	,264	45	<,001	,747	45	<,001
	SP3	Negative	,319	35	<,001	,744	35	<,001
		Positive	,332	45	<,001	,745	45	<,001
	SP4	Negative	,474	35	<,001	,530	35	<,001
		Positive	,403	45	<,001	,618	45	<,001
	SP5	Negative	,297	35	<,001	,743	35	<,001
		Positive	,253	45	<,001	,803	45	<,001
Involvement	INV1	Negative	,288	35	<,001	,790	35	<,001
		Positive	,344	45	<,001	,750	45	<,001
	INV2	Negative	,287	35	<,001	,776	35	<,001
		Positive	,315	45	<,001	,745	45	<,001
	INV3[1]	Negative	,296	35	<,001	,785	35	<,001
		Positive	,219	45	<,001	,846	45	<,001
	INV4	Negative	,323	35	<,001	,744	35	<,001
		Positive	,367	45	<,001	,715	45	<,001
Experienced Realism	REAL1[1]	Negative	,231	35	<,001	,894	35	<,001
		Positive	,249	45	<,001	,889	45	<,001
	REAL2	Negative	,390	35	<,001	,702	35	<,001
		Positive	,245	45	<,001	,786	45	<,001
	REAL3	Negative	,348	35	<,001	,748	35	<,001
		Positive	,274	45	<,001	,855	45	<,001
	REAL4	Negative	,337	35	<,001	,711	35	<,001
		Positive	,313	45	<,001	,742	45	<,001

[1] Item is reverse-coded, as defined by the author [374]

The Kruskal-Wallis test (*H*) conducted to assess the differences in the four subscales of sense of presence between the positive and the negative IVEs revealed no statistically significant differences Table 30, specifically:

- regarding overall presence ($H(1)$ = ,203, p = ,652);
- regarding spatial presence: ($H(1)$ = ,857, p = ,354);
- regarding involvement: ($H(1)$ = ,766 , p = ,381);
- regarding experienced realism: ($H(1)$ = ,204, p = ,651).

Table 30 Independent-samples Kruskal-Wallis test (hypothesis test summary)

	Null Hypothesis	Sig.[a,b]	Decision
1	The distribution of Overall_Presence is the same across categories of IVE.	,652	Retain the null hypothesis.
2	The distribution of Spatial_Presence is the same across categories of IVE.	,354	Retain the null hypothesis.
3	The distribution of Involvement is the same across categories of IVE.	,381	Retain the null hypothesis.
4	The distribution of Experienced_Realism is the same across categories of IVE.	,651	Retain the null hypothesis.

[a] The significance level is ,050.
[b] Asymptotic significance is displayed.

Nevertheless, it is important to check whether a Type II error occurred, i.e., a statistical error of failing to detect a significant effect when, in fact, it exists [372], also known as a false negative. According to Martín and Martinez [375], eta squared is a suitable test to assess the effect size (η^2) when performing the Kruskal-Wallis test. So, it was calculated using the following formula [376], considering that SPSS does not calculate it [371]:

$$\eta^2 = \frac{H}{N-1}$$

Results demonstrate, for all the IPQ subscales, a very small ($\eta^2 < 0{,}01$) to small ($0{,}01 < \eta^2 < 0{,}05$) effect size [375], indicating that the grouping variable accounts for a very small proportion of the variance in the dependent variable [376]. This aligns with the Kruskal-Wallis test result reinforcing that there are no statistically significant differences between the groups, and, consequently, discarding the likelihood of a type II error:

- regarding overall presence (η^2 = 0,0026);
- regarding spatial presence: (η^2 = 0,01084);

- regarding involvement: (η^2 = 0,0096);
- regarding experienced realism: (η^2 = 0,0026).

4.5. ASQ results

As previously explained in section 3.5, the goal of ASQ is to assess users' overall satisfaction in terms of ease, time required, and available information to finish the task, in a Likert scale with a maximum of 7 points, as clarified by Lewis [364]. Results obtained (Table 31) showed a high level of satisfaction, mainly regarding the information available to complete the tasks (M = 6,81), but also regarding the easiness of the tasks (M = 6,56), and the time required to perform them (M = 6,54).

Table 31 ASQ results

ASQ Item	Mean	Median	Minimum	Maximum
ASQ_1 (Easiness)	6,56	7,00	4	7
ASQ_2 (Time)	6,54	7,00	4	7
ASQ_3 (Information)	6,81	7,00	4	7

5. Users’ emotional responses according to different stimuli combinations

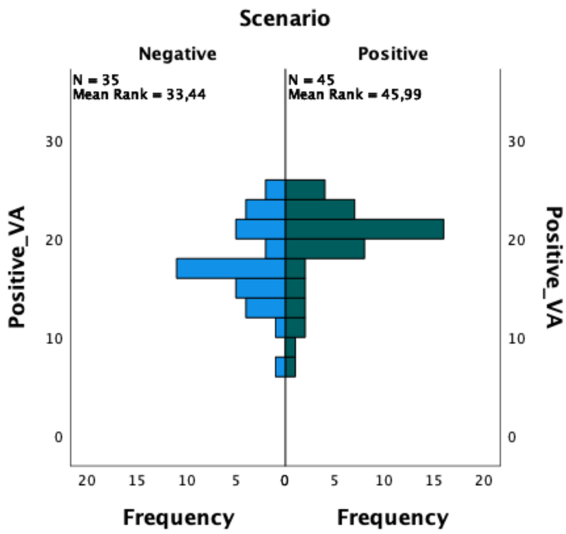
In light of the ongoing advancements in VR technology, there is a notable gap in understanding the effects of various combinations of multisensory stimuli on users' emotions. As virtual experiences become more intricate by incorporating diverse sensory inputs, it becomes imperative to comprehend how different combinations elicit distinct emotional responses. This section, aligned with R.Q. 1, focuses on exploring users' emotions within a multisensory virtual experience, encompassing both positive and negative multisensory stimuli combinations. Building on the introduced IVEs in section 3, an analysis was conducted to evaluate the impact of each multisensory stimuli combination on users' emotions. The goal is to uncover how the addition of specific stimuli, such as taste, haptics, or smell, either individually to the basic V+A, or collectively in the form of V+A+T+H+S, influences users' emotional responses.

This section starts by previewing the data analysis process, followed by the presentation of results regarding the positive IVE, aligned with R.Q. 1.1 (section 5.2), and the negative IVE, corresponding to R.Q. 1.2 (section 5.3). Subsequently, a unified discussion of these results is provided in section 5.4.

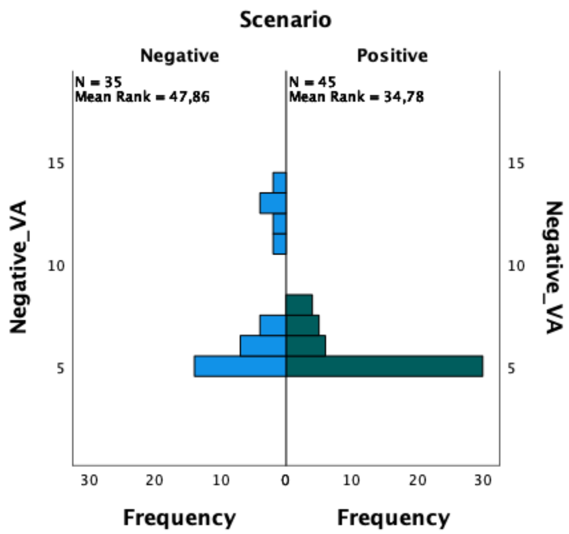
5.1. Data analysis

The initial step to determine the emotional differences according to the stimuli combinations involved a comparative analysis of the effect of each multisensory combination. This approach aids in comprehending how the incorporation of each specific stimulus (taste, haptics, or smell) to the basic V+A, or their collective application (V+A+T+H+S), influences the users' emotional responses. So, first, an analysis regarding the normal distribution of PANAS-PA and PANAS-NA according to each multisensory stimuli combination used in the IVEs was done, revealing that they were not normally distributed, as assessed by visual inspection (Graph 3 to Graph 12).

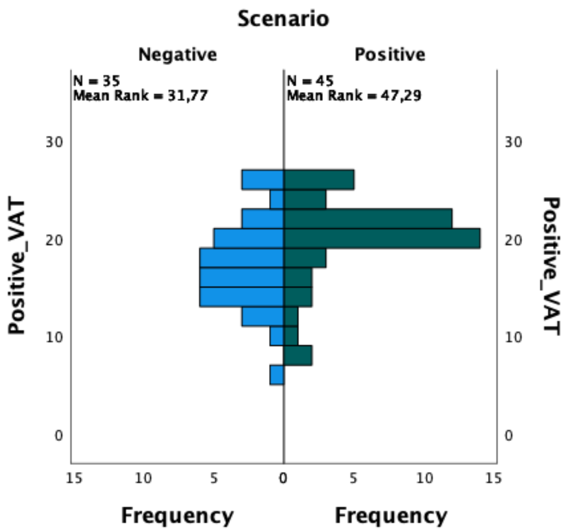
Graph 3 Distribution regarding PANAS-PA for V+A



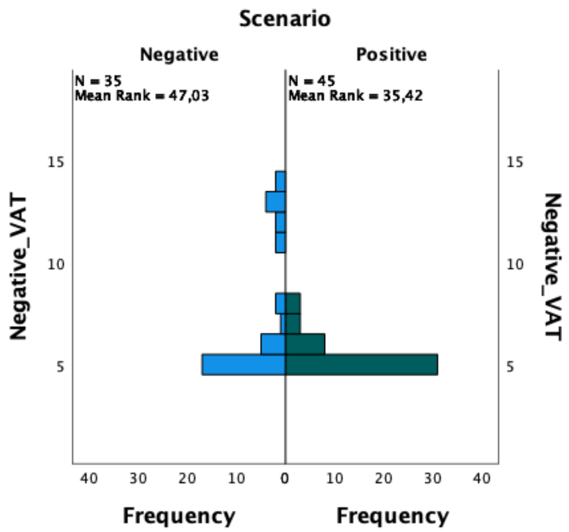
Graph 4 Distribution regarding PANAS-NA for V+A



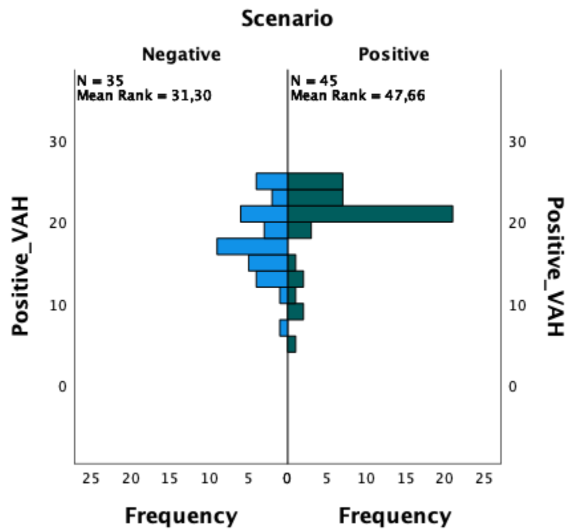
Graph 5 Distribution regarding PANAS-PA for V+A+T



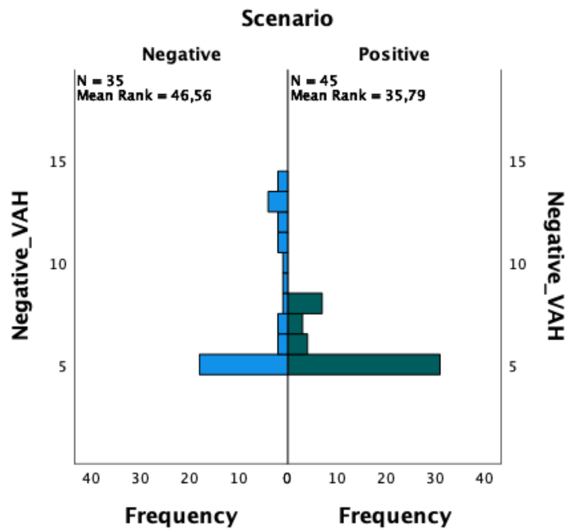
Graph 6 Distribution regarding PANAS-NA for V+A+T



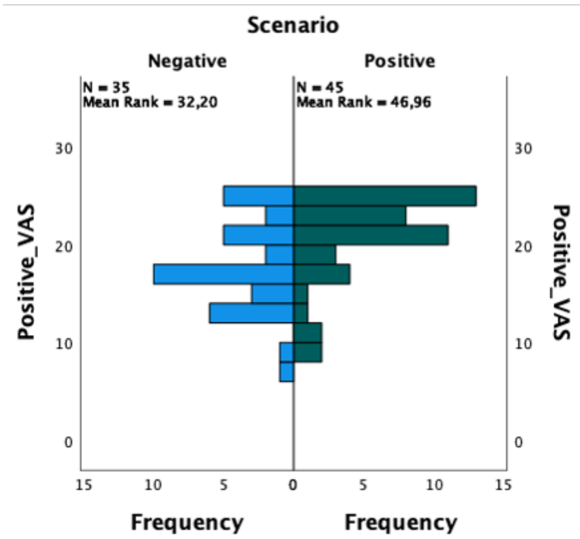
Graph 7 Distribution regarding PANAS-PA for V+A+H



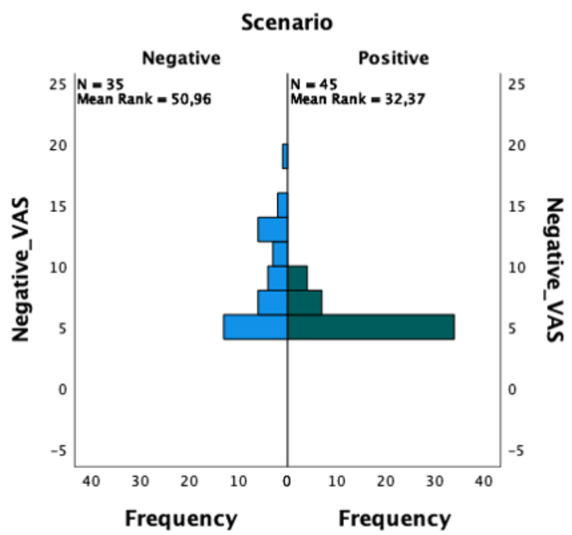
Graph 8 Distribution regarding PANAS-NA for V+A+H



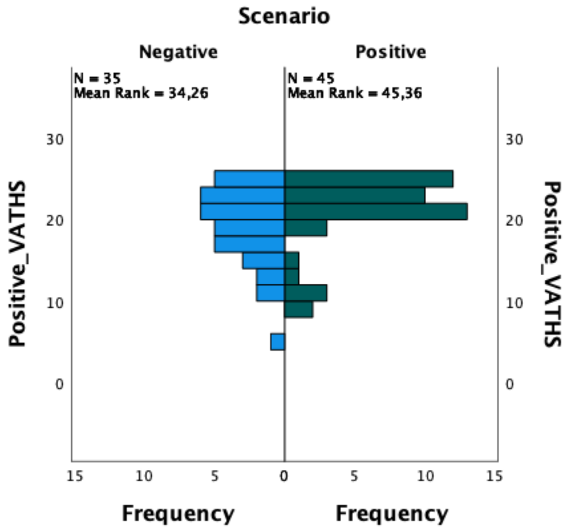
Graph 9 Distribution regarding PANAS-PA for V+A+S



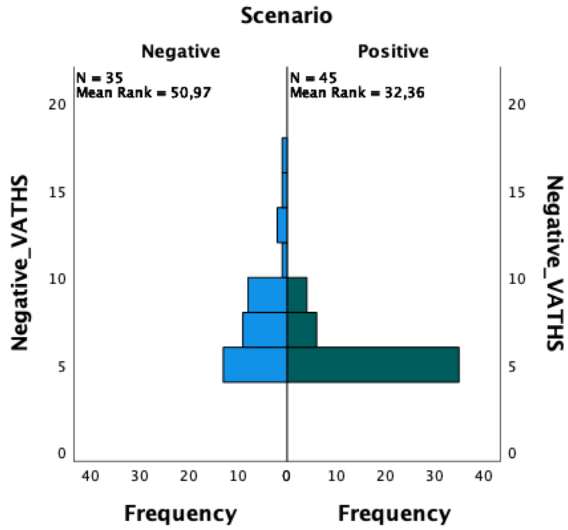
Graph 10 Distribution regarding PANAS-NA for V+A+S



Graph 11 Distribution regarding PANAS-PA for V+A+T+H+S



Graph 12 Distribution regarding PANAS-NA for V+A+T+H+S



Now, to adequately address R.Q. 1, which concern the impact of the different multisensory stimuli combinations on the user's emotions, considering the positive IVE (R.Q. 1.1) and the negative IVE (R.Q. 1.2), an analysis using the Mann-Whitney U Test (*H*) was done. This non-parametric test was chosen considering that this investigation is composed of two independent groups (participants exposed to the positive IVE and those exposed to the negative IVE), and the resultant emotional data was ordinal. This test is suitable for identifying potential statistical differences between two groups regarding a continuous or ordinal dependent variable [371]. All the three basic assumptions this test requires were valid, which are as follows [377]:

1. The groups being investigated must be drawn randomly from the population of interest;
2. There should have independence of observation, indicating that there is no relationship or dependency among the observations within each group of the independent variable or among the groups themselves;
3. The dependent variable that is being tested (emotional responses) is continuous or ordinal.

Thus, ten tests were performed to compare the differences between the two independent groups according to each stimuli combination, based on the following null hypothesis:

H_0: There are no differences between the positive and negative IVE regarding the users' emotions.

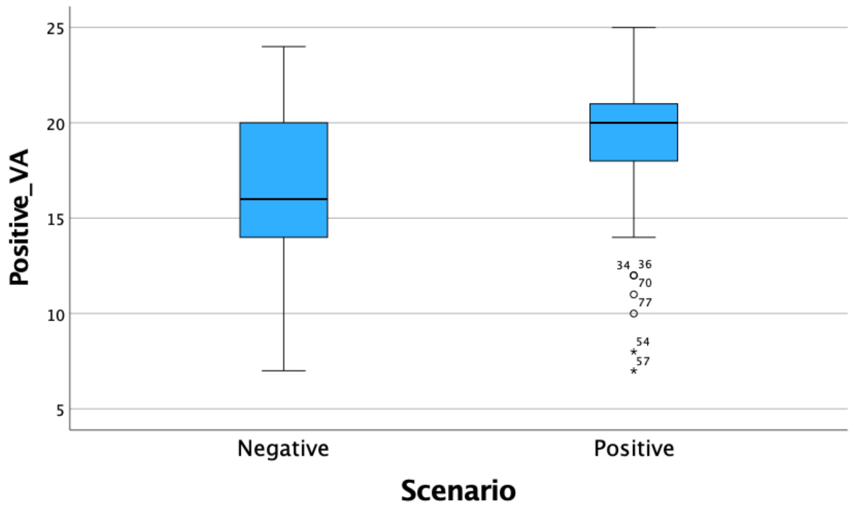
Results allowed us to reject the null hypothesis for all the stimuli combinations (Table 32), which means that there is evidence to support that statistically significant differences exist between the two groups for all the stimuli combinations. As α is considerably greater than p for all the stimuli combinations, this suggests that there is no evidence of an association (type I error) between the two groups, i.e., it supports the rejection of the null hypothesis [371].

Table 32 Mann-Whitney U Test (hypothesis test summary)

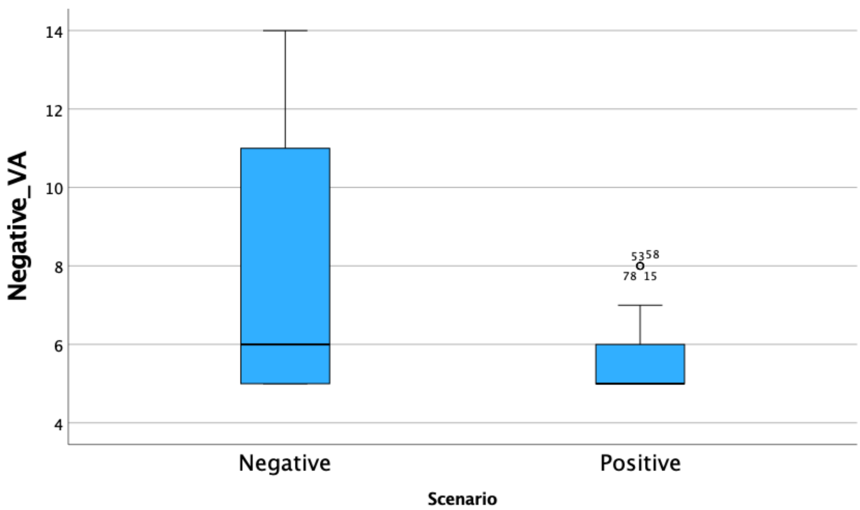
	Null Hypothesis	Sig.[a,b]	Decision
1	The distribution of Positive_VA is the same across categories of IVE.	,016	Reject the null hypothesis.
2	The distribution of Positive_VAT is the same across categories of IVE.	,003	Reject the null hypothesis.
3	The distribution of Positive_VAH is the same across categories of IVE.	,002	Reject the null hypothesis.
4	The distribution of Positive_VAS is the same across categories of IVE.	,005	Reject the null hypothesis.
5	The distribution of Positive_VATHS is the same across categories of IVE.	,033	Reject the null hypothesis.
6	The distribution of Negative_VA is the same across categories of IVE.	,006	Reject the null hypothesis.
7	The distribution of Negative_VAT is the same across categories of IVE.	,012	Reject the null hypothesis.
8	The distribution of Negative_VAH is the same across categories of IVE.	,019	Reject the null hypothesis.
9	The distribution of Negative_VAS is the same across categories of IVE.	< ,001	Reject the null hypothesis.
10	The distribution of Negative_VATHS is the same across categories of IVE.	< ,001	Reject the null hypothesis.

[a] The significance level is ,050.
[b] Asymptotic significance is displayed.

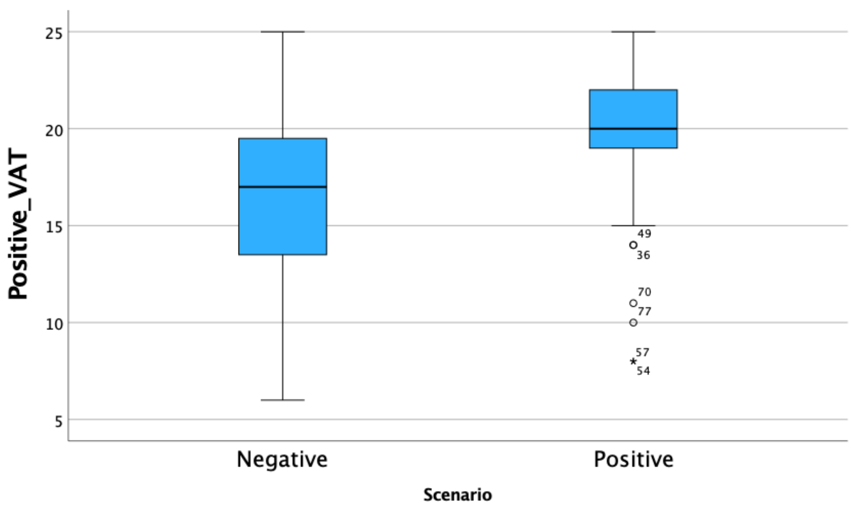
Also, the respective boxplots were built to visually inspect the differences between the two groups (Graph 13 to Graph 22). As observed, in the context of the positive IVE, PANAS-PA tends to have a greater central value than PANAS-NA, meaning that, on average, participants reported more intense positive emotional responses than negatives. Conversely, in the negative IVE, PANAS-NA shows a greater central value than PANAS-PA, meaning that, on average, participants reported more intense negative emotional responses than positives. This reinforces the differences between the two groups based on the various combinations of multisensory stimuli.



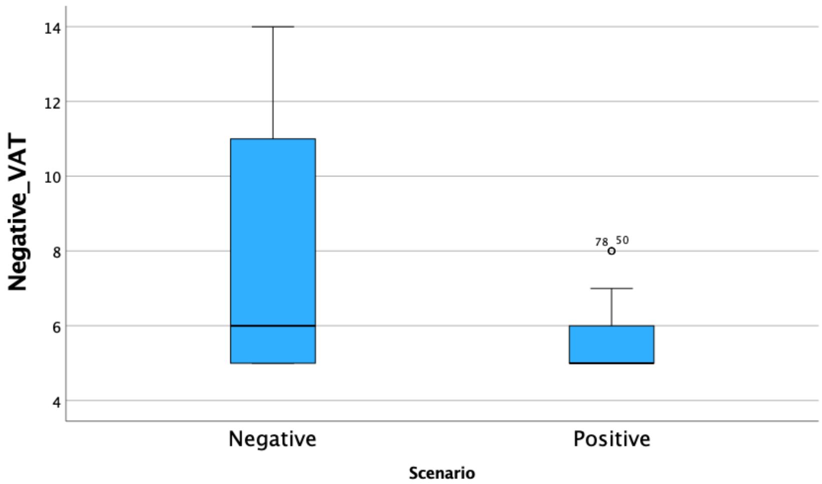
Graph 13 Differences regarding PANAS-PA for V+A



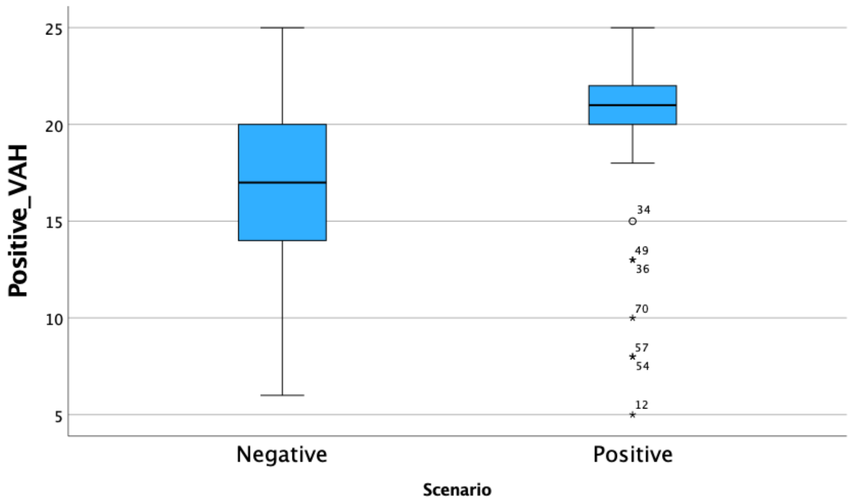
Graph 14 Differences regarding PANAS-NA for V+A



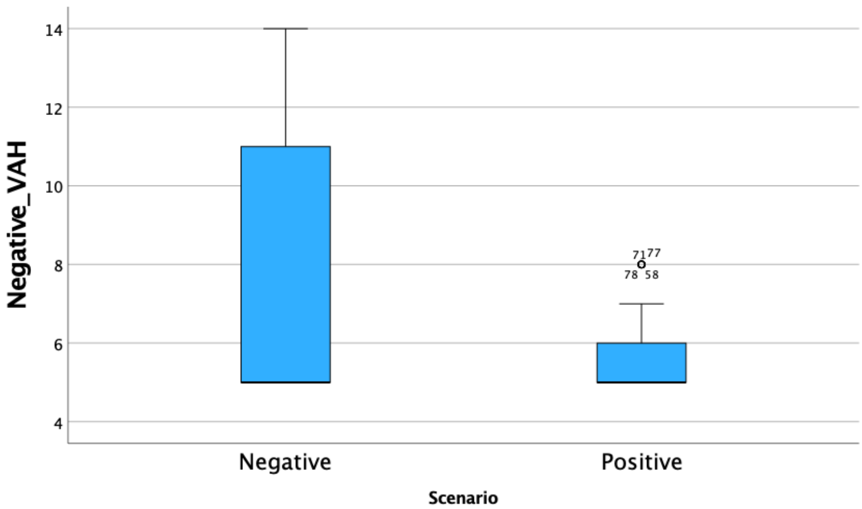
Graph 15 Differences regarding PANAS-PA for V+A+T



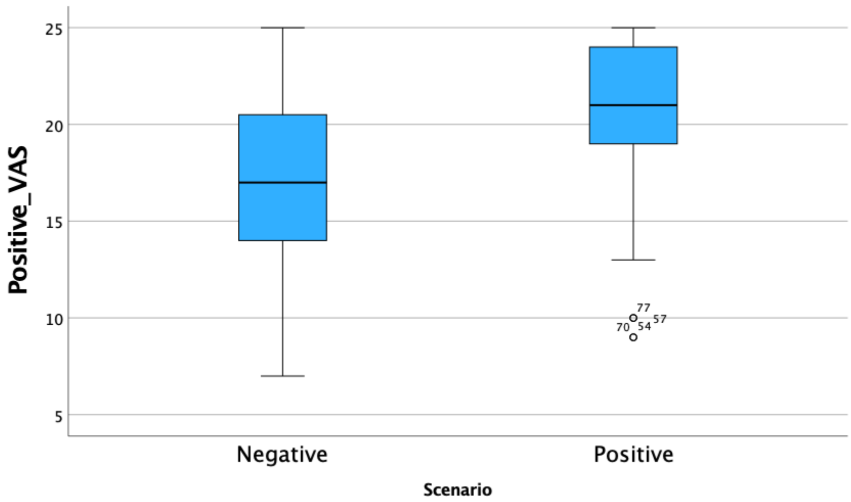
Graph 16 Differences regarding PANAS-NA for V+A+T



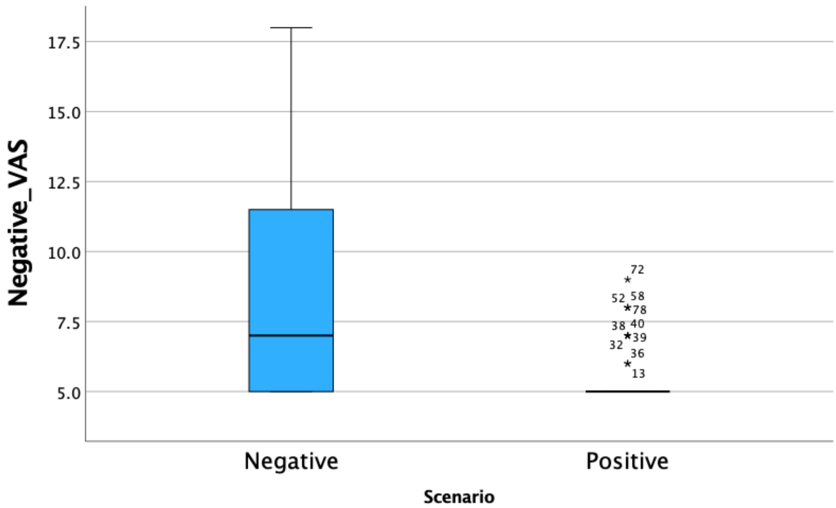
Graph 17 Differences regarding PANAS-PA for V+A+H



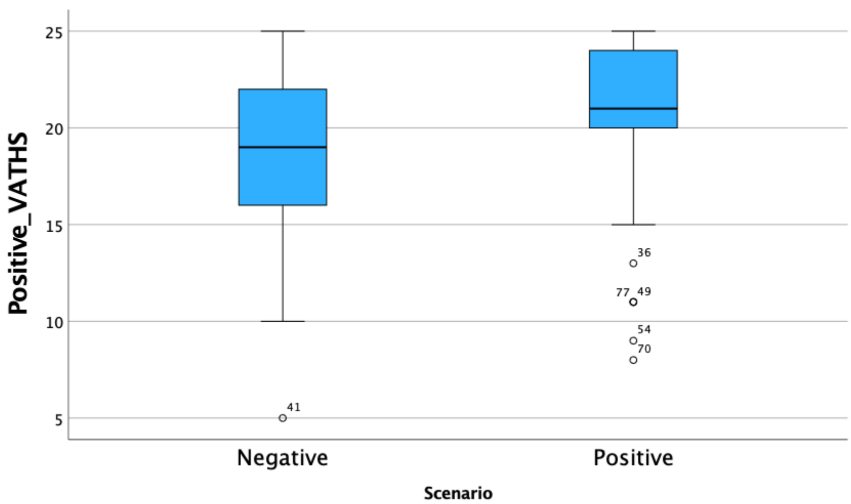
Graph 18 Differences regarding PANAS-NA for V+A+H



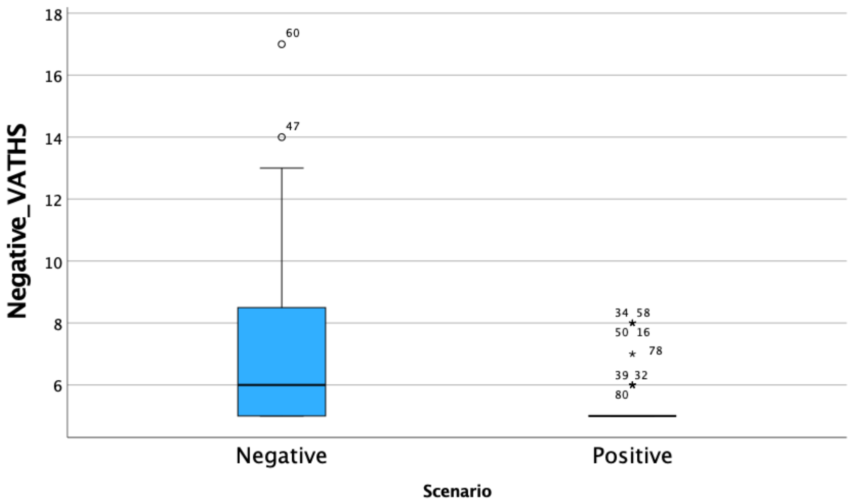
Graph 19 Differences regarding PANAS-PA for V+A+S



Graph 20 Differences regarding PANAS-NA for V+A+S



Graph 21 Differences regarding PANAS-PA for V+A+T+H+S



Graph 22 Differences regarding PANAS-NA for V+A+T+H+S

Nevertheless, to assess the effect size of the differences, the rank-biserial correlation coefficient (r_b) was performed (Table 33). According to Martín and Martinez [375], this is a suitable test to assess the effect size associated with the Mann-Whitney U test. So, it was calculated using Wendt's formula [378], where U stands for the Mann-Whitney U statistic value, $n1$ for the maximum sample size of the two groups ($n1 = 45$), and $n2$ for the minimum sample size of the two groups ($n2 = 35$):

$$r_b = 1 - \frac{2U}{n1 \times n2}$$

For all the stimuli combinations, independently on the IVE, results demonstrate small ($0,1 < r_b < 0,29$) to moderate effect sizes ($0,3 < r_b < 0,49$), which reinforces the discard of an eventual type I error, as significant differences could be detected between the two IVEs ($r_b > 0,27$).

Table 33 Rank-biserial correlation coefficient

	U (from the Mann-Whitney U Test)	**r_b**
Positive_VA	1034,5	-,314
Negative_VA	530	,327
Positive_VAT	1093	-,388
Negative_VAT	559	,290
Positive_VAH	1109,5	-,409
Negative_VAH	575,5	,269
Positive_VAS	1078	-,369
Negative_VAS	421,5	,465

Positive_VATHS	1006	-,277
Negative_VATHS	421	,465

5.2. Effects on the users' emotions using positive stimuli combinations

To achieve a conclusion regarding the effect of using different positive stimuli combinations on the users' emotional responses (R.Q. 1.1), a careful analysis of the Mann-Whitney U test results was done. The comparison of their effects revealed the following insights:

1. Positive emotions scores for V+A were statistically significantly lower (mean rank = 45,99, U = 1034,500, z = 2,406, p = 0,016) than the following combinations:
    - V+A+H (mean rank = 47,66, U = 1109,500, z = ,141, p = 0,002)
    - V+A+T (mean rank = 47,29, U = 1093, z = 2,974, p = 0,003)
    - V+A+S (mean rank = 46,96, U = 1078, z = 2,828, p = 0,001)

    But statistically significantly higher than:

    - V+A+T+H+S (mean rank = 45,36, U = 1006, z = 2,129, p = 0,033)

2. Negative emotions scores for V+A were statistically significantly lower (mean rank = 34,78, U = 530, z = -2,745, p = 0,006) than the following combinations:
    - V+A+H (mean rank = 35,79, U = 575,500, z = -2,345, p = 0,019)
    - V+A+T (mean rank = 35,42, U = 559, z = -2,510, p = 0,012)

    But statistically significantly higher than the following combinations:

    - V+A+S (mean rank = 32,37, U = 421,500, z = -3,980, p = < 0,001)
    - V+A+T+H+S (mean rank = 32,36, U = 421, z = -4,023, p = < 0,001)

It should be highlighted, according to descriptive analysis illustrated in Table 34, that the users' emotional responses did not significantly vary across the different combinations of positive stimuli. In fact, a pattern can be observed: "interest" and "enthusiasm" were the most elicited PANAS-PA (represented in green) for all the stimuli combinations regarding the positive IVE; whereas "nervousness" and "afraidness" (and also with similar scores for V+A, "scariness") were found to be the most evoked PANAS-NA (represented in orange).

Table 34 Elicited emotions in the positive IVE (descriptive statistics)

Object	Emotional responses according to the stimuli combination	N	Minimum	Maximum	Mean	Std. Deviation
1	Interested_V+A	45	2	5	**4,07**	,939
	Nervous_V+A	45	1	4	**1,36**	,679
	Enthusiastic_V+A	45	2	5	**4,02**	1,033
	Afraid_V+A	45	1	2	**1,09**	,288
	Inspired_V+A	45	1	5	3,58	1,118
	Active_V+A	45	1	5	3,56	1,119
	Scared_V+A	45	1	2	**1,09**	,288
	Guilty_V+A	45	1	2	1,04	,208
	Determined_V+A	45	1	5	3,69	1,062
	Upset_V+A	45	1	2	1,04	,208
2	Interested_V+A+T	45	2	5	**4,27**	,889
	Nervous_V+A+T	45	1	2	**1,24**	,435
	Enthusiastic_V+A+T	45	1	5	**4,13**	,968
	Afraid_V+A+T	45	1	2	**1,09**	,288
	Inspired_V+A+T	45	1	5	3,71	1,160
	Active_V+A+T	45	1	5	3,71	,968
	Scared_V+A+T	45	1	2	1,07	,252
	Guilty_V+A+T	45	1	2	1,04	,208
	Determined_V+A+T	45	1	5	3,67	1,108
	Upset_V+A+T	45	1	2	1,07	,252
3	Interested_V+A+H	45	1	5	**4,38**	,936
	Nervous_V+A+H	45	1	2	**1,24**	,435
	Enthusiastic_V+A+H	45	1	5	**4,20**	1,036
	Afraid_V+A+H	45	1	2	**1,16**	,367
	Inspired_V+A+H	45	1	5	3,91	1,276
	Active_V+A+H	45	1	5	3,67	1,044
	Scared_V+A+H	45	1	2	1,04	,208
	Guilty_V+A+H	45	1	2	1,04	,208
	Determined_V+A+H	45	1	5	3,62	1,134
	Upset_V+A+H	45	1	4	1,20	,548
4	Interested_V+A+S	45	2	5	**4,36**	,908
	Nervous_V+A+S	45	1	3	**1,18**	,442
	Enthusiastic_V+A+S	45	2	5	**4,27**	,986
	Afraid_V+A+S	45	1	5	**1,16**	,638
	Inspired_V+A+S	45	1	5	4,00	1,148
	Active_V+A+S	45	2	5	3,89	1,005
	Scared_V+A+S	45	1	2	1,04	,208
	Guilty_V+A+S	45	1	2	1,04	,208
	Determined_V+A+S	45	1	5	3,71	1,199
	Upset_V+A+S	45	1	4	1,13	,505
5	Interested_V+A+T+H+S	45	2	5	**4,51**	,869
	Nervous_V+A+T+H+S	45	1	2	**1,18**	,387
	Enthusiastic_V+A+T+H+S	45	2	5	**4,31**	1,019
	Afraid_V+A+T+H+S	45	1	2	**1,09**	,288
	Inspired_V+A+T+H+S	45	1	5	4,13	1,179
	Active_V+A+T+H+S	45	2	5	3,84	1,021
	Scared_V+A+T+H+S	45	1	1	1,00	,000
	Guilty_V+A+T+H+S	45	1	2	1,04	,208

	Determined_V+A+T+H+S	45	1	5	3,71	1,160
	Upset_V+A+T+H+S	45	1	2	1,11	,318
	Valid N (listwise)	45				

5.3. Effects on the users' emotions using negative stimuli combinations

To understand the effect of different multisensory combinations of negative stimuli (R.Q. 1.2), following the approach of the analysis conducted in the previous section, a comparative analysis using the Mann-Whitney U test was carried out. This analysis revealed the following outcomes:

1. Positive emotions scores for V+A were statistically significantly higher (mean rank = 33,44, U = 1034,500, z = 2,406, *p* = 0,016) than the following combinations:
   - V+A+S (mean rank = 32,2, U = 1078, z = 2,828, *p* = 0,001)
   - V+A+T (mean rank = 31,77, U = 1093, z = 2,974, *p* = 0,003)
   - V+A+H (mean rank = 31,3, U = 1109,500, z = 3,141, *p* = 0,002)

   But statistically significantly lower than:

   - V+A+T+H+S (mean rank = 34,26, U = 1006, z = 2,129, *p* = 0,033)

2. Negative emotions scores for V+A were statistically significantly lower (mean rank = 47,86, U = 530, z = -2,745, *p* = 0,006) than the following combinations:
   - V+A+T+H+S (mean rank = 50,97, U = 421, z = -4,023, *p* = < 0,001)
   - V+A+S (mean rank = 50,96, U = 421,500, z = -3,980, *p* = < 0,001)

   But statistically significantly higher than:

   - V+A+T (mean rank = 47,03, U = 559, z = -2,510, *p* = 0,012)
   - V+A+H (mean rank = 46,56, U = 575,500, z = -2,345, *p* = 0,019)

According to the descriptive analysis illustrated in the Table 35, similarly to the positive IVE, a pattern can be observed regarding the use of negative stimuli. "Interest" and "enthusiasm" emerged as the most frequently reported PANAS-PA. On the other hand, regarding the PANAS-NA, a greater intensity of "scariness" and "upset" was noted across all multisensory combinations, with the exception of the basic V+A. Specifically within the V+A, "nervousness" and "scariness" stood out as the most significant PANAS-NA.

The next section provides a comprehensive discussion of these findings, encompassing a comparison with the results from the positive IVE.

Table 35 Elicited emotions in the negative IVE (descriptive statistics)

Object	Emotional responses according to the stimuli combination	N	Minimum	Maximum	Mean	Std. Deviation
1	Interested_V+A	35	2	5	**4,11**	,796
	Nervous_V+A	35	1	3	**1,71**	,710
	Enthusiastic_V+A	35	2	5	**3,86**	,845
	Afraid_V+A	35	1	3	1,37	,690
	Inspired_V+A	35	1	5	2,91	1,222
	Active_V+A	35	1	5	3,14	1,089
	Scared_V+A	35	1	5	**1,80**	1,256
	Guilty_V+A	35	1	2	1,11	,323
	Determined_V+A	35	1	5	2,97	1,224
	Upset_V+A	35	1	4	1,60	,976
2	Interested_V+A+T	35	2	5	**4,11**	,867
	Nervous_V+A+T	35	1	3	1,57	,698
	Enthusiastic_V+A+T	35	1	5	**3,71**	1,100
	Afraid_V+A+T	35	1	3	1,43	,698
	Inspired_V+A+T	35	1	5	2,97	1,272
	Active_V+A+T	35	1	5	3,06	1,110
	Scared_V+A+T	35	1	5	**1,77**	1,262
	Guilty_V+A+T	35	1	2	1,14	,355
	Determined_V+A+T	35	1	5	3,00	1,213
	Upset_V+A+T	35	1	4	**1,63**	,973
3	Interested_V+A+H	35	2	5	**4,09**	,781
	Nervous_V+A+H	35	1	3	1,54	,701
	Enthusiastic_V+A+H	35	1	5	**3,83**	,891
	Afraid_V+A+H	35	1	3	1,40	,695
	Inspired_V+A+H	35	1	5	3,20	1,324
	Active_V+A+H	35	1	5	3,11	1,157
	Scared_V+A+H	35	1	5	**1,86**	1,240
	Guilty_V+A+H	35	1	3	1,17	,453
	Determined_V+A+H	35	1	5	3,09	1,269
	Upset_V+A+H	35	1	4	**1,71**	1,045
4	Interested_V+A+S	35	1	5	**4,06**	,873
	Nervous_V+A+S	35	1	4	1,66	,802
	Enthusiastic_V+A+S	35	1	5	**3,80**	,994
	Afraid_V+A+S	35	1	4	1,54	,817
	Inspired_V+A+S	35	1	5	3,26	1,336
	Active_V+A+S	35	1	5	3,20	1,232
	Scared_V+A+S	35	1	5	**1,97**	1,272
	Guilty_V+A+S	35	1	4	1,29	,667
	Determined_V+A+S	35	1	5	3,00	1,328
	Upset_V+A+S	35	1	4	**1,86**	1,089
5	Interested_V+A+T+H+S	35	1	5	**4,29**	,926
	Nervous_V+A+T+H+S	35	1	3	1,40	,651
	Enthusiastic_V+A+T+H+S	35	1	5	**3,97**	1,150

	Afraid_V+A+T+H+S	35	1	4	1,34	,725
	Inspired_V+A+T+H+S	35	1	5	3,63	1,262
	Active_V+A+T+H+S	35	1	5	3,60	1,143
	Scared_V+A+T+H+S	35	1	5	**1,63**	1,190
	Guilty_V+A+T+H+S	35	1	3	1,20	,473
	Determined_V+A+T+H+S	35	1	5	3,03	1,361
	Upset_V+A+T+H+S	35	1	4	**1,83**	1,014
	Valid N (listwise)	35				

5.4. Discussion

Results regarding the R.Q. 1 allow to understand that during the positive IVE, the different multisensory stimuli combinations provided affected the users' emotional responses, as expected (H 1). In particular, in the positive IVE, in which positive multisensory stimuli combinations were used, high intensity of both positive and negative emotional responses was reported, particularly accentuated when using V+A+H and V+A+T. Although such outcomes were expected for the V+A+T+H+S (H 1.1), the opposite occurred, suggesting that the haptic stimulus and taste were the most emotionally impactful for the users.

For the negative IVE, it was projected that, similarly as the positive IVE would lead to increasing positive emotions especially when using V+A+T+H+S, the negative IVE would lead to increasing negative emotions, heightened when using V+A+T+H+S. However, low intensity of negative emotional responses was registered, even in the fully multisensory stage V+A+T+H+S, surprisingly (H 1.2), with "scariness" and "upset" being the most noticeable negative emotions. This result suggests two possibilities:

1. The negative stimuli used may not have been intense enough to provoke strong negative emotional responses in the users; and/or
2. The application of the PANAS might have been unsuitable to self-report emotional responses, especially due to the negative affects it encompasses. This assumption began to hold true as the virtual experiment progressed, when some users started to point out that certain negative adjectives of PANAS, especially "guilty" and "upset," were excessively strong and somewhat irrelevant for assessing that IVE. This was registered for both positive and negative IVE, although much more frequently by those who concluded the positive IVE, understandably. Conversely, the PANAS-PA, which generally showed high scores, effectively captured the users' emotional responses.

Curiously, both IVEs demonstrated to enhance the user users' "interest" and "enthusiasm". This conclusion supports earlier research that emphasizes the ability of immersion to elicit a wide range of emotional responses [19, 174, 176], varying in intensity [1, 2, 177], irrespective of whether these stimuli are positive or negative.

Based on the quantitative results exposed in sections 5.2 and 5.3, the following table (Table 36) was elaborated. It illustrates an efficiency ranking, representing from 1 to 5 the most recommended combinations to elicit positive and negative emotions in accordance with the use of positive stimuli (used in the positive IVE) or negative stimuli (used in the negative IVE). One was attributed to the stimuli combination that presented the better results in generating positive or negative emotions, whereas five was attributed to the combination demonstrating the worst results.

Table 36 Illustration of the results for the R.Q.1 – Efficiency ranking

Positive IVE			Negative IVE		
Stimuli combinations	Positive emotions	Negative Emotions	**Stimuli combinations**	Positive emotions	Negative Emotions
(V+A)	4	3	**(V+A)**	2	3
(V+A+T)	2	2	**(V+A+T)**	4	4
(V+A+H)	1	1	**(V+A+H)**	5	5
(V+A+S)	3	4	**(V+A+S)**	3	2
(V+A+T+H+S)	5	5	**(V+A+T+H+S)**	1	1

In full, this table presents, firstly, a precise interchange in the efficiency ranking of stimuli combinations V+A+T, V+A+H, and V+A+T+H+S between the positive and negative IVEs: in the positive IVE, V+A+H demonstrated the highest efficiency in emotional engagement, followed by V+A+T, and, lastly, V+A+T+H+S, whereas in the negative IVE, the situation was precisely the reverse. In other words, this reveals that greater stimulus complexity is required to generate more intense emotions in negative virtual environments, whereas less complex combinations will readily ensure intense emotions in positive virtual environments. These results regarding the positive IVE are somewhat surprising, considering that it was expected that a fully multisensory IVE would provide the most intense levels of emotional responses, especially when compared to the basic V+A, as commented regarding H 1. V+A, in turn, and also the addition of smell to it (V+A+S), did not reveal a special impact to enhance the users' emotional responses.

These interesting differences lead to the conclusion that a fully-immersive environment, characterized by a complete positive multisensory stimulation, might actually hinder the elicitation of positive emotions in users. Instead, V+A+H and V+A+T were demonstrated to be the most effective combinations to evoke intense levels of emotional responses in general in the positive IVE. This means that the addition of haptics and taste in a VR experience might be the most beneficial to evoke highly intense emotional responses. This result suggests that positive stimulation with all stimuli presented simultaneously might overwhelm the user, leading to cognitive overload, as discussed by some authors [328, 329]. In turn, in the negative IVE, these two combinations registered the opposite: the lowest scores regarding their effect to evoke intense levels of overall emotional responses.

6. Users' VIV according to different stimuli combinations

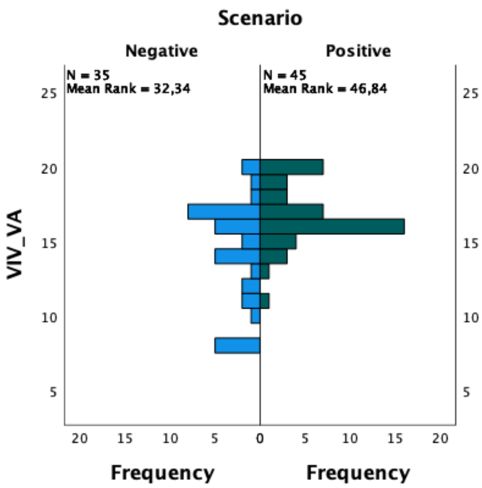
Despite the rapid growth of VR technology, there is limited understanding of how different combinations of multisensory stimuli impact users' VIV. So, this section, corresponding to the R.Q. 2, investigates the users' VIV ability when exposed to different positive and negative multisensory stimuli combinations in VR. Based on the developed IVE, introduced in section 3, similarly to what was done to address R.Q. 1, an analysis of the effect of each multisensory stimuli combination used on the users' VIV was performed. This approach helps to understand how adding specific stimuli (taste, haptics, or smell) to the basic V+A, or their collective application (V+A+T+H+S) influences the users' VIV ability.

This section begins by offering an overview of the data analysis process, followed by the presentation of results related to the positive IVE, in accordance with R.Q. 2.1 (section 6.2), and the negative IVE, which addresses R.Q. 2.2 (section 6.3). Finally, a comprehensive discussion of these outcomes is presented in section 6.4.

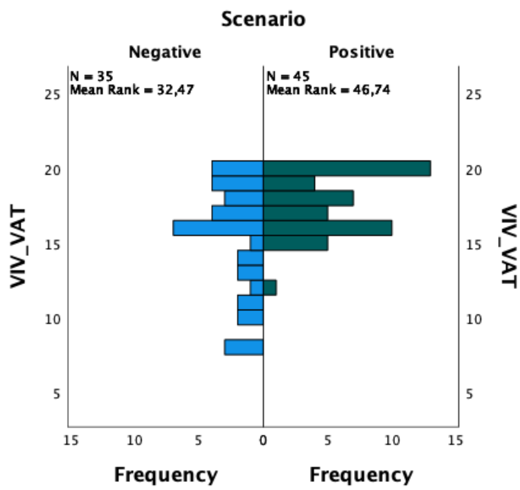
6.1. Data analysis

To start the data analysis process, the examination of the normal distribution of VIV data according to each multisensory stimuli combination for both IVEs was conducted, revealing that they were not similar, as assessed by visual inspection (Graph 23 to Graph 27).

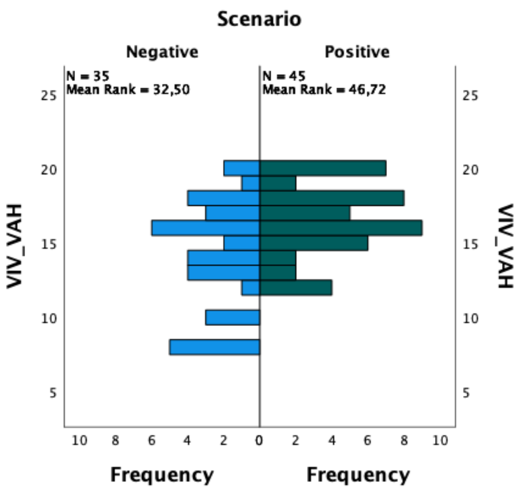
Graph 23 Distribution regarding users' MI for V+A



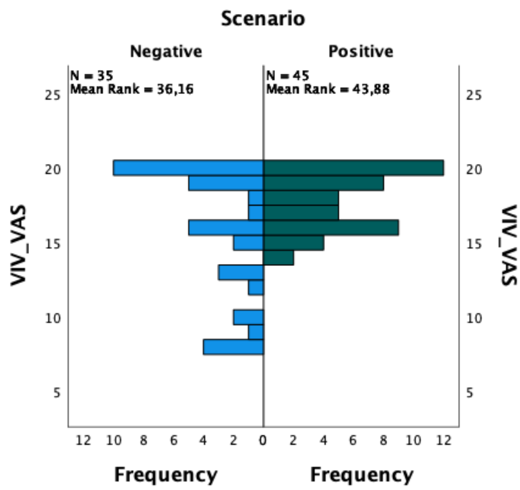
Graph 24 Distribution regarding users' MI for V+A+T



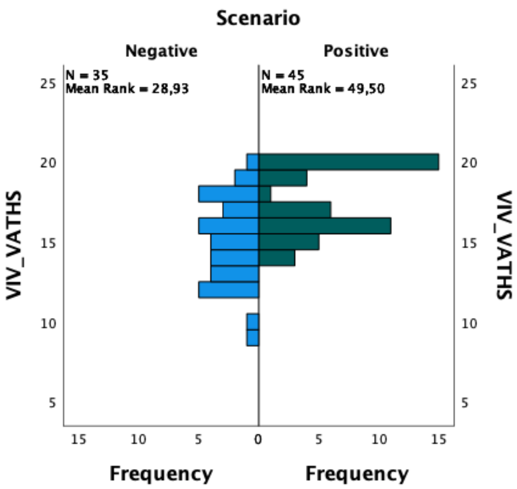
Graph 25 Distribution regarding users' MI for V+A+H



Graph 26 Distribution regarding users' MI for V+A+S



Graph 27 Distribution regarding users' MI for V+A+T+H+S



Now, to address R.Q. 2, which examines the impact of different multisensory stimuli combinations on the user's VIV in the positive (R.Q. 2.1) and negative (R.Q. 2.2) IVEs, a Mann-Whitney U Test (H) analysis was conducted. As VVIQ resorted to a Likert scale, results originated ordinal outcomes. So, the non-parametric Mann-Whitney U test was chosen to determine if there were statistically significant differences between the two groups, as recommended [371], regarding the users' VIV data.

All the three basic assumptions this test requires were valid, which are as follows [377]:

1. The groups being investigated must be drawn randomly from the target population;
2. There should have independence of observation, indicating that there is no relationship or dependency among the observations within each group of the independent variable or among the groups themselves;
3. The dependent variable that is being tested (VIV) is continuous or ordinal.

Then, five Mann-Whitney U tests were performed to compare the differences in the users' VIV between the two independent groups according to each multisensory stimuli combination, based on the following null hypotheses:

> H_0: *There are no differences between the positive and negative IVE regarding the users' VIV*

Results allowed us to reject four of the five null hypotheses (Table 37), which means that there is evidence to support that statistically significant differences exist between the two groups, for those four stimuli combinations. Moreover, as α is considerably greater than p for that four stimuli combinations, this suggests that there is a substantial differences in the distributions of the two groups, i.e., it supports to reject the null hypothesis [371], and, consequently, to discard the likelihood of a type I error. Nevertheless, to assess the effect size of the differences, the rank-biserial correlation coefficient (r_b) was performed (Table 38). According to Martín and Martinez [375], this is a suitable test to assess the effect size associated with the Mann-Whitney U test. The rank-biserial correlation coefficient was calculated using Wendt's formula [378], explained in section 5.1, where U stands for the Mann-Whitney U statistic value, $n1$ for the maximum sample size of the two groups ($n1$ = 45) and $n2$ for the minimum sample size of the two groups ($n2$ = 35).

For all the referred four stimuli combinations (all excepting V+A+S), results demonstrate moderate (0,3 < r_b < 0,49) to large (r_b ≥ 0,5) effect sizes.

Table 37 Mann-Whitney U Test (hypothesis test summary)

	Null Hypothesis	Sig.[a,b]	Decision
1	The distribution of VIV_VA is the same across categories of IVE.	,005	Reject the null hypothesis.
2	The distribution of VIV_VAT is the same across categories of IVE.	,006	Reject the null hypothesis.
3	The distribution of VIV_VAH is the same across categories of IVE.	,006	Reject the null hypothesis.
4	The distribution of VIV_VAS is the same across categories of IVE.	,134	Retain the null hypothesis.
5	The distribution of VIV_VATHS is the same across categories of IVE.	< ,001	Reject the null hypothesis.

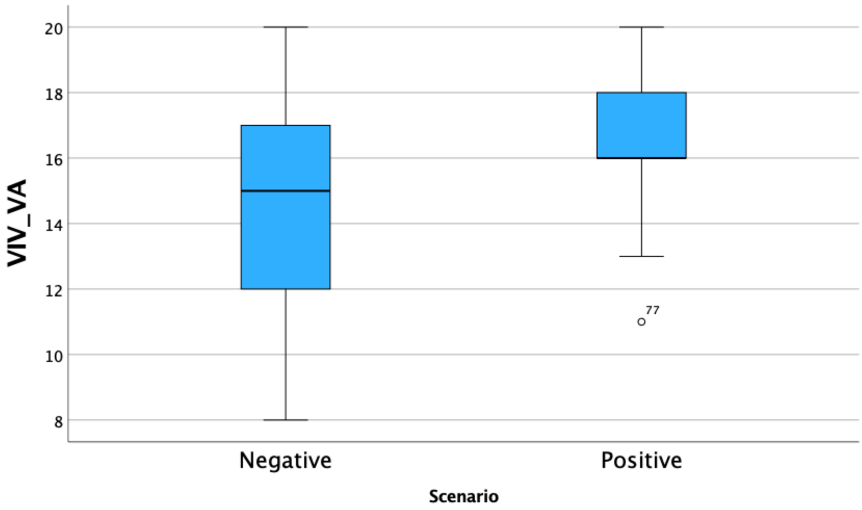
[a] The significance level is ,050.
[b] Asymptotic significance is displayed.

However, regarding the stimuli combination (V+A+S), results suggest retaining the null hypothesis, i.e., the analysis did not find sufficient evidence to support statistically significant differences between the two groups being compared. Nevertheless, to evaluate the effect sizes, the analysis of the rank-biserial correlation coefficient (Table 38) demonstrate a small effect size ($0,1 < r_b < 0,29$). Consequently, this result suggests discarding a type II error, as only a very weak association regarding VIV between the positive and the negative IVE could be detected ($r_b = 0,193$). In practical terms, these results means that the positive and negative V+A+S used in the fourth object did not present any differences in enhancing the users' VIV ability. In other words, either the pine scent (in the case of the positive IVE), the liquid smoke scent (in the case of the negative IVE), or both, had little impact on the users' VIV.

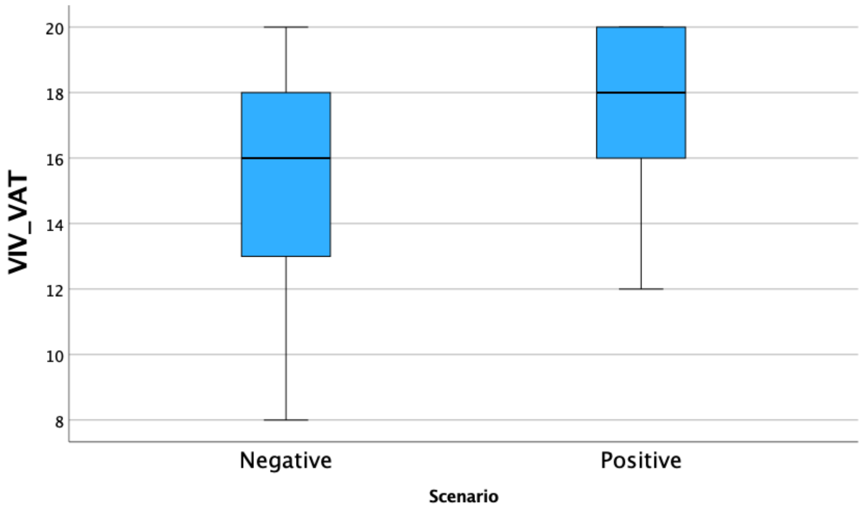
Table 38 Rank-biserial correlation coefficient

	U (from the Mann-Whitney U Test)	r_b
VIV_VA	1073	-,363
VIV_VAT	1068,5	-,357
VIV_VAH	1067,5	-,356
VIV_VAS	939,5	-,193
VIV_VATHS	1192,5	-,514

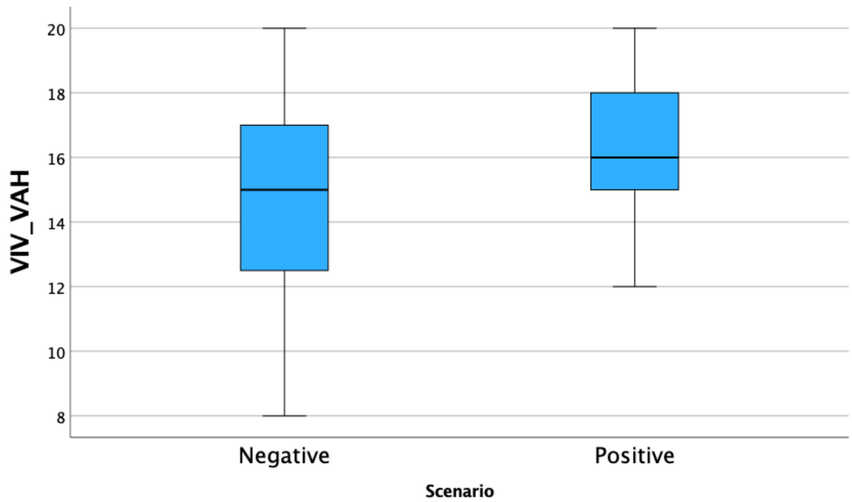
Finally, the respective boxplots were built to visually inspect the differences between the two groups (Graph 28 to Graph 32). By analyzing these graphs, it can be observed that the combinations involving positive multisensory stimuli consistently contributed more to improving users' VIV, with the exception of V+A+S (Graph 31), where it is possible to observe similar maximum values (observed through the upper whisker), which suggests that the overall range of the data is similar between the groups. This finding aligns with the previous analysis conducted.



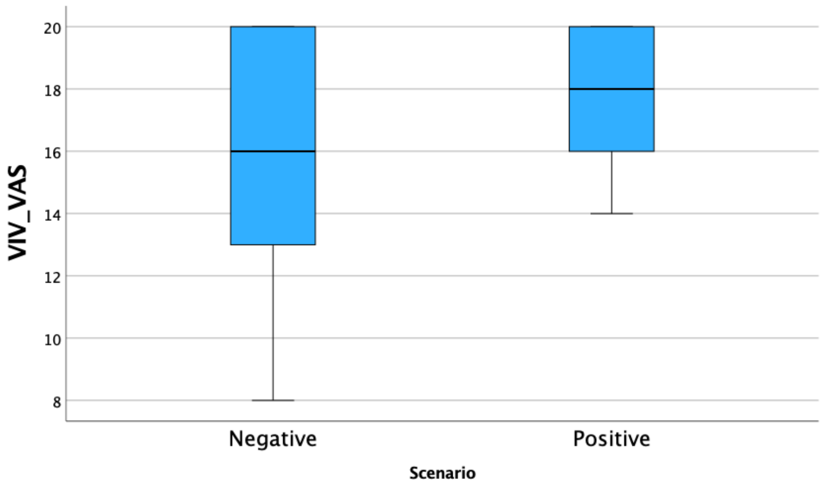
Graph 28 Differences regarding VIV for V+A



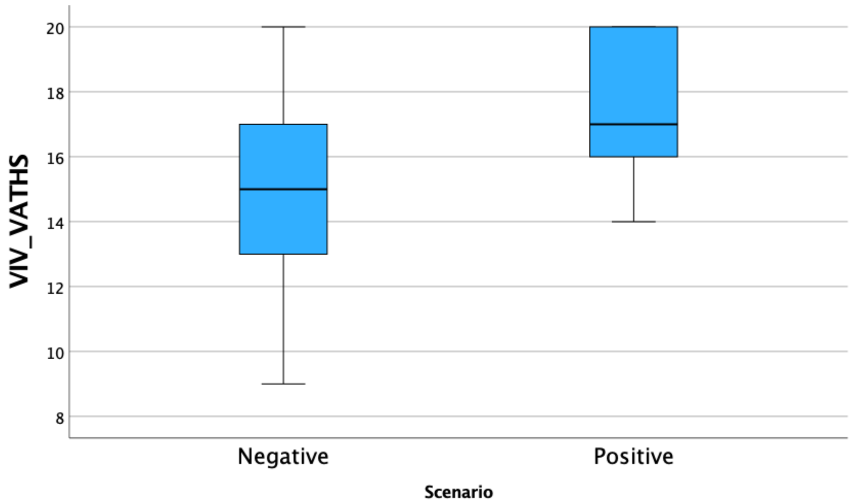
Graph 29 Differences regarding VIV for V+A+T



Graph 30 Differences regarding VIV for V+A+H



Graph 31 Differences regarding VIV for V+A+S



Graph 32 Differences regarding VIV for V+A+T+H+S

6.2. Effects on the users' VIV using positive stimuli combinations

In order to reach a conclusion about the impact of various combinations of positive stimuli on the users' VIV (R.Q. 2.1), a detailed examination of the Mann-Whitney U test results was conducted. This analysis allowed a comparison of their effects, which led to the following insights:

- VIV scores for V+A were statistically significantly higher (mean rank = 46,84, U = 1073, z = 2,808, p = 0,005) than the following combinations:
  - V+A+T (mean rank = 46,74, U = 1068,500, z = 2,759, p = 0,006)
  - V+A+H (mean rank = 46,72, U = 1067,500, z = 2,736, p = 0,006)
  - V+A+S (mean rank = 43,88, U = 939,500, z = 1,498, p = 0,134)

But statistically significantly lower than:

- V+A+T+H+S (mean rank = 49,50, U = 1192,500, z = 3,969, $p < 0{,}001$)

Firstly, it should be highlighted that significant differences were anticipated among all the stimuli combinations in terms of users' VIV ability. However, as previously mentioned, the V+A+S did not show evidence supporting this expectation. This outcome indicates a certain lack of significant impact when using either a positive or negative smell to improve users' VIV.

The results obtained allow to determine that positive V+A+T+H+S was the most powerful combination to increasing the users' VIV, followed by the basic V+A, and finally V+A+T, V+A+H, and V+A+S, respectively. This result can be achieved by observing the corresponding mean ranks, as indicated in [372]. Reasoning for these results is further addressed in section 6.4.

6.3. Effects on the users' VIV using negative stimuli combinations

To draw conclusions regarding the effects of different positive stimuli combinations on the users' VIV (R.Q. 2.2), an in-depth analysis of the Mann-Whitney U test results was performed. This analysis facilitated a comparison of their impacts, leading to the following insights:

- VIV scores for V+A were statistically significantly higher (mean rank = 32,34, U = 1073, z = 2,808, $p = 0{,}005$) than the following combinations:
  - V+A+T+H+S (mean rank = 28,93, U = 1192,500, z = 3,969, p < 0,001)

But statistically significantly lower than:

- V+A+S (mean rank = 36,16, U = 939,500, z = 1,498, $p = 0{,}134$)
- V+A+H (mean rank = 32,50, U = 1067,500, z = 2,736, $p = 0{,}006$)
- V+A+T (mean rank = 32,47, U = 1068,500, z = 2,759, $p = 0{,}006$)

The obtained results allow to determine that the negative V+A+T+H+S was the less powerful combination for increasing the users' VIV, in contrast to the same combination in the positive IVE. In turn, V+A+S was the best combination to enhance the users' VIV, followed by V+A+H, V+A+T, and the basic audiovisual combinations (V+A), respectively. This result can be achieved by observing the corresponding mean ranks [372]. Implications of these results and the comparison of them with the previous from the positive IVE will be addressed in the next section.

6.4. Discussion

Considering R.Q. 2, no similarities could be found between the two groups (those who experienced the positive and the negative IVE) regarding VIV, with the exception of the smell used during the presentation of the fourth object (V+A+S). This result indicates that either the pine scent (in the case of the positive IVE), the liquid smoke scent (in the case of the negative IVE), or both, were not effectively pleasant and unpleasant, respectively. Moreover, it means that employing the most positive scent might have yielded the same effect on users' VIV as using the most negative scent, surprisingly. For example, the pleasant aroma of pine might have been as impactful on a participant's VIV as the unpleasant scent of liquid smoke. This result is somehow related to findings from Archer, et al. [128], who found no differences between pleasant and unpleasant odors regarding the side effects. Although these authors did not explore VIV in particular, their interest findings help understanding why the unpleasant odors used in the negative IVE (smoke odor and concentrated fragrance of fish) might have the same effect on the users' VIV as the positive ones. One possible explanation, although requiring further investigation, is that, isolated, the smell might provoke little impact on the users' VIV. We believe that these findings, particularly regarding smell, need a more in-depth investigation, resorting to other positive and negative scents.

The total multisensory combination in the positive IVE was demonstrated to be the most impactful in enhancing the users' VIV, as predictable (H 2.1). However, the opposite was observed regarding the negative IVE: the total multisensory combination was found to be the less impactful combination, which was not as expected (H 2.2). This result suggests that a total multisensory combination of negative stimuli may present some irrelevance in increasing one's VIV, in contrast with findings reported by Bywaters, et al. [38], defending that extreme scenarios, arising either from intensely intense positive emotions or from negative emotions, are associated with improved VIV ability. A possible explanation for this unexpected result lies in the eventual mental confusion caused by the large number of stimuli presented, as previously addressed regarding the emotional responses' results. In this case, we hypothesize that the total multisensory combination might have influenced one's focus toward a specific stimulus (e.g., taste), rather than to the object itself, as the task required. The unpredicted is that this result was different for the positive IVE, which reported V+A+T+H+S as the most powerful combination to increase the users' VIV ability. A potential reason for this is related to the higher pleasantness provided by the positive IVE, compared to the negative IVE, which might have contributed to maintaining the users' attention and, consequently, to assist them in retaining the visual information regarding that object. On the contrary, the unpleasant V+A+T+H+S provided in the negative IVE might have contributed, in turn, to distracting the user from the task of memorizing the object's visual details.

Based on the quantitative results exposed in sections 6.2 and 6.3, the following table (Table 39) was elaborated. It illustrates an efficiency ranking, representing from 1 to 5 the most recommended combinations to elicit positive and negative emotions in accordance with the use of positive stimuli (positive IVE) or negative stimuli (negative IVE). One was attributed to the stimuli combination that presented the best results in enhancing the users' VIV, whereas five was attributed to the combination demonstrating the worst results for the users' VIV.

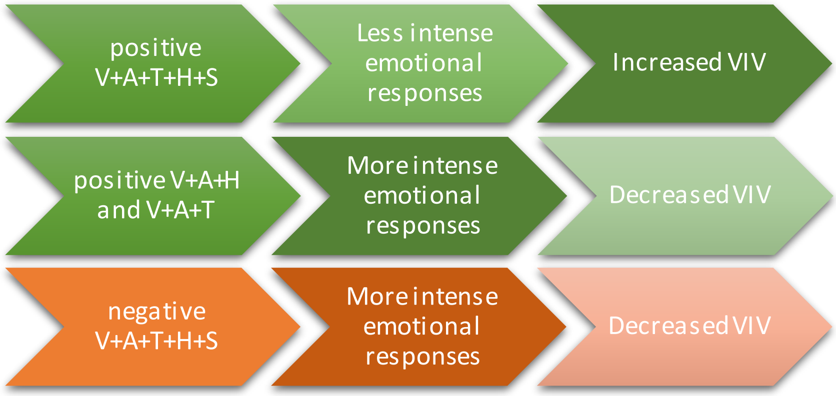
Table 39 Results for the R.Q. 2 – Efficiency ranking

Positive IVE		**Negative IVE**	
Stimuli combinations	VIV	**Stimuli combinations**	VIV
(V+A)	2	**(V+A)**	4
(V+A+T)	5	**(V+A+T)**	3
(V+A+H)	4	**(V+A+H)**	2
(V+A+S)	3	**(V+A+S)**	1
(V+A+T+H+S)	1	**(V+A+T+H+S)**	5

This table indicates, in the case of the positive IVE, that the V+A and V+A+T+H+S were the most beneficial for enhancing VIV. Conversely, in the negative IVE, the same combinations were found to be the least advantageous in increasing the VIV ability. Surprisingly, in the negative IVE, the combinations V+A+S and V+A+H emerged as more effective in augmenting users' VIV, meaning that smell and haptics have a powerful effect on enhancing VIV.

By the comparative analysis of this table alongside the one focusing on the efficiency ranking of emotional responses (Table 36), two interesting and solid conclusions can be drawn regarding the use of total multisensory in VT (Diagram 4): positive V+A+T+H+S lead to less intense emotional responses but to a higher VIV ability. In turn, negative V+A+T+H+S elicit more intense emotional responses but contribute to a decrease in the users' VIV. Another solid pattern can be achieved regarding the positive stimuli combinations V+A+H and V+A+T, which generated more intense emotional responses but, in turn, contributed to a decrease in the VIV ability.

Diagram 4 Patterns regarding the relationship between stimuli, users' emotions, and VIV



These findings suggest that the improvement in the VIV ability is inversely proportional to the intensity of reported emotions. This important conclusion could potentially be explained by the observation that intense emotions require a considerable amount of cognitive resources, as attested by Hofstee, et al. [379]. When emotions are particularly intense, the brain tends to prioritize processing these emotions, which may result in a reduced availability of cognitive resources for other functions, such as VIV. In contrast, at lower levels of emotional intensity, there could be a surplus of cognitive resources that can be directed to enhancing MI. Additionally, this registered phenomenon might also be linked to the fact that intense emotions, particularly negative ones, can lead to stress. Since stress has been demonstrated to negatively impact behavior and cognitive functions in VR contexts, as noted by Feng, et al. [380], this could be a critical factor in the reduction of VIV ability.

7. The relationship between emotional responses and VIV

To further address the gaps in understanding the impact of different combinations of multisensory stimuli on users' emotions and VIV ability, this section investigates the effects of the demographics age and gender on the interplay between the users' emotional responses and their VIV ability. Based on the developed IVE introduced in section 3, this section starts with an outline of the data analysis process, followed by the presentation of results concerning the positive IVE, in accordance with R.Q. 3.1 (section 7.2), and the negative IVE, aligned with R.Q. 3.2 (section 7.3). Finally, a comprehensive discussion of these outcomes is presented in section 7.4.

7.1. Data analysis

To determine whether a relationship between VIV and emotions exists (R.Q. 3), first, the Spearman's rank-order correlation test was performed, considering that the sample is not normally distributed, as attested before. This test was performed to assess the strength and direction of the relationship between these two variables [372, 381]. All the four basic assumptions this test requires were valid, which are as follows:

1. The dependent variable that is being tested (presence) is ordinal;
2. The association between the variables is linear in nature;
3. There should have independence of observation, indicating that there is no relationship or dependency among the observations within each group of the independent variable or among the groups themselves;
4. Each pair of data points is autonomous, meaning they do not interact or relate to other pairs.

Results are shown between Table 40 and Table 44.

Table 40 Spearman's rank-order correlations for V+A

Spearman's rho		VIV_VA	Positive_ VA	Negative_ VA
VIV_VA	Correlation Coefficient	1,000	,430**	-,351**
	Sig. (2-tailed)	.	<,001	,001
	N	80	80	80
Positive_VA	Correlation Coefficient	**,430****	1,000	-,118
	Sig. (2-tailed)	**<,001**	.	,299
	N	80	80	80
Negative_VA	Correlation Coefficient	**-,351****	-,118	1,000
	Sig. (2-tailed)	**,001**	,299	.
	N	80	80	80

* Correlation is significant at the 0,05 level (2-tailed).

** Correlation is significant at the 0,01 level (2-tailed).

Table 41 Spearman's rank-order correlations for V+A+T

Spearman's rho		VIV_VAT	Positive_ VAT	Negative_ VAT
VIV_VAT	Correlation Coefficient	1,000	,595**	-,382**
	Sig. (2-tailed)	.	<,001	<,001
	N	80	80	80
Positive_VAT	Correlation Coefficient	**,595****	1,000	-,307**
	Sig. (2-tailed)	**<,001**	.	,006
	N	80	80	80
Negative_VAT	Correlation Coefficient	**-,382****	-,307**	1,000
	Sig. (2-tailed)	**<,001**	,006	.
	N	80	80	80

* Correlation is significant at the 0,05 level (2-tailed).

** Correlation is significant at the 0,01 level (2-tailed).

Table 42 Spearman's rank-order correlations for V+A+H

Spearman's rho		VIV_VAH	Positive_ VAH	Negative_ VAH
VIV_VAH	Correlation Coefficient	1,000	,570**	-,265*
	Sig. (2-tailed)	.	<,001	,018
	N	80	80	80
Positive_VAH	Correlation Coefficient	**,570****	1,000	-,353**
	Sig. (2-tailed)	**<,001**	.	,001
	N	80	80	80
Negative_VAH	Correlation Coefficient	**-,265***	-,353**	1,000
	Sig. (2-tailed)	**,018**	,001	.
	N	80	80	80

* Correlation is significant at the 0,05 level (2-tailed).

** Correlation is significant at the 0,01 level (2-tailed).

Table 43 Spearman's rank-order correlations for V+A+S

Spearman's rho		VIV_VAS	Positive_ VAS	Negative_ VAS
VIV_VAS	Correlation Coefficient	1,000	,510**	-,430**
	Sig. (2-tailed)	.	<,001	<,001
	N	80	80	80
Positive_VAS	Correlation Coefficient	**,510****	1,000	-,427**
	Sig. (2-tailed)	**<,001**	.	<,001
	N	80	80	80
Negative_VAS	Correlation Coefficient	**-,430****	-,427**	1,000
	Sig. (2-tailed)	**<,001**	<,001	.
	N	80	80	80

* Correlation is significant at the 0,05 level (2-tailed).

** Correlation is significant at the 0,01 level (2-tailed).

Table 44 Spearman's rank-order correlations for V+A+T+H+S

Spearman's rho		VIV_VATHS	Positive_ VATHS	Negative_ VATHS
VIV_VATHS	Correlation Coefficient	1,000	,369**	-,291**
	Sig. (2-tailed)	.	<,001	,009
	N	80	80	80
Positive_VATHS	Correlation Coefficient	**,369****	1,000	-,201
	Sig. (2-tailed)	**<,001**	.	,074
	N	80	80	80
Negative_VATHS	Correlation Coefficient	**-,291****	-,201	1,000
	Sig. (2-tailed)	**,009**	,074	.
	N	80	80	80

* Correlation is significant at the 0,05 level (2-tailed).

** Correlation is significant at the 0,01 level (2-tailed).

Between Table 40 and Table 44, it is possible to note statistically significant results for all the correlations performed for each stimuli combination. These analyses will help validate the subsequent results for both Partial Spearman's rank order tests, as discussed in section 7.4.

7.2. The impact of gender

In the demographic questionnaire carried out, the gender-related question allowed for open-ended responses, enabling participants to express the gender they identify with in their own words. Only male and female genders were reported. Subsequently, to more effectively examine their influence on the relationship between VIV and emotions, the dataset was divided based on these two gender groups, facilitating the analysis and comparison of the correlations' strengths and directions.

To understand the effect of the control variables (gender and age), the Partial Spearman's rank order test was performed. This is an adequate test to assess the strength and direction of the relationship between two variables, while examining the effect of control variables [371, 372]. Regarding the gender effect for V+A, results show two statistically significant correlations between the users' VIV and their negative emotional responses for males (r_s = -0,319, p = 0,042) and women (r_s = -0,399, p = 0,012). This means that for both genders, VIV increased with the decrease of negative emotional responses. Also for women, another statistically significant correlation was found between their VIV and the positive emotional responses (r_s = 0,566, $p < 0,001$), meaning that the increased intensity of positive emotional responses contributed to an increased VIV ability (Table 45).

Table 45 Partial Spearman's rank-order correlations for V+A regarding gender

Spearman's rho				VIV_VA	Positive_ VA	Negative_ VA
Gender	Male	VIV_VA	Correlation Coefficient	1,000	,284	-,319*
			Sig. (2-tailed)	.	,072	,042
			N	41	41	41
		Positive_VA	Correlation Coefficient	,284	1,000	-,019
			Sig. (2-tailed)	,072	.	,907
			N	41	41	41
		Negative_VA	Correlation Coefficient	**-,319***	-,019	1,000
			Sig. (2-tailed)	**,042**	,907	.
			N	41	41	41
	Female	VIV_VA	Correlation Coefficient	1,000	,566**	-,399*
			Sig. (2-tailed)	.	<,001	,012
			N	39	39	39
		Positive_VA	Correlation Coefficient	**,566****	1,000	-,254
			Sig. (2-tailed)	**<,001**	.	,119
			N	39	39	39
		Negative_VA	Correlation Coefficient	**-,399***	-,254	1,000
			Sig. (2-tailed)	**,012**	,119	.
			N	39	39	39

** Correlation is significant at the 0,01 level (2-tailed).

* Correlation is significant at the 0,05 level (2-tailed).

With respect to the gender effect for V+A+T, results present four statistically significant correlations were found: two statistically significant correlations between the users' VIV and their negative emotional responses for men (r_s = -0,369, p = 0,018) and women (r_s = -0,425, p = 0,007). This means that for both genders, VIV increased with the decrease of negative emotional responses. Also two statistically significant correlations were found between users' VIV and the positive emotional responses for males (r_s = 0,485, p = 0,001) and females (r_s = 0,716, $p < 0,001$), meaning that the increased intensity of positive emotional responses contributed to an increased VIV ability (Table 46).

Table 46 Partial Spearman's rank-order correlations for V+A+T regarding gender

Spearman's rho				VIV_VAT	Positive_ VAT	Negative_ VAT
Gender	Male	VIV_VAT	Correlation Coefficient	1,000	,485**	-,369*
			Sig. (2-tailed)	.	,001	,018
			N	41	41	41
		Positive_VAT	Correlation Coefficient	**,485****	1,000	-,188
			Sig. (2-tailed)	**,001**	.	,239
			N	41	41	41
		Negative_VAT	Correlation Coefficient	**-,369***	-,188	1,000
			Sig. (2-tailed)	**,018**	,239	.
			N	41	41	41
	Female	VIV_VAT	Correlation Coefficient	1,000	,716**	-,425**
			Sig. (2-tailed)	.	<,001	,007
			N	39	39	39
		Positive_VAT	Correlation Coefficient	**,716****	1,000	-,425**
			Sig. (2-tailed)	**<,001**	.	,007
			N	39	39	39
		Negative_VAT	Correlation Coefficient	**-,425****	-,425**	1,000
			Sig. (2-tailed)	**,007**	,007	.
			N	39	39	39

** Correlation is significant at the 0,01 level (2-tailed).
* Correlation is significant at the 0,05 level (2-tailed).

Regarding V+A+H, results demonstrate three statistically significant correlations: two positive correlations between VIV and PANAS-PA for both men (r_s = 0,421, p = 0,006) and women (r_s = 0,742, p < 0,001), meaning that as the intensity of the positive emotional responses increased, VIV increased too. Also, one negative correlation between VIV and PANAS-NA for women only (r_s = -0,372, p = 0,020) was found (Table 47). This negative correlation shows that as women's intensity of PANAS-NA decreased, VIV tended to increase.

Table 47 Partial Spearman's rank-order correlations for V+A+H regarding gender

Spearman's rho				VIV_VAH	Positive_ VAH	Negative_ VAH
Gender	Male	VIV_VAH	Correlation Coefficient	1,000	,421**	-,146
			Sig. (2-tailed)	.	,006	,361
			N	41	41	41
		Positive_VAH	Correlation Coefficient	**,421****	1,000	-,211
			Sig. (2-tailed)	**,006**	.	,186
			N	41	41	41
		Negative_VAH	Correlation Coefficient	-,146	-,211	1,000
			Sig. (2-tailed)	,361	,186	.
			N	41	41	41
	Female	VIV_VAH	Correlation Coefficient	1,000	,742**	-,372*
			Sig. (2-tailed)	.	<,001	,020
			N	39	39	39
		Positive_VAH	Correlation Coefficient	**,742****	1,000	-,528**
			Sig. (2-tailed)	**<,001**	.	<,001
			N	39	39	39
		Negative_VAH	Correlation Coefficient	**-,372***	-,528**	1,000
			Sig. (2-tailed)	**,020**	<,001	.
			N	39	39	39

** Correlation is significant at the 0,01 level (2-tailed).
* Correlation is significant at the 0,05 level (2-tailed).

Concerning the gender effect for V+A+S, three statistically significant correlations were found: two positive correlations between VIV and positive emotions for both men (r_s = 0,365, p = 0,019) and women (r_s = 0,683, p < 0,001), meaning that, in general, when the users reported higher intensity of PANAS-PA, VIV also tended to increase. Also, a negative correlation between VIV and PANAS-NA for women only was found (r_s = -0,581, p < 0,001) (Table 48). This negative correlation informs that when women reported less intensity of PANAS-NA, VIV tended to increase.

Table 48 Partial Spearman's rank-order correlations for V+A+S regarding gender

Spearman's rho				VIV_VAS	Positive_ VAS	Negative_ VAS
Gender	Male	VIV_VAS	Correlation Coefficient	1,000	,365*	-,244
			Sig. (2-tailed)	.	,019	,125
			N	41	41	41
		Positive_VAS	Correlation Coefficient	**,365***	1,000	-,332*
			Sig. (2-tailed)	**,019**	.	,034
			N	41	41	41
		Negative_VAS	Correlation Coefficient	-,244	-,332*	1,000
			Sig. (2-tailed)	,125	,034	.
			N	41	41	41
	Female	VIV_VAS	Correlation Coefficient	1,000	,683**	-,581**
			Sig. (2-tailed)	.	<,001	<,001
			N	39	39	39
		Positive_VAS	Correlation Coefficient	**,683****	1,000	-,543**
			Sig. (2-tailed)	**<,001**	.	<,001
			N	39	39	39
		Negative_VAS	Correlation Coefficient	**-,581****	-,543**	1,000
			Sig. (2-tailed)	**<,001**	<,001	.
			N	39	39	39

** Correlation is significant at the 0,01 level (2-tailed).

* Correlation is significant at the 0,05 level (2-tailed).

Finally, regarding the gender effect for V+A+T+H+S, three more statistically significant correlations could be found: two positive correlations between VIV and PANAS-PA for both men (r_s = 0,457, p = 0,003) and women (r_s = 0,365, p = 0,022), meaning that, in general, when the users reported high intensity of PANAS-PA, VIV tended to increase. Also, a negative correlation between VIV and negative emotional responses for women only was registered (r_s = -0,409, p = 0,010) (Table 49). This negative correlation informs that when women reported less intensity of PANAS-NA, VIV tended to increase.

Table 49 Partial Spearman's rank-order correlations for V+A+T+H+S regarding gender

Spearman's rho				VIV_ V+A+T+H+S	Positive_ V+A+T+H+S	Negative_ V+A+T+H+S
Gender	Male	VIV_VATHS	Correlation Coefficient	1,000	,457**	-,138
			Sig. (2-tailed)	.	,003	,391
			N	41	41	41
		Positive_VATHS	Correlation Coefficient	**,457****	1,000	-,367*
			Sig. (2-tailed)	**,003**	.	,018
			N	41	41	41
		Negative_VATHS	Correlation Coefficient	-,138	-,367*	1,000
			Sig. (2-tailed)	,391	,018	.
			N	41	41	41
	Female	VIV_VATHS	Correlation Coefficient	1,000	,365*	-,409**
			Sig. (2-tailed)	.	,022	,010
			N	39	39	39
		Positive_VATHS	Correlation Coefficient	**,365***	1,000	-,147
			Sig. (2-tailed)	**,022**	.	,372
			N	39	39	39
		Negative_VATHS	Correlation Coefficient	**-,409****	-,147	1,000
			Sig. (2-tailed)	**,010**	,372	.
			N	39	39	39

** Correlation is significant at the 0,01 level (2-tailed).

* Correlation is significant at the 0,05 level (2-tailed).

Finally, by globally analyzing the strengths obtained with the results from the Partial Spearman's Rank-Order correlations, for almost all the stimuli combinations, there were notable stronger correlations registered for women than for men. Only for the positive V+A+T+H+S men registered a slightly stronger correlation than women. Implications of this finding will be further addressed in section 7.4.

7.3. The impact of age

To further explore the impact of age on the correlation between VIV and emotional responses, two age groups composed of the same number of individuals were created (low-age group: 18 ≥ 33, N = 40; high-age group: ≥ 34, N = 40). Consequently, results will be presented according to the lower (first group) and higher ages (second group). This segmentation allows to conduct similar correlations to the previous performed regarding the gender effect.

Regarding the age effect for V+A, results show three statistically significant correlations between the users' VIV and their emotional responses (Table 50): low-age group showed enhanced VIV when they reported high intensity of PANAS-PA (r_s = 0,351, p = 0,026); high-age group demonstrated enhanced VIV when PANAS-PA were more intense (r_s = 0,515, p < 0,001) and when PANAS-NA presented low intensity (r_s = -0,436, p = 0,005).

Table 50 Partial Spearman's rank-order correlations for V+A regarding age

Spearman's rho				VIV_VA	Positive_ VA	Negative_ VA
Age Groups	Low-age group	VIV_VA	Correlation Coefficient	1,000	,351*	-,230
			Sig. (2-tailed)	.	,026	,153
			N	40	40	40
		Positive_VA	Correlation Coefficient	**,351***	1,000	-,039
			Sig. (2-tailed)	**,026**	.	,811
			N	40	40	40
		Negative_VA	Correlation Coefficient	-,230	-,039	1,000
			Sig. (2-tailed)	,153	,811	.
			N	40	40	40
	High-age group	VIV_VA	Correlation Coefficient	1,000	,515**	-,436**
			Sig. (2-tailed)	.	< ,001	,005
			N	40	40	40
		Positive_VA	Correlation Coefficient	**,515****	1,000	-,179
			Sig. (2-tailed)	**< ,001**	.	,268
			N	40	40	40
		Negative_VA	Correlation Coefficient	**-,436****	-,179	1,000
			Sig. (2-tailed)	**,005**	,268	.
			N	40	40	40

** Correlation is significant at the 0,01 level (2-tailed).

* Correlation is significant at the 0,05 level (2-tailed).

For V+A+T, results show three statistically significant correlations between the users' VIV and their emotional responses (Table 51): low-age group showed enhanced VIV when they reported high intensity of PANAS-PA (r_s = 0,506, p < 0,001) and low intensity of PANAS-NA (r_s = -0,462, p = 0,003); high-age group demonstrated enhanced VIV when PANAS-PA were more intense (r_s = 0,656, p < 0,001).

Table 51 Partial Spearman's rank-order correlations for V+A+T regarding age

Spearman's rho				VIV_VAT	Positive_ VAT	Negative_ VAT
Age Groups	Low-age group	VIV_VAT	Correlation Coefficient	1,000	,506**	-,462**
			Sig. (2-tailed)	.	< ,001	,003
			N	40	40	40
		Positive_VAT	Correlation Coefficient	**,506****	1,000	-,356*
			Sig. (2-tailed)	**< ,001**	.	,024
			N	40	40	40
		Negative_VAT	Correlation Coefficient	**-,462****	-,356*	1,000
			Sig. (2-tailed)	**,003**	,024	.
			N	40	40	40
	High-age group	VIV_VAT	Correlation Coefficient	1,000	,656**	-,310
			Sig. (2-tailed)	.	< ,001	,052
			N	40	40	40
		Positive_VATHS	Correlation Coefficient	**,656****	1,000	-,262
			Sig. (2-tailed)	**< ,001**	.	,102
			N	40	40	40
		Negative_VAT	Correlation Coefficient	-,310	-,262	1,000
			Sig. (2-tailed)	,052	,102	.
			N	40	40	40

** Correlation is significant at the 0,01 level (2-tailed).

* Correlation is significant at the 0,05 level (2-tailed).

For V+A+T, results also show three statistically significant correlations between the users' VIV and their emotional responses (Table 52): low-age group showed enhanced VIV when they reported high intensity of PANAS-PA (r_s = 0,599, p < 0,001); high-age group demonstrated enhanced VIV when PANAS-PA were more intense (r_s = 0,539, p < 0,001) and low intensity of PANAS-NA (r_s = -,0340, p = 0,0032).

Table 52 Partial Spearman's rank order correlations for V+A+H regarding age

Spearman's rho				VIV_VAH	Positive_ VAH	Negative_ VAH
Age Groups	Low-age group	VIV_VAH	Correlation Coefficient	1,000	,599**	-,127
			Sig. (2-tailed)	.	< ,001	,435
			N	40	40	40
		Positive_VAH	Correlation Coefficient	**,599****	1,000	-,346*
			Sig. (2-tailed)	**< ,001**	.	,029
			N	40	40	40
		Negative_VAH	Correlation Coefficient	-,127	-,346*	1,000
			Sig. (2-tailed)	,435	,029	.
			N	40	40	40
	High-age group	VIV_VAH	Correlation Coefficient	1,000	,539**	-,340*
			Sig. (2-tailed)	.	< ,001	,032
			N	40	40	40
		Positive_VAH	Correlation Coefficient	**,539****	1,000	-,370*
			Sig. (2-tailed)	**< ,001**	.	,019
			N	40	40	40
		Negative_VAH	Correlation Coefficient	**-,340***	-,370*	1,000
			Sig. (2-tailed)	**,032**	,019	.
			N	40	40	40

** Correlation is significant at the 0,01 level (2-tailed).
* Correlation is significant at the 0,05 level (2-tailed).

Regarding V+A+S, results show four statistically significant correlations between the users' VIV and their emotional responses (Table 53): low-age group showed enhanced VIV when they reported high intensity of PANAS-PA (r_s = 0,455, p = 0,003) and low intensity of PANAS-NA (r_s = -0,418, p = 0,007); high-age group demonstrated enhanced VIV when PANAS-PA were more intense (r_s = 0,528, p < 0,001) and low intensity of PANAS-NA (r_s = -0,476, p = 0,002).

Table 53 Partial Spearman's rank-order correlations for V+A+S regarding age

Spearman's rho				VIV_VAS	Positive_ VAS	Negative_ VAS
Age Groups	Low-age group	VIV_VAS	Correlation Coefficient	1,000	,455**	-,418**
			Sig. (2-tailed)	.	,003	,007
			N	40	40	40
		Positive_VAS	Correlation Coefficient	**,455****	1,000	-,565**
			Sig. (2-tailed)	**,003**	.	< ,001
			N	40	40	40
		Negative_VAS	Correlation Coefficient	**-,418****	-,565**	1,000
			Sig. (2-tailed)	**,007**	< ,001	.
			N	40	40	40
	High-age group	VIV_VAS	Correlation Coefficient	1,000	,528**	-,476**
			Sig. (2-tailed)	.	< ,001	,002
			N	40	40	40
		Positive_VAS	Correlation Coefficient	**,528****	1,000	-,334*
			Sig. (2-tailed)	**< ,001**	.	,035
			N	40	40	40
		Negative_VAS	Correlation Coefficient	**-,476****	-,334*	1,000
			Sig. (2-tailed)	**,002**	,035	.
			N	40	40	40

** Correlation is significant at the 0,01 level (2-tailed).

* Correlation is significant at the 0,05 level (2-tailed).

Finally, regarding V+A+T+H+S, results show three statistically significant correlations between the users' VIV and their emotional responses (Table 54): low-age group showed enhanced VIV when they reported high intensity of PANAS-PA (r_s = 0,341, p = 0,0031); high-age group demonstrated enhanced VIV when PANAS-PA were more intense (r_s = 0,385, p = 0,014) and low intensity of PANAS-NA (r_s = -0,332, p = 0,0037).

Table 54 Partial Spearman's rank-order correlations, for V+A+T+H+S regarding age

Spearman's rho				VIV_VATHS	Positive_ VATHS	Negative_ VATHS
Age Groups	Low-age group	VIV_VATHS	Correlation Coefficient	1,000	,341*	-,248
			Sig. (2-tailed)	.	,031	,123
			N	40	40	40
		Positive_VATHS	Correlation Coefficient	**,341***	1,000	-,339*
			Sig. (2-tailed)	**,031**	.	,032
			N	40	40	40
		Negative_VATHS	Correlation Coefficient	-,248	-,339*	1,000
			Sig. (2-tailed)	,123	,032	.
			N	40	40	40
	High-age group	VIV_VATHS	Correlation Coefficient	1,000	,385*	-,332*
			Sig. (2-tailed)	.	,014	,037
			N	40	40	40
		Positive_VATHS	Correlation Coefficient	**,385***	1,000	-,135
			Sig. (2-tailed)	**,014**	.	,407
			N	40	40	40
		Negative_VATHS	Correlation Coefficient	**-,332***	-,135	1,000
			Sig. (2-tailed)	**,037**	,407	.
			N	40	40	40

** Correlation is significant at the 0,01 level (2-tailed).

* Correlation is significant at the 0,05 level (2-tailed).

7.4. Discussion

Regarding the relationship between the users' emotional responses and the VIV ability (R.Q. 3), this study denotes, in general, a clear pattern regarding both gender and age, which confirms H 3. This can be observable by comparing the Spearman's rank-order correlation tests (Table 55) with the results from the partial correlation tests performed for gender (Table 56) and age (Table 57).

Table 55 Impact of the users' emotional responses to enhance VIV

Stimuli combinations	Emotional responses	
	Positive	Negative
(V+A)	↑	↓
(V+A+T)	↑	↓
(V+A+H)	↑	↓
(V+A+S)	↑	↓
(V+A+T+H+S)	↑	↓

Caption:

↑ high intensity (with statistical significance) | ↑ high intensity (with no statistical significance)

↓ low intensity (with statistical significance) | ↓ low intensity (with no statistical significance)

Table 56 Impact of the users' gender and their emotional responses to enhance VIV

	Women		Men	
Stimuli combinations	Emotional responses		Emotional responses	
	Positive	Negative	Positive	Negative
(V+A)	↑	↓	↑ (no statistical significance)	↓
(V+A+T)	↑	↓	↑	↓
(V+A+H)	↑	↓	↑	↓ (no statistical significance)
(V+A+S)	↑	↓	↑	↓ (no statistical significance)
(V+A+T+H+S)	↑	↓	↑	↓ (no statistical significance)

Caption:

↑ high intensity (with statistical significance) | ↑ high intensity (with no statistical significance)

↓ low intensity (with statistical significance) | ↓ low intensity (with no statistical significance)

Table 57 Impact of the users' age and their emotional responses to enhance VIV

Stimuli combinations	Low-age group		High-age group	
	Emotional responses		Emotional responses	
	Positive	Negative	Positive	Negative
(V+A)	↑	↓	↑	↓
(V+A+T)	↑	↓	↑	↓
(V+A+H)	↑	↓	↑	↓
(V+A+S)	↑	↓	↑	↓
(V+A+T+H+S)	↑	↓	↑	↓

Caption:

↑ high intensity (with statistical significance) | ↑ high intensity (with no statistical significance)

↓ low intensity (with statistical significance) | ↓ low intensity (with no statistical significance)

It was determined for both genders that, as the intensity of negative emotions decreases and the intensity of positive emotions increases, VIV also increases, regardless of the multisensory combinations.

Although some findings were not statistically significant, results suggest evidence to accept a pattern between genders, indicating that this variable has no impact on the relationship between emotions and VIV. This is evident from the nearly identical results observed between men and women when considering negative and positive emotional responses for all the multisensory combinations. Moreover, all the statistically insignificant results were found only regarding men (in 4 correlations, as Table 56 demonstrates). This result might have been influenced by the strong correlations found for women, as seen in section 7.2.

This result is not in line with what was anticipated (H 3.1), as significant differences were expected between genders, considering the idea of women self-reporting their emotions more freely than men, as defended by Fischer [39], which consequently would affect the MI results. Moreover, considering the potential social desirability, which is predominantly observed in men, as noted by Paulhus [226], it was expected to note gender affecting this relationship.

As far as we know, no existing literature aims to investigate the impact of gender on the relationship between VIV and emotions. Thus, our findings can only be compared individually with each of these variables. Even though, the impact of gender on emotional responses and MI is not consensual in the literature, as respectively discussed in sections 2.3.3 and 2.4.3. On the one hand, some authors defend its influence on emotional responses [228, 229] and MI [5, 27, 227, 292-294]. On the other hand, our findings reinforce previous work's results which also did not find gender impact on emotional responses ([90, 145, 224, 230]), VIV [295], or CC [5].

Finally, regarding the impact of age, this thesis' results suggest no impact of this variable on the relationship between emotions and VIV, in contrast with what was anticipated (H 3.2). This is evident from the identical results observed for age groups when considering negative and positive emotional responses. Although some findings were not statistically significant, it seems evident that for both age groups, intense positive emotions, irrespective of the multisensory stimuli combination, improved VIV ability. On the opposite, intense negative emotions, again, regardless of the multisensory stimuli combination used, worsen VIV ability. These findings are illustrated in Table 57, which denotes how to enhance VIV based on the multisensory stimuli combinations, regarding low and high age groups and their corresponding emotional responses.

With these results, it is possible to conclude that there is no evidence to suggest that there are differences in the type of emotions (positives/negatives) that enhance VIV ability between the low and high age groups. This conclusion can be determined by the similar results obtained regarding the VIV outcomes considering the positive and negative emotions for both age groups. However, the results concerning age require further in-depth investigation. In short, the absence of influence from both variables, age and gender, on the relationship between user emotions and their VIV indicates that the use of multisensory stimuli could help reduce potential gender and age disparities VR, as already suggested by Melo, et al. [90] regarding the influence of gender in passive VR experiences.

8. Conclusions

This thesis embarked on a comprehensive study to understand how various multisensory stimuli combinations in VR impact the users' emotions and VIV within the context of VT. It was motivated by the gap in research, particularly concerning VT, despite the growing interest in the connection between emotions, VIV, and tourism. This investigation proposed three main R.Qs.: 1) to understand the effect of different multisensory stimuli combinations on users' emotional responses; 2) to comprehend the impact of these stimuli on the users' VIV; and 3) to determine the influence of users' emotional responses on their VIV ability, considering age and gender differences. To do so, a between-subjects experimental study was designed, involving the creation of two different IVEs – one positive and one negative – distinguished by the pleasantness of the stimuli. To validate the environments, initially, an in-depth exploration of multisensory stimuli typically used in VR and a focus group were developed. The results allowed the conclusion that the purpose of both IVEs had been successfully achieved. This was evidenced by the high levels of sense of presence obtained in both IVEs, coupled with the results from pre and post-tests of the users' emotional responses. These tests revealed that the positive IVE successfully elicited intense positive emotions and reduced negative emotions following VR exposure, leading to its perception as a pleasant experience. In turn, the negative IVE increased the intensity of the negative emotions, as intended, highlighting its potential to be considered unpleasant. Nevertheless, the negative IVE also, unexpectedly, increased some positive ones. This underscores the complex emotional landscape that VR can evoke, irrespective of the stimulus nature. Furthermore, the observed differences in multisensory combinations' impact on positive and negative emotions emphasizes the importance of carefully designing VR experiences, considering the emotional and cognitive impacts on users, and opens new avenues for research in multisensory stimulation and its applications in VR.

One of the main purposes of this thesis' results is to guide VR developers in selecting the best multisensory stimuli combinations to elicit intense emotions and to improve the individuals' VIV.

This information is particularly valuable for the tourism sector, as this thesis studies. Nonetheless, their results might also be applicable to others, such as entertainment, marketing (e.g., advertising or brand engagement), and clinical domains, to name a few. As argued by Comer (2015) in Allbutt [7], predicting the multisensory stimuli that would improve the patient's VIV, while also safely controlling their emotional responses, could benefit the therapy sector, such as phobia therapy. Another example: in guided imagery therapy method, which involves a person envisioning thoughts prompted by a therapist, aiding fostering relaxation and positive thinking, knowing how to enhance the patients' positive emotional responses and VIV according to their age and gender might also be beneficial.

8.1. Answers to the research questions

For a clearer understanding of this thesis's findings, this section provides a concise response to each of the proposed research questions:

R.Q. 1 Do different multisensory stimuli combinations in a VT experience elicit variations in the user's emotional responses?

This study's primary outcomes revealed significant insights into the role of multisensory stimuli in eliciting variations in the users' emotional responses in both positive and negative IVEs.

R.Q. 1.1 What is the effect of positive multisensory stimuli combinations?

In the positive IVE, simpler positive stimuli combinations were more effective than complex ones. In particular, V+A+H and V+A+T were more effective in evoking intense emotional responses in general, in the positive IVE. This indicates that the addition of haptics and taste in VR might be beneficial in evoking intense emotional responses when using positive stimuli, in contrast with V+A+T+H+S.

R.Q. 1.2 What is the effect of negative multisensory stimuli combinations?

In the negative IVE, in general, a lower intensity of negative emotional responses than positive was registered. Nevertheless, a greater complexity of multisensory stimuli (V+A+T+H+S) was required to achieve higher intensity of emotional responses in general, in opposition to the positive IVE.

Main outcomes of R.Q. 1: These results highlight the crucial role of stimulus complexity in emotional engagement within VR. They show that using combinations of positive and negative multisensory stimuli leads to varying effects on the users' emotional responses. Additionally, important clues were provided concerning the effect of each stimuli combination to elicit specific emotional responses in the user. This conclusion fills a gap in the literature that has been highlighted for many years by several authors [22-26], which is the urge to determine some relationships between multisensory stimulus and the corresponding elicited specific emotions. Detailed results can be consulted in Table 34 and Table 35. Outcomes from R.Q. 1 lead to a better understanding of how individuals perceive and react to different stimuli and their combinations in a VR experience, offering valuable insights for the development of effective VT experiences. By accurately triggering emotions, VR experiences can become more engaging and realistic, enhancing the overall user experience. Moreover, recognizing how different users respond to various stimuli can lead to more personalized and accessible VR experiences, involving a wider audience.

R.Q. 2 How does the users' VIV ability change in response to different combinations of multisensory stimuli in a VT experience?

Results revealed significant insights into the role of multisensory stimuli in eliciting variations in the users' VIV ability in both positive and negative IVEs.

R.Q. 2.1 What is the effect of positive multisensory stimuli combinations?

It was demonstrated that the total combination of multisensory elements in the positive IVE was the most influential in enhancing the users' VIV. On the opposite, positive V+A+H and V+A+T were the less influential combinations to enhance the users' VIV.

R.Q. 2.2 What is the effect of negative multisensory stimuli combinations?

In contrast with the positive IVE, in the negative IVE, V+A+T+H+S was the least effective in enhancing the users' VIV ability. V+A+S and V+A+H emerged as more effective in augmenting users' VIV, meaning that smell and haptics have a powerful effect on enhancing users' VIV.

<u>Main outcomes of R.Q. 2</u>: Results obtained for R.Q. 2 suggest an inversely proportional relationship between VIV ability and the intensity of the users' emotional responses. They also underscore the negative impact of overloading the user with too much multisensory information, which can be more distracting, as previously discussed.

R.Q. 3 What is the relationship between the users' emotional responses and VIV in a VT experience?

Regarding the relationship between the users' emotional responses and their VIV, interestingly, no significant differences were found across different genders and age groups, challenging some existing perceptions.

R.Q. 3.1 What's the impact of gender on that relationship?

No impact of gender was found.

R.Q. 3.2 What's the impact of age on that relationship?

No impact of age was found.

Main outcomes of R.Q. 3: As far as we know, this is the first study based on multisensory VR involving the five human senses to seek a relationship between the stimuli used and the users' VIV ability. Generically, our findings suggest that different multisensory stimuli combinations influence the individuals' emotional responses, which, consequently, plays a critical role in influencing their VIV ability, irrespective of users' age and gender.

Finally, below is presented a conclusive table summarizing the confirmation or rejection of the initially proposed research hypotheses (Table 58), considering that the potential justifications for these outcomes have already been examined in the respective discussion chapters (sections 5.4, 6.4, and 7.4).

This thesis significantly contributes to the fields of VR and VT, in particular, by providing a deeper understanding of the emotional effects of multisensory stimuli. It highlights the potential of VR in creating emotionally resonant and engaging VT experiences. The research outcomes suggest that VR developers in general, and the tourism industry in particular, can strategically use multisensory stimuli to enhance VT experiences, making them more appealing, memorable, and user oriented. Moreover, these outcomes also shed light on the potential of VR in understanding and manipulating emotional responses for various applications, for instance, for therapeutic contexts, where emotional engagement and VIV, as discussed, are keys.

Table 58 Summary on the confirmation/rejection of the hypotheses according to each R.Q.

Research Question	Expected Results	Hypothesis
R.Q. 1: Do different multisensory stimuli combinations in a VT experience elicit variations in the user's emotional responses?	Yes. It was expected that different combinations of multisensory stimuli in a VT experience would differently impact the user's emotional responses.	Confirmed
R.Q. 1.1: What is the effect of positive multisensory stimuli combinations?	As the positive IVE resorted to positive multisensory stimuli, it was expected to trigger more intense positive emotions, particularly accentuated when using the full multisensory combinations (V+AT+H+S).	Rejected
R.Q. 1.2: What is the effect of negative multisensory stimuli combinations?	As the negative IVE resorted to negative multisensory stimuli, it was expected to trigger more intense negative emotions, particularly accentuated when using the full multisensory combinations (V+AT+H+S).	Rejected
R.Q. 2: How does the users' VIV ability change in response to different combinations of multisensory stimuli in a VT experience?	The expected results were that the greater the combination of multisensory stimuli, the more realistic and vivid the scenario would be, regardless of whether negative (negative IVE) or positive (positive IVE) stimuli were used.	Rejected
R.Q. 2.1: What is the effect of positive multisensory stimuli combinations?	As more vivid and realistic an event is perceived in VR, it was advanced that V+A+T+H+S would enhance VIV independently on the IVEs, when compared to any other combination.	Confirmed
R.Q. 2.2: What is the effect of negative multisensory stimuli combinations?		Rejected
R.Q. 3: What is the relationship between the users' emotional responses and VIV in a VT experience?	It was anticipated that a statistically significant relationship would be found between the users' emotional responses and VIV.	Confirmed
R.Q. 3.1: What's the impact of gender on that relationship?	It was expected that women would report higher intensity of emotional responses than men.	Rejected
R.Q. 3.2: What's the impact of age on that relationship?	It was expected that younger individuals would report higher VIV ability.	Rejected

8.2. Limitations

The relationship between emotions and MI is a complex field of study with numerous challenges. This complexity becomes even more pronounced in the context of multisensory VR, as discussed. This investigation was not an exception facing these challenges. In this section, we outline the identified limitations of this work and provide recommendations for future research in this field of study.

Our findings suggest that exposure to a multisensory IVE has a significant impact on the users' emotional responses, thus corroborating previous findings regarding the intense emotions that are awakened with multisensory stimulation [1-4]. However, one limitation was the unexpected emotional responses observed in the negative IVE, where, despite the intention to particularly amplify negative emotions, it also heightened positive emotions. Although not totally against the study's initial aim, this outcome was not totally predictable, highlighting the complex nature of exploring emotional responses in immersive environments and the challenge of eliciting specific emotional reactions, as already highlighted by several authors [22-26].

Another limitation is the method for assessing emotional reactions. This study revealed that the PANAS scale was somewhat ineffective in assessing the users' emotional responses, as discussed regarding the R.Q. 1, particularly in terms of the PANAS-NA. Therefore, we believe that a more in-depth evaluation of using the PANAS scale to analyze user emotions in VR contexts is needed.

Specifically regarding the methodology, we noticed that the HTC Vive cable was occasionally intrusive, with some participants becoming entangled by the wires during the VR experience.

8.3. Future work

Considering the gaps identified in the literature review and the limitations highlighted previously, this section proposes several recommendations for future research.

First, a more comprehensive understanding of how different demographic factors, like age and gender, interact with VR experiences is needed. Our results found no interference of age regarding the relationship between the users' emotional responses and their VIV. This conclusion is not in line with previous studies [288, 290, 301, 302], mentioning that cognitive functions and, consequently, VIV ability would decline with advancing age. We believe that this controversy may be attributed to the fact that our sample consisted of individuals aged between 18 and 66 years, all professionally active. It is possible that age-related differences in VIV could be more noticeable if the sample included a wider age range, i.e., including children and professionally inactive individuals. Alternatively, it might be the case that there are indeed no differences in the VIV of users between the ages of 18 and 66, which needs to be further investigated. Based on this, and considering the literature review, we believe that there is still a need for a broader understanding of how different demographic factors interact with VR experiences, further exploring the role of age and gender. In summary, a larger and diverse sample could have aligned our results more closely with those found in previous studies.

The unexpected results of the obtained emotional responses when using negative stimuli combinations allowed us to present one important recommendation. Future research should concentrate on exploring different multisensory stimuli with a more powerful negative impact when developing negative IVEs (for instance, acrider flavors or more stinky smells). In fact, the absence of a stronger smell might have contributed to the obtained results regarding the inexistent differences between the positive and the negative aromas on the users' VIV. However, this approach raises concerns regarding the users' well-being. Hence, extreme caution is recommended in any future experiments. Thus, we suggest that this outcome should be further investigated, for instance, by comparing other positive and negative olfactory stimuli.

Considering the evidence of PANAS-NA as somewhat ineffective in assessing the users' emotional responses in this study, we recommend a deeper concern regarding the method for assessing the emotional reactions of users. This, on the one hand, would help uncover whether the PANAS scale is truly effective in studies of emotional VR, and on the other hand, it would contribute to understanding the most suitable subjective instrument for measuring emotions in VR.

An important future work resulting from this thesis involves the development of a framework for defining and validating multisensory virtual experiences. This includes developing a set of guidelines to assist in selecting multisensory stimuli based on the emotional responses intended to evoke in the user, as well as validating these stimuli through a well-structured methodological process. This can be applied, for instance, for therapeutic purposes, such as well-being and mindfulness, which particularly benefit from the manipulation of the patients' emotional states.

Additionally, investigating VT with impaired users could also yield particularly interesting conclusions. Taking into account earlier research that highlights the significance of audio and haptic signals for VR users with visual impairments (e.g., [382]), or visual and haptic signals for those with hearing impairments (e.g., [383]), it can be expected that there will be a contrast between the findings of those studies and the outcomes of this thesis.

Finally, although no formal collection of cybersickness data was conducted, after each participation, users were informally inquired about any discomfort caused by the HMD usage at the end of the VR session. No one reported any symptoms. This hint, along with the high levels of presence reported and the overall satisfaction indicated in the ASQ, strengthens the argument that the experience was successful within this methodology. Consequently, we believe that replicating this experiment in future research would be advantageous in other VR contexts.

9. References

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10. Appendix

10.1. Narratives (Portuguese version)

Table 59 Narratives developed according to the IVE (Portuguese version)

Objeto	Positive IVE	Negative IVE
GUITARRA PORTUGUESA	Pensa-se que a origem do fado remonta ao início do ano 1800. Atualmente, assume uma posição central na cultura musical portuguesa, que se acentuou, sobretudo, desde a Revolução do 25 de abril, ou seja, após a censura vivida até então. A presença da Guitarra Portuguesa nas melodias do fado faz com que não haja barreiras linguísticas para perceber a emoção que se pretende transmitir, tornando-se, assim, uma linguagem universal. O fado foi considerado património cultural imaterial da UNESCO em novembro de 2011 [332].	Não é conhecida a origem da guitarra portuguesa, mas conhece-se bem a sua ligação ao fado. Apesar de atualmente ser mundialmente aclamado, o fado começou por ser fortemente rejeitado por grupos de pessoas tidos como intelectualmente superiores. Quando finalmente tentava inserir-se na cultura portuguesa, através do teatro e de festivais de música, por exemplo, a forte censura vivida em Portugal durante o regime do Estado Novo, trouxe maus momentos para este género musical, que foi fortemente afetado [332].
BARRIL DE VINHO DO PORTO	Os barris de vinho do Porto carregam uma forte herança cultural da cidade do Porto. Ainda nos dias de hoje a tradição das vindimas e da pisa da uva artesanal se mantém, o que torna este processo especial e diferente do de outros vinhos [333]. A região do Alto Douro vinhateiro, onde se produz o vinho do Porto, criada em 1756 pelo Marquês de Pombal, é a mais antiga do mundo, e, atualmente, património da Unesco [334].	O vinho do Porto é aclamado pelo seu sabor inconfundível. Contudo, a sua fama e o seu forte legado levaram a enormes fraudes, como por exemplo a sua reprodução ilegal por preços inferiores, que em muito contribuiu para uma grave crise no setor agrícola, a crise da Lavoura, no séc. XIX. Nessa altura, o Douro era visto como um retrato de miséria, um rótulo que perdurou bastantes anos [334]!

BARCO RABELO	O Barco Rabelo foi idealizado para o transporte de mercadorias, nomeadamente para o transporte de vinho do Porto. Circulava pelo Rio Douro, por onde seguia até chegar a Vila Nova de Gaia, para envelhecer e ganhar o seu sabor caraterístico. Apesar de atualmente o Barco Rabelo já não servir para o mesmo propósito, ainda é possível ver alguns exemplares a embelezar o rio Douro como atração turística. Cada barco mede entre 19 e 23 metros de comprimentos, e pode transportar, em média, até 100 barris [335]!	O barco Rabelo foi idealizado para o transporte de mercadorias, nomeadamente para o transporte de vinho do Porto. A sua arquitetura permite-lhe resistir às fortes correntes do rio Douro. Contudo, muitas foram as vidas que se perderam a bordo de um Rabelo. Uma das mais conhecidas está relacionada com a morte do barão de Forrester em 1861, que se terá afogado devido ao volumoso e pesado cinto de dinheiro e ouro que usava à cintura [335].
PINHEIRO	O Pinheiro é uma das árvores mais dominantes em Portugal. Adapta-se muito bem a diferentes tipos de solo e a altas temperaturas [336]. Por essa razão, após os incêndios de 2017 que devastaram grandes áreas florestais, o Pinheiro-manso, em particular, tem sido fundamental para a reflorestação do distrito de Leiria [337]!	Aproximadamente metade da área ardida em Portugal nos terríveis incêndios de 2017 era composta por pinheiros. A sua forma cónica, e a estrutura das suas folhas e ramos potencia a progressão rápida do fogo [336], e uma alta intensidade das chamas. Apesar de ser bem conhecido o perigo desta espécie, os procedimentos de gestão florestal continuam a não ser devidamente implementados [338].
BÚSSOLA	Originário da China, o chá foi introduzido na Europa pelos Portugueses, no século XVI. Através de Macau, que servia como porto para o comércio marítimo de várias especiarias, o chá foi uma das que mais se popularizou no Ocidente. Por exemplo, o chá das 5, um dos mais típicos costumes britânicos, foi introduzido pela princesa portuguesa, Catarina de Bragança, aquando do seu casamento com Carlos II de Inglaterra [339].	A bússola foi dos instrumentos de navegação mais importantes para a expansão marítima Portuguesa. Uma viagem marítima era uma aventura extremamente desconfortável e perigosa. Estima-se que 1 em cada 3 navios que partiam de Portugal no século XVI e XVII afundava, e que cerca de 40% da população do navio morria durante a viagem, vítima de fome, ataques piratas, ou doenças [340].

10.2. VVIQ adapted questionnaire (Portuguese version)

Table 60 VVIQ questionnaire (in Portuguese, as originally written)

Objeto	*Briefing*	Detalhes
GUITARRA PORTUGUESA	Represente visualmente na sua cabeça a imagem que tem de uma **Guitarra Portuguesa.**	1. Consegue visualizar o aspeto geral dessa Guitarra Portuguesa? 2. Consegue visualizar as cores que compõem essa Guitarra Portuguesa? 3. Consegue visualizar as formas geométricas que compõem essa Guitarra Portuguesa? 4. Consegue visualizar essa Guitarra Portuguesa pendurada numa parede?
BARRIL DE VINHO DO PORTO	Represente visualmente na sua cabeça a imagem que tem de um **barril de vinho do Porto**.	1. Consegue visualizar o aspeto detalhado desse barril de vinho do Porto? 2. Consegue visualizar as cores que compõem esse barril de vinho do Porto? 3. Consegue visualizar as formas geométricas que compõem esse barril de vinho do Porto? 4. Consegue visualizar a imagem geral desse barril de vinho do Porto numa adega, junto a mais umas dezenas de barris?
BARCO RABELO	Represente visualmente na sua cabeça a imagem que tem de um **barco Rabelo**.	1. Consegue visualizar o aspeto detalhado desse barco Rabelo? 2. Consegue visualizar as cores que compõem esse barco Rabelo? 3. Consegue visualizar as formas geométricas que compõem esse Barco Rabelo? 4. Consegue visualizar a imagem geral desse barco Rabelo a navegar no rio?
PINHEIRO	Represente visualmente na sua cabeça a imagem que tem de um **pinheiro**.	1. Consegue visualizar o aspeto detalhado desse pinheiro? 2. Consegue visualizar as cores que compõem esse pinheiro? 3. Consegue visualizar as formas geométricas que compõem esse pinheiro? 4. Consegue visualizar a imagem geral desse pinheiro numa floresta, no meio de centenas de outros pinheiros?
BÚSSOLA	Represente visualmente na sua cabeça a imagem que tem de uma **bússola**.	1. Consegue visualizar o aspeto detalhado dessa bússola? 2. Consegue visualizar as cores que compõem essa bússola? 3. Consegue visualizar as formas geométricas que compõem essa bússola? 4. Consegue visualizar a imagem geral de uma bússola a apontar para Sul na sua própria mão?

10.3. Focus group

10.3.1. Q1, Q2, and Participant's Informed Consent Statement

Q1 – Questionário sociodemográfico

Idade: _____ Nacionalidade: ____________________ Género: __________________

Habilitações académicas: __________________________ Área de formação: _______________________________________

Q2 – Intolerâncias alimentares e gostos pessoais

É intolerante a algum dos seguintes alimentos? E quanto ao seu gosto pessoal, gosta ou tolera os seguintes alimentos? (X)

	Intolerâncias alimentares		**Gostos Pessoais**		
	Sim*	Não	Gosto/Tolero	Não gosto/Não tolero	Rejeito provar*
Álcool (proveniente do vinho)					
Vinagre					
Café (sem cafeína)					
Sal					
Amendoim					
Marisco					

* No caso de assinalar que "sim" ou "rejeito provar" em alguma das opções, por favor comunique de imediato à investigadora.

Declaração de Consentimento Informado, livre e esclarecido para a participação num *Focus Group*

Este *focus group*, realizado no dia 3 de março de 2023, pelas 10h30, na Faculdade de Engenharia da Universidade do Porto, tem como propósito recolher a sua opinião acerca da metodologia de investigação relativa à tese de doutoramento levada a cabo pela estudante do Programa Doutoral em Medias Digitais, Mariana de Oliveira Magalhães (número de estudante: up201100991). Concretamente, procura-se com este *focus group* a validação de alguns estímulos multissensoriais que serão aplicados num cenário de realidade virtual.

Neste *focus group:*
- As questões podem ser respondidas por escrito (assinalando uma opção com um "X"), ou oralmente, dependendo do que lhe for pedido em cada momento;
- Os registos escritos anexos a este documento, relativos a algumas das suas respostas, serão mantidos por um período máximo de 3 anos, para que possa ser confirmado, se necessário, qualquer dado estatístico.
- Tratando-se de uma experiência multissensorial, haverá lugar a uma prova olfativa de alguns cheiros e à prova de alguns sabores mais ou menos agradáveis, mas sempre tendo em consideração as suas eventuais intolerâncias alimentares e os seus gostos pessoais (conforme acima descrito);
- Haverá uma gravação de áudio, cujo início e fim lhe serão comunicados. Estes dados servirão unicamente para fins desta investigação. O ficheiro de áudio será descartado assim que a investigação tenha fim, previsivelmente no fim do ano 2023.

Ao participar neste estudo, é-lhe garantida total confidencialidade, anonimato e uso exclusivo dos dados recolhidos para a presente investigação. **<u>Esta primeira folha deve ser desanexada das restantes após totalmente preenchida, e ser entregue à investigadora.</u>** Desta forma, é-lhe garantido que não haverá qualquer ligação entre as respostas fornecidas e o(a) seu (sua) autor(a).

Declaro ter lido e compreendido este documento, incluindo todos os esclarecimentos que prestou às dúvidas por mim colocadas.

Nome (primeiro e último): ____

Assinatura: ____ Data: 3 de março de 2023

10.3.2. Focus Group transcription with codification

Table 61 Focus group transcription

Participant	Conversation	Code
Mariana	Obrigada desde já até agora por terem preenchido estes questionários. Sei que não é a parte mais emocionante da tarefa, mas tinha que se feita. Vamos passar agora então a um momento de discussão entre todos, sendo que, inicialmente, vou-vos pôr aqui dois áudios. Quero que foquem mais do que no que está a ser dito, no tom da pessoa que está a falar. Portanto, esqueçam um pouco o que está a ser dito. Até porque o que está a ser dito são as histórias que vocês leram inicialmente. Portanto, foquem-se, por favor, mais no tom das pessoas.	
Áudio 1 -> play [História sobre os barcos rabelo – Pessoa 1]		
Mariana	Este foi o primeiro sample, a primeira pessoa. Peço agora que se foquem no segundo áudio.	
Áudio 2 -> play [História sobre a Guitarra Portuguesa – Pessoa 2]		
Mariana	Depois de ouvirem estas duas falas, gostava que refletissem uns com os outros acerca do tom. Vamos chamar-lhe "pessoa 1" e "pessoa 2". Queria perceber, antes de mais, se toda a gente conseguiu identificar 2 tons diferentes.	
Todos	Sim / aceno com a cabeça a indicar um "sim"	
Mariana	Ok. E agora que sabem que são duas pessoas diferentes, vamos chamar-lhe "Pessoa 1" que foi a primeira pessoa, e "Pessoa 2", que falou em segundo lugar, que diferenças mais acentuadas é que vocês notam entre o tom uma da outra?	
P1	A primeira é mais entusiasta do que a segunda.	VF1, VF2
P2	Sim. A outra… Não será esse o adjetivo, mas nota-se uma espécie de tom pesaroso, que está ligada ao tema.	VF2
Mariana	Na segunda?	
P2	Sim.	
P3	Sim. A segunda tem um tom mais monocórdico.	VF2
Mariana	Ok. Alguém quer acrescentar mais alguma coisa em relação a isto?	
P4	Uma é mais rápida, outra é mais lenta.	VF1, VF2
Mariana	Ok	
P6	Eu tive dificuldade em perceber essas caraterísticas uma e da outra.	VF1, VU1, VF2, VU2
Mariana	Ok, é válido! Qualquer opinião é válida!	
P5	Eu reparei que era mais monocórdico o segundo, e o primeiro eu não estava focada no conteúdo. Mas sinto que se estivesse a dar uma notícia má seria aquele tom. Não sei se a notícia ou a história era positiva	VF2
Mariana	Ok. Conseguiste abstrair-te mesmo bem, então!	
P5	Sim, estava só focada no tom.	
P2	Acho que ainda recolho aqui outra coisa, que foi algo que me foi sendo ensinado no percurso doutoral, que é: postura e projeção da voz. Na primeira, consegue isso. Na	VF1, VF2

	segunda, possivelmente pode ser para enquadrar o assunto, mas torna-se menos interessante à conta do tom empregue e do ritmo que também é empregue.	
P4	As duas acho que são bastante... como se estivesse a contar uma história... estão muito relacionadas com a ideia de história, de documentário. O tom é um tom de documentário. Não é um tom nem de conversa nem de...	VF1, VU1, VF2, VU2
Mariana	Mais descritivo, se calhar?	
P4	Com mais imparcialidade.	
Todos	Sim / aceno com a cabeça a indicar um "sim"	
P2	Por acaso, eu concordo que ambas são tons para exprimir histórias. Só que a diferença é que uma consegue expressar de uma forma mais dinâmica e acho que puxa mais a atenção de quem está a ouvir. A outra nem tanto. Mas lá está, depende! Seriam necessários outros estímulos, além do sonoro.	VF1, VF2
Mariana	Ok, perfeito. Alguém quer acrescentar mais alguma coisa?	
Todos	Não / aceno com a cabeça a indicar um "não"	
Mariana	Ok. Vamos então passar para a secção do clima. Portanto, eu queria saber a vossa opinião geral sobre o calor e o frio. E, portanto, queria perceber o que é que cada um de vocês sente acerca do calor e acerca do frio. Se gostam mais do calor, se gostam mais do frio, se isso depende do contexto, se isso depende do momento, se isso depende se estão lá fora ou se estão cá dentro. Gostava de saber a vossa opinião acerca disso.	
P4	Olha, a nível geral gosto mais do quente. Mas também porque sou friorenta, e, portanto, gosto mais do quente, do calor.	CF2, CF1
P3	Eu acho que depende muito do contexto, não?	CF2
Todos	Sim / aceno com a cabeça a indicar um "sim"	
P3	Portanto, se estiver um dia muito quente, e a pessoa quando entra num shopping e está fresquinho, ou num hotel... sei lá... maravilha! Mas também gosto muito do calor... de ir para a praia, o calor, para o campo. E também o contrário, às vezes. Portanto, estar frio lá fora e chegar a um lugar quentinho, uma lareira, por exemplo. Quer dizer, eu acho que tem muito a ver com o contexto e a mudança de contexto até!	CF2
Todos	Sim / aceno com a cabeça a indicar um "sim"	
P2	Eu era até capaz de esticar um bocado a coisa. Tem a ver com o nosso próprio desenvolvimento, porque até há bem pouco tempo, há coisa de dois anos, eu adorava o frio e detestava o calor. Isso tornou-se um bocado mais acentuado no último ano, por causa das alterações do clima. Continuo a não gostar tanto do calor, só que neste momento não suporto tanto o frio.	CU2, CF1
Mariana	Então, neste momento, se pudesses, consegues dizer se gostas mais de um ou de outro?	
P2	Hm... Não. Tem sempre de ser um meio termo.	
Mariana	Ok. Então estamos todos de acordo, que esta sensação térmica depende do contexto, não é?	
Todos	Sim / aceno com a cabeça a indicar um "sim"	
Mariana	Portanto, especificando, se estivermos num dia de primavera, se estivermos lá fora, com cerca de 15ºC, considerando que estamos bem, que estamos com a roupa certa para estarmos termicamente bem, por assim dizer. Eu queria então saber se se vocês estiverem lá fora, com cerca de 15ºC, é Primavera, em que estão confortáveis com a roupa que estão a usar, se preferem sentir uma brisa, em que se vê e escuta alguma chuva a correr, com o	

	vento a passar por vocês com a sensação mais de frio, com uma sensação de frio na cara, ou se preferem mais sentir o calor do sol, e estarem a apanhar sol.	
P1, P3, P4	Calor do sol!	3x (CF2, CF1)
P2, P5	Frio!	2xCU1
P6	Mas está sol ou não está sol?	
Mariana	É um dia de primavera, um dia como hoje, em que estão 15ºC.	
P3	No fundo, é estar à sombra com uma brisa fresca, ou se escolhem o sol, apanhar o sol na cara.	
Mariana	Isso, exatamente!	
P3	Eu vou logo para o sol. Eu sou logo energia solar!	CF2, CF1
Todos	(Risos)	
P5	Eu prefiro o fresquinho, até porque eu tenho rosáceas. E quando estou com muito calor, é muito desconfortável para mim. Então, sem dúvida, preferia uma brisazinha.	CU1, CU2
P2	Idem	
P1, P3, P4, P7	Calor! Chuva não!	4x (CF2, CF1), 4x AF1
P6	Depois de ouvir a explicação, prefiro o calor.	CF2, CF1
Todos	(Risos)	
Mariana	Agora, uma última questão em relação ao clima, queria perceber se conseguem fazer alguma associação entre as emoções que vos traz, no mesmo ambiente a que nos estávamos a referir, se conseguem fazer uma relação entre as emoções que vos traz um cenário e outro: ou seja, um cenário em que estão lá fora, ao sol, num cenário de 15ºC, em que estão com a temperatura estável, e em que se sentem bem termicamente. Conseguem associar algumas emoções a esse momento, e, por outro lado, se conseguem associar algumas emoções a estar na sombra, a passar-vos uma brisa pela cara, num momento em que não há sol, ou seja, na sombra. (Silêncio). Podem não conseguir, podem não conseguir fazer alguma associação!	
P4	Eu gosto muito de sentir o sol. Parece que estou a fazer a fotossíntese.	CF2, CF1
P3	Eu também! O sol dá-me sempre emoções positivas!	CF2, CF1
P2	Repõe energias.	CF2, CF1
P1	Sim, é mais isso.	CF2, CF1
P5	Se calhar, a sensação disso, de repor energias de que falaste lá fora... Eu estava aqui a imaginar esse cenário da brisa na praia, e acho que é... essa sensação das energias. Portanto, é uma sensação boa, agradável.	CF2, CF1
Mariana	Todos de acordo, então?	
Todos	Sim / aceno com a cabeça a indicar um "sim"	
Mariana	Ok, vamos então passar à reflexão geral sobre a experiência de realidade virtual. Eu queria perceber então... Eu acho que já vos expliquei, já todos conhecem mais ou menos o meu propósito. Portanto... Vou ter dois cenários de realidade virtual, um positivo, que é suposto gerar emoções positivas nos participantes, e um cenário negativo, que é suposto gerar emoções negativas no participante. E, portanto, eu queria perceber o que é que vocês acham acerca da introdução de sabores e de cheiros... Aliás, primeiro vamos aos cheiros, que foi a ordem que fizemos. De cheiros negativos, numa experiência de	

	realidade virtual académica... o que é que vocês acham acerca dos cheiros que eu vos apresentei?	
P4	Eu não sei o que é que tu consideraste negativo, não é?	
Mariana	É o que vocês consideraram negativo.	
Todos	(Todos retomam à página do questionário inicial acerca dos cheiros)	
P6	Eu só considerei o um.	OF1, OU2
P3	Sim, eu também.	OF1, OU2
Mariana	Pronto, eu queria saber se esse ou esses cheiros que vocês consideraram negativos, se acham que são válidos para uma experiência de realidade virtual.	
P4	Eu não tenho cheiros negativos.	OU1, OU2, OF3, OF4
P1	Eu tenho. Tenho o um.	OF1, OU2
Mariana	Ok. O que eu queria mesmo perceber é se acham aceitável para uma experiência de realidade virtual em contexto académico introduzir cheiros e sabores negativos. Parece-vos ok?	
Todos	Sim / aceno com a cabeça a indicar um "sim"	7x (OA1, GA1)
P7	Sim, parece-me normal.	OA1
P3	No contexto da experiência, acho que pode ser muito interessante!	OA1
Mariana	Ok, e em relação a providenciar níveis em muito baixa quantidade de álcool, associados ao vinho, o que é que vos parece? Parece-vos aceitável, desde que em quantidades mínimas, obviamente?...	
Todos	Sim, sim, sim.	7x GA1
P3	Sim, parece-me muito bom! Se for um público adulto, até porque temos sempre de ver a questão mais da ética, se é um público adulto, e não intolerante, ou que não seja abstémia... Portanto, então sim.	GA1
Mariana	Sim, claro. Vai sempre haver esse cuidado em relação a isto que o P3 referiu, que, claro, é super importante. Aliás, isso será sempre questionado antes da experiência: idade do participante, as alergias, os gostos pessoais, ...	
P3	Agora é mais paladar, certo?	
Mariana	Sim, desculpem. Vamos então fazer a transição.	
Todos	(Todos retomam a página do questionário inicial acerca do paladar)	
P3	Em relação ao paladar, eu tinha só um comentário, não sei se faz sentido ou não, mas tem a ver com a temperatura. Alguns podem dar experiências mais agradáveis ou menos, dependendo da temperatura.	GU3
Todos	Sim!	
Mariana	Ok, e qual é o número do que vocês consideravam que devias ficar mais quente ou frio?	
Todos	O 4!	
P3	Frio não sabe tão bem, mas quer dizer... espoleta emoções positivas na mesma, em mim, pelo menos, mas quentinho é outra coisa.	GF3, GU3
P4	Exato! Eu foi mais pelo sabor do que achei que era, do que pelo sabor que aconteceu! Porque, ainda por cima, como era descafeinado...	GU3
Todos	(Risos)	

P4	Ou seja, quem gosta de café, e está habituado ao café quentinho, não é? E, quer dizer, aquele era um café fraco!	GU3
P1	E sem açúcar!	GU3
P4	Portanto, eu acabei por escrever porque percebi que era café e espoletou-me a emoção do que é para mim o café, e não o que bebi.	GF3
P3	Pois	
P6	Eu tenho uma opinião contrária. No meu caso, eu sou "cafeholic", eu adoro café e, portanto, teve um efeito totalmente contrário. Portanto, eu até pus aqui: soube-me a café descafeinado, café deslavado com 3 dias.	GU3
Todos	(Risos)	
Mariana	Mas foi desta manhã, posso garantir!	
Todos	(Risos)	
P2	Vocês estão-se a referir ao número...	
Todos	Número 4.	
P2	Quatro... Coloquei chá ou marisco.	GU3
Todos	(Risos)	
P2	Eu não identifiquei isto como café.	GU3
P6	Ou seja, neste caso que, por norma, seria um sabor que a mim me iria despertar sabores com muitas emoções, nomeadamente, ativação, entusiasmo, etc., foi exatamente o oposto.	GU3
P3	Pois	
Mariana	Ok, mas então agora sabendo, vamos começar precisamente por isso. Portanto, sabendo todos agora que realmente, quer dizer, sabendo não, confirmando, que é um café descafeinado, e tendo sempre em atenção que há quem seja alérgico à cafeína, e portanto, daí considerar o descafeinado... consideram que é um sabor que pode ser incluído numa experiência de realidade virtual à vontade?	
Todos	Sim	
Mariana	... ainda que, tendo em consideração a temperatura, que poderá ajudar. Visto que este será um estímulo positivo, se calhar ter em consideração uma temperatura mais quente. Todos concordam que conseguirá ser um estímulo mais positivo?	
P4	Não sei se vais conseguir!	GU3
P3	Pois! Eu acho que a temperatura é essencial, como disse a P6.	GU3
P2	A temperatura é, mas o sabor não é indicativo. Podia ser muitas coisas. Eu enganei-me, mas podia ser cevada, podia ser um outro líquido qualquer aparentado com algo reconfortante do género do café, mas que tu não identificas como café, porque o café tem efetivamente um sabor muito forte. O descafeinado, às vezes também tem, mas....	GU3
P3	É. Eu acho que o café é perigoso! Ou seja, pode ser dual: quem gostar muito de café vai ficar desapontado, a não ser que seja um bom café.	GU3
Todos	Pois...	
P3	... muita gente, por exemplo, eu às vezes nem tomo café, porque associo também a... pronto, é estimulante, e pronto, muita gente até nem toma café... se calhar o chá pode ser mais consensual. Porque o chá, quase toda a gente toma...	GU3, GF5
P4	Mas já há chá!	

P1, P3, P5, P6, P7	Não... Não há chá!	
Mariana	Os sabores são subjetivos.	
P4	Pronto, eu vou dizer-te que, para mim...	
Mariana	Qual foi o sabor que te soube a chá, P4?	
P4	Para mim era chá verde. Qual é o número... é o quatro.	
P6	Isso foi no cheiro	
P1, P3	O café?	
P4	Ah, nos cheiros... Ah, pois foi! Não, não, não! Isso foi no sabor. Foi nos cheiros. Os cheiros já passaram. Tens razão.	
Mariana	Ok, então nos sabores nada te soube a chá, certo?	
P4	Não, não, não. Mas se calhar aqui o chá aqui podia ser mais aceitável...	GF5
P3	É... O chá quando a pessoa está nervosa, pode ser um chá de tília...	GF5
P4	Tisana.	
P3	Tisana, exato!	
P6	De quantos sabores é que precisas?	
Mariana	Preciso de quatro, só que o chá não vai poder acontecer, porque eu preciso de um objeto que esteja associado a um sabor. Portanto, com o café eu consigo isso, através de uma história contada acerca do café, e com um objeto que lembra o café. E eu não estou a identificar nenhum que eu possa associar ao chá. Alguém me consegue ajudar nisso?	
P4	Mas os descobrimentos estão ligados ao chá!	GF5
P2	Um bule.	
P1, P3, P4, P6	Especiarias!	
Mariana	Boa ideia!	
P1	Tens a canela, que toda a gente gosta!	OF5
P3	Olha, a canela é ótimo! Eu adoro canela!	OF5
Mariana	Pois, mas provar a canela...	
P4	Não há chá de canela? O chá de maçã e canela é bom!	OF5
P5	Pois... Eu não sei se é assim tão bom...	OF6
Mariana	Tu não gostas de...	
P5	... canela! Mas se calhar é mesmo muito pessoal.	
Mariana	Mas sim, o chá parece-me boa ideia.	
P3	E tens os pacotinhos, que podes dar a cheirar! Assim é mais fácil...	OF5
P6	Eu até diria que o melhor, do ponto de vista de artefacto físico, é mesmo as folhas de chá. E do ponto de vista de história, podes ir buscar as histórias, por exemplo, às plantações de chá dos Açores...	OF5, GF5
P4	Foi o que me cheirou! Foi a chá verde	
P3	O chá da China, o bule, a porcelana...	GF5
P6	Eu não iria para as especiarias porque são coisas distintas.	
Mariana	O chá, de facto, está bem ligado aos descobrimentos. Por isso, acho que faz todo o sentido!	

P3	Sim, aliás, o chá foi incorporado na Inglaterra por uma portuguesa, por uma rainha portuguesa. Foi ela que levou o chá das 5 para Inglaterra.	GF5
Mariana	Ok, obrigada! Ok, eu queria fazer agora aqui o desvendar dos cheiros e dos sabores que vocês sentiram, para perceber se há aqui alguma concordância entre todos. Portanto, ia-vos pedir para irem para a página 4, que é relativa aos cheiros, e então, a que é que vos cheirou o primeiro cheiro?	
P6	Pinheiro.	OF4
P3, P7	Pinho.	2x OF4
P1	Detergente da roupa, tipo roupa lavada.	OF4
P4	Ambientador de casa de banho, limpezas.	OF4
P3	A mim lembra-me aqueles pinheirinhos que havia nos retrovisores dos automóveis, a cheirar a pinho.	OF4
P5	Hall de entrada, de casa.	OF4
P2	Eu não identifiquei...	OU4
P6	Estás a dizer o cheiro ou as memórias?	
Todos	O cheiro.	
P6	Ok. O cheiro é pinheiro para mim.	OF4
P5	Perfume.	OF4
Mariana	Ok, mas no geral, é um cheiro agradável ou desagradável?	
Todos	Sim, agradável!	7xOF4
Mariana	Ok, e o cheiro número dois?	
P6	Enchidos!	OF1
P2	Exato!	OF1
P4, P3	Chouriço!	2xOF1
P1	Alheira!	OF1
P6	Queimado!	OF1
P2	Madeira queimada, e depois chouriços.	OF1
P5	Madeira queimada, incêndios.	OF1
P4	A mim é chouriços, e fez-me lembrar os chouriços da dona [...], que são caseiras. (Risos)	OF1
P6	Para mim é problemático. É como o café: tem uma dualidade.	OU1
Mariana	Mas essa dualidade é boa, porque a única coisa que eu quero é isso que vocês já todos referiram, que é o cheiro a fumeiro, a queimado, a madeira, ... Portanto, a ideia é precisamente essa, portanto está tudo ok. E não referi, em relação ao primeiro, que o cheiro é pinho. O segundo cheiro, que foi o mais difícil de encontrar... Aquilo que eu consegui arranjar é o chamado *liquid smoke*, não sei se já ouviram falar, que é uma coisa muito usada pelos americanos, por isso eu tive muita dificuldade de encontrar, que é usado na carne, para os grelhados, para dar aquele sabor a fumado. Eles usam muito nas carnes!	
Todos	(Risos)	
P4	Olha, mas eu achei que era café!	
P1	O primeiro, já agora?	

Mariana	Era pinho. O segundo então é *liquid smoke*, é assim que se chama. É fumo líquido.	
P4	Ah, o segundo! Chouriço, sim.	
P3	Era a nossa dúvida! Como é que ela tinha conseguido aquele cheiro: se tinha andado ali a esfregar...	
Todos	(Risos)	
P2	Ou se tinha metido água para dentro do forno, tinha metido lá umas achas, ...	
Mariana	Não, mas tentei! Tentei de tudo! Ainda acendi a lareira para uma das experiências	
P3	Eu acho que estes cheiros depois, associados a uma imagem, mudam logo. Esta, se estiver associada a uma floresta queimada, as pessoas associam logo a madeira queimada, não é? Ma se for uma lareira, já pensamos nas alheiras, e nos enchidos...	OF1
Mariana	O quarto cheiro, que acho que foi aquele que vos intrigou mais, o que é que vocês acham que é?	
P5	Camarão.	OF2
P2, P3	Lixo!	OF2
P4	A mim, lá está, era chá verde, das plantações dos Açores. Pelo menos foi o que me lembrou. E, por isso, foi uma coisa boa, não é? Porque como eu estive nos Açores e nas plantações, e, portanto... Cheirou-me a chá verde.	OU2
P6	Olhem, eu no início tive dificuldade. Não identifiquei o cheiro, mas passado algum tempo identifiquei-o como sendo algo desagradável. E as memórias... tive algumas memórias associadas a este cheiro, que também não são agradáveis.	OF2
Mariana	Portanto, no geral este cheiro é agradável ou não, para vocês?	
P1, P3, P5, P6, P6, P7	Desagradável!	5x OF2
P1	A mim cheirou-me a sardinha!	OF2
P2	Para mim era marisco.	OF2
P5	É isso, era marisco!	OF2
Mariana	Cheirava-vos a marisco?	
P1	Cheirava-me a sardinha.	OF2
Mariana	Ok, boa. A ideia era essa, que cheire a peixe.	
P3	Pois, cheirava a lixo. Pois!	OF2
Mariana	Isto é Ómega-3.	
Todos	(Risos)	
P3	Ah, óleo de fígado de bacalhau!	
Mariana	Neste caso não é de bacalhau, é de salmão.	
Todos	(Risos)	
P3	Mas é mesmo desagradável! E é difícil associar, o que é bom!	2xOF2
P6	Mas olha, se queres mesmo o cheiro a peixe, tenho uma forma de teres cheiro a peixe:	
Mariana	Mas tem de ser algo sempre comestível, algo não tóxico ...	
P4	O molho do peixe!	
P6	Não, mas se quiseres algo frio, tens a água de lavar o peixe.	
Mariana	Mas tem de ser algo durável!	
P6	Mas dura! A água de lavar o peixe dura imenso.	

Mariana	Há outra questão, que é a logística. É-me mais fácil, até porque não como tantas vezes peixe, fazer isto com as cápsulas de Ómega-3, do que com o peixe propriamente dito, que envolve outra logística.	
P3	Mas, de qualquer maneira, eu acho que o cheiro é desagradável, e não é muito facilmente identificável, o que quer dizer que podes associar com uma imagem qualquer e, por isso, podia ser um caixote do lixo, podia ser uma estrada, ...	2x OF2
Mariana	Mas, da mesma forma, que há bocado o P3 referiu, em relação ao cheiro anterior, se vir o objeto... Por exemplo, há bocado referiu, em relação ao chouriço, que conseguia, se visualizasse o chouriço, e estivesse a sentir aquele cheiro, conseguia identificar ali uma correlação, neste aqui, se eu lhe apresentasse...	
P3	Acho que sim, acho que é fácil este. Pões qualquer coisa desagradável e eu associo logo, não é? Pode ser uma lixeira, pode ser um peixe podre, pode ser um caminho, não é? Um caminho de lama, lameado. Portanto...	
Mariana	Ok, então se estiverem a olhar para o mar, sujo, conseguem, com este cheiro ver uma correlação entre ambos?	
P2	Eu não. Eu mais rapidamente... Isto mais rapidamente reporta-me para uma cozinha, nem sequer para um mercado de peixe e, curiosamente, eu não senti que isto fosse desagradável. Não é muito intenso e não se insinua.	2x OU2
Mariana	Ok. E não foi desagradável para vocês então?	
P2	Para mim não.	OU2
P4	Para mim também não! Para mim, foi o chá verde e, portanto, associei aos Açores. Estava toda contente com os Açores!	OU2
P5	A mim lembrou-me um almoço de domingo. Estar ali a preparar camarões...	OU2
P6	As minhas memórias são: túmulo, lugar fechado devoluto, morte. Foi o que eu pus.	OF2
Mariana	Ok. Bastante criativa!	
P6	Eu não associei ao peixe. Para mim foi desagradável, mas não associei ao peixe.	OU2+OF2
P3	Mas eu acho que esta dualidade também demonstra que pode ser usado para muitos fins, dependendo da imagem e do ambiente. Eu acho que depois a pessoa vai desassociar. O cheiro é sempre complementar, não é?	OF2
Mariana	Exatamente! E é precisamente este o ponto onde eu queria chegar, e também para cumprirmos os nossos tempos, que é precisamente a última questão, que é, agora sim, o geral. Eu vou ter então dois cenários com diferentes estímulos. Vocês estiveram aqui a experienciar vários positivos e vários negativos, e eu quero perceber então se vos faz sentido um eventual cenário positivo ser um espaço exterior, amplo, onde vocês podem caminhar à vontade, que está a ser irradiado pelo sol, portanto, vocês conseguem sentir o sol a iluminar-vos. Escuta-se o chilrear dos pássaros, que acho que foi claro para todos, que foi o que ouvimos, certo?	
Todos	Sim.	7x AF2
Mariana	E onde se ouvem as histórias, se quiserem sublinhar, um, cinco, sete, oito e nove.	
P3	São as positivas, não é?	
Mariana	Hm... Espero que seja a opinião de todos!	
P3	Eu confirmo. Quer dizer, por acaso a primeira foi um bocado negativa.	NF2, NF3, NF4, NF5, NU1

P7	Para mim também foi negativa essa.	NU1
Mariana	E deixem-me só acrescentar, que este cenário é tendo em consideração o tom da primeira pessoa. De acordo com a vossa discussão, vocês consideraram um tom mais animado, mais alegre, mais estimulante, mais ou menos de acordo com as vossas palavras.	
P4	Eu considerei tudo o que tu disseste o positivo.	NF1, NF2, NF3, NF4, NF5
P1	Eu também!	NF1, NF2, NF3, NF4, NF5
P3	Eu só o um é que considerei negativo, mas por alguns detalhes, como é o "inutilizados".	NF2, NF3, NF4, NF5, NU1
Mariana	Ok	
P3	Depois estava assim meio esquisito o texto. Portanto: "o vinho do porto circulava pelas margens"... margens não, circulava no rio. E depois o "apesar de atualmente inutilizados" é assim um bocadinho negativo para mim. Eu acho que, se retirarmos isso... porque eles, na verdade, até estão a ser utilizados! Há sempre a corrida... os que estão em Gaia são barcos que realmente não são utilizados para a sua função, mas são utilizados para corridas. Portanto, foram estes os aspetos que achei mais negativos.	2xNU1
Mariana	Concordam todos?	
P2	Isto, para mim, é tudo positivo.	NF1, NF2, NF3, NF4, NF5
P1, P6	Também.	2x (NF1, NF2, NF3, NF4, NF5)
Mariana	Ok. Portanto, temos aqui a sugestão do P3, que acho que faz todo o sentido, claro. E então, queria passar agora para o cenário negativo, e, portanto, as histórias que vocês não sublinharam, que são a dois, três, quatro, seis e dez, se toda a gente está de acordo que foram histórias negativas.	
P1, P3	Sim.	2x (NF6, NF7, NF8, NF9, NF10)
P2	É assim, eu gostava só de fazer aqui um parêntesis. Eu considero todas estas histórias positivas, porque isto é histórico. E eu também sou "bias", porque eu nasci e vivi sempre em Gaia, portanto, para mim, nenhuma destas histórias... Eu só estou a dizer isto, continua a ser interessante para mim, mas já tenho alguma distância que faz parte da minha vida.	NU6, NU7, NU8, NU9, NU10
Mariana	Sim, mas o facto de saber as histórias não significa que não as consigam considerar positivas ou negativas, digo eu, não?	
P1	Eu consegui. Como tu disseste, eu consegui fazer a diferenciação das positivas e negativas, tal e qual como tu disseste. Mas há ali... Eu concordo com o P3, quando diz que tu escreveste que os barcos Rabelos estavam inutilizados. Não é 100% verdade, por causa das corridas. No dia de S. João faz-se normalmente as regatas, e há o estaleiro em Gaia, que faz a construção dos barcos Rabelo, e parece que estão inutilizados, mas não, estão em construção ou restauro.	NF2, NF3, NF4, NF5, NF6, NF7, NF8, NF9, NF10, NU1
P4	É só retirar o não terem esta função. A questão é...	
P3	Exato! Embora já não tenham esta função, já que têm uma função mais turística. Mas o "inutilizados" é que transforma um bocadinho negativo.	NU1

Mariana	Ok	
P2	É assim, deixa-me só esclarecer uma coisa: eu fui ao encontro daquilo que era expectável em termos da história. Portanto, eu considerei estes negativos. Aquilo que eu estava a dizer é que, no geral, se eu estivesse descontextualizado disto tudo, isto parecia-me história, e era nivelado a uma experiência positiva, porque é conhecimento. É só isso que eu queria dizer.	NF6, NF7, NF8, NF9, NF10, NF1, NF2, NF3, NF4, NF5, NU6, NU7, NU8, NU9, NU10
Mariana	Certo! Não vos querendo roubar mais tempo, porque ficamos de terminar ao meio-dia, e é meio-dia mesmo, pedia-vos só mais 2 minutos, só para perceber a vossa opinião. São três questões muito simples: se alguma das tarefas vos pareceu complexa?	
Todos	Não / aceno com a cabeça a indicar um "não"	
Mariana	Ok. Todos de acordo?	
Todos	Sim / aceno com a cabeça a indicar um "sim"	
Mariana	Se gostaram do focus group, foi um momento divertido? Se acham que poderia ter sido feito de outra forma...	
Todos	Sim / aceno com a cabeça a indicar um "sim"	
P4	Sim, diverti-me!	
P3	Foi excelente!	
P1, P2, P7, P5	Foi ótimo	
P6	Muito bem organizado!	
P3	Sim, muito bem organizado!	
P1	Mariana, desculpa interromper, na parte dos sabores, tu saltaste essa parte de repente. O primeiro era o quê o sabor?	
Mariana	Ah, não vos disse o que é que eram os sabores! O que é que acharam?	
P4	Soro fisiológico!	GF1
P3	Leite meio aguado.	GF1
P5	Para mim era água efervescente.	GF1
P6	Eu pus água. Aquela água com o pH "xpto".	GF1
P4	Fez-me lembrar as inalações, por isso é que eu não pus como desagradável!	GU1
Mariana	É água com sal, que se associa ao soro fisiológico, exatamente. O segundo acho que é consensual...	
Todos	Vinho do Porto!	7xGF4
Mariana	O terceiro...	
Todos	Vinagre!	7xGF2
P2	Vinagre balsâmico.	GF2
P1	Água com vinagre.	GF2
Mariana	Isso. Água avinagrada. E o quarto então era o café. Não sei se alguém tem mais algum comentário a fazer. Está tudo ok? Sugestões?	
Todos	Não / aceno com a cabeça a indicar um "não"	

Mariana	Por último, eu só vos queria mostrar isto: isto foi a termos que eu usei para o café, mas eu fiz questão de a deixar aberta, para o café não estar muito quente. Tinha receio que vocês se queimassem, e, portanto, preferi que o café estivesse... não sei como é que estava a temperatura...	
Todos	Estava frio!	
Mariana	Completamente frio? Ok. Então, da próxima vez, se calhar deixo fechada, para ficar mais morno. Pronto, obrigada a todos pela presença! Desculpem se ultrapassei um bocadinho a hora, especialmente à P5 e à P6, que são as que já me tinham pedido para cumprir o horário...	
P4	Foram só quatro minutos!	
Mariana	Pronto, acho que consegui cumprir tudo. Obrigada a todos mais uma vez!	
P5	Muito interessante!	
P3, P4	De nada, parabéns!	

10.3.3. Codebook

Table 62 Focus group codification

CODE LABEL															
Categories (Positive/ Negative)			Favorable Aspects		CODE	Unfavorable Aspects		CODE	Favorable acceptability of including in an academic VR experiment		CODE	Unfavorable acceptability of including in an academic VR experiment		CODE
			Description	Examples		Description	Examples		Description	Examples		Description	Examples	
Auditory Cues	Positive Narratives	Story 1	Fundaments to consider Story 1 as positive	"Isto, para mim, é tudo positivo."	NF1	Fundaments to consider Story 1 as negative/not positive	"Eu só o um é que considerei negativo, mas por alguns detalhes, que é o «inutilizados»"	NU1	-			-		
		Count	N = 6			N = 6								
		Story 5	Fundaments to consider Story 5 as positive	"Eu considerei tudo o que tu disseste o positivo."	NF2	Fundaments to consider Story 5 as negative/not positive	-	NU2						
			N = 9			N = 0								
		Story 7	Fundaments to consider Story 7 as positive	"Eu considerei tudo o que tu disseste o positivo."	NF3	Fundaments to consider Story 7 as negative/not positive	-	NU3						
		Count	N = 9			N = 0								
		Story 8	Fundaments to consider Story 8 as positive	"Eu considerei tudo o que tu disseste o positivo."	NF4	Fundaments to consider Story 8 as negative/not positive	-	NU4						
		Count	N = 9			N = 0								

CODE LABEL															
Categories (Positive/ Negative)			**Favorable Aspects**		**CODE**	**Unfavorable Aspects**		**CODE**	**Favorable acceptability of including in an academic VR experiment**		**CODE**	**Unfavorable acceptability of including in an academic VR experiment**		**CODE**
			Description	**Examples**		**Description**	**Examples**		**Description**	**Examples**		**Description**	**Examples**	
		Story 9	Fundaments to consider Story 9 as positive	"Eu considerei tudo o que tu disseste o positivo."	NF5	Fundaments to consider Story 9 as negative/not positive	-	NU5						
		Count	N = 9			N = 0								
	Negative Narratives	Story 2	Fundaments to consider Story 2 as negative	"(…) eu consegui fazer a diferenciação das positivas e negativas, tal e qual como tu disseste."	NF6	Fundaments to consider Story 2 as positive/not negative	"Eu considero todas estas histórias positivas, porque isto é histórico."	NU6						
		Count	N = 4			N = 2								
		Story 3	Fundaments to consider Story 3 as negative	"(…) eu consegui fazer a diferenciação das positivas e negativas, tal e qual como tu disseste."	NF7	Fundaments to consider Story 3 as positive/not negative	"Eu considero todas estas histórias positivas, porque isto é histórico."	NU7						
		Count	N = 4			N = 2								
		Story 4	Fundaments to consider Story 4 as negative	"(…) eu consegui fazer a diferenciação das positivas e negativas, tal e qual como tu disseste."	NF8	Fundaments to consider Story 4 as positive/not negative	"Eu considero todas estas histórias positivas, porque isto é histórico."	NU8						
		Count	N = 4			N = 2								
		Story 6	Fundaments to consider Story 6 as negative	"(…) eu consegui fazer a diferenciação das positivas e negativas, tal e qual como tu disseste."	NF9	Fundaments to consider Story 6 as positive/not negative	"Eu considero todas estas histórias positivas, porque isto é histórico."	NU9						
		Count	N = 4			N = 2								

CODE LABEL																
Categories (Positive/ Negative)			Favorable Aspects		CODE	Unfavorable Aspects		CODE	Favorable acceptability of including in an academic VR experiment		CODE	Unfavorable acceptability of including in an academic VR experiment		CODE
			Description	Examples		Description	Examples		Description	Examples		Description	Examples	
		Story 10	Fundaments to consider Story 10 as negative	"(…) eu consegui fazer a diferenciação das positivas e negativas, tal e qual como tu disseste."	NF10	Fundaments to consider Story 10 as positive/not negative	"Eu considero todas estas histórias positivas, porque isto é histórico."	NU10						
		Count	N = 4			N = 2								
Auditory Cues	Positive stimuli	Voice Tone 1	Fundaments to consider voice tone 1 as positive	"A primeira é mais entusiasta do que a segunda."	VF1	Fundaments to consider voice tone 1 as negative/not positive	"Eu tive dificuldade em perceber essas caraterísticas uma e da outra."	VU1	-			-		
		Count	N = 6			N = 2								
	Negative stimuli	Voice Tone 2	Fundaments to consider voice tone 2 as negative	"A segunda tem um tom mais monocórdico."	VF2	Fundaments to consider voice tone 2 as positive/not negative	"Eu tive dificuldade em perceber essas caraterísticas uma e da outra."	VU2						
		Count	N = 13			N = 2								
Haptic Clues	Negative stimuli	Cold	Fundaments to consider cold as negative	"Continuo a não gostar tanto do calor, só que neste momento não suporto tanto o frio."	CF1	Fundaments to consider cold as positive/not negative	"Eu prefiro o fresquinho, até porque eu tenho rosáceas."	CU1	-			-		
		Count	N = 16			N = 3								
	Positive stimuli	Heat	Fundaments to consider heat as positive	"Eu gosto muito de sentir o sol. Parece que estou a fazer a fotossíntese."	CF2	Fundaments to consider heat as negative/not positive	"Quando estou com muito calor, é muito desconfortável para mim."	CU2						
		Count	N = 13			N = 2								

CODE LABEL															
Categories (Positive/ Negative)			Favorable Aspects		CODE	Unfavorable Aspects		CODE	Favorable acceptability of including in an academic VR experiment		CODE	Unfavorable acceptability of including in an academic VR experiment		CODE
			Description	Examples		Description	Examples		Description	Examples		Description	Examples	
Olfactory Cues	Negative stimuli	Liquid Smoke	Fundaments to consider liquid smoke as negative	"Madeira queimada, incêndios."	OF1	Fundaments to consider liquid smoke as positive/not negative	"Para mim é problemático. É como o café: tem uma dualidade."	OU1	Fundaments to consider admissible the inclusion of negative olfactory stimuli in an academic VR experiment	"No contexto da experiência, acho que pode ser muito interessante!"	OA1	Fundaments to consider inadmissible the inclusion of negative olfactory stimuli in an academic VR experiment	-	OI1
		Count	N = 13			N = 2								
		Fish-oil	Fundaments to consider fish-oil as negative	"Não identifiquei o cheiro, mas passado algum tempo identifiquei-o como sendo algo desagradável."	OF2	Fundaments to consider fish-oil as positive/not negative	"(…) curiosamente, eu não senti que isto fosse desagradável."	OU2						
		Count	N = 21			N = 11			N = 9			N = 0		
	Positive stimuli	Coffee	Fundaments to consider coffee as positive	"Eu não tenho cheiros negativos."	OF3	Fundaments to consider coffee as negative/not positive	-	OU3	-			-		
		Count	N = 1			N = 0								
		Pine	Fundaments to consider pine as positive	"A mim lembra-me aqueles pinheirinhos que havia nos retrovisores dos automóveis, a cheirar a pinho."	OF4	Fundaments to consider pine as negative/not positive	"Eu não identifiquei (…) o cheiro."	OU4						
		Count	N = 17			N = 1								

CODE LABEL														
Categories (Positive/ Negative)			Favorable Aspects		CODE	Unfavorable Aspects		CODE	Favorable acceptability of including in an academic VR experiment		CODE	Unfavorable acceptability of including in an academic VR experiment		CODE
			Description	Examples		Description	Examples		Description	Examples		Description	Examples	
		Cinnamon (Not included in the food samples)	Fundaments to consider cinnamon (suggested by one of the participants) as positive	"Tens a canela, que toda a gente gosta!"	OF5	Fundaments to consider cinnamon (suggested by one of the participants) as negative/not positive	"Eu não sei se é assim tão bom…"	OF6						
			N = 5			N = 1								
Taste Cues	Negative stimuli	Salted Water	Fundaments to consider salted water as negative	"Soro fisiológico!"	GF1	Fundaments to consider salted water as positive/not negative	"Fez-me lembrar as inalações, por isso é que eu não pus como desagradável!"	GU1	Fundaments to consider admissible the inclusion of negative taste stimuli in an academic VR experiment	"Sim, parece-me muito bom!"	GA1	Fundaments to consider inadmissible the inclusion of negative taste stimuli in an academic VR experiment	-	GI1
		Count	N = 4			N = 1								
		Water with vinegar	Fundaments to consider water with vinegar as negative	"Vinagre!"	GF2	Fundaments to consider water with vinegar as positive/not negative	-	GU2						
		Count	N = 9			N = 0			N = 15			N = 0		
	Positive stimuli	Coffee	Fundaments to consider coffee as positive	"(…) espoleta emoções positivas na mesma, em mim, pelo menos."	GF3	Fundaments to consider coffee as negative/not positive	"soube-me a café descafeinado, café deslavado com 3 dias."	GU3	-			-		
		Count	N = 2			N = 14								

CODE LABEL														
Categories (Positive/ Negative)			Favorable Aspects		CODE	Unfavorable Aspects		CODE	Favorable acceptability of including in an academic VR experiment		CODE	Unfavorable acceptability of including in an academic VR experiment		CODE
			Description	Examples		Description	Examples		Description	Examples		Description	Examples	
		Port Wine	Fundaments to consider Port wine as positive	"Sim!"	GF4	Fundaments to consider Port wine as negative/not positive	-	GU4						
		Count	N = 7			N = 0								
		Tea (Not included in the food samples)	Fundaments to consider cinnamon tea (suggested by one of the participants) as positive	"se calhar o chá pode ser mais consensual. Porque o chá, quase toda a gente toma…"	GF5	Fundaments to consider cinnamon tea (suggested by one of the participants) as negative/not positive	-	GU5						
		Count	N = 8			N = 0								
Ambient Sound Cues	Negative stimuli	Rain	Fundaments to consider rain as negative	"Chuva não!"	AF1	Fundaments to consider rain as positive/not negative	-	AU1	-			-		
		Count	N = 4			N = 0								
	Positive stimuli	Birds chirping	Fundaments to consider birds chirping as positive	"Sim"	AF2	Fundaments to consider birds chirping as negative/not negative	-	AU2						
		Count	N = 7			N = 0								

10.4. Informed consent statement, Q1, Q2, Q3, Q4, and ASQ

Declaração de Consentimento Informado, livre e esclarecido

Este estudo, provisoriamente designado "Exploring the impact of multisensory stimuli on mental imagery – a virtual tourism case study based on emotional responses", é levado a cabo pela estudante do Programa Doutoral em Medias Digitais, Mariana Magalhães (número de estudante: up201100991). Esta tese é supervisionada pelo Professor Doutor António Fernando Vasconcelos Cunha Castro Coelho (Professor Associado do Departamento de Engenharia Informática, da Faculdade de Engenharia da Universidade do Porto), e sob coorientação do Professor Doutor Maximino Esteves Correia Bessa (Professor Associado do Departamento de Engenharias da Universidade de Trás-os-Montes e Alto Douro). O principal objetivo desta investigação é perceber o impacto dos estímulos multissensoriais em **Realidade Virtual** (RV) nas emoções dos utilizadores, e como é que isso influencia a construção da imagem mental de objetos.

As experiências decorrem num único momento, na Faculdade de Engenharia da Universidade do Porto, e têm uma duração média de 30 minutos. A sua participação é voluntária e pode desistir em qualquer momento, sem ter de dar qualquer justificação, e sem ter qualquer tipo de consequência.

Esta experiência pressupõe o seguinte:

- O preenchimento de três curtos questionários (Q1, Q2 e Q3) antes da experiência com RV, e de um último (Q4) após a experiência;
- Durante a experiência com RV, surgirão alguns questionários, cujo preenchimento é feito *in-VR* (dentro da própria experiência).
- Por se tratar de um estudo com RV, será usado um *headset*, que, dependendo da sensibilidade de cada um, pode causar sensação de cansaço ocular, enjoo, desorientação, entre outros. Estes são sintomas habituais e tendem a desaparecer em poucos minutos;
- Tratando-se de uma experiência multissensorial, haverá lugar à prova olfativa de alguns cheiros e à prova de alguns sabores mais ou menos agradáveis, mas sempre tendo em consideração as suas eventuais intolerâncias alimentares e os seus gostos pessoais (conforme o Q2);
- Qualquer sabor que lhe for apresentado durante a experiência é comestível, e foi previamente testado;
- Qualquer cheiro que lhe for apresentado durante a experiência é adequado ao contacto com humanos, e foi previamente testado;
- Todo o material descartável será dispensado após a sua utilização única. O *headset* e os comandos são higienizados através da *Cleanbox*®, que possui uma tecnologia UVC-LED, que elimina eficazmente 99,999% de germes, vírus e bactérias.

As suas respostas serão mantidas por um período máximo de 3 anos, para que possa ser confirmado, se necessário, qualquer dado estatístico. Ao participar neste estudo, é-lhe garantida total confidencialidade, anonimato e uso exclusivo dos dados recolhidos para a presente investigação.

Esta primeira folha deve ser desanexada das restantes após totalmente preenchida, e ser entregue à investigadora. Desta forma, é-lhe garantido que não haverá qualquer ligação entre as respostas fornecidas e o(a) seu (sua) autor(a).

Declaro ter lido e compreendido este documento, incluindo todos os esclarecimentos que prestou às dúvidas por mim colocadas.

Nome (primeiro e último): ___________________________________

Q1 – Questionário sociodemográfico e individual

1. Idade: ☐ **2.** Género: __________________ **3.** Nacionalidade: __________________

4. Habilitações Académicas: __________________ **5.** Área de formação: __________________

6. Experiência com RV (X): Nenhuma | 1 | 2 | 3 | 4 | 5 | Praticamente todos os dias

7. Consegue ver bem (naturalmente ou com correção)? (X) Sim ☐ Não ☐

8. Consegue ouvir bem (naturalmente ou com correção)? (X) Sim ☐ Não ☐

9. Consegue cheirar corretamente? (X) Sim ☐ Não ☐

10. Consegue sentir o sabor dos alimentos? (X) Sim ☐ Não ☐

11. Tem alguma condição que o impeça de experienciar RV (ex. epilepsia, enxaquecas frequentes, doença ocular) Sim ☐ Não ☐

Q2 – Intolerâncias alimentares e gostos pessoais

Por favor, assinale (X) as suas intolerâncias alimentares e os seus gostos pessoais:

	Intolerâncias alimentares		Gostos Pessoais		
	Sim*	Não	Gosto/Tolero	Não gosto, mas provo	Rejeito provar*
Álcool (proveniente do vinho)					
Vinagre					
Canela					
Sal					
Amendoim					
Marisco					

* No caso de assinalar que "sim" ou "rejeito provar" em alguma das opções, por favor comunique de imediato à investigadora.

Q3 – Emoções

Por favor, assinale (X) como se sente neste momento:

	1. Nada ou muito ligeiramente	2. Um pouco	3. Moderadamente	4. Bastante	5. Extremamente
Interessado/a					
Nervoso/a					
Entusiasmado/a					
Amedrontado/a					
Inspirado/a					
Ativo/a					
Assustado/a					
Culpado/a					
Determinado/a					
Atormentado/a					

Q4 – Questionário pós-experiência

Por favor, assinale **(X)** o seu nível de concordância com cada uma das seguintes questões:

1. No geral, estou satisfeito com a **facilidade** com que concluí esta tarefa.

Discordo fortemente	1
	2
	3
	4
	5
	6
Concordo plenamente	7

2. No geral, estou satisfeito com o **tempo** que levei a concluir estas tarefas.

Discordo fortemente	1
	2
	3
	4
	5
	6
Concordo plenamente	7

3. No geral, estou satisfeito com a **informação** de suporte que me foi fornecida para concluir esta tarefa.

Discordo fortemente	1
	2
	3
	4
	5
	6
Concordo plenamente	7

Apercebeu-se da presença de dois cheiros diferentes na experiência com RV? Sim ☐ Não ☐

Esses cheiros eram agradáveis ou desagradáveis? Agradáveis ☐ Desagradáveis ☐

Apercebeu-se da presença de dois sabores diferentes na experiência com RV? Sim ☐ Não ☐

Esses sabores eram agradáveis ou desagradáveis? Agradáveis ☐ Desagradáveis ☐

Apercebeu-se da presença de calor ou frio (ar quente/ar frio) na experiência com RV? Sim ☐ Não ☐

Essa sensação de calor/frio foi agradável ou desagradável? Agradável ☐ Desagradável ☐

10.5. Igroup Presence Questionnaire (Portuguese version)

1	Eu tive a sensação de “estar” no ambiente virtual	1	2	3	4	5
2	De alguma forma eu senti que o mundo virtual me envolveu	1	2	3	4	5
3	Senti-me como se estivesse apenas a visualizar imagens	1	2	3	4	5
4	Não me senti presente no ambiente virtual	1	2	3	4	5
5	Tive a sensação de estar a atuar num espaço virtual	1	2	3	4	5
6	Senti-me presente no ambiente virtual	1	2	3	4	5
7	Durante a experiência continuei a prestar atenção ao local onde estava a ter a experiência	1	2	3	4	5
8	Eu não estava consciente do mundo real que me rodeava	1	2	3	4	5
9	Estive consciente do mundo real enquanto navegava no ambiente virtual	1	2	3	4	5
10	Senti-me completamente atraído pelo ambiente virtual	1	2	3	4	5
11	O ambiente virtual pareceu-me completamente real	1	2	3	4	5
12	A experiência no ambiente virtual pareceu-me tão real como as minhas vivências do dia-a-dia	1	2	3	4	5
13	O ambiente virtual pareceu-me tão real como o mundo que conheço	1	2	3	4	5
14	O ambiente virtual pareceu-me mais realista do que o mundo real	1	2	3	4	5