Effect of Emotional Stimulation and Spatial Awareness on the Perceived Realism of Virtual Art

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Ph.D. Thesis

Effect of Emotional Stimulation and Spatial Awareness on the Perceived Realism of Virtual Art

バーチャルアートの臨場感に及ぼす感情刺激と空間認識の影響

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Abstract

Enhancing the realism in virtual reality (VR) presents several technical, economic, and functional challenges. In particular, designers have to solve several cognitive and technical challenges related to immersion and perception when it comes to the virtual representation of the artwork. The objective of this thesis was to provide innovative and unified methods that can be utilized to improve realism in the virtual portrayal of artworks.

To this end, two novel approaches, namely emotional hacking enabled VR (EHVR) and smooth transition and hybrid reality (STHR), were developed, experimentally verified, and ultimately demonstrated in a real-world setting.

Emotional hacking is based on the interaction of physiological condition and emotional stimulation and on the notion that emotional involvement during a virtual experience significantly impacts the degree of immersion. In the EHVR, vibrotactile biofeedback was provided through the footrest, simulating the feeling of a heartbeat. Syncing the vibrotactile feedback at the start of the experience

and then introducing a fake faster heartbeat to produce fear in the middle of the experience. A total of 103 individuals participated in the EHVR experiment. The use of subjective questionnaires showed that most of the participants found the VR experience extremely realistic and frightening. Heart rates were found to increase to 118% of the resting value at the end of the experience, implying that the physiological state of the participants was influenced by exposure to the system.

During the EHVR study, users were observed to remember the real world during VR and overlay it on VR content in their minds. So, to further enhance the realism in the virtual representation of artwork, the concept of STHR was implemented by deliberately blocking out the real space to prevent creating a memory of the real space so that it does not conflict with the VR content. At the start, the users were exposed to a 3D-printed real object that was a replica of one of the virtual items they would encounter during VR. This step was intended to give haptic input consistent with both the real world and the virtual environment. It was designed to have a minimum mismatch between VR and real-world setup. By introducing minimal haptic feedback by felicitating physical matching interactions, users' perception of the VR environment could be altered to think everything they see in VR exists in reality. Feedback from visitors to a virtual art gallery created using the STHR concept confirmed that including STHR improves the immersion and believability of VR.

Overall, the findings of this thesis will play a critical role in sparking future research into emotional stimulation and haptic feedback to improve VR realism.

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概要

仮想現実（virtual reality ： 以下 VR）における臨場感の向上には、技術面、人間工学面、機能面での課題が存在する。特に、仮想現実空間でアート作品の展示を行うにあたっては、アーティストやデザイナーには没入感と知覚に関連した認知的、技術的課題への対処が求められる。本研究では、仮想現実空間におけるアート作品展示の臨場感向上を目的とし、二つのレンダリング方法、EHVR （Emotional Hacking enabled VR）、STHR(Smooth Transition and Hybrid Reality）の開発を行い、バーチャルアート作品の提示と体験を通してそれぞれの効果確認と実践的検証を行う。これは感情と感覚との両方の刺激を通した統合的な方法の提案である。

仮想現実空間では感情の関与が没入感の度合いに重要な役割を果たしていることが知られている。このことから EHVR を感情的刺激と生理的状態の組み合わせを基盤とした仮想現実体験として開発する。EHVR では心臓の拍動を模した振動触覚刺激をフットレストを通じて体験者に提示する。振動刺激は仮想現実体験の開始時点では体験者の心拍と同期した周期で提示

され、体験の進行に従い提示周期を短く変化させる。これによって体験者に自己の心拍数の増加を錯覚させ、恐怖感の増大を演出する。

EHVR の実験には 103 人が参加し、体験に関する主観評価が行われた。多くの参加者が、臨場感と恐怖感を非常に高く評価した。心拍数は体験開始前を平常時とすると体験の終了時には 118%に増加した。これらから人工的な心拍数変化の刺激が体験者の恐怖感に影響を与えることが認められた。

この実験過程において体験者は体験中も現実世界の様子を記憶に留めており、その記憶したイメージを体験者の頭の中で仮想現実空間に投影していると推測された。そこで現実世界での情報を遮断し記憶の想起を防ぐことで仮想現実空間が現実世界と競合することを防ぐことで仮想現実空間の臨場感を向上させると考え、仮想と現実との間のスムーズな移行および両者の融合現実感を提示する方法 STHR(Smooth Transition on Hybrid Reality)を提案する。

STHR は現実空間と仮想空間との間の視覚情報と触覚情報を一致させ、両者の間の移行をスムーズにし、かつ両者の融合感覚を演出するものである。3D プリンターで作成された作品のレプリカを現実空間に置く。これは仮想空間で展示されるものと一致しており、現実の触覚情報として体験者に提示する。現実と仮想の両空間での情報を一致させることで仮想作品の鑑賞時の意識のミスマッチを下げることが目的である。実践的な試行実験では、視覚情報と触覚情報が一致することから、体験者の意識での現実世界から仮想現実空間へのスムーズな移行、仮想現実空間への没入感と信頼感の向上が認められ、仮想現実体験における臨場感の向上に貢献すると認められた。

本研究ではバーチャルアート作品の提示、環境を想定し、感情的刺激、視覚と触覚情報の併用による仮想現実体験の臨場感の向上を行った。実践的な実験・体験からもこれらの効果が有効であることが確認された。本研究を通じて得られた知見をもとに、今後更なる発展的研究が行われることが期待される。

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Chapter 1

1 Introduction

Given the subjectivity and cognitive load associated with the interpretation of artworks, it is extremely challenging to provide a unified solution for the design and delivery of virtual artwork (Nechvatal 1999, Sillaurren and Aguirrezabal 2012). This thesis attempts to provide simple yet scalable solutions for rendering virtual artwork. Furthermore, detailed examinations are conducted on the factors that could influence immersion in VR experience. In this context, emotional hacking, seamless transition from the physical space to the virtual environment, and tactile feedback are given the key focus. The following sections in this chapter introduce different terms associated with VR and the perception of the artwork, as well as provide a glimpse of the methodological framework and thesis structure.

1.1 Overview of VR

Virtual reality (VR) has a long and illustrious history that goes back to the 1960s (Huh 2020). According to reports, the first commercial virtual reality devices were introduced in the late 1980s. As VR technologies are getting refined, there is a growing interest in merging art and technology to form one seamless form of expression. In a significant work, MacLeod and colleagues presented perspectives from a variety of fields, including cultural studies, communication, art history, art criticism, English, and women's studies, followed by a discussion of the nine virtual environments and statements of what the artists are trying to achieve in both theoretical and technical terms (MacLeod and McLeod 1996). In another interesting development, Barbieri et al. presented a methodology based on user studies for the comparative evaluation of different design alternatives related to the user interaction with VM systems. In accordance with the findings of the user study, this technique can be successfully used in the development process of virtual reality systems in order to maximize its outcomes in terms of usability, as well as its potential for entertainment and

education (Barbieri, Bruno et al. 2017). Recently, Wu et al. presented an analysis of user capabilities in eye-free spatial target acquisition in immersive virtual reality environments (Wu, Deng et al. 2021). The findings revealed that the target locations at the front and middle horizontal angles, as well as those at the middle vertical angles, may be acquired with high precision and low workload while maintaining a low task load. Meanwhile, it is impossible to establish a satisfactory trade-off between acquisition accuracy and job load when the target is located at a significant distance from the user's body. Other studies also revealed important factors that can influence the realism of the VR experience (Long, Tang et al. 2020, O'Brien 2020, Ryding, Spence et al. 2020, Hacmun, Regev et al. 2021). Consequently, modern digital technologies in the production of interactive works of art and exhibitions have become more prevalent in recent years (Bannon, Benford et al. 2005, McConchie and Ensom 2019, Alex, Wünsche et al. 2021). In this regard, the creation of virtual environments for the diffusion of cultural heritage and virtual experimentation has been a significant step forward, integrating 3D image collection methods such as digital photogrammetry (captured reality) with computer 3D modeling to get realistic results (Loaiza Carvajal, Morita et al. 2020). It is expected that by using virtual reality, the contemporary art scene can be made more engaging and accessible to the masses (Fraser, Bowers et al. , Tennent, Martindale et al. 2020).

Virtual reality relies on technological as well as cognitive dimensions (Paes and Irizarry 2016, Li, Legault et al. 2020). Technologically, VR involves a portable platform with display, tracking, and rendering capabilities. In the physical world, users' motions are monitored and recorded, and then the relevant virtual world transitions are performed. Therefore, in VR, it is important to monitor and quantify movements along the translational and orientational axes. Different sensor modules and feedback mechanisms, such as finger controllers, wearable LED lights, or thermal sensors that

collect body heat indicators are generally employed to monitor motions and other relevant parameters. In terms of cognitive dimensions, the VR experience must be designed considering human psychology and expectations (Burt and Louw 2019).

Immersion is the sensation of being physically present in a non-physical environment (Sanabria 2015). Valkov and co-workers introduced an essential notion of seamless immersion, as well as the advantages of making the shift from real-world to virtual settings a continuous process (Valkov and Flagge 2017). A suspension of disbelief is required to experience a high degree of immersion. In VR, there is considerable interest in allowing users to focus on the rendered content without any distraction (Strauss, Fleischmann et al. 1999). Therefore, users of the VR system are generally surrounded by visuals, music, and other inputs that form an engaging environment. The role of immersion and VR content in enhancing VR realism has been a focus of several studies (Lo and Cheng 2020, Radianti, Majchrzak et al. 2020). Most of the findings indicate that both immersion and affective content affect VR realism. Notably, immersion is more relevant for non-emotional environments than for emotional ones (Baños, Botella et al. 2004, Baños, Botella et al. 2008), and to enhance immersion in virtual representations of art, which includes subjective emotional reactions, multifactorial approaches are necessary (Dey, Chen et al. 2018, Eriksson 2018, Yeo, White et al. 2020). Marn-Morales et al. performed a comprehensive assessment of emotion recognition studies employing physiological and behavioral measurements with head-mounted displays as elicitation devices and provided recommendations for future study (Marín-Morales, Llinares et al. 2020).

The tracking abilities of a VR system and the field of view are common immersive characteristics (Ragan, Bowman et al. 2015). The ability of technology to construct a surrounding by blocking the external stimulus and replacing it with virtual sensory input using a chosen stimulation is an

important factor in yielding a high degree of immersion (Slater and Wilbur 1997). The notion of presence, contrary to immersion, relates to the subjective sense of feeling physically present while having a VR experience (Sadowski and Stanney 2002). Immersion relates to the actual characteristics of the system, whereas presence pertains to individual emotional response. Interaction and engagement are other crucial aspects of VR (Tolmie, Benford et al. , Reeves, Benford et al. 2005). As a result, monitoring expectations, reality, engagement, and attention of participants throughout the VR experience has received a lot of attention and given a prime focus in this work.

Physical reality is a construct formed by the symbolic, geometric, and dynamic information that our senses perceive. As a result, VR systems aim to stimulate all five senses of the human body. Vison is often regarded as the most important sense for human cognition. Indeed, when it comes to appreciation of art, vision is likely the primary sense engaged since the tactile, auditory, and olfactory senses are almost excluded from the experience. One of the essential aspects of vision is depth perception, and in the setting of art galleries, multiple factors may induce subjectivity in perception, interaction, and engagement with the artwork. Furthermore, in art galleries, the displayed artworks are either enclosed in a glass enclosure or covered by a barrier, allowing various observers to see the item from various distances and viewing angles. This may imply that giving the spectator optimal visual engagement with the artwork is crucial in achieving a high degree of VR realism (Maleshkova 2018, Manghisi, Uva et al. 2018, Bozzelli, Raia et al. 2019). Furthermore, the diversity of displays and customization choices available in a typical art gallery may restrict the ability to build a unified VR set-up. In particular, depending on the approach in which VR is rendered, some observers may get overwhelmed and quickly disoriented in a virtual

environment, while others may devote their time exploring irrelevant elements, negatively impacting engagement and general realism (Degraen, Zenner et al. 2019).

1.2 Approaches for enhancing VR realism

1.2.1 Emotional stimulation

Emotional engagement with a task significantly affects the level of immersion (Riva, Mantovani et al. 2007, Visch, Tan et al. 2010, Caldas, Aviles et al. 2020). Nordahl et al. reported that the use of auditory and haptic input at the foot level improves the realism in a virtual environment (Nordahl, Serafin et al. 2012). In Chapter 3, a succinct overview of emotional stimulation is provided.

1.2.2 Mixed reality and smooth transition

To improve the realism in the overall VR experience, techniques for integrating real and virtual settings to create mixed realities, spatial spaces where users can interact with physical and digital information seamlessly, are gaining popularity (Hall, Ciolfi et al. , Pérez , Giannachi, Lowood et al. 2012). The phrase "Mixed Reality" refers to settings that include both actual and virtual items, as well as visual representations of both real and virtual space (Strauss, Fleischmann et al. 1999). Therefore, in mixed reality, there can be a dynamic interaction between the real and virtual worlds. To separate the actual world from the virtual world, Benford et al. suggested using transparent borders between the two (Benford, Greenhalgh et al. 1998). On the other hand, Suzuki et al. recently introduced the concept of substitutional reality (Suzuki, Wakisaka et al. 2012), where an integrated exposure to the physical world and the real world was provided. However, existing systems are very rudimentary, especially in terms of user interfaces and the general realism of VR (Hoffman 1998, Whitson and Galinsky 2008, Tatli, Altinişik et al. 2021). There is a need to

research the factors that can enhance VR realism to create an engaging experience with a virtual art gallery (Senior and Jaimes 2010, Borg, Dunn et al. 2020, Radianti, Majchrzak et al. 2020).

1.2.3 Haptic feedback

Feedbacks are another important tool to enhance the VR experience. Aimed at improving VR realism, there has also been a significant amount of work on developing advanced systems for haptic rendering (Styliani, Fotis et al. 2009, Almutawa and Ueoka 2019). Although virtual features may be easily changed in VR, changing haptic sensations is more complicated. Haptic methods need a lot of physical proxies; it is desirable to develop flexible equivalents that can be easily developed and implemented in different scenarios.3D-printed items have the potential to provide excellent haptic feedback in virtual reality (Degraen, Zenner et al. 2019). Likewise, the addition of physiological feedback in virtual reality can also alter participants' emotional states (Dey, Chen et al. 2018). However, in virtual representations of artwork, including suitable feedback into the VR experience requires the development of novel approaches.

These and other methods of increasing realism in virtual reality have been actively explored; however, while research into the user experience of virtual art continues to expand, there are numerous gaps in our understanding of the relationship between immersion and the technical characteristics that are used to present virtual art. The effects of external emotional stimulation and seamless transitions on the realism of VR artwork, in particular, need further exploration.

1.3 Definition and key terms

Virtual reality may be described as the use of technology to create the illusion of an interactive three-dimensional environment in which objects have a spatial presence. In this definition, "spatial presence" means that the virtual objects have a location in a three-dimensional space with respect

to the observer. The fundamental concept is to provide the right signals to the perceptual and cognitive systems in such a way that the brain perceives those stimuli as things "out there" in the three-dimensional environment rather than as internalized information. Virtual reality is an interactive, participatory environment that can support a large number of remote users who are all in the same virtual location at the same time. It can be divided into three categories:

Non-Immersive: In this case, the user's perceptions are partly involved, and the person retains a feeling of peripheral awareness of the actual world beyond the VR environment.

Semi-Immersive: It is a kind of virtual reality that enables participants to explore three-dimensional virtual environments while staying engaged with real-world views, audio, scents, and haptics, as well as maintaining control over tangible items.

Immersive: Immersive virtual reality (sometimes known as fully immersive virtual reality) is a digital technology that enables users to experience artificial surroundings as if they were in the real world.

1.4 Key Elements of a VR Experience

1. Virtual environment: The content of the virtual experience should be defined by the expectations of the observers. The instructional designers who build the virtual world must understand how the environment affects the user's experience.

2. Immersion: Immersion, as previously mentioned, is associated with the sense of being present in a nonphysical environment.

3. Sensory feedback: VR demands the stimulation of as many relevant senses as possible through sensory feedback, which requires a mix of hardware and software.

4. Interactivity: To preserve the feeling of immersion and naturalness in the environment, viewers must be able to interact with the virtual world. It is possible that limiting the observer's ability to engage with the virtual environment would be distracting.

1.5 VR input and output

Technologically, devices utilized in virtual worlds are critical to the effective delivery of virtual experiences. Input devices are used to interact with the virtual world and may vary from a basic joystick or a keyboard to a glove that records finger motions or a monitor that records positions. More precisely, the keyboard, mouse, trackball, and joystick are all examples of simple-to-use desktop input devices that enable the user to initiate static and dynamic instructions or motions in the surroundings. Other input devices include bend-sensing gloves that record hand motions, positions, and movements, squeeze gloves that detect finger movements and trackers that can monitor the user's actions in the real world and convert them into the virtual environment. On the contrary, the output devices allow the user to see, hear, smell, and touch all aspects of the virtual world. Visual devices come in a wide variety of configurations, ranging from the simplest or least immersive (computer monitor) to the most immersive (head-mounted display, or CAVE systems).

1.6 Aims and Objectives

This thesis aims to research practical tools and techniques for enhancing the virtual depiction of artworks, thereby enhancing the overall virtual reality experience. Specifically, the primary goal is to create an engaging experience with a virtual art gallery utilizing already available commercial technologies. To achieve these goals, it is essential to investigate the viability of virtual reality technology in art, the value it may offer, and its particular features and limits. The next stage is to

design an artwork that incorporates the set of unique characteristics in order to create a new experience appropriate for this new medium.

A multidimensional approach was utilized to accomplish the thesis's goals, which included creating a technological, physical, and tactile feedback system. For VR designers, a deeper knowledge of the setup and feedback mechanisms associated with mixed reality user interfaces is essential. Due to the absence of well-established algorithms and design patterns, developers of such programs need additional assistance. This research effort is motivated by the lack of grounded frameworks to assist in the creation of next-generation virtual reality applications. In light of this objective, a concerted effort is undertaken to ensure that the area of the problem investigated is sufficiently covered and relevant. An initial prototype system is constructed in each of the cases. Then, in controlled user studies and field tests, the performance and experience of the users were assessed. As a consequence, the following two main methods serve as the foundation for the innovative approaches used in this study:

Emotion Hacking VR (EHVR)

Unlike the widely held notion that emotions are ambiguous variables, cognitive scientists have recently shown that the intensity of emotions may be changed by changing one's physiological state (Ando, Watanabe et al. 2012). Indeed, several cases of vibrotactile feedback have been documented in the literature. The audio-haptic feedback technique, in particular, was shown to be the most preferred of the different forms of heart rate representation. Oliveira et al. developed a vibrotactile HMD and demonstrated it is easy to use and entertaining. Lee et al., on the other hand, provided vibrotactile feedback through the floor and reported that the inclusion of this vibrotactile feedback led to more remarkable avoidance behavior when the virtual human invaded participants' personal space(Lee, Bruder et al. 2017). The wearable vibrotactile haptic device for stiffness

perception during an interaction with virtual objects focused on another study, reporting improvement in the average Weber fraction values after adding the tactile feedback.

In this thesis, the effectiveness of providing emotional stimulation by inducing false vibrotactile feedback to enhance the VR experience has been examined. Explore the notion of emotional hacking in a diverse range of challenging and relevant vibrotactile feedback situations. One of the most compelling aspects of virtual reality is the feeling of "psychological presence," which is when the motor and perceptual systems respond to the virtual world as they would in the physical world. This actuation is beneficial because it may enhance the feeling of presence by detecting a shock or vibration. Specifically, this is accomplished by developing a technologically interactive system that intercepts and controls a person's pulse in order to increase the pace of a frightening VR simulation.

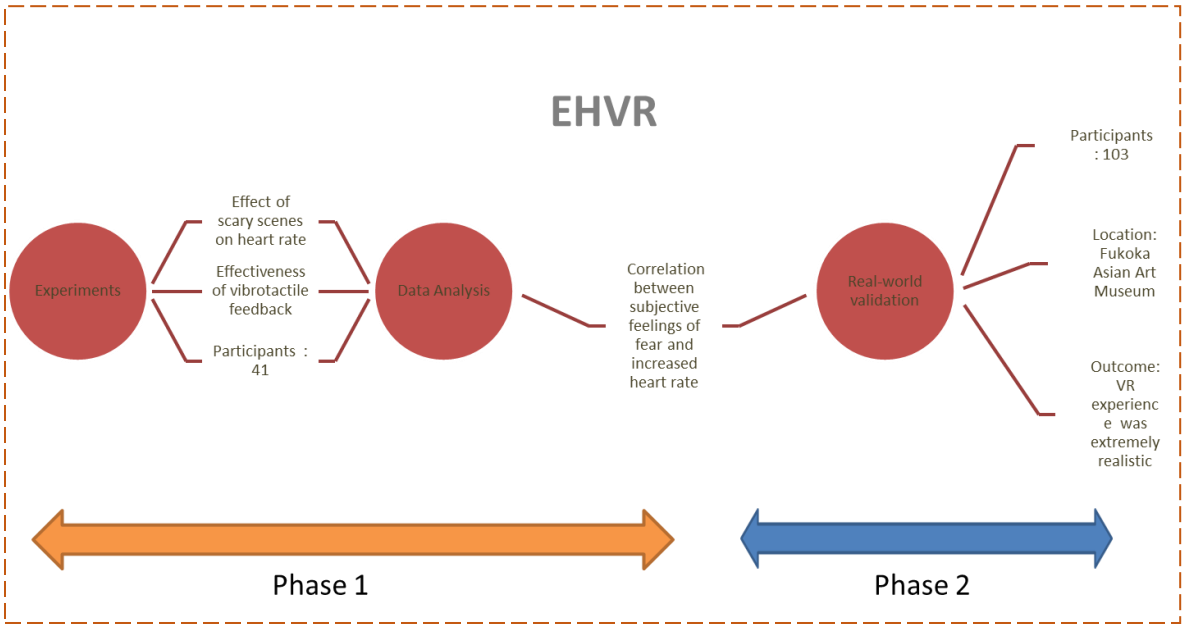

Figure 1.1: Schematic representing key features of the EHVR

Smooth Transition Coupled Hybrid Reality (STHR):

This approach attempts to enhance the realism of VR by inducing a smooth transition from the real world to the virtual world and providing haptic feedback. The concept of STHR was implemented by deliberately exposing participants to a 3D printed real object that was a replica of one of the virtual items they would encounter during VR and designing VR setup and the real-world setup to have a minimum mismatch. This step was intended to give haptic input that was consistent with both the real world and the virtual environment. By showing a three-dimensional object from the point of view that correlates to the positions of the viewers' eyes as they move about, these methods have proved surprisingly simple to render. When objects in the environment interact with the viewer, the sense of spatial presence is greatly increased.

STHR relies on the fact that vision has higher reliability and spatial acuity than kinesthesis, so the brain gives more weight to visual information. This factor is even more dominant in the case of artwork, wherein perception mainly relies on visual information processing. The objective of STHR was to reduce the impact of spatial awareness of actual space on the VR experience and to employ hybrid reality to improve VR realism. By spatial awareness, we imply that even if VR users cannot see the real world because they are wearing a headset, they may nevertheless have knowledge about the layout of the physical space. The brain has a remarkable ability to extract statistical connections, and this spatial knowledge may undermine the illusion produced by VR and may decrease immersion, since the real-world (physical space) environment does not always match the virtual area. For example, if a user perceives the physical area to be empty, he may be unafraid of colliding with virtual items; but, if users have no previous knowledge of the physical space, it will be impossible for them to draw any conclusion about the spatial existence of virtual

things. In our study, the median time required to perform the task was much longer in the group that did not have previous knowledge of the physical area than in the group that did.

Furthermore, if some of the elements in the virtual world are also present in physical space, this may increase the realism of VR. It indicates that allowing participants to engage with a physical replica of a virtual object during the virtual art gallery experience would create a situation of hybrid reality in which the user is aware that some of the things are virtual, but others are also tangible. The goal is to design a simpler configuration that will work in as many scenarios as feasible. The configuration will allow for a smooth transition to VR without interfering with the experience. We believe that if we start with a blank mental picture (spatial memory) of actual space, we may make a seamless transition into VR, enhancing immersion. As a result, rather than utilizing pre immersion, we began with a blank mental picture of the surrounding area, limiting access to as much information about the physical place as possible. We restricted the view of the experimental area so that participants did not develop a mental picture of the place ahead of time; this reduced their probability of pondering the difference between the actual space and the VR environment, since they had no frame of reference. We conducted controlled studies to investigate this feature. Furthermore, if some of the objects in the virtual space are also present in real space, this will increase the realism in VR.

Although these concepts are new and have not been documented before, similarities may be made with other media, such as conventional video editing transitions in films. In some ways, this technique is comparable to how a black screen fades into a video to create a transition from a blank canvas to the content. This transition technique borrowed from video editing is comparable to a transparent, seamless cross-fade between two similar images when recreating actual space in VR with 3D models. Given that users are unaware of the contents of the real-world setup, we aim to

increase the realism that VR items have a physical existence. As mentioned previously, this was accomplished by presenting proxy objects early in the VR experience that correspond in size and position to the actual world and the VR content. The subject then experiences the uncanny illusion that the touch sensations are felt from a real replica of the artwork. In order to get this look, we utilized a 3D-printed replica of an artwork. However, commonplace items such as glass boxes, seats, or museum barriers can create a similar effect in other contexts. These early matching exchanges contribute to a higher level of realism in VR.

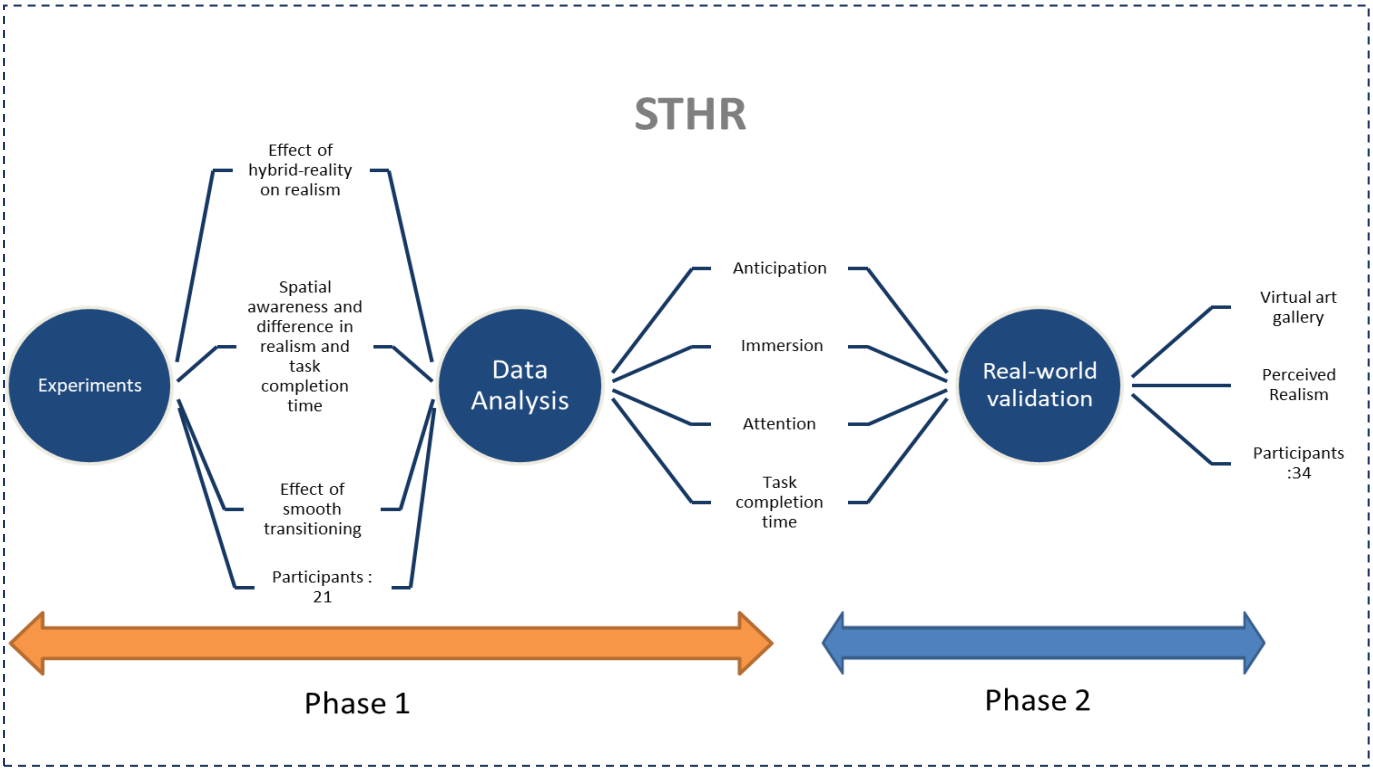

Figure 1.2: Schematic representing key features of STHR

1.7 Research question

What role do emotional stimulation, haptic input, and spatial awareness of the physical environment play in the realism of virtual artworks?

1.8 Methodological framework

The aforementioned research questions are addressed in this thesis through a series of separate but thematically linked experiments and real-world validation. Due to the distinct characteristics of the two situations, a different strategy was used. Chapters 3 and 4 go into more detail on the research strategy that was utilized in this study; however, the fundamental approach is briefly explained here to provide an overview of the methodology used. In both cases, the experiments were conducted in two phases (Phase 1 and Phase 2). The first phase involved conducting pilot / controlled experiments, and the second phase was the real-world validation. Validation in the real world involves performing field trials with a random sample of participants. To evaluate the effectiveness of these methods, we conducted a series of randomized studies in which we evaluated the anticipation, realism, immersion, and attentiveness of the participants throughout their virtual reality experience (Poeschl, Wall et al. 2013, Gaggioli 2015). In addition, we tracked the amount of time it took for tasks to be completed and the number of collisions that occurred in various research groups. A final step was shown by establishing a virtual art exhibition accessible to the general public and documenting the realism experienced by random visitors to the gallery. The participants were observed while they engaged with two virtual reality applications, and the data was gathered via a semi-structured interview.

1.9 Systems

1.9.1 EHVR

To conduct comparative experiments, a virtual 3D movie theater system with an HMD (Oculus rift dk1) was developed. This virtual environment was created to fit the story setting of the movie. To measure the subject's heart rate in real-time and generate the false heart rate as vibrotactile feedback, a photodiode pulse sensor was used. Below the standing area, a quiet subwoofer (Buttkicker BKA-113-C) was placed to provide vibrotactile feedback of the false pulse from below the feet.

1.9.2 STHR

The system included an HTC Vive headset with a Leap Motion sensor placed on it for hand tracking and Vive motion controllers with 3D printed ankle attachments to detect foot movement. Semi-realistic avatars were used in VR to help maintain the level of immersion (Jay and Hubbold 2003, Steed, Frlston et al. 2016). The VR content was run on an ASUS laptop (model GL502VS) equipped with an Intel Core i7-6700HQ 2.60 GHz CPU, 16 GB RAM, and a GTX 1070 graphics card. The content was created using Unreal Engine 4, which showed a 3D room modeled in Autodesk 3DS Max.

1.10 Participants

There were 40 participants (Phase 1) in the EHVR and 21 participants (Phase 1) in the STHR experiments. Before the experiments, all participants were asked to complete a questionnaire related to basic information and previous VR experience. Each participant had to participate in all experiments.

1.11 Experiments

1.11.1 EHVR

During the pre-test phase, a subject entered a box-shaped theater system, donned the HMD, and remained motionless for 4 minutes while gazing at a spot on the screen. Subjects, with the exception of those in the control group, were informed that while viewing a horror movie, vibrotactile feedback of their pulse would be provided beneath their feet. The prerest heart rate was used to compute the mean heart rate, which was then utilized to estimate the maximum value of the raised heart rate and produce the fake heart rate. After the pretest, the horror film was shown, along with vibrotactile feedback, to all participants except those in the control group.

1.11.2 STHR

Three experiments were carried out at the same location in a particular order, one person at a time. To remove any knowledge of the place, we selected a room that was unknown to all participants. Participants were instructed to put on an eye mask before entering the experiment room, close their eyes, and keep them closed until they entered the room and put on the HMD. After the trial, the participants were instructed to close their eyes again until they left the room. In STHR, after each experiment, they were asked to fill out a Presence and Reality judgment questionnaire (Baños, Botella et al. 2000); the questionnaire had 25 questions that were to be scored on a scale of 1–10. The anticipation, reality, immersion, and attention during VR were analyzed from the questionnaire. At the end of the three experiments, we also conducted a survey and an interview with questions based on the behavior of the participants.

1.11.3 Haptic feedback

In STHR, the haptic feedback that matched between the real world and the VR was an important aspect. It was introduced at the beginning of the VR experience by using a 3D printed replica of an artwork. Additionally, to ensure a smooth transition from the real world to VR, important features of the real space were also maintained in VR. In our case, it was the windows of the building and the ceiling.

1.11.4 Real-world validation

To test the real-world validity of EHVR, a hands-on exhibition was held at the Asia Digital Art Award 2017 show at the Fukuoka Asian Art Museum. In the case of STHR, a VR art gallery (VAG) was created to test the validity in a real-world setting. It was hosted on the second level of Kyushu University's built common building in a multi-purpose area. The VR gallery was inspired by traditional Japanese home design. The exhibition included four distinct 3D sculpted artworks based on Bonsai trees, which are an important element of Japanese culture.

1.12 Data analysis

Normally distributed binary data were presented as mean and standard deviation (SD), and nonnormally distributed data were shown as median (M) and interquartile (IQR) values. The t-test was used to compare the normally distributed data, and the Mann–Whitney U test was used to compare the data with the nonnormal distribution. The significance was established at $p<0.05$.

1.13 Thesis Outline

The following sections describe the remaining chapters of this thesis. Chapter 2 provides a comprehensive summary of the literature associated with different VR techniques that are used to enhance the effectiveness of the VR experience. It situates this study within a larger body of research and investigates the many current methods used to create improved VR experiences. It

also examines a modest but growing collection of work that attempts to establish design principles for hybrid reality applications. The third chapter provides both a theoretical basis and practical confirmation of the notion of "Emotional Hacking" for the aim of improving the VR experience. The outcomes of a real-world display are also thoroughly discussed. The novel concept of STHR is introduced in Chapter 4, which combines haptic feedback with a smooth transition to create a hybrid reality with a high degree of immersion. This chapter also includes a case study that illustrates how the concept has been validated in the real world virtual art gallery. It offers a practical method for dynamically adjusting the VR setup to the physical environment deployed. The effect of interactions with the physical real-world on VR immersion is also explored in-depth, as are the findings of a diverse and representative dataset gathered through a semi-structured questionnaire. Chapter 5 offers a comprehensive examination of the thesis's findings, placing them in the context of prior research and providing practical applicability of the findings. Finally, in Chapter 6, the thesis is concluded. It returns to the study questions and core hypothesis and comments on the answers given by this study. The major contributions of this research project are emphasized. Future work constraints and possibilities are also highlighted.

1.14 verdict

Virtual reality in the context of art is a complicated process that involves a significant amount of subjective, technical, and psychological complexity. VR can be immersive or non-immersive, depending on the application requirements. Achieving a high level of realism in virtual art is a technological challenge, and a mismatch between physical and virtual space may have a detrimental effect on VR realism. This thesis attempts to utilize the concept of EHVR and STHR for enhancing the VR experience in art galleries. This research project aims to provide a unified yet simple solution for enhancing the realism in a virtual representation of artwork, as well as to

elucidate factors such as spatial awareness and emotional stimulation in the context of perceived realism, using controlled pilot experiments and real-world validation of the findings.

Chapter 2

2 Literature review

1.1 Introduction

This chapter explores research related to the central research question. It is important to understand the basics of these concepts before moving forward, as all play a role in the research question and the study conducted. The chapter starts with an introduction background of virtual reality, and then the research and developments in the field of virtual art are reviewed and compared. This leads to a discussion of immersive, interactive, and competitive VR environments.

2.1 Technical Background of VR

Several researchers have conducted extensive research on VR processes, effects, and implementations over the past few decades to gain a deeper understanding of the technology. A scan of the scientific database (Web of Science Core Collection) shows more than 24,000 items pertaining to virtual reality and about 7500 entries pertaining to augmented reality (AR).

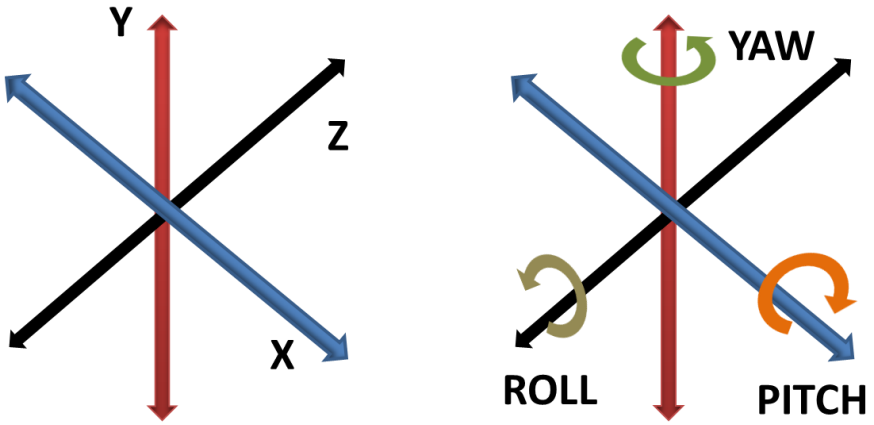

Figure 2.1: Axis of rotational and positional movements of the human head as relevant to VR

The visual above (Figure 2.1) displays the six different axes in which the human head can move while wearing an HMD, also called the six degrees of freedom (Oh, Park et al. 2019, Zhou 2019). Curved lines show how the human head can rotate (rotational movement), and straight lines show

how it can change position within the space (positional movement). Essentially, VR is an immersive, multisensory experience. VR relies on three-dimensional, stereoscopic, head-tracked displays, hand/body tracking, and binaural sound. It has the potential to provide additional perceptual fidelity.

VR systems are usually made up of VR headgear, a computer, and video. Chairs, gloves, and sensors have recently been added to improve the virtual environment (Anthes, García-Hernández et al. 2016). VR headsets refer to head-mounted displays. They have a speaker or headphones installed. Many desktop VR systems come with controllers that convey their movements, so users have their heads in VR and their hands. Unlike augmented reality, which brings artificial objects into the real world, virtual reality places the user into digitally-created spaces that can be used for training, education, simulation, and entertainment. High-end VR headsets like the HTC Vive and the Oculus Quest can track both rotational and positional motion, which is necessary for "room-scale." It may be noted that mobile headsets like the Samsung Gear VR and Google Cardboard can only track rotational movement because they rely on the smartphone's internal accelerometer and gyrometer, which restricts mobile VR to being seated and stationary activity.

2.2 Perception of physical art and virtual art

Human perception is inherently multisensory, and the theoretical framework/constructs for the factors affecting perception during VR are not fully established. Therefore, we must rely on multiple theories to explain the perception of virtual objects and how surroundings, emotional state, and haptic feedback can affect perception. In the current thesis, the concepts of mixed reality, haptic feedback, and other relevant issues have been presented with the help of pertinent and recent references. Emotional reactions as an additional axis to the Autonomy, Interaction, and Presence (AIP) cube are generally added (Chapter 3), in the context of VR immersive experience (Yoshida,

Sakurai et al. 2013). Integrating input from various systems is critical in such an analysis, since no information-processing system, whether technological or biological, is strong enough to give a precise and accurate approximation of human perception under all circumstances. It is often claimed that the illusion is caused primarily by the 'Bayesian logic' of all perception. The brain's extraordinary capacity to identify statistical connections in sensory input in order to build meaningful perceptual representations of the environment is the primary component. Neurologists, cognitive scientists, and psychologists' surgeons are still working on developing theories related to the perception of art (Bhattacharya and Petsche 2002, Ekweariri 2021). With the recent rise in technological progress and the present focus on recording human experience during VR, it is anticipated that a significant quantity of data will be accessible in the near future to build and verify underlying frameworks (Garoian 2006, Nordahl and Nilsson 2014). In the following paragraphs, first, perception in the context of art has been discussed, followed by a discussion on virtual reality as it relates to art.

Perception involves the acquisition, interpretation, selection, and structuring of sensory information. Although perception is influenced by a variety of physiological and social variables, perception of art includes quite different processes from those used in everyday life. Art perception may be divided into three major procedures: the brain's attempt to evaluate the visual content and style; (ii) the flow of connections triggered by it; and (iii) the emotional reaction it elicits (Pavlova 2009, Guilé 2010, Melcher and Bacci 2013, Aviv 2014). Of course, since art is created for no immediate productive purpose, it generally allows the spectator to maintain a certain distance from "reality." A basic premise of contemporary brain research is that each action in the mental, cognitive, and emotional domains corresponds to a particular pattern of brain activity. Because each activity reflects and creates the resulting experience, much effort has been expended in

finding neural correlates of the art experience and trying to derive the principles underlying brain processing. Furthermore, different types of art elicit different types of responses. Using construal level theory, Durkin et al. defined that different levels of creative abstract concept elicit distinct forms of psychological extrapolation (Durkin, Hartnett et al. 2020); abstract drawings have been delegated to the faraway scenario significantly more than truly representative paintings, implying that visual expressionism elicited greater psychological spacing (Pepperell 2011, Escobar 2013). Kawabata and Zeki showed in an fMRI imaging research that various types of painting—landscape, portrait, and still life—elicited activity in localized and category-specific brain areas (Zeki 1992). Abstract art, on the other hand, did not stimulate a certain localized brain area. Rather, abstract art-related brain activity was seen in areas of the brain that are engaged by all other categories. Lengger et al. showed that viewers equally favored abstract and representational paintings by combining behavioral and low-resolution electromagnetic tomography research (Lengger, Fischmeister et al. 2007).

However, abstract cues elicited more pleasant feelings. When contrasting brain activation in response to truly representative and abstract works of art, representational works of art were found to have significantly greater excitation in many areas of the brain, most notably the left frontal lobe and bilaterally in the temporal, frontal and parietal lobes, limbic system, insula, and other areas. Increased brain function in reaction to representational art was linked mostly to the mechanism of object identification, as well as the participation of memory and associative processes (Taylor, Spehar et al. 2011). Given the richness and diversity of art, it may seem naive to try to encapsulate visual art perception in a single system because the visual perception of art is seen to contain both cognitive and emotional aspects (Baltissen & Ostermann, 1998; Silvia 2005a).

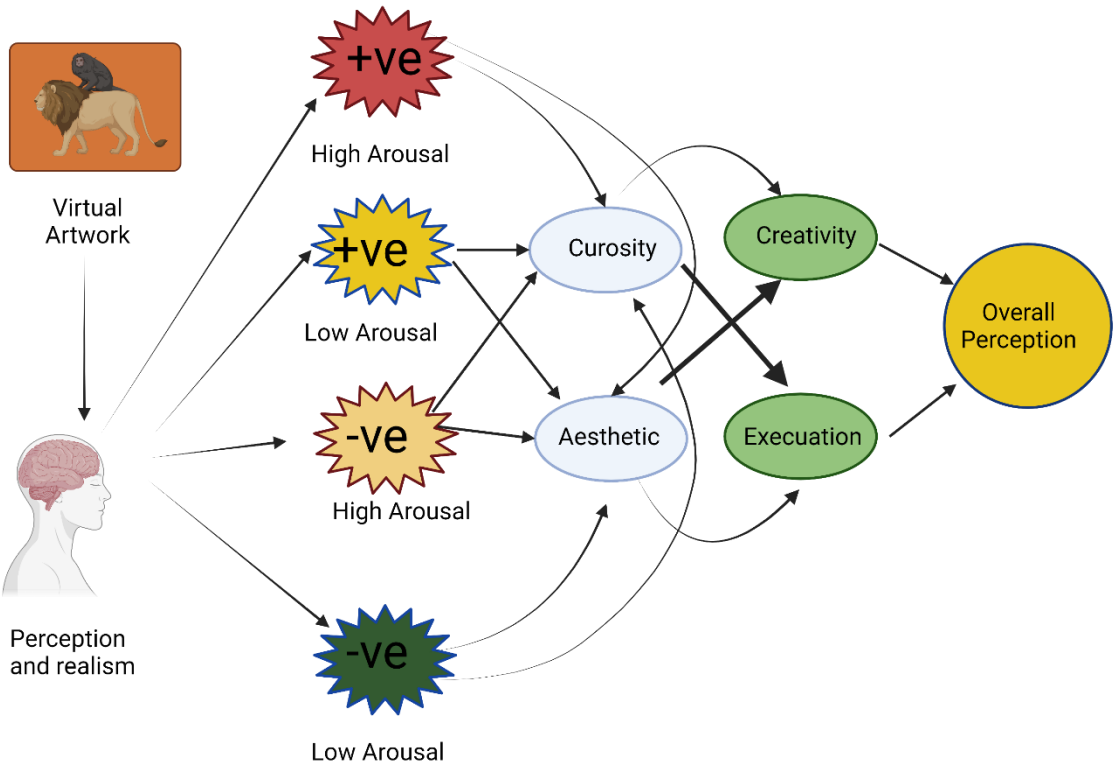

Figure 2.2: The perception of an artwork involves the interplay of emotions, interpretations, and aesthetics.

In the case of digitally rendered art, a spectator mainly activates several learning systems in the brain in synchronicity. The capacity to comprehend how data, events, and actions affect present and future circumstances is referred to as monitoring (Tishby and Polani 2011). These variables are influenced by psychoanalytic theory and cognitive science and are regulated by various neural systems of computational complexity and cognitive processing. It is feasible to create illusions in VR that cause users to identify and act as though they have encountered changed circumstances and identities. The impact may be strong enough even for individuals to react "truthfully," which means that their actions change as if they were subjected to the situations in real life (Gonzalez-

Franco and Lanier 2017). In the context of VR realism and perception, presence describes immersive experience (Lombard and Ditton 1997). People who feel as though they are in a virtual world are considered to be "present." Innovative methods to increase presence in virtual reality include tactile feedback, surround or 3D audio, and raised head-mounted displays (HMDs). Individuals have been predicted to feel greater degrees of presence if they were subjected to an emotional stimulus (Munyan, Neer et al. 2016, Lecuyer 2017).

2.3 Examples of Virtual Reality in Art Galleries

Art galleries strive to bring their treasures to life, and virtual reality is a great medium to do so. It provides a unique sense of complete immersion in an exhibit. Many museums and art galleries around the world are already embracing its potential. VR is being utilized to produce museum tours, interactive exhibitions and to bring sceneries to life. It may assist curators in placing items in context and displaying their actual size. As stated at the outset of the study, technological advances are required to make virtual representations of art more realistic and acceptable to the general public. It must offer a fresh and distinct dimension to the art. The technical advantages of VR systems generate high-quality sensory virtual environments that filter out real-world information, influencing how users think, feel, and behave. According to Slater, VR provides "a fundamentally different type of experience, with its own unique conventions and possibilities, a medium in which people respond with their whole bodies, treating what they perceive as real" (Slater 2009).

Google Expeditions is a virtual reality platform developed by Google and designed for educational institutions. It exposes students to both virtual and augmented reality field trips through their mobile devices(Parmaxi 2017). Compatible with Google Cardboard HMDs, Google Expeditions

tours of the Ms Guggenheim Museum of Art in New York City, and the Musée d'Orsay in Paris provided by the Google Arts & Culture initiative (Google LLC, 2016).

Figure 2.3: Virtual representation of Mikhail Bulgakov Museum Moscow, Russia under Google Arts & Culture initiative (2011)

The Louvre Museum in Paris and VIVE Arts collaborated on a virtual reality experience called Mona Lisa: Beyond the Glass to commemorate the 500th anniversary of Leonardo da Vinci's demise. This virtual reality event was created to supplement and enhance visitors' interactions with the work of Leonardo da Vinci. It consists of a 7-minute VR experience. A throng is shown in front of the artwork, with the spectator positioned behind it. As a result, the crowd thins and the

spectator is pulled close to the picture. The protective glass and frame have been removed. The finer elements, such as the grain of the wood panel visible through the paint layer and the intricacies in the original natural landscape of the painting, can now be read. The experience also includes a representation of Da Vinci's 'Sfumato' method. Moving pictures, music, and interactive design all work together to create a truly unique overall experience.

Figure 2.4: Finer details of the Mona Lisa painting begin to unravel through the VR experience (Raut 2019)

In 2018, the National Museum of Finland in Helsinki debuted a new virtual reality exhibit. Visitors may go back in time to 1863 by seeing VR. W. Ekman's artwork The Opening of the Diet 1863 by Alexander II. VR gear enables users to feel as if they are inside the artwork. Visitors are immersed in the setting and may see the Hall of Mirrors from a 3D viewpoint. They can even converse with the Russian Emperor and other figures portrayed in the artwork. Visitors can see images in the VR experience that do not exist as a tangible collection.

Figure 2.5: Virtual representation of R. W. Ekman's painting 'The Opening of the Diet 1863 by Alexander II' (Hills-Duty 2018)

Users explore an island home to 99 mini museums in Secret Habitat, a free simulation by the Manchester-based indie video game company Strangethink. Their algorithmically produced 37 structures are packed with equally inhabited unintuitive abstract art exhibits. The psychedelic game is situated in a region with neon blue and pink dirt, where leafless, turquoise trees swing like they are made of Jell-O (or imitating the motions of a crazy waving inflated flailing tube guy), and tiny pools of water glow a toxic-looking yellowish green. The museum buildings are intensely sober and somber by comparison, with their slide-like ramps and heavy walls looking like a fantasy collaboration between Carsten Holler and Tadao Ando. The exhibits inside include randomly produced wall art ranging from Gerhard Richter-style color splashes to pieces that resemble Wade Guyton's inkjet printer works. Sound art pieces that users may turn on and off in each gallery offer

a similarly random, but sometimes unexpectedly complimentary, soundtrack to the images. Exploring Secret Habitat's surreal landscape and surprisingly believable randomized approximations of contemporary abstraction is a remarkably smooth experience. And unlike most museums, all the exhibitions change every time one visits.

Figure 2.6: Procedurally generated abstract art in Secret Habitat (2019)

There is a presentation of the best mixed reality experience in the United States. The artwork "Concrete Storm" (concrete storm) using Microsoft's HoloLens was exhibited at the Armory Show in New York. It consists of a virtual sculpture based on reality, depicting The expansion of the boundaries in the room. When someone visits for the first time, they feel solid forms of concrete and beautifully created motifs. HoloLens headsets are worn inside the museum, providing a picture of reality invigorated by responsive holograms that complement the installation's physical setting. With Concrete Storm, DRIFT travels through a layer among similar spheres, whereby the actual and the virtual worlds co-exist, blurring the line between reality and computer graphics. When a

visitor visits this space, their attention is continuously divided between the two, allowing artists to study unstoppable evolution.

Fig. 2.7: Mixed reality seen through the Microsoft HoloLens, in Concrete Storm (Drift 2014)

Nothing Happens is an animated VR experience that questions the role of the spectator by inviting the individual to participate in an even. VR enables us to select our point of view, focus on the details, and take in the unique environment. The project investigates a new type of story, a new way of being in a painting, resulting in a fully complete and engaging piece of art. It is about being a witness, about observing, and being observed. The participants believe that they are part of this remarkable painting, providing artists with a new narrative of thinking and looking at the picture. It involves the presence of human beings, their thinking, and unique perspectives.

Fig. 2.8: A shot from VR expanded animation in Nothing Happens(Tatli, Altinişik et al. 2021)

"Swing" is another playful VR installation using the HTC Vive and Kinect. The swing is the primary input element. This novel mix of analog and digital components offers the player a very immersive experience. The impact of swing set play on the human psyche has remained unknown until this point, despite being studied in hospitals and clinics for quite some time. It is certain that the rhythmic rocking movement has a positive effect on the psyche and well-being. With each swing movement, participants envision themselves soaring higher and higher. They feel like they are there in space, which has a positive effect on their psyche. The experience can be found in exhibits and galleries around the world. The swing exists, in fact, but the perspective is a virtual setting.

Fig. 2.9: Swing VR an immersive VR experience (2015)

The Thresholds is a traveling exhibition that recreates the world's first big photographic show. Visitors go back in time to 1839 when British scientist William Henry Fox Talbot first displayed his photographic prints to the public at Birmingham's King Edward's School. The experience is a completely immersive gateway to the past; guests can freely roam around a digitally rebuilt room, touching custom vitrines, fittings, and moldings; even the heat and smell of a coal fire are replicated. Infrared sensors monitor guests' movements, generating ghostly avatars that identify their location and add to the illusion of time travel.

Fig. 10: Thresholds recreates through VR an exhibition held in 1839 to showcase Fox Talbot's pioneering photography, Mat Collishaw: Thresholds(2018)

The above examples demonstrate that virtual reality has the ability to improve the perceived quality of the artwork. It enables designers to bring themes to life and alter the viewer's viewpoint. But, like every new technology, it has its drawbacks. The main challenge is that VR experiences are not immersive enough to render a realistic experience to the user. In this regard, cost-effective and scalable solutions are necessary. Furthermore, a framework for embodied cognition is needed that may explain why VR can affect cognition, behavior, and perception.

2.4 Enhancing the quality of the VR experience

Exhibits and galleries are being designed and developed to promote the interaction of visitors and to improve their overall experience while also increasing their learning possibilities (Fosh, Benford et al. , Rey, Brock et al. , Benford, Drozd et al. 2006). This has been made possible by the

development of new tools and technologies that have enabled museum designers, curators, as well as museum managers to create exhibits that encourage interactivity and allow visitors to participate in more complex forms of participation in museums and gallery spaces than they previously could (Fosh, Benford et al. , Kosmopoulos and Styliaras 2018, Sundnes Løvlie, Ryding et al. 2021). In this regard, initiatives such as Situating Hybrid Assemblies in Public Environments (SHAPE), which aim to create a more engaging experience during the visit to art galleries or museums, are particularly noteworthy (Hall, Ciolfi et al. 2001, Hall and Bannon 2005).

The development of new methods of engagement in museums and art galleries has become increasingly popular in recent years (Back, Bedwell et al. , Sacher, Weyers et al. , Vom Lehn, Heath et al. 2005, Salar 2009, Rennick-Egglestone, Brundell et al. 2016, Carvajal, Morita et al. 2020). The concept of "mixed reality" is gaining popularity in the field of human-computer interaction (HCI) (Benford and Giannachi 2011, Nisi, Dionisio et al. 2018). This method uses virtual and/or augmented reality to take advantage of the capabilities of digital technology, building the experience in conjunction with a physical presence and social settings(Koleva, Taylor et al. , Nilsson, Hogsden et al. 2016, Løvlie, Eklund et al. 2020). Artifacts that encourage passersby to be placed on exhibit and lookalike items that guide visitors around the gallery depending on their point of view and preferences are examples of embedded hybrid experiences in museums and art galleries (Koleva, Egglestone et al. 2009). To put it differently, the bulk of hybrid experience design effort is concerned with figuring out how to combine physical and digital interactions(Hindmarsh, Fraser et al. , Benford, Fraser et al. 2001, Benford and Giannachi 2011). On the other hand, Suzuki et al. recently introduced the concept of substitutional reality, in which an integrated exposure to the physical world and the real world was provided (Suzuki, Wakisaka et al. 2012). Spence et al. extended applied substitution reality in the virtual representation of

museum objects for addressing the limitations of object handling and the desire for visitors to create their own interpretations (Spence, Darzentas et al. 2020). These writers argued that museum visitors should be allowed to physically touch 3D models or scans of museum items to contribute personal experiences about them.

Virtual reality technology has been developing for what appears to be a long time, yet the potential inherent in this new medium has numerous limitations, particularly in terms of immersion (Baños, Botella et al. 2004, Loaiza Carvajal, Morita et al. 2020). This limits the practical utility of virtual reality in real-world settings (Reaney 1999, Grau 2004, Zhou and Deng 2009). Immersion refers to the number of senses that are engaged, the interactions that occur, and the actual similarity of the stimuli used to simulate other environments. The degree to which a person believes and participates in an activity can be used to measure their level of immersion (Benford 2005, Rowe 2015). On the other hand, the presence in VR is a complex psychological experience that includes the perception and experience of physical presence, as well as the ability to interact and respond as if the user were in the real world (Gerhard, Moore et al. , Mütterlein , Witmer and Singer 1998, Baños, Botella et al. 2000, Gerhard, Moore et al. 2002, Sanchez-Vives and Slater 2005, Herrera, Jordan et al. 2006). Likewise, the level of realism is related to the user's anticipation of the stimuli and experience. If the stimuli provided are comparable to reality, the VR user's experience will match reality, improving the VR experience. Similarly, the greater the degree of interaction with virtual stimuli, the greater the degree of realism (Benford, Giannachi et al. , Riley and Nash , Sernani, Vagni et al. , Crabtree, Benford et al. 2010, Argelaguet, Hoyet et al. 2016, Koutsabasis and Vosinakis 2018).

Although many of the techniques discussed in this section are applicable to a variety of interaction settings and deployments, there are a few characteristics of mixed reality that need special

consideration. The design of the VR user interface presents a number of new difficulties. First, unlike traditional 2D interaction settings, virtualization of the interface in 3D increases the physical interaction space. Such embodied interactions are usually conducted with less accuracy across greater magnitudes, resulting in user input with significant noise characteristics. Second, the expanded interaction area significantly broadens the design space. This is a major difficulty for designers as they attempt to find locations in the high-dimensional design space that suit their needs. Third, the incorporation of virtual information into the environment results in a contextual connection. The designer, on the other hand, cannot know the range of deployment scenarios at the time of design. The difficulty of integrating various sources of interactions inside the virtual and real worlds is an extension of this idea. These distinct sources of uncertainty in mixed reality serve as helpful case studies throughout this thesis. They provide a difficult and relevant test of probabilistic user interface design.

Haptic rendering is the procedure of calculating and generating forces in response to user interactions with virtual objects (Sherman and Craig 2003). Although visual systems are only capable of detecting, the haptic sense can sense and act on the environment (Dantas, Burlamaqui et al. , Dantas, de Melo et al. , Marín-Morales, Higuera-Trujillo et al. 2019). As a result, it has become an essential component of many VR activities. To offer the realism required for successful applications, VR systems must give inputs and reflect the outputs of the haptic system (Slater and Usoh 1993, Salisbury, Brock et al. 1995). Displacements and forces are the primary input/output variables for the haptic sense (Kuksa and Childs 2014, Wang, Guo et al. 2019), and haptic sensory information is distinguished as either tactile or proprioceptive information (Ortega, Redon et al. 2007, Cho, Ku et al. 2014, Giroux, Barra et al. 2018, Sra, Jain et al. 2019, Valori, McKenna-Plumley et al. 2020).

The space setup and the method to transition to VR significantly influence the overall VR experience (Ali, Bedwell et al. , Edmonds, Benford et al. 2013, Jaller and Serafin 2020). It has been reported that creating a gentle transition from the real world into the virtual and back into the real environment could be an excellent solution to enhance the realism of VR. In a recent study, the effect of a gradual transition between the real world and VR was investigated by using a video feed from a stereo camera that gradually faded into virtual content, creating a smooth transition, significantly affecting the participant's perception of virtual body ownership and presence (Jung, Wisniewski et al. 2018). The major issue with this smooth transition method is that a new 3D model must be provided for each different space. Constructing realistic 3D spaces is time-consuming, and, in several cases, the meant-to-be-shown virtual environment is entirely different from the real space. Furthermore, there can be differences in the scale of the space or in content (Williams, Narasimham et al. 2007, Sun, Patney et al. 2018). However, despite considerable study in this field, the variables that influence the quality of the VR experience have not yet been fully identified.

Rostami et al. discovered that performers sometimes blend VR and real-world experiences to exploit physical and digital friction (Rostami, Rossitto et al. 2017, Rostami, Rossitto et al. 2018). Dobricki et al., on the other hand, advocated for creating an experience trajectory for user actions so that they can be tracked while providing feedback that users may act on (Dobricki, Weibel et al. 2021). In the context of museum experiences, Fosh et al. suggested a technique to overlay digital experiences on sculptures in which visitors walked through each show in five phases: approach, engage, experience, disengage and reflect, with the official interpretation disclosed only during the reflection stage. With advances in VR and physiological sensing technology, it is now possible to have even more immersive computer-mediated communication via the use of life-like

features and realistic traits. In an exciting study, the effect of situations generating affective states (such as joy, sorrow, boredom, anger, and anxiety) on VR experience was investigated. The findings indicated that virtual park situations were successful in eliciting the desired feeling, although presence did not influence the emotional response. Bernal et al. suggested a two-pronged strategy in response to the current lack of culture, expression, and emotions in virtual reality avatars (Bernal and Maes 2017). The integration of bio-signal sensors into the HMD, as well as techniques for identifying aspects of the user's emotional state, is the first step, and the development of expressive avatars is the second step. This method encourages users' self-expression in a virtual reality environment, as well as their view of other individuals in that setting, and will offer us some helpful tools for eliciting the proper emotional reaction. These examples demonstrate the need to understand how the digital and real worlds interact in hybrid experiences and that a wholly integrated experience is not always feasible or the optimal option.

2.5 Verdict

This chapter presented an overview of the existing literature in the fields of virtual reality and its applications in art galleries. There is a lot of research out there that indicates virtual reality has the potential to present and expand artistic representations. However, there is a scarcity of scalable methods that may be utilized to improve the realism of virtual reality. When developing a virtual reality experience, it is critical to consider how methods such as haptic feedback and substitutional reality impact interaction, engagement, and the overall perceived quality of the virtual artwork. Future research is required to better understand the variables that influence the perceived realism of virtual artwork.

Chapter 3

3 Emotion Hacking

3.1 Introduction

Virtual reality has been proven to be effective in generating emotional reactions from participants (Benford, Greenhalgh et al. 2018). The role of emotions in virtual reality has been validated in many studies by tracking changes in physiological data associated with the user's emotional state (Dey, Piumsomboon et al. 2017, Kaur, Sun et al. 2019, Bolinski, Etzelmüller et al. 2021, Mostajeran, Krzikawski et al. 2021). In a similar vein, generating emotional responses during virtual reality engagement may improve the entire VR experience; however, the stimulation of emotions by external input has not been extensively studied in the context of VR experience quality. This chapter focuses on the first objective of this thesis i.e, "How can emotional hacking be utilized to improve the virtual artwork VR experience, and how can a reliable trigger for emotional stimulation be employed in real-world VR representation of artworks?" A case study that analyzes a basic emotion, fear, was used to investigate several facets of this issue. Due to the remarkable perceptual and sensory possibilities it offers, the horror genre, which has traditionally been associated with fear, was chosen to demonstrate the concept of EHVR in virtual reality.

Contrary to the common view, which contends that emotions are ambiguous variables controlled by human perception, physiological reactions, and behaviors, cognitive scientists have identified that the intensity of emotions can change by changing one's physiological state (Ando, Watanabe et al. 2012). Within the context of the social information processing paradigm, emotions, experiences, and physiological factors all contribute to the development of the cognitive process that defines emotional and behavioral responses (Klein Tuente, Bogaerts et al. 2018). The flow of the process is shown in Figure 3.1. It is a rapid and automated one that comprises six distinct stages, all of which are given in the order in which they occurred. Affective and physiological

experiences, as well as the emotions that underlie them, all, have an impact on the various stages of information processing. Primarily, this implies that changing the physiological state of the body in accordance with the subject matter of virtual reality may be utilized to improve the VR experience. In this paper, we propose that adding emotional reactions as an additional axis to the Autonomy, Interaction, and Presence (AIP) cube would improve the VR immersive experience (Yoshida, Sakurai et al. 2013). As an example, if the topic of the virtual reality artwork is melancholy in nature, exterior physiological signals that trigger an emotional response such as sadness may help to increase its authenticity.

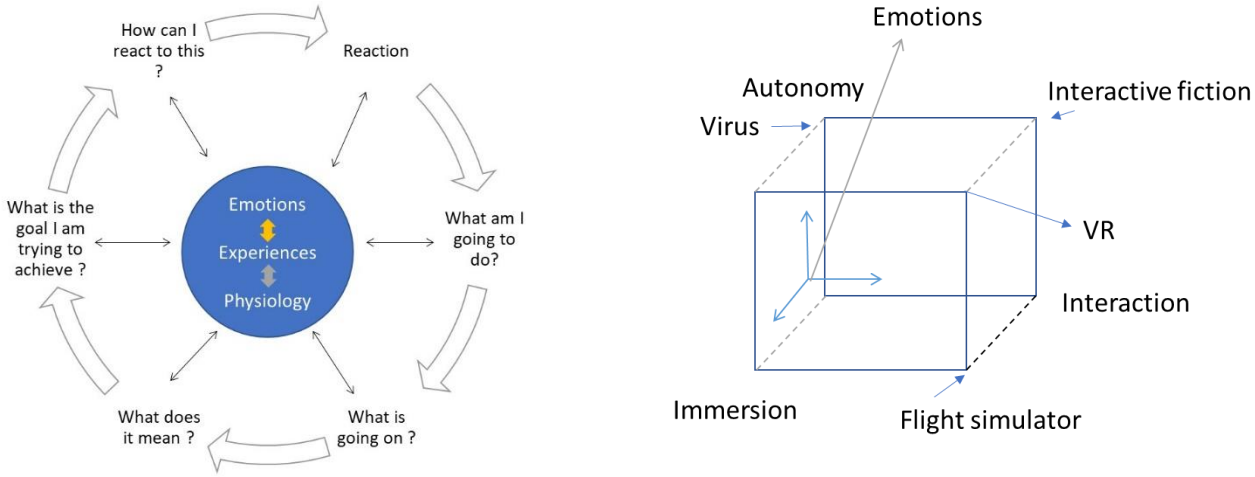

Figure 3.1 Adapted social information processing model and emotions as a dimension in AIP cube (Yoshida, Sakurai et al. 2013)

Emotion regulation is the process by which individuals are able to regulate, express, and understand their emotions. Table 3.1 lists the most frequently used study stimuli and techniques. The scientific community's interest in virtual reality and emotions has grown at an astounding rate

in recent years. The improved performance of modern HMD in terms of resolution, the field of view, immersion, and affordability has expanded the number of applications in emotion-related research that may be conducted with them. Figure 3.2 depicts the number of articles published on VR in the context of different emotions. Arousal-related emotions such as anxiety and stress were the focus of most of the research.

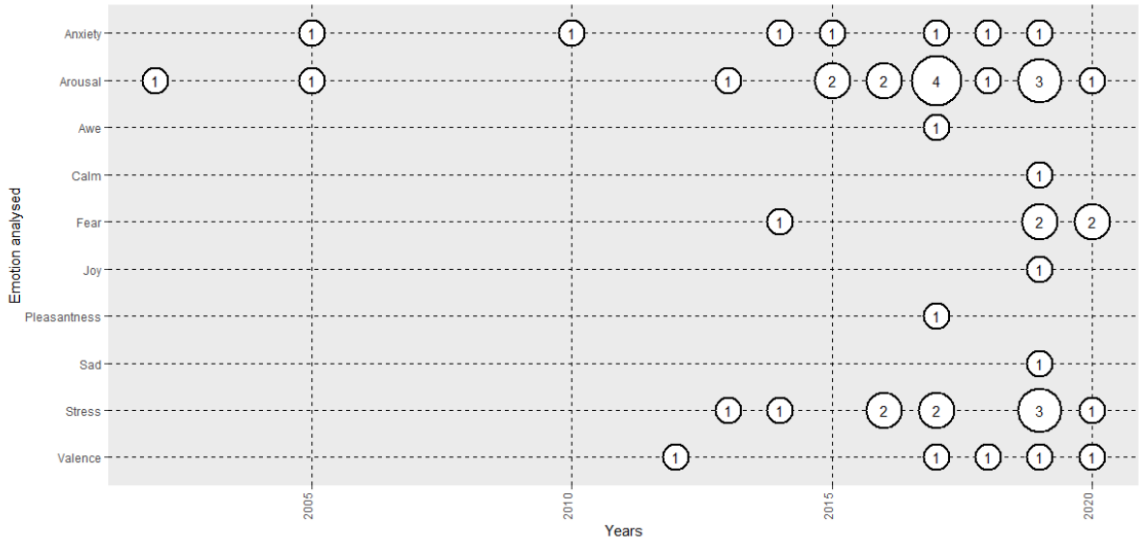

Figure 3.2: The number of articles produced each year based on emotion has been charted (Marín-Morales, Llinares et al. 2020).

Table 3.1. Overview of the main implicit techniques used in human behavior research (Marín-Morales, Llinares et al. 2020)

Implicit Technique	Biometric Signal Measured	Sensor	Features	Psychological parameter

1.	EDA (electrodermal activity)	Changes in Skin Conductance	Electrodes attached to the fingers and palms or soles	Skin conductance response, tonic activity and phasic activity	Attention and arousal
2.	HRV (heart rate variability)	Variability in heart contraction intervals	Electrodes attached to chest or limbs or optical sensor attached to finger, toe or earlobe	Time domain, frequency domain, non-linear domain	Stress, anxiety, arousal, and valence
3.	EEG (electroencephalogram)	Changes in electrical	Electrodes placed on the scalp	Frequency band power, functional	Attention, mental

		activity of the brain		connectivity, event-related potentials	workload, drowsiness, fatigue, arousal and valence
4.	fMRI (functional magnetic resonance imaging)	Concentrations of oxygenated vs. deoxygenated hemoglobin in the blood vessels of the brain.	Magnetic resonance signal blood-oxygen-level-dependent		Motor execution, attention, memory, pain, anxiety, hunger, fear, arousal, and valence.
5.	ET (eye-tracking)	Corneal reflection and pupil dilation	Infrared cameras point toward the eyes	Eye movements (gaze, fixation, saccades), blinks, pupil dilation	Visual attention, engagement, drowsiness, and fatigue

6.	FEA (facial expression analysis)	The activity of facial muscles	Camera points towards the face position and orientation of the head.	Activation of action units	Basic emotions, engagement, arousal, and valence

It has been shown that being able to view one's physiological response in a virtual environment makes the program more pleasant to work with. Dey et al. examined the impact of altering heart rate feedback given to participants in an immersive virtual world of a single user to see how it affected their performance. They discovered that giving significantly faster or slower real-time heart rate input may have a more significant impact on participants' moods than just providing unaltered data. On the other hand, modifying the feedback does not affect the actual physiological signals. Coen et al. researched to assess the relationship between a negative emotional state and unique visceral sensations in terms of how the brain interprets information (Coen 2006). They compared the brain activity of a person listening to emotionally upsetting music with the brain activity of a person when the distal esophagus was artificially stimulated, finding that external stimulation can amplify negative emotions. Harada and colleagues demonstrated that an objective evaluation of emotional states is possible by explaining the relationship between changes in biological signals and various emotions, such as excitement and surprise. Fukushima et al. developed a device to generate piloerection in order to test the hypothesis that haptic interfaces could be utilized to enhance surprise emotions (Fukushima and Kajimoto , Fukushima and

Kajimoto 2012). In this method, the piloerection of the forearm was intentionally induced to create surprising movements in a spectator watching a film or listening to noises. External impulses from the piloerection control interface create physiological changes in the body, attempting to exert control over internal emotions. Angular displays in somatosensory areas transmitting an emotional body image have also been claimed to effectively alter emotions (Fukushima and Kajimoto). Affectively VR, a personalized real-time emotion detection system with an emotion-adaptive virtual environment, was used in recent research, resulting in a 96.5 percent emotion identification rate (Pizzoli, Mazzocco et al. 2019).

Vibration-tactile biofeedback has been demonstrated to effectively provide spontaneous real-time notification of physical states. In an interesting study, vibrotactile biofeedback was investigated as a real-time method to correct positive control and lateral sway in the elderly (Jay and Hubbold 2003). Haptic biofeedback has also been shown to be more effective in rehabilitation, complementing conventional physical therapy techniques or using implicit instructions related to partial weight-bearing (Fu, DeLuke et al. 2014). A low-cost haptic virtual interaction platform for upper limb rehabilitation using vibrotactile feedback in a virtual environment was reported to help stroke patients perform simple repetitive motions and thus overcome motor planning deficits. According to another study, the effects of vibrotactile feedback on the body for pedestrian navigation were investigated, and it was discovered that vibrotactile feedback on foot decreases visual attention while simultaneously having the ability to alleviate stress (Raveh, Portnoy et al. 2018).

Valins (1967) found that the emotional impact of photographs of seminude women could be influenced by the use of false heart sounds with segregated subjects (Valins 1967). Nishimura et al. created a tactile feedback mechanism that could apply the vibrations of a false heartbeat either

directly to the chest or through a cushion to supply the fake heartbeat in a more subtle manner (Nishimura, Hachisu et al. , Nishimura, Ishi et al. 2012). Valin's experiments were expanded in another study, which examined the impact of simulated tactile heartbeats on how participants rated the attractiveness of pictures of men and women, respectively (Valins 1966). In this study, researchers discovered that faking heartbeats may affect the emotional and physiological condition of a subject. Although this study did propose the use of a vibrotactile fake cardiac feedback system, the architecture of the system and the purpose of the research vary significantly from this study. The software utilized in Nishimura et al.'s study was very simple in that it merely applied fake heartbeats at higher or lower levels; it did not monitor the subject's heart rate in real-time and used that to influence the false heartbeat rate.

In general, virtual reality interfaces do not provide users with feedback on their own heart rate. Chen et al. conducted an intriguing study in which they examined the impact of this feedback on the overall experience. They investigated whether adding heart rate input improved the participant's overall experience of using virtual reality and discovered that participants liked receiving their heart rate feedback while they were immersed in virtual reality. Hwan et al. provide a critical review of Skin-Integrated Vibrohaptic Interfaces (Jung, Kim et al.). Indeed, several use cases for vibrotactile feedback have been documented in the literature though, such as interactions requiring a high precision that is hard to achieve with pure visual feedback (Hürst, Rosa et al. 2016). In particular, the audio-haptic feedback method was shown to be the most favored of the various types of heart rate representation, whereas visual feedback was found to be intrusive. Oliveira et al. developed a vibrotactile Head-mounted Display and demonstrated it is easy to use and entertaining (Oliveira, Brayda et al. 2017). Lee et al., on the other hand, provided vibrotactile feedback through the floor and reported that the inclusion of this vibrotactile feedback led to more

remarkable avoidance behavior when the virtual human invaded participants' personal space (Lee, Bruder et al. 2017). Wearable vibrotactile haptic device for stiffness perception during an interaction with virtual objects was a focus on another study, reporting improvement in the average Weber fraction values after adding the tactile feedback (Maereg, Nagar et al. 2017).

This discussion provides strong evidence on the suitability of vibrotactile feedback to enhance different functions related to emotions and VR. Herein, the development of Emotion Hacking VR (EHVR), an interactive walk-through system that can monitor and trigger users' heart rates in order to increase their feelings of dread while using virtual reality, has been discussed. EHVR is accomplished by using a vibrotactile stimulation that emanates from the floor; the stimulus resembles the beat of a heart and produces a sense of fear. In particular, despite the fact that fear is a psychological state of great complexity, it provides us with the ability to make instantaneous decisions about how safe any given action is for us. The system uses real-time monitoring to evaluate the heart rates of users and then generates a fake heart rate that is much faster than the user's actual heart rate. A prototype system without a walk-through function was constructed to evaluate the effectiveness of the vibrotactile feedback. Three alternative methods of estimating the fake heartbeat rate were also evaluated. The EHVR system was tested during the Asia Digital Art Award 2017 exhibition, Fukuoka Asian Art Museum (上岡玲子 2019). This chapter presents both the subjective and objective outcomes of these experiments. The chapter focuses on two critical aspects of emotional hacking in virtual reality via vibrotactile feedback. The first is concerned with the technical elements of vibrotactile feedback delivery and the evaluation of the response. The second is about recording the participants' experiences once they have experienced EHVR.

3.2 Methodology

3.2.1 Setup

To undertake comparative experimentation, we created a virtual 3D movie theater using an HMD (Oculus rift DK1) that used a slit in a closed locker to simulate viewing a Screen showing the zombie movie (Puckett 2011). The virtual environment was designed to match the plot of the film, in which the viewer was looking out through the slits in a locker. Subjects were asked to enter the closed box-shaped theater wearing an HMD through which they would view the 3D movie (fig.3.3 B). The HMD tracks the head movement to simulate the behavior of peeping through the slits in a locker.

3.2.2 Vibrotactile Feedback

For the measurement of subjects' heart rates in real-time and for the generation of false heart rates using vibrotactile feedback, we used a photodiode pulse sensor that subjects wore on their right earlobe so that the interval between beats could be measured in milliseconds. A silent subwoofer (ButtkickerBK113-C) was placed beneath a wooden plate measuring 20 cm high and 50 cm deep and wide, but it was placed underneath the floor of the theater so that the subjects would receive vibrotactile feedback of a false heartbeat through their feet.

3.2.3 False heart rate calculation

To evaluate the effectiveness of vibrotactile feedback employing a false heart rate, a trio of calculation methods (fixed, variable, and synchronized) to create false heartbeats. The variations in vibration intervals are illustrated in fig. 3.4 and Table 3.2. Our previous research found that when viewing the horror movie for 120 seconds, the highest accelerated heart rate for a subject was 20 bpm over its mean heart rate at rest. Therefore, we set the maximum false heart rate at 20

bpm above the mean heart rate of each subject for 120 seconds. The heart rate acceleration model mimics a quadratic function ($y=ax^2$). Here y represents the maximum increase in heart rate (20 beats a minute), and x represents the time span over which false heartbeat vibrations were supplied to the subject (120 seconds); the proportionality constant (a) was found to be 720. Equation 1 represents a basic expression for the calculation of the false heart rate fIBI, with IBI being the intervals between beats. The following equation is employed for the calculation of the fixed condition fIBI:

$$fIBI[i] = 60000\ t\ 2\ 720 + BPM \quad (1)$$

The time elapsed after the supply of the false heart rate is represented by t, with BPM representing the mean intervals between beats before rest. A correction factor (dif) was added, as shown in Equation 2, so that the fIBI could be corrected to close to the latest fIBI. This correction factor is used for the calculation and correction of the variable condition of fIBI every 10 seconds.

$$fIBI[i] = 60000\ t\ 2\ 720 + BPM\ dif \quad (2)$$

Equation 3 is used to calculate the synchronization of the phase oscillator between IBI and fIBI.

$$PhaseOscillator\ [i] = 2 \times fIBI[i]\ IBI \quad (3)$$

For the best possible synchronization between real and false IBIs, we employed the Kuramoto model, which describes the phenomena of synchronization phenomena (Kuramoto 2003, Acebrón, Bonilla et al. 2005) as an evaluation formula. This model has been employed in attempts at analysis of phase oscillators that run at arbitrary intrinsic frequencies, e.g., random function or Gaussian function, that are coupled via the sine of their respective phase differences.

Equation 4 provides the definition of the order parameter described as the Kuramoto model order parameter for measuring oscillator synchronization between fIBI and IBI, with a population of N when N = 2. The parameter SR (synchronization rate) parameter has a range from 0 (no synchronization) to 1 (complete synchronization) and provides a measurement of the degree of synchronization of the system.

$$SR = N\ j=1\ e\ ij \times 1\ N \quad (4)$$

Equation 4 is used to run a calculation program for the correction of the value of the fIBI phase oscillator rate until the synchronization rate is in excess of 0.99. We then undertake inverse transformation to find the corrected fIBI from phase oscillator values when the synchronization rate with the IBI is high. The fIBI is employed as a synchronization condition.

3.3 Experiment

In a laboratory, each participant carried out the experiment on their own. The experiment involved a cohort of 40 subjects with a mean age of 21 years, 16 women and 24 men. Subjects went into the box-shaped theater space wearing the HMD, standing still while gazing at a point on the screen for four minutes prior to commencement. In addition to the subjects in the control group, the subjects were informed that they would feel a vibrotactile response of their heartbeat through their feet while watching the horror movie.

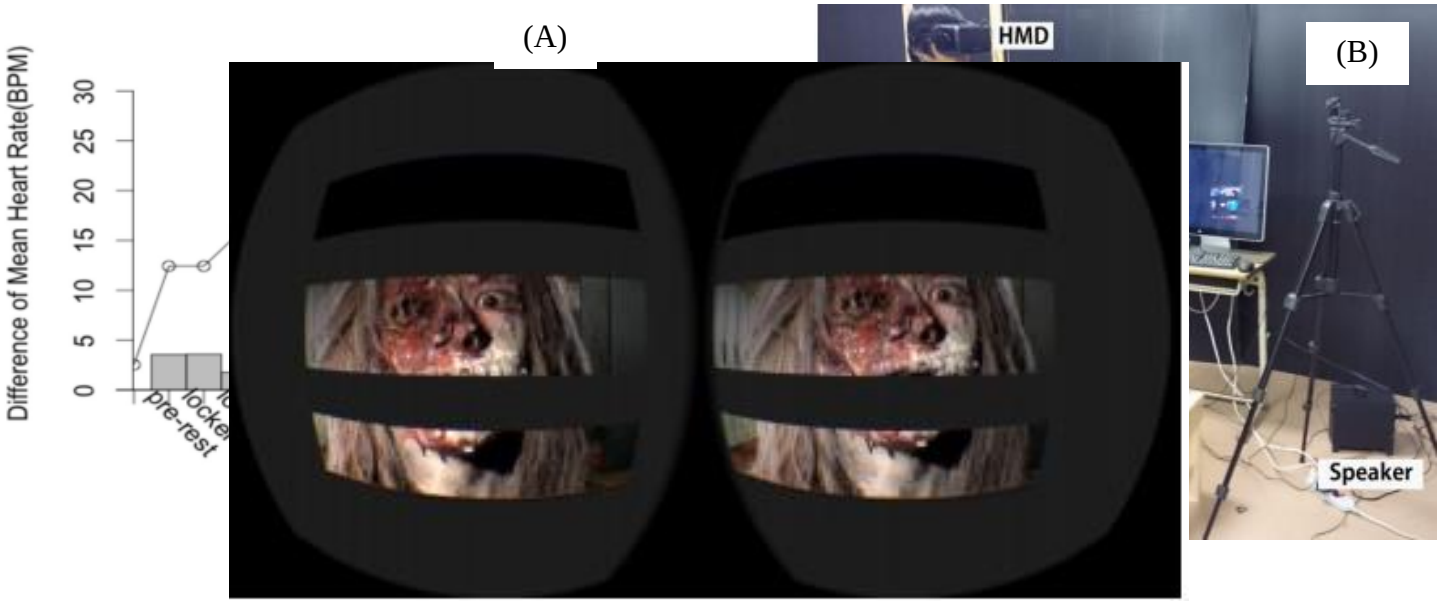

Figure 3.3: (A) Difference in mean heart rate and subjective assessment of fear; (B) setup of the experiment. The subwoofer that supplies the false heartbeat is positioned under the feet of the subject (C). Close-up image of a zombie in a movie scene, as viewed through the virtual slits.

The mean heart rate was calculated on the basis of the heart rate recorded in the pre-rest the period in order to set the upper value for increased heart rate and thereby create a false heart rate. Following the pretest period, the participants were shown the horror film, with all except those in the control group receiving vibrotactile feedback. In order to carry out analysis, the time span of the experiment, including the pre- and post-rest periods, was divided into 12 segments. The results from the period of watching the horror movie and experiencing vibrotactile feedback are shown in Table 3.2.

Table. 3.2 Horror movie scene description, duration, and vibrotactile feedback.

Scene No.	**Scene Description**	**Duration**	**Vibrotactile Feedback**
1	Prerest (pre-movie show)	240	none.
2	Introduction 1	40	Real heart
3	Introduction 2	35	rate pattern
4	A friend being dragged into a locker and killed	41	
5	Zombie appeared	24	False heart
6	Hide and seek w/ zombie	47	rate pattern
7	Zombie wandering around	30	
8	Zombie Close-up	24	
9	Post- rest 1	30	None.

10	Post- rest 2	30	None.
11	Post- rest 3	30	None.
12	Post- rest 4	30	None.

During scenes 2, 3, and 4, the subject's real heart rate was used to create vibrotactile feedback so that they could become used to the feeling of the simulation coming through their feet. In scenes 5,6,7 and 8, we calculated and provided false vibrotactile feedback. When the movie had ended, subjects were asked to remain standing still for 120 seconds (scenes 9-12) so that their post-rest heart rate could be recorded. Each subject received one of the three forms of vibrotactile stimulus or was in the control group (Fig. 3.5). No subject had previously viewed the movie.

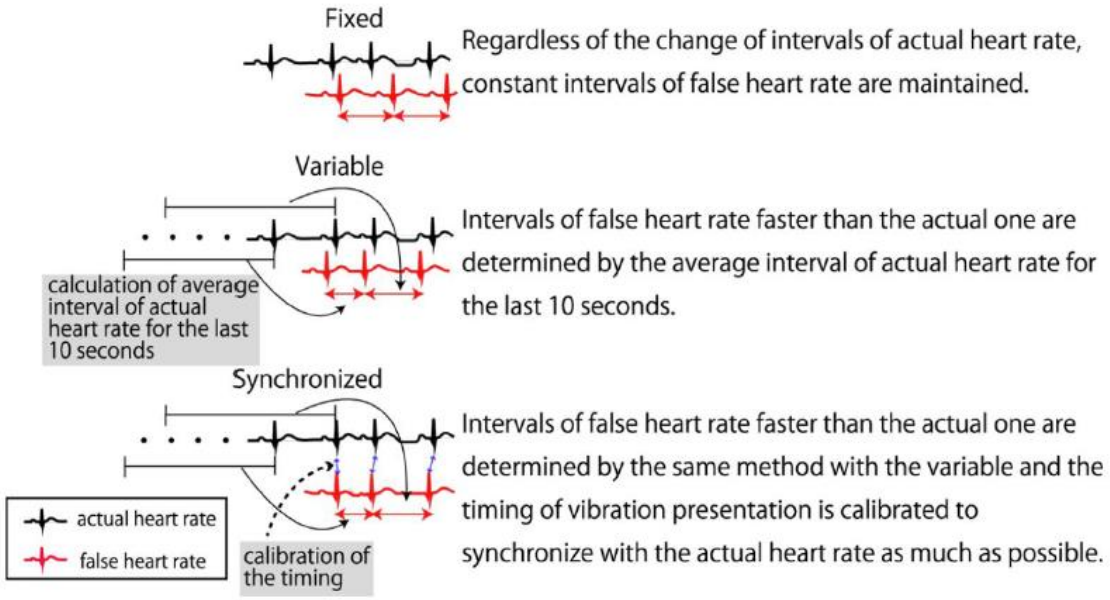

Figure 3.4 The three vibrotactile stimulus calculation methods

3.3.1 EHVR system

Using the data obtained from the previous experiment, we started working on our Emotion Hacking VR (EHVR). The basic structure of the system is similar to the setup of the experiment described above, but we added an interactive walk-through feature and swapped the HMD from Oculus DK1 to Oculus DK2. A subject sitting in the EHVR system is shown in Fig 3.6A.

A wheelchair is used to control the interactive walk-through feature of the EHVR. This is mounted on a wooden base to prevent the wheel from touching the ground so that the wheels can be rotated without creating movement. The wheel rotates using an Xbox 360 USB controller. This is mounted under the seat, facing the wheel. A vinyl fin is attached to the left analog stick so that when the wheel rotates, the spokes will push the fin. The tip of the fin will be the only part that contacts the spokes, so when the fin has pushed the analog stick to the maximum angle, it will be released and returned to its original position. When the wheel is rotated forward, the fin will be pushed upward, and when rotated backward, it will be pushed downward. This means that the stick will provide values between 1 and -1, signaling that the wheelchair moves forward or backward in the walk-through VR environment. Movement speed is assessed by the time gap between inputs. When the input values do not change for more than half a second, the wheel is registered as still, and whatever the input value is, it is recalibrated to its original state until a different value is received.

To provide the vibrotactile feedback, a wireless speaker (JBL Charge2) was installed on the wooden footrest plate; this is a more compact setup than the subwoofer speaker originally used, but it produces the same amount of vibration. The feet of the subject rests on the footrest, and the false vibrotactile heartbeat is played through it at a gradually accelerating pace.

3.3.2 EHVR Content

The EHVR system was used to create a walk-through VR experience of the artwork "Pressure of the Unknown." The idea is based on the fear of standing in the middle of a crowd. "Pressure of the Unknown" is an example of a failure metaphor. It is the sensation of being judged and not knowing what other people are thinking. This generates a great deal of unpredictability, which leads to tension and pressure. It is frequently experienced while speaking or speaking in front of a large group of people. The 3D modeling was built using 3dsMax and then exported to Unreal Engine 4 to apply real-time rendering/interactivity.

The participant sits on a wheelchair in the artwork and uses it as a controller to move forward. Technically, using a wheelchair allows us to standardize the height of the users in VR. However, it also creates the impression of being weak and unable to move freely. This helps create a sense of fear, similar to why we used the locker for our previous zombie movie experience. Furthermore, we put a black cloth on the lap of the participants to unify the look of the avatar legs for all the users. The wheelchair is on a wooden base to leave it from the ground to prevent the wheelchair from moving. In addition, slight pressure is applied on the breaks to give the feeling of weight.

Vibration feedback is applied to the wooden base. The VR environment is a dark tunnel that looks like the interior of a living body. The closed unfamiliar organic environment, seemingly built of human body parts, gives the feeling of being digested. Moreover, the whole space has a slight movement with flesh-like materials with glossiness and glitter to reflect lights and give the impression of being alive. Dim lights were scattered around the environment to provide a sense of scale. However, the primary source of light is a flashlight located on the forehead of the participants. They can see a few meters ahead of them with this. It is a progressive experience.

The path that the wheelchair walks on is like a bridge made of a huge long tongue. We play with the speed of the movement to simulate the bumps on the surface of the path. While moving forward, there are many objects and structures that are made from bone or flesh. Along the way, there are many eyeballs of different sizes that can be seen. When at a close visible distance, the eye reacts to the subjects and starts looking at them. This is an imitation of the pressures an audience places on performers on stage. Then, around half of the path, we start to increase the heartbeat. At the endpoint, a mouth / jaw-like object is located. It opens and becomes like a platform move over it. It starts elevating until it reaches the top. At the highest point, there is a chandelier-like structure filled with eyeballs that reacts to the participant. At this point, a light flashes and shows how much the heart rate has increased during the experiment. The full artwork can be seen from a side view, and first-person perspectives of it can be seen in Fig. 3.6.

3.3.3 ADAA Exhibition

The Fukuoka Asian Art Museum hosted the Asia Digital Art Award (ADAA) between February 22 and 27th, 2017. This is a competitive award created in 2001 to promote digital arts that offers a combination of the best new technology and Asian cultural sensibilities. This is an annual competition with the Fukuoka Museum that exhibits the winning entries. The EHVR-based artwork submitted for the prize was chosen as a finalist in the interactive arts category of students. In the exhibition space, a black tent was erected, with a custom-made video for EHVR content projected onto the fabric walls. This tent can be seen in Fig.3.7A. Participants were invited to enter the tent and sit on a wheelchair, with a pulse sensor attached to the earlobe, and to don noise-canceling headphones and an HMD. Participants were asked to take a few deep breaths, and before beginning the audiovisual content, the heart rate was calculated. This artwork was displayed six

hours a day for five days; participants in the ADAA exhibition space can be seen in fig. 3.7B. Before participating, subjects were asked to review the additional consent form that provided warnings to those with heart disease and notification of the fact that the data would be used for analysis for this work. Participants only entered the artwork once they had provided this consent. Following their experience, participants were invited to rate the experience in relation to how real they felt it and how frightening they felt it on a five-point scale.

3.4 Result and discussion

3.4.1 Dependence of the mean heart rates on the stimuli and vibrotactile feedback

We analyzed 36 valid log data sets, with each condition represented by nine subjects. Changes in mean heart rates (MHR) and heart rates during the pretest phase were examined for all scenarios so that the heart rates experienced in each circumstance could be compared. The MHR and standard error for each condition are illustrated in Fig. 3.5. It was noted that for all conditions receiving vibrotactile feedback, the MHR either stayed constant or was higher than it had been at commencement. For those in the control group who did not receive feedback, the MHR decreased.

Specifically, under synchronized and variable conditions, there was a similar steady increase in MHR near the end of the movie when the false heart rate was administered (scenes 5-8). For all the conditions, MHR was highest for the synchronized condition at scene 8. One-way ANOVA results ($F(3,40) = 6.80$, $p<0.01$) showed that experimental manipulation under the four conditions had a statistically significant impact. It was found through multiple comparison tests that the increase in MHR for variable and synchronized conditions was significant compared to the control condition ($p<0.01$). It could also be seen that MHR increased significantly for variable conditions in comparison to the fixed condition ($p<0.05$). For the observation of variations in heart rate trends,

a gradient of an approximate linear equation was calculated with the data from scenes 5 to 8, the time span over which false vibrotactile feedback was applied.

3.4.2 Heart rate acceleration

Fig. 3.5B shows the results, where the larger positive gradient is representative of a higher heart rate acceleration. The highest value is shown in the synchronized condition (1.7), showing that in this scenario, heart rates were higher than in any other condition. A positive gradient lower than the gradient for the synchronized condition is shown for the variable condition (1.0), with the fixed condition showing a negative gradient (-0.63); there was a slight gradient for the control condition (0.43). These findings indicate that when false vibrotactile feedback is applied, the real heart rate is affected, and the influence is greater under synchronized and variable conditions. Of the two conditions, the heart rate exhibited greater acceleration on receiving false vibrotactile biofeedback in the synchronized condition. Subjects experiencing the fixed the condition stated that they suffered discomfort over time with the vibrotactile feedback as they could clearly identify the discrepancy between the true heart rate and the false one. The reported discomfort could be responsible for the decrease in heart rate during the time that they received false feedback. Our conclusion is that the synchronized condition created and sustained a faster heart rate than any of the other conditions. As a result, we implemented the synchronized computation technique into the EHVR system for the production of false vibrotactile heartbeat feedback.

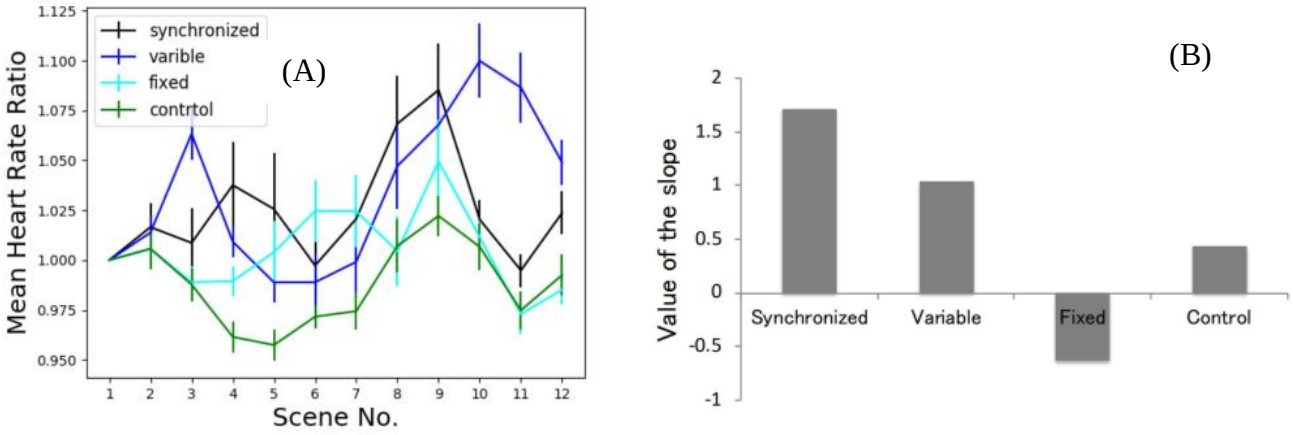

Fig. 3.5 (A) MHR of four conditions (B) Gradient of the approximate linear equation for the four conditions.

3.4.3 Heart rate acceleration evaluation EHVR

A total of 103 individuals, ranging in age from 13 to 68 years, participated in the EHVR experiment. Almost half of the participants (48%) were in their twenties or thirties. Participants were nearly evenly divided by sex, and half of them had never used VR before. Without accounting for the preparation time, each participant was exposed to the installation for approximately 3 1/2 minutes. A total of 71 authentic heart rate log data sets were examined. The average duration of the erroneous vibrotactile feedback was around 2.6 minutes, and the mean increased heart rate was approximately 11% (mean BPM during the rest period = 86; mean final BPM = 102). The mean increase in heart rate is shown in Fig. 3.8. After accounting for the shortest duration of the experience, the time length was adjusted to 1.7 minutes. This demonstrates how heart rates were raised and maintained at higher levels throughout the event.

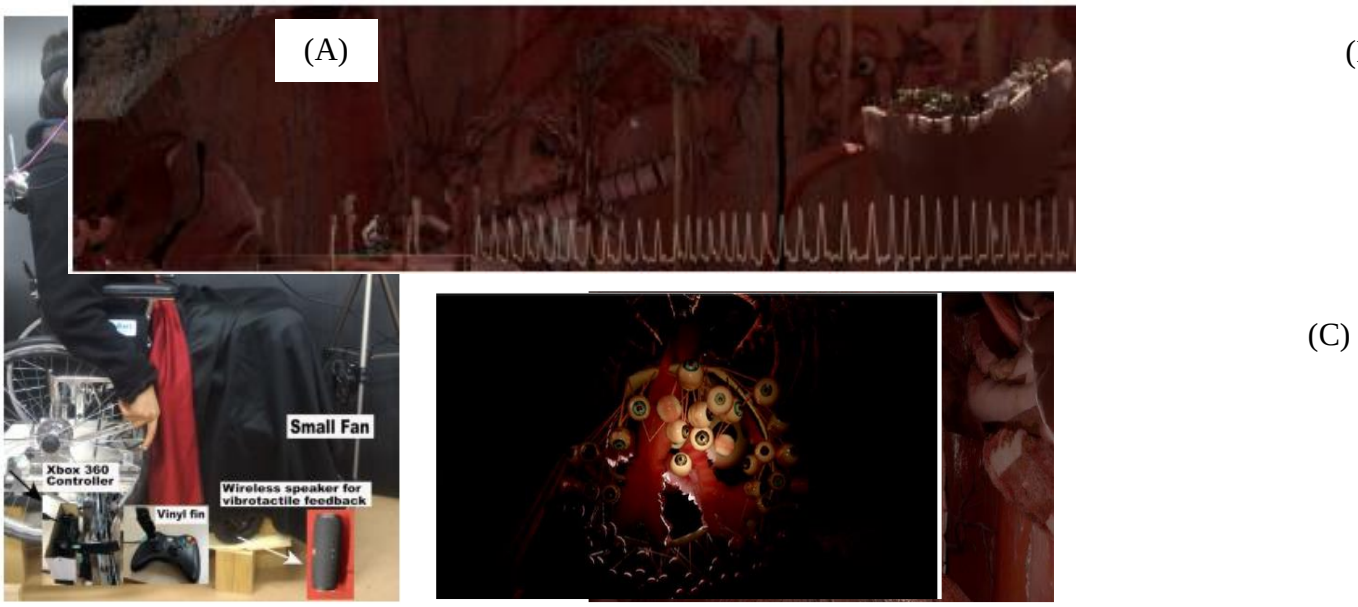

Fig. 3.6 (A) Images of the EHVR system (B) Overall walk-through VR scene from side view (C) Captures the artwork space

Based on the correlation between subjective feelings of fear and increased heart rate, we created a system that provides participants with virtual reality false vibrotactile heartbeat feedback. The rate of this false feedback was set by comparative experimentation and synchronized calculations whereby the heart rate of the participants was monitored every 10 seconds and the false feedback synchronized to it. Testing of this approach was undertaken at the Fukoka Asian Art Museum's Asia Digital Art exhibition 2017. 103 people participated in the test. It was shown that heart rates were raised to 118% of resting value by the finish of the experience, implying that the physiological state of participants was influenced by exposure to the system.

3.4.4 Subjective questionnaires

Employing subjective questionnaires demonstrated that most of the participants found the experience extremely realistic and frightening. The results of the questions concerning subjective

emotions about fear and reality in the experiment are shown in Fig. 3.9. Regarding how real participants felt the experience, 78% rated it as 'feeling real,' 40% of this cohort stated that it was indistinguishable from reality. This shows that they had become completely immersed in the subject matter. In terms of fear levels, 6% of the participants said it was 'scary' or worse. This shows that many of the participants experienced fear during the experience. In terms of unsolicited, unstructured comments given by 41 participants, many spoke of the experience being enjoyable. Many also commented positively on the quality of the artwork and the way in which fear had increased through vibrotactile feedback. One participant stated that the fact that their real heart rate had gone up by the end caused them some surprise. In terms of employing a wheelchair to create an input interface, numerous participants commented positively that this made them feel more immersed in the content.

(A)

(B)

Fig. 3.7 (A) EHVR in ADAA exhibition space (B) Participants in ADAA

Certain participants expressed dissatisfaction with the wheelchair's mobility, claiming that it made them tired. Wheelchair brakes were used to limit wheel rotation, making participants feel more confined and reducing the chance of VR sickness. Although more testing is needed to prove that the sense of fear was created by changes to physiological states, the evidence allows the conclusion that the EHVR offered a novel means of allowing empathy and emotion to be created in a VR system through the control of particular emotions through manipulation with external stimuli. We anticipate that if we can trigger certain emotions in VR users, they will become more immersed, which will enhance their empathy. Because spikes and heart rates are linked to other emotions, such as enthusiasm, we will utilize the same method in the future to determine whether it can be used with exciting material to generate an increased reaction, as has been done with fear. It is also

intended to try to stimulate pleasant feelings by using relaxing content and slowing down fake vibrotactile feedback to induce a slower heartbeat.

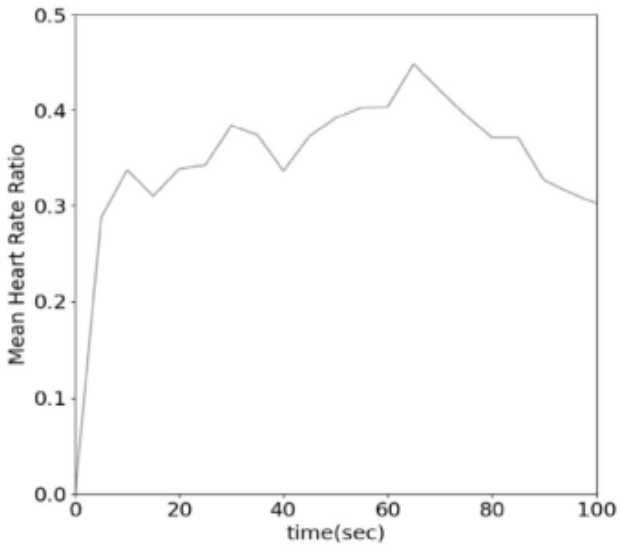

Fig.3.8 Mean increase rate of heart rate

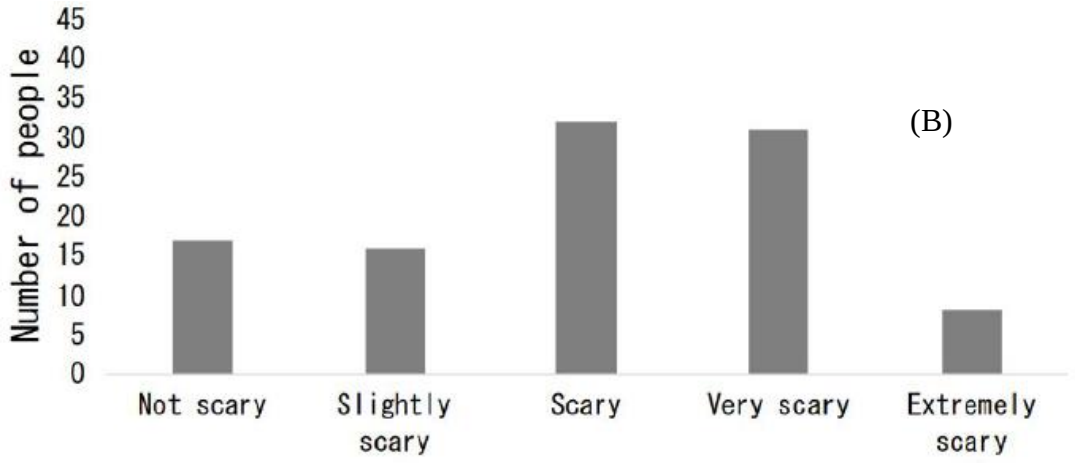

Fig. 3.9 (A) How real do you feel about the space? (B) How scary do you feel about space?

Although the EHVR gave positive results, we know it can only be used in limited cases that involve stimulating feelings. And we know that we need a different approach that can be used in more general situations. While doing the testing and presenting our work in SIGGRAPH Asia, we noticed many participants commented about the similarities between the virtual world and the real one. They thought it made the transition more accessible to the virtual space. Therefore, we hypothesized that the surrounding area of the VR experience influences the VR content. We conducted a side experiment during the show at the Asian Digital Art Prize Gallery to further investigate this. Inside the tent where we conducted the event, we split the participants into two groups. The first was the control group, which was housed in a dark tent. We tried to eliminate as many cues as possible that could affect their emotions and expectations of the event. For the second group, there was a projection within the tent that resembled the dark environment of the VR world, as well as frightening ambient music. For each group, we looked at the increase in heart rate. Over the control group, the second group exposed to the audiovisual stimuli showed a 5% rise in heart rate.

3.5 Verdict

A comprehensive research approach is required to achieve a high level of immersion in virtual representations of art. The technique described in this chapter is an effort to improve the realism of virtual reality by eliciting human emotions. Other methods are certainly conceivable; however, the methodology used herein enables for the subjective element of virtual art perception as well as physiological linkages of emotions to be capitalized on. This contributes to the development of recognized concepts and design standards for immersive VR experiences.

In order to create a better VR experience via emotion stimulation, an emotion hacking virtual reality (EH-VR) system is built in this work as an interactive system that hacks and regulates a person's pulse to speed up a scary VR experience. The EH-VR technology provides vibrotactile biofeedback through the footrest, simulating the feeling of a heartbeat. By monitoring the user's pulse rate in real-time, the system calculates an erroneous heartbeat frequency. The technology was tested on more than 100 individuals, and all participants' heart rates increased as a result of feedback. A number of further tests confirmed that the EH-VR might have produced this effect by displaying a synthetic pulse to the subject. When asked how genuine they thought the experience was, the vast majority of participants said they thought it was "feeling real" This indicates that a significant number of participants were frightened during the VR event. The participants also mentioned the positive impacts of parallels between the real and virtual world, which prompted us to look into the influence of the surrounding environment in more depth. A more in-depth discussion of this concept will be provided in the next chapter.

Chapter 4

4 Influence of Spatial Awareness on VR Gallery

4.1 Introduction

As stated in Chapter 3, the result of EHVR was overwhelmingly favorable; nevertheless, the idea is only applicable in a few particular VR situations. A more general method to enhancing the VR experience, STHR, that may be utilized in a number of settings and scenarios, has been described in this chapter. The concept for STHR was partly identified during the presentation of EHVR, during which participants remarked that the parallels between the virtual world and the actual world are beneficial elements in the transition from the real world to the virtual world (or vice versa). For example, establishing a scary ambiance using audiovisual content before donning the VR headset was found to increase the perceived intensity of fear experienced during VR.

Indeed, the surroundings have always figured prominently in the delivery of artwork, and the design of the exhibition space has a major effect on the way artwork is presented. Gallery designers employ light, music, colors, and artwork layout to enhance the effect of the artwork on the viewer. One of the most convincing reasons for using the surroundings as a tool to improve the experience is that people rely largely on their visual senses to absorb information and make decisions. When several sensory modalities provide competing information, the visual system takes precedence. Observers often examine artwork from a distance in art galleries and museums. Furthermore, the perceived quality of the artwork often varies from person to person, based on their past experiences and subjective interpretation of the visual information, based on multiprocess cognition and emotional connections (Zaidel 2010, Aviv 2014).

When it comes to art, the ultimate aim of virtual reality technology is to attain digital art appreciation in the digital art environment that is at least on par with that of its conventional equivalent; as a result, visual displays used in virtual reality should provide stereoscopic vision,

the capacity to detect head motions, and the ability to refresh the visual display in real-time to reflect the user's movement through the virtual world. In addition, the user should have visual stimuli that are of sufficient resolution, in full color, with appropriate brightness, and that depict motion in high quality. Perception is based primarily on the processing of visual information of depth, distance, and angle. However, in the context of virtual art galleries, as the viewers already know they are observing a virtual object, comprehension of "reality" gets complicated and greatly depends on the immersion and presence rendered by the overall VR experience (Slater and Usoh 1993, Poeschl, Wall et al. 2013).

As a result, given the current state of VR technology, virtual representations of artworks seldom reproduce artworks with high fidelity. According to Slater et al., a promising strategy for improving the VR experience might be a gradual transition from the real world to the virtual and back again (Slater and Usoh 1993, Slater 2009). In a number of investigations, Murcia et al. used this approach (Murcia-López and Steed 2016). Mat Collishaw's "Thresholds" and Rogue Fong's "Firewood" are two examples of artwork that make use of the idea of comparable spaces. Suzuki et al. (2012) proposed a concept of substitutional reality by presenting a combined video of participants who were physically present at live events, previously recorded in the same location using an HMD (Suzuki, Wakisaka et al. 2012). This concept was utilized in the MIRAGE performance artwork. By altering the spatial information before the user put on the HMD, the overall VR performance was able to track the user. Simeone et al. (2015) investigated a different kind of substitutional reality (Simeone, Velloso et al. 2015). They replaced existing furniture and other items in the actual area with comparable scaled 3D models, which may give the viewer a similar spatial picture of both real and VR environments, resulting in a smoother transition to the VR environment.

Figure 4.1: (A) Hepatic device uses multiple strings attached of hands to simulate the feeling of obstacles(Pizzoli, Mazzocco et al. 2019) (B) Proposal for an Encounter-type haptic interface for Virtual Reality Musical Instruments(Boem and Iwata 2018)

Before putting on the VR headset, a matched real world and virtual world may pre-immerse the user in the VR experience. Pre-immersion may be accomplished by minimizing mismatches between the mental model generated from actual space and VR material, allowing the mind to detect similarities, resulting in spatial awareness and understanding of its position. Essentially, creating the right setup before wearing the VR headset helps in putting the user in the right frame of mind, thereby resulting in an increased possibility to be tricked into believing in the illusion, similar to the work by Azmandian et al. (2016), where they used the re-targeting technique (Azmandian, Hancock et al. 2016). They showed the user three boxes before wearing the headset, removed two boxes after wearing the VR headset, and re-targetted all three boxes into one box. With the lack of information of the real space, and because the users could not see the real world while wearing the VR HMD. We can manipulate the perception of users inside the VR environment even if the

surrounding real space does not match by introducing minimal matching haptic feedback, and as Hoffman et al. (1998) discovered in their research that physical matching interactions play a significant role in increasing VR believability (Hoffman 1998). Examples of haptic feedback are shown in Figs. 4.1 A-B. In another recent study, the effect of a gradual transition between the real world and VR was investigated by using a video feed from a stereo camera that gradually faded into virtual content, creating a smooth transition, which significantly affected the participant's perception of virtual body ownership and presence.

The studies above clearly indicate that the area and setting around the VR experience environment have a significant effect on VR realism. We also believe that by reducing the amount of information gathered from real-world space just before the VR experience, we will be able to create a smooth transition to virtual reality. However, although earlier research has shown the benefits of a seamless transition between the virtual and real worlds, there is a dearth of controlled trials that may propose the optimum kind of setup required to offer the least amount of misfit between the real and virtual worlds. Furthermore, creating a physical replica of artwork in the virtual world will also present several challenges. The major issue with this smooth transition method is that a new 3D model must be provided for each different space. Constructing realistic 3D spaces is time-consuming, and, in several cases, the meant-to-be-shown virtual environment is entirely different from the real space. Furthermore, there can be differences in the scale of the space or in content. However, despite all significant research in this area, the factors that affect VR experience quality are not yet fully established.

In this work, we introduced the concept of smooth transition-coupled hybrid reality (STHR), wherein the participants were first deliberately introduced to a physical object, which was the replica of one of the virtual objects that the participant would see during VR. This step was

expected to provide haptic feedback that matched the real world and VR. In some ways, this technique is comparable to how a black screen fades into a video to create a transition from a blank canvas to the content. This transition technique borrowed from video editing is comparable to a transparent, seamless crossfade between two similar images when recreating actual space in VR with 3D models. Given that users are unaware of the contents of the real-world setup, we aim to increase the realism that VR items have a physical existence. As previously mentioned, this was accomplished by presenting proxy objects early in the VR experience that correspond in size and position to the actual world and the VR content. The subject then experiences the uncanny illusion that the touch sensations are felt from a real replica of the artwork. In order to get this look, we utilized a 3D-printed replica of an artwork. However, in other contexts, commonplace items such as glass boxes, seats, or museum barriers may create a similar effect. These early matching exchanges contribute to a higher level of realism in VR. Furthermore, the setup was designed to allow a smooth transition from the real world to the virtual world and vice-versa. This step involved making the real-world theme highly relevant to the virtual world and blocking all extraneous content to the maximum extent possible. By covering it and blocking the view of the physical space of an art gallery, it would not be visible from the outside. This would prevent the user from implicitly creating a spatial or mental image before the VR experience. By doing this, we believe that the user will not compare the real space and the virtual environment during the VR experience. Thus, no mismatching would occur that could break the illusion. We expect that the reduction in information would ease the transition into the virtual environment, increase the feeling of immersion, and improve the believability in an art space.

To examine this hypothesis, a series of experiments were carried out to investigate how awareness of physical space affects VR realism and how haptic feedback using a replica of an item that is

also present in VR affects the perceived reality of VR. Finally, the results were put into action by establishing a virtual art exhibition for common participants and recording the realism experienced by random visitors.

4.2 Methodology

4.2.1 Participants and Questionnaire

There were 21 participants in the experiment. Before the experiments, all participants were asked to complete a questionnaire related to basic information and previous VR experience. Each participant had to participate in all the experiments. After each experiment, they were asked to complete a Presence and Reality judgment questionnaire; The questionnaire had 25 questions that were to be scored on a scale of 1 to 10. Anticipation, reality, immersion, and attention during VR were analyzed from the questionnaire. At the end of the three experiments, we also conducted a survey and an interview with questions based on the behavior of the participants.

4.2.2 Task

In the experiments, the participants were asked to perform a simple task of touching some red glowing boxes, which turned green when touched and then spawned a new red box in a new location in the virtual room. This task encouraged the participants to look and walk around the space while avoiding some obstacles in the room.

4.2.3 System

The system consisted of an HTC Vive headset with a Leap Motion sensor mounted on it for hand tracking and Vive motion controllers with 3D printed mounts placed around the ankle to track foot movement. We tried to represent the use with a semirealistic avatar in VR to help maintain the level of immersion. The dimensions of the experiment space were 4.4 m x 3.7 m, with the HTC

Vive lighthouses set at two opposite corners. We run VR content on an ASUS laptop (model GL502VS) equipped with an Intel Core i7-6700HQ 2.60 GHz CPU, 16 GB RAM, and a GTX 1070 graphics card. The content was created using Unreal Engine 4, which showed a 3D room modeled in Autodesk 3DS Max.

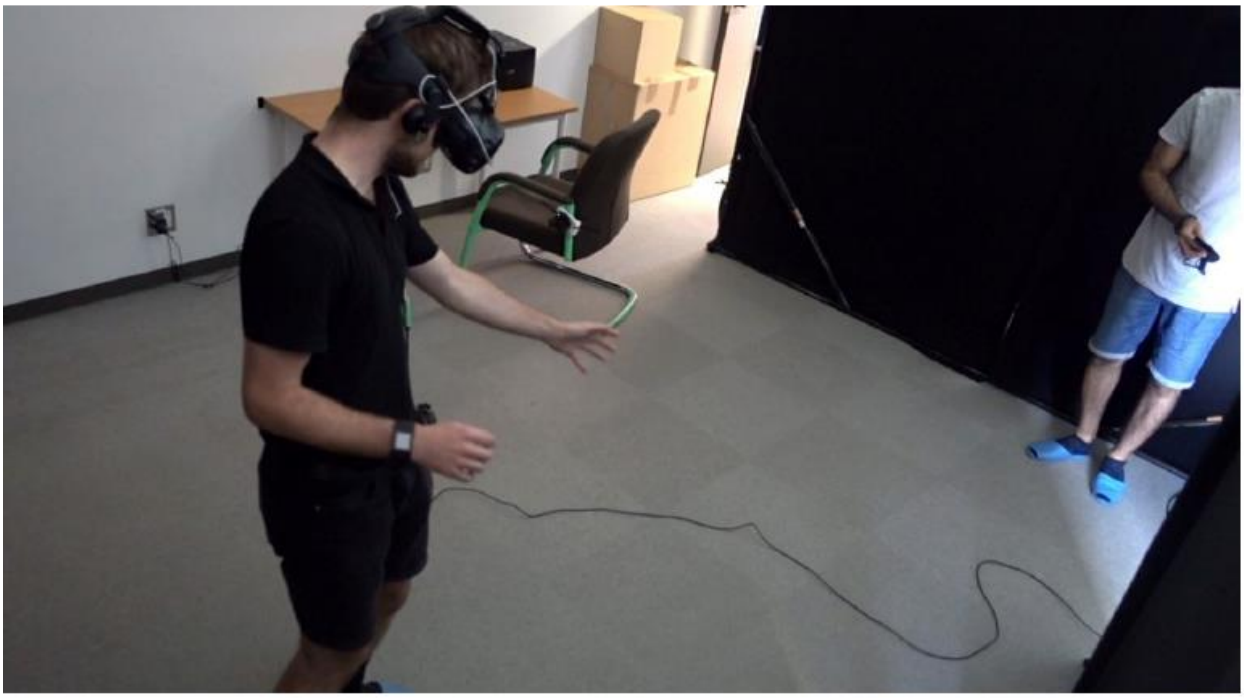

Fig. 4.2 Physical space used in experiments

4.3 Experiments

A total of three experiments were conducted at the same place in a specific sequence, one participant at a time. We chose a room that was unknown to all participants to eliminate any knowledge of the space. Before entering the experiment room, the participants were asked to wear an eye mask, close their eyes, and keep them closed until they entered the room and put on the head-mounted display (HMD). When the experiment was over, they were asked to close their eyes again until they left the room.

In the first experiment, we examined the effect of hybrid reality on realism, i.e., we created the setup so that the participants interact with a real-world object (RWO) in the initial stage of the VR

experiment. This approach provides haptic feedback that matches the real world and the VR gallery. The virtual space was a room with some furniture, a column offset from the center of the room creating a narrow passage, and some traffic cones to act as obstacles while walking in the room to perform the task (Fig. 4.3 and 4.4). The participants were divided into two groups and randomly assigned to one of the two conditions. The first condition introduced some real-world objects (RWO) (a table and chair) with similar shape, size, and VR location as in the real environment. These objects were placed near the participant's starting point, which forced a natural interaction through either deliberate or accidental. These matching objects were the only things inside the experimental space. In the control group (CG), there were no real objects. For each group, we measured the time it took to complete the task of touching the red boxes, noted their routes of movement, and observed the distance traveled by the participants to avoid the obstacles and compared them.

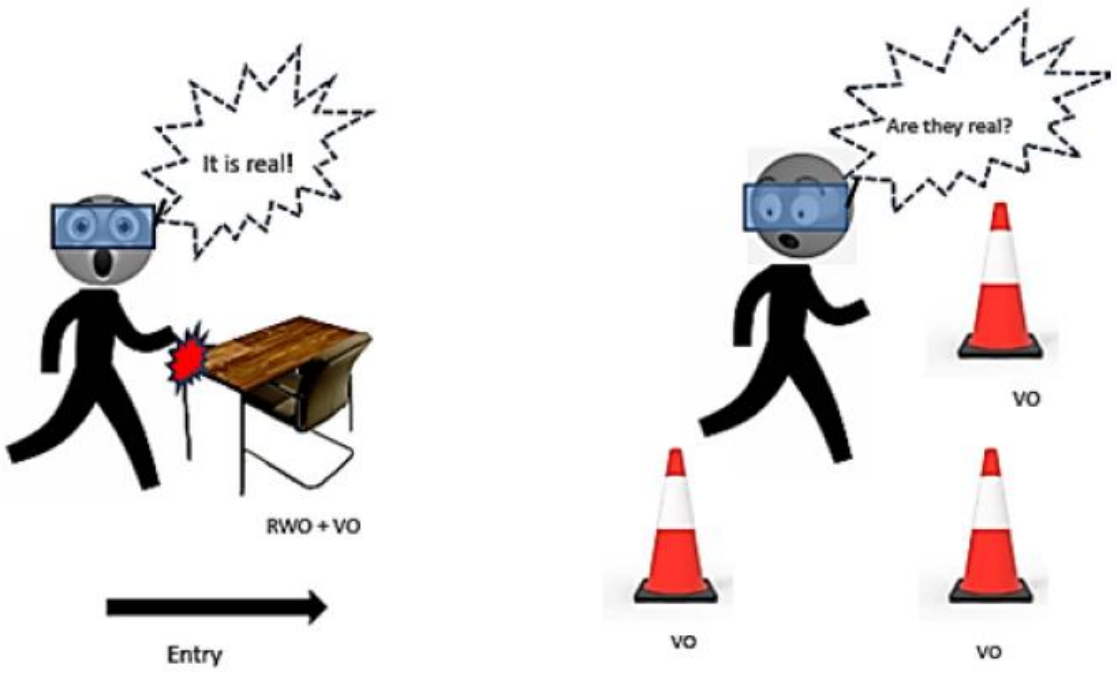

Fig. 4.3 Pictorial representation of the setup used in experiment 1.

In the second experiment, we examined the difference in realism and task completion time when the participant is already aware of the real space. Essentially, it was a measure of the effect of spatial awareness of the real space on VR realism. The boundaries of the virtual and physical worlds were the same. Traffic cones were scattered around the virtual space that acted as obstacles when a participant walked into the room To perform the task of touching the red boxes (Fig. 4.5). However, the experimental space did not have any physical object; it was empty. The experiment had two primary setup conditions: an environment where the participants can see the room set up to know it is empty (control group) and a group where the participants cannot see the actual space where the VR experiment was conducted. In this setup, a barrier (wall) blocked the participants' view of the real space. We compared the time taken to complete the tasks, the route of movement, and the distance traveled by the participants.

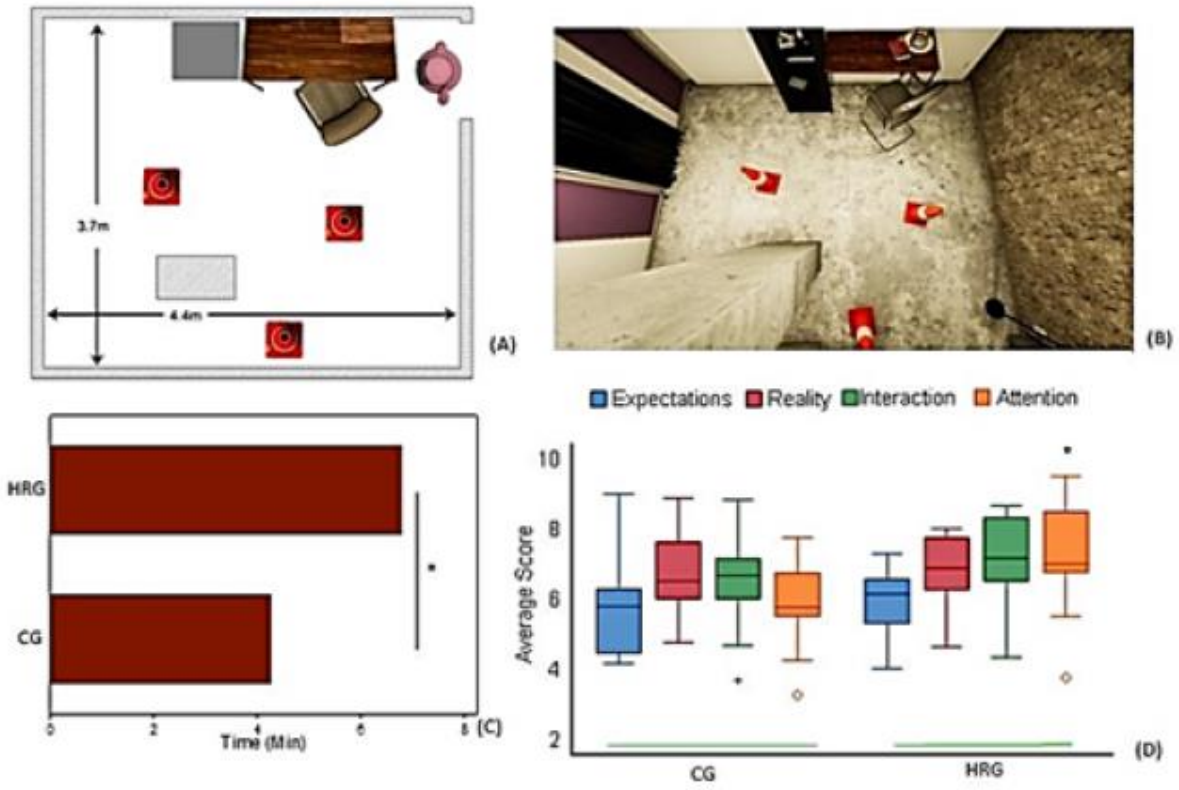

Fig. 4.4 VR space and dimensions of VR realism after Experiment 1(hybrid reality) (A) Experimental space (B) Virtual-space (top-view) (C) Task completion time (HRG: Hybrid reality group, CG: Control group) (D) Assessment of different dimensions of VR realism (* p¡0.05).

In the last experiment, all participants were allowed to see the room before wearing the VR headset; however, the VR setup was clearly different from the real space (Fig. 4.6). Our objective was to examine whether the participant's memory of the real world would persist during the VR experience and how this knowledge affects their decision-making while experiencing VR. This experiment focused on the route and actions taken by the participants. There was an obstacle (table) in the real environment that did not exist in the VR space. This obstacle blocked the path needed to reach the second red box. Thus, this was a bad environmental setup for VR. However, this

answers the following question: 'How will the participants treat the real-life obstacles if they do not see them in VR?' Will they remember them?" Besides, after touching the second-to-last box and on the way back to the starting point where the last box was, a new obstacle (chair) was rendered, which did not exist in the real world. This will answer the question 'How will the participants handle the newly spawned virtual obstacle?' Will they prioritize their knowledge of the real space or trust the visual information provided in VR?'

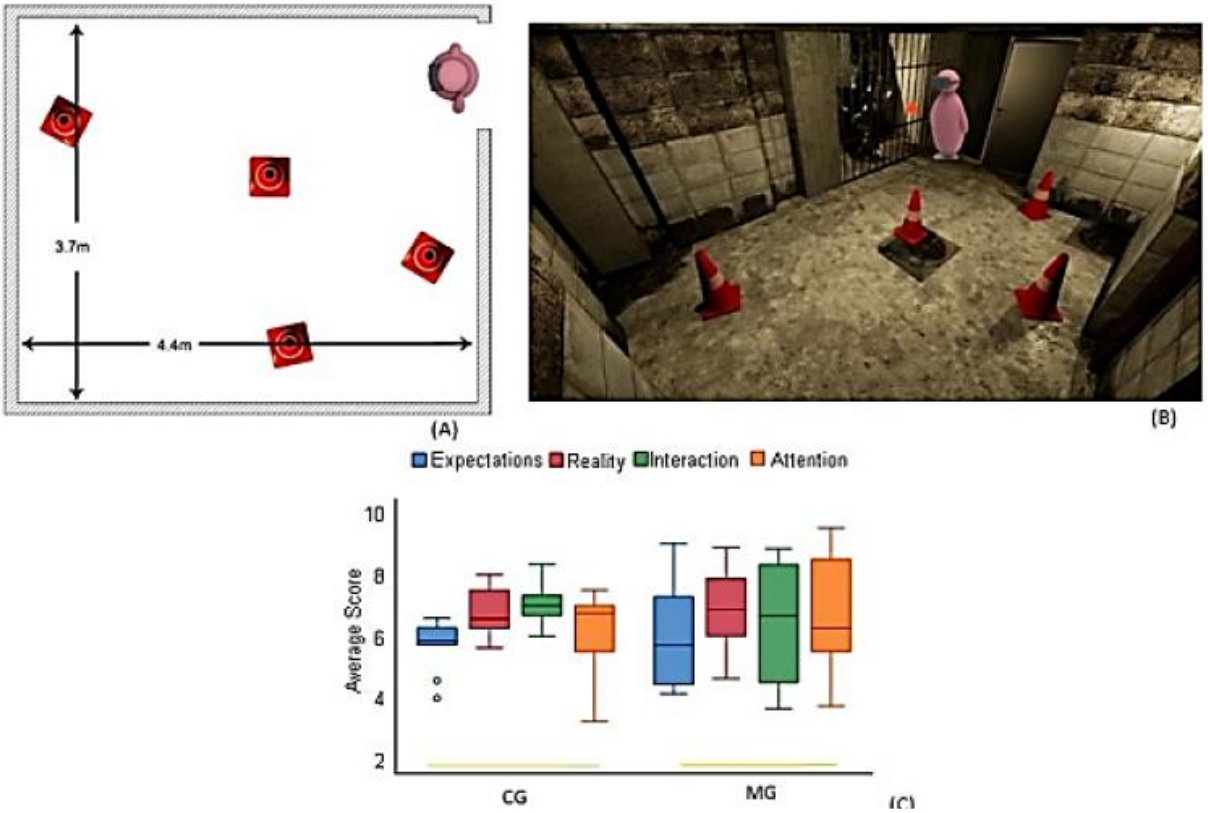

Fig. 4.5 VR space and dimensions of VR realism after Experiment 2 (spatial awareness) (A) Experimental space (B) Virtual-space (C) Assessment of different dimensions of VR realism. (MG: Mask group, CG: Control group)

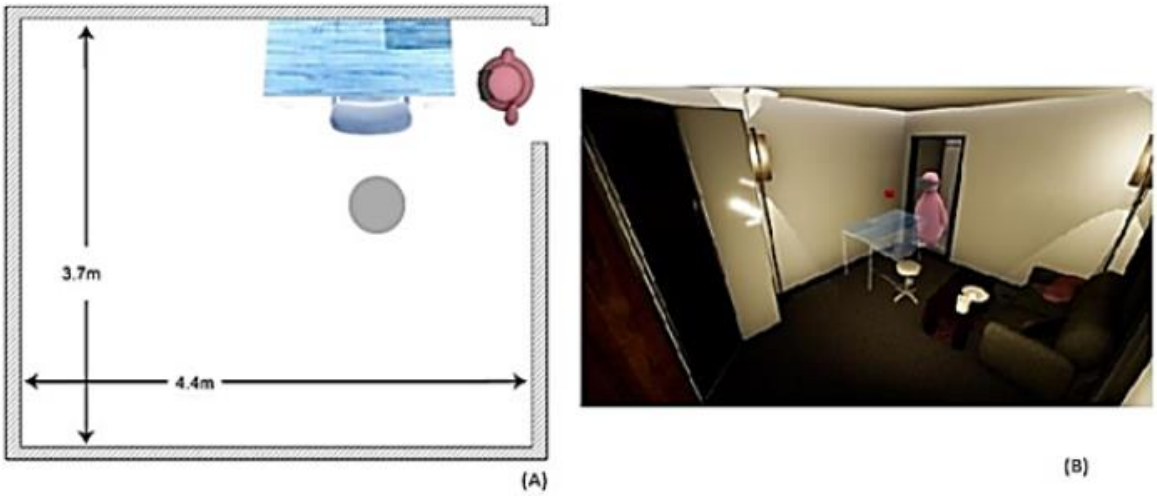

Fig. 4.6 Effect of prior knowledge of real space on the decisions made in VR space (A) Experimental space (B) Virtual space [Table chair (blue) was not part of VR space but were present in the room, and all participants have seen the room. The chair (gray)
was introduced in between the VR experience].

4.3.1 Virtual Art Gallery

To verify the validity of STHR in a real-life situation, we built a VR art gallery (VAG) that was open to the public for four days (Fig. 4.7-4.9). It was held in a multipurpose space on the second floor of the designed common building of Kyushu University. The gallery showed four different 3D sculpted artworks with themes based on Bonsai plants, which are an integral part of Japanese culture. The VR gallery design was based on conventional Japanese interior design. We used elements such as Tatami (Japanese flooring), Byoubu (Japanese folding partitions), and Shoji doors Fig. 4.9).

STHR was defined as delivering a smooth transition from the real world to the virtual world and providing haptic feedback by creating a mix of real-world and virtual objects. In VAG,

STHR involved four main concepts. Most important among them is the haptic feedback that matched the real world and the VAG. It was introduced at the beginning of the VR experience by using a 3D printed replica of an artwork (fig. 4.8). Additionally, to ensure a smooth transition from the real world to VR, important features of the real space were also maintained in VR. In our case, it was the windows of the building and the ceiling. Following are more details on the public V system used in the gallery that was similar to the previous experiments. It consisted of an HTC Vive headset, and a Leap Motion Controller mounted on it for hand tracking. Vive motion controllers were not used to track the movement of feet because collisions were not anticipated.

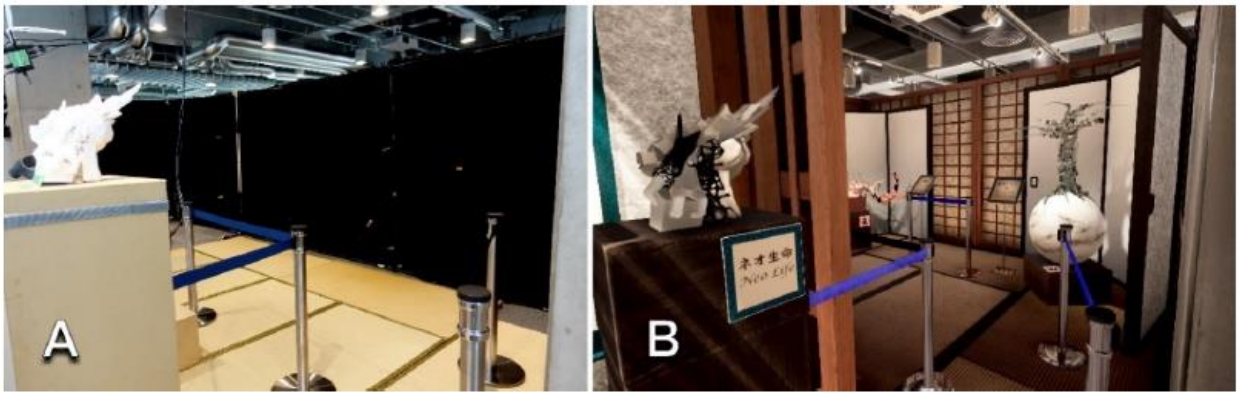

Fig. 4.7 VR Art Gallery - Real space vs. VR space

The dimensions of the gallery space were 4 m × 6.5 m, with the HTC Vive lighthouses set at two opposite corners. The computer was equipped with Intel Core i7-6700HQ 2.60 GHz CPU, 24 GB RAM, GTX 980Ti graphics card, and Windows 10. The content was created using Unreal Engine 4, which showed a 3D room modeled in Autodesk 3DS Max and ran at 90 fps with 6 ms latency. Before the gallery was set up, we created a poster that informed the visitors that the gallery was in a traditional Japanese style. The poster showed a space with a Japanese scroll with calligraphy of the Bonsai kanji symbol, Tatami flooring, and Japanese sliding doors. The idea behind this was to

set the expectations of the visitors regarding the content of the gallery. The gallery area was covered with black cloth on all sides to ensure that the visitors did not form a spatial image of the area of the gallery space (Fig. 4.7). We created a small corridor between the wall and the covered space that led to the entry point so that visitors could not peek inside the content of the covered area through the entrance. Here, we indirectly introduced them to a simple common element (museum barriers) that they would encounter and interact with within the VR space.

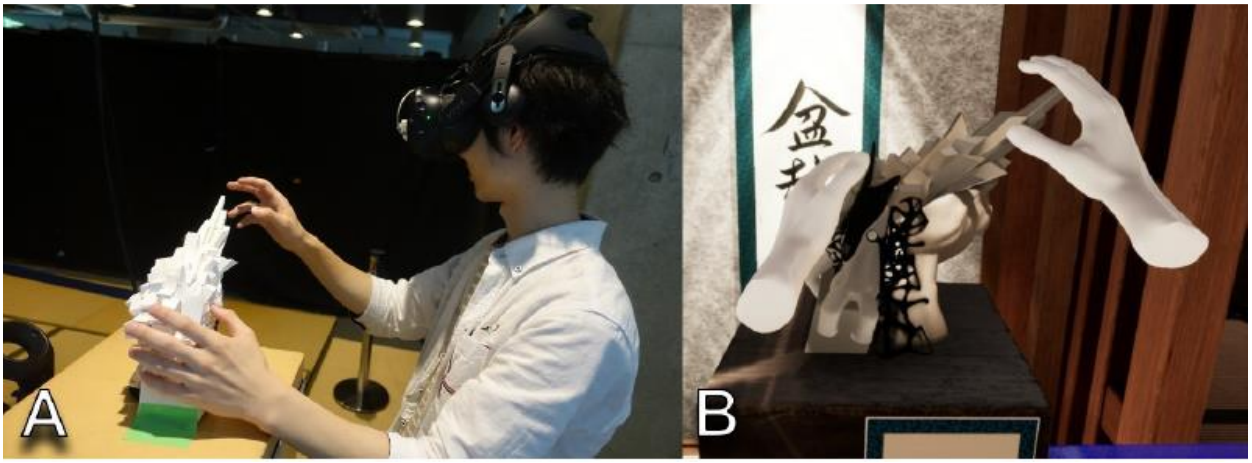

Fig. 4.8 3D printed artwork

We used barriers to mark the entry point and to stop anyone from entering the corridor. At the starting point outside the corridor, we asked the visitors to follow three instructions. First, to took off their shoes and wore slippers because it was a traditional style gallery and Tatami flooring had been used. This helped us provide constantly matching haptic feedback through the feet. Second, they had to close their eyes (we guided them through the corridor) and only open them after wearing the VR headset. Third, they could touch the first artwork but were not allowed to touch the other three artworks. The sign 'don't touch' was clearly visible inside the VR gallery, similar to what is commonly seen in art galleries. As soon as a visitor opened their eyes, they saw the first

artwork. This first artwork, titled" Neo Life," was 3D printed and fixed on a display table (Fig. 6.9). Out of the four, it was the only artwork that existed in a physical form.

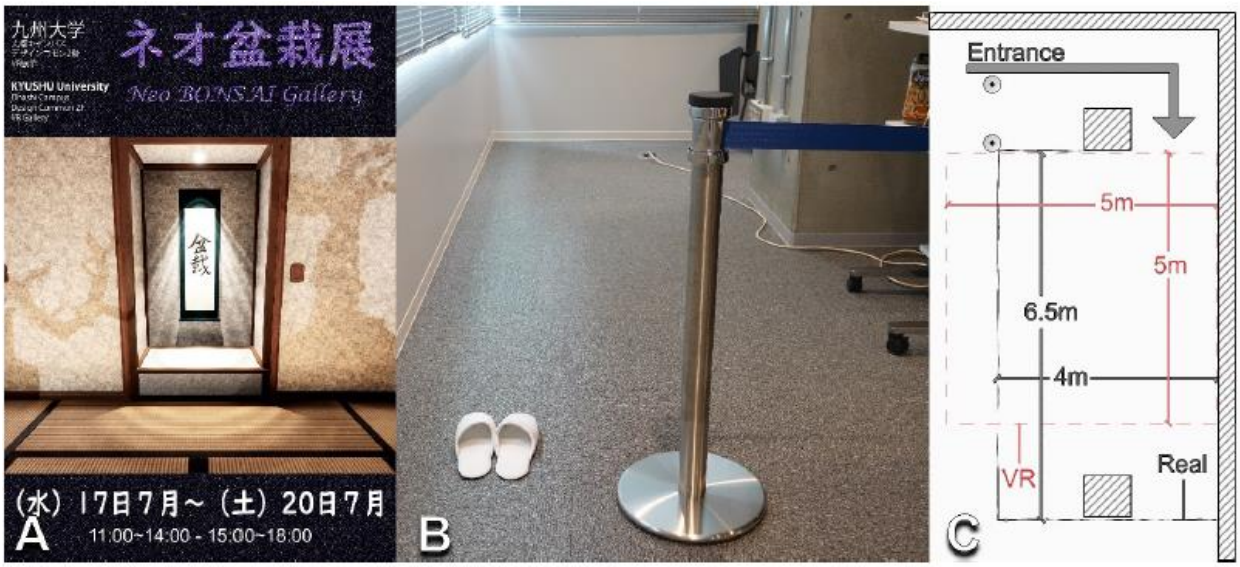

Fig. 4.9 VR Art Gallery from the outside

In addition, we fixed a Vive tracking sensor on the backside of a display table to make sure that the table and the artwork are always in the correct position. The first thing the visitors did was step onto the Tatami flooring. This was the first matching and constant haptic feedback between the real world and the VR gallery throughout the whole experience. Then, we encouraged them to touch the first artwork, which provided a more detailed matching haptic feedback. A leap motion sensor was mounted on the Vive headset. Tracked and displayed the hands of the visitors while interacting with the physical objects. When they finished experiencing the first artwork, they entered the main gallery space on their right, passing between two pairs of museum barriers. We narrowed the passage to increase the chance of physical interaction with the barriers or their straps:

these barriers matched their real-world counterparts in shape and scale. However, there were no matching objects other than the Tatami floor; of course, the visitors did not know that the gallery was empty. Visitors freely looked at the artworks and were free to leave whenever they wanted. We answered any questions and provided some verbal explanations regarding the concept of the artwork. When they finished, they went back to the starting point, closed their eyes, removed the VR headset, and were guided outside. In the end, we asked them to fill out a questionnaire to collect data about their VR gallery experience.

4.3.2 Statistical analysis

Normally distributed binary data were presented as the mean and standard deviation(SD), and nonnormally distributed data were shown as the median (M) and interquartile(IQR) values. The t-test was used to compare normally distributed data, and the Mann-Whitney U test was used to compare data with the nonnormal distribution. The significance was set at $p<0.05$.

4.4 Results and discussion

4.4.1 Participants

There were 21 participants (6 women). The mean age of participants was 29.0±11.7 years, and there was no difference between men and women with respect to age ($p=0.934$). Overall, 9 (40.9%) participants had a previous VR experience. None of the participates had seen the real space before experiment 1. Nine (42.9%) participants had no video game experience, while 6 (28.6%) had significant video game exposure.

4.4.2 Effect of haptic feedback in hybrid reality on VR experience

In experiment one, there were 11 participants in the hybrid reality group (HRG) and 10 in the control group (CG) (Figure 2). There were no differences between the participants of these two

groups with respect to gender, previous VR experience, or age (all $p<0.05$). The median time taken to complete the task was considerably longer in HRG than in CG [HRG:7.0 (6.4-7.6)vs. CG 4.0 (2.5-5.0); $p=0.007$]. The average number of collisions was not significantly different between the CG and HRG ($p=0.888$). The median value of anticipation, immersion, and reality were all slightly higher in the HRG; however, the difference was not statistically significant (all $p<0.05$). The median attention score (IQR) was 23.0 (22.0- 27.0) in the CG and 28.0 (27.0-34.0) in the HRG ($p = 0.045$). In interviews, 10 out of 11 participants in the HRG, who had an initial physical interaction with objects in the real space, reported that they thought that all the furniture, columns, and cones shown in the VR existed real. On the other hand, participants in the CG were not sure of the realism of the objects and used phrases such as 'maybe there was,' 'might be there' and 'avoiding it just in case' while talking about objects in VR. The participants in the CG also moved closer to the obstacles. The participants thought that not avoiding collisions with the virtual objects was part of the experiment.

4.4.3 Effect of complete spatial awareness on VR experience

In the second experiment, we attempted to determine the effect of an unfamiliar environment on the actions of the participants (Figure 3). There were 11 participants in the mask group (MG) and 10 in the CG. There were no differences between the participants in these two groups with respect to gender, previous virtual experience, or age (all $p<0.05$). The median time taken to complete the task was considerably longer in MG than in CG [MG:4.8 (4.2-5.8)Vs. CG: 3.4 (2.6-4.2); $p=0.038$]. The average number of collisions was not significantly different between CG and MG ($p=0.504$). Anticipation, immersion reality, and attention were not different between the groups (all $p<0.05$). Upon observing the video capture, the completion time, and the discussion during interviews, we noticed that people who saw the real space before wearing the headset had more freedom in their

movement and were faster in completing the task. The participants in the MG were more cautious while moving around the obstacles, and 8 out of 11 used phrases such as" maybe there was, " might be there," and" avoiding it just in case" when talking about the existence of virtual objects. Two participants from this group attempted to touch and verify the presence of traffic cones.

4.4.4 Effect of hybrid reality on VR experience

Interestingly, 52.4% of the participants remembered the RWO (table) and avoided it without even seeing it. Participants who answered 'no' had a physical interaction with the RWO. For the second question, which asked whether the participants remembered the table at the end of the experiment, 66.7% of the participants voted 'yes.' However, some people who voted 'no' mentioned that they remembered the table but were unsure of its exact location. In particular, 8 of 10 participants who had a physical interaction with the table did not forget it. Regarding the VO (chair) present in the middle of the room, most of the participants tried to check if it was real. This experiment revealed that almost 50% of the participants relied on prior knowledge of the real space, even when different visual information is delivered through VR. Furthermore, participants who did not remember the RWO became aware of it after the physical interaction, suggesting that the physical interactions resulted in more vivid mental images. When we introduced an obstacle (a chair) at the end of experiment 3, for most, it was not as important as the table present in the real world, which was invisible in VR.

4.4.5 Virtual art gallery

There were 38 visitors to the VAG. The average time spent in the gallery was 5 min, 57 s. As a percentage, 18.4% of the participants in this gallery participated in our previous three experiments. The age of the visitors ranged from 17 to 70 years, with an average age of 31.26 years; out of the

total, 58% were women. A total of 51.6% of the participants reported not having any previous experience with VR, while the rest had some prior experience with VR; however, none of them was a frequent user. Furthermore, 46.4% mentioned that they did not play video games; however, most of them were interested in art. We asked the participants about the artwork they liked the most. The third artwork, titled" Distress," got the highest percentage with 47.4% of the votes. However, it received only 23% (77 s) of the view time, almost similar to the second artwork titled" Natural: Artificial" (76 s). The fourth artwork, titled" Incomplete Sculpt," recorded the longest observation time of 95 s (29%); however, it was liked by only 13% of the participants. The second and third artworks had similar sizes and viewing times. The first artwork received 78.5 s (24.5%) of the view time despite being the smallest in size. We believe this was due to the opportunity provided to visitors to touch and interact with it. We did not want to ask if the visitors thought there were physical artworks present in the VR gallery directly because we thought such a question might induce bias. Therefore, we asked them an indirect question:" Did you feel you wanted to touch the artworks?" 73.7% scored it with a five, which was the highest rating on our scale (Table 6.1).

The main limitation of our approach is that we need the user to be unfamiliar with the physical space, which will make it less effective in an already familiar space such as home VR experiences. However, it will be beneficial in exhibitions or museums. Additionally, it will make the use of robotic haptic feedback solutions more believable, something like the use of the Baxter Robot. Future prospects The technological framework presented in this work offers many possibilities to enhance user immersion in VR by carefully smoothing the transition to the VR environment and using a perceptual stimulus. Future research should focus on the generalizability of this approach. As demonstrated in our work by the example of a real-world VR art gallery, STHR is particularly

useful in museums and art galleries. We believe that the use of STHR in VR art galleries will have a significant impact on the way patrons connect with art, as the interaction with artworks involves advanced cognitive function and substantial processing of visual information. In future studies, we believe that by deliberately exposing the VR user to specific visual or auditory information while blocking extraneous information, some targeted emotions can be amplified. Using this approach, the believability of VR can be further manipulated. As VR use is going to increase in the near future, STHR could play a pivotal role in enhancing the quality of the VR experience.

4.5 Verdict

In this chapter, we showed how spatial awareness of the real-world impacts the entire VR experience as part of our ongoing attempts to create methods for improving realism in virtual representations of art. By introducing STHR, where a mix of real-world objects and virtual objects are presented during the VR experience, a smooth transition could be made from the RW space to the VR space. Our results suggest that this approach significantly increases the time taken to complete the VR tasks and affects the participants' overall attention. Furthermore, in STHR based virtual art gallery made for the public, the visitors' overall feedback was highly positive. To examine the impact of spatial awareness and haptic feedback, we first compared the VR experience of participants with and without STHR. For the STHR, the room was set up so that participants interacted with an RWO and experienced haptic feedback. This interaction affected the perceived realism of VR, as was observed from increased task completion time and change in attention. It found that by introducing minimal haptic feedback by felicitating physical matching interactions, the users' perception inside the VR environment could be altered. The potential fundamental implications of STHR and EVHR are discussed in the next chapter.

Chapter 5

5 Discussion

This chapter discusses the key contributions made by this research to the field of virtual reality technology and its applications, particularly in the area of the virtual portrayal of artwork. The major aim of this research was to investigate how certain variables might improve the perceived realism of virtual artwork. To this end, haptic feedback and spatial awareness compliant design were utilized to improve the perceived realism of the virtual artwork. Two novel tools (emotional hacking and STHR) were developed during this research, and VR prototypes that incorporate these two unique VR concepts were created and validated in the real-world trial. The findings of the study, which were given in the preceding chapter, represent the research that was guided by the following two fundamental hypotheses:

- It is possible to improve the overall VR experience by including physical stimulation that may elicit emotional responses from the user.
- It is possible to further improve the entire experience by ensuring a smooth transition from the real world to the virtual world and by including haptic input via the use of 3D printed artwork.

"The object is art to crystalize emotion into thought, and then fix it in form" – Francois Delsarte

Before delving into the realm of virtual art, it is necessary to discuss the fascinating aspects of art. In today's world, art can be found anywhere, whether it's in the form of a museum, a city center, or even on the internet. Modern civilizations dedicate a considerable amount of time, money, and public space to the practice and display of creative work and ideas. This connection between people and art is driven by a distinct psychological viewpoint. However, what transpires when we look at art is a question that has yet to be conclusively addressed by science. Art may evoke personalized

emotions as well as a wide range of viewpoints, judgments, and physiological responses. As is true of all art, it can be profoundly admired and mystifying; it can be rational or irrational; invigorating or dispiriting; and reactions to art, whether positive or negative, fatuous or substantial, vary significantly between two individuals, between different positions, or even within a single interaction on its own (Vygotsky 1972, Solso 2003).

Perception involves the cognitive skills learning system in the brain, which is controlled by the prefrontal cortex, hippocampus, and related medial temporal lobe structures and is highly dependent on working memory and attention. Gaining a strong behavioral repertoire, on the other hand, is dependent on the brain's behavioral skills acquisition system, which is controlled by the basal ganglia and slow, incremental dopamine-driven changes in behavior. It should be emphasized in the topic of STHR that human cognitive processes do not depend on active memory and attention and are negatively impacted by "overthinking it." Another significant problem in the transmission of visual perception is perceptual conflict, which has the potential to decrease VR reality. The visual pattern we normally perceive is intricately linked to other sensory inputs such as auditory and motor feeling. If our sensory inputs are contradictory, our brain attempts to adjust or establish itself, but it creates perceptual illusions. The visual-motor is very important in virtual reality setups (Proske and Gandevia 2012). As a result, a mismatch between physical and virtual environments, as well as existing experiences of the real location, may result in incongruent cognitive processing. The visual system, which is the vehicle through which visual art is processed, attempts to filter, organize, and give (functional) order to the massive quantity of data flowing into our visual cortex (Aviv 2014). Surprisingly, during the early phases of visual processing, the visual image is decomposed into its fundamental elements such as light spots, lines, edges, simple shapes, colors, movement, and so on. The system reconstructs these components into complex shapes and

things at subsequent (higher) phases (Zeki 1992, Sacks and Siegel 2006, Bertamini, Palumbo et al. 2016).

5.1 Smooth Transition and Hybrid -reality (STHR)

In the setting of hybrid reality in STHR, the consistent of seen and felt the touch, as well as the exact nature of the seen and felt the touch, had a significant influence on the dependability of the illusion. Participants in our tests stated that being able to touch the 3D printed art improved their experience. Notably, when we asked participants whether they wanted to touch the artwork, 73.7 % of them gave it a five. Furthermore, in STHR controlled tests, 10 out of 11 individuals who had first physical contact with items in actual space stated that they believed all of the furniture, columns, and cones depicted in the VR existed in real life. The majority of them thought they saw a genuine work of art.

In terms of spatial awareness, when asked about the existence of the table, 52.4 % of the participants recalled it and avoided it without ever seeing it. Those that responded 'no' had tactile contact with the table. Eight out of ten individuals who had tactile contact with the table remembered it. Most participants attempted to confirm whether the virtual item was verified, indicating that this hybrid reality is feasible. Furthermore, individuals who did not recall the physical space were aware of the table after the physical contact, indicating that the physical interactions produced more vivid mental pictures. The mechanism behind this illusion, we believe, is comparable to Bayesian perceptual learning. This concept proposes that when two sensations from distinct modalities co-occur with a high probability, they are 'bound.' As a result, when the user receives haptic input (tactile) from a 3D item and visual picture via VR, it increases temporal synchrony and enriches the VR experience. In our instances, the brain's ability to extract statistical connections in sensory information is most evident. In this instance, the brain prefers to exploit

statistical relationships. It should be emphasized that the user may have a good understanding of the facts and a robust behavioral toolbox; nevertheless, the user must ultimately choose the facts and behavior that are more suitable to the current situation. Emotional and sensory processing significantly influence cognitive and behavioral skill acquisition and are essential to VR realism. A disconnected or emotionally disturbed person is unlikely to enjoy a highly immersive VR experience since high levels of immersion occur when cognitive, behavioral, emotional, and experiential learning systems combine.

5.2 Emotion Hacking VR

Furthermore, as shown by EHVR, physiological stimulation seemed to be very efficient given that many participants spontaneously reported increased heart rate and was highly helpful in strengthening the illusion. It should be emphasized that uniformity in the exact nature of the visible and felt touch is critical, and different kinds of tactile feedback have been observed to reduce the illusion. It should be emphasized that the user may have a good understanding of the facts and a robust behavioral toolbox; nevertheless, the user must ultimately choose the facts and behavior that are more suitable to the current situation. Emotional and sensory processing significantly influence cognitive and behavioral skill acquisition and are essential to VR realism. A disconnected or emotionally disturbed person is unlikely to enjoy a highly immersive VR experience since high levels of immersion occur when cognitive, behavioral, emotional, and experiential learning systems combine. Furthermore, as shown by EHVR, physiological stimulation seemed to be very efficient given that many participants spontaneously reported increased heart rate and was highly helpful in strengthening the illusion. It should be emphasized that uniformity in the exact nature of the visible and felt touch is critical, and different kinds of tactile feedback have been observed to reduce the illusion.

According to affective-cognitive theories, the overall assessment of the stimuli results from an interaction between both the effect produced by the stimuli and the cognitive reactions to the stimuli (Wyer Jr, Clore et al. 1999). The interaction between impact and cognition is complicated, and neither previous nor present studies can claim to have captured this interaction entirely. While the three categories-based model and evaluation theory imply that cognitive evaluations may generate emotional responses, neuropsychological data suggests that cognition's anticipatory affective responses outweigh cognition (Hagtvedt, Patrick et al. 2008). This concept would also imply that emotions, which must inevitably pertain to the person who is experiencing them, should affect the cognition of characteristics pertaining to art. Thus, the characteristics of an artwork that underpin its artistic or intellectual attraction may be seen as being to the artwork itself, despite the fact that the perception of these characteristics is formed in part by the emotions elicited in the spectator. As a result, it seems reasonable to incorporate both emotions and artistic and logical appeal judgments in measures of art perception in VR and in general (Figure 2.2). Future studies should examine the relative significance of emotions, tactile stimulation, and synchronization in the VR realism of artworks, as well as the relationship between them.

5.3 **Challenges in the VR for art**

In the real-world implementation of VR-based technology, the failure to produce a realistic virtual reality experience is a critical challenge (Ludlow 2015). This issue is more complicated in the context of the virtual rendering of an artwork or an entire art museum that contains multiple virtual artworks. To comprehend a work of art, one typically needs to employ a higher level of abstract cognitive skills than is needed in other popular VR applications such as entertainment, education, and marketing (Herrington, Reeves et al. 2007, Maghool, Moeini et al. 2018, Xie, Chu et al. 2019). Moreover, the perceived quality of artwork differs from person to person, depending on their

previous experiences and subjective interpretation of visual information. Despite such subjectivities and diversity of artworks, an effective VR experience requires that the VR rendered must be compatible with the participants' expectations, feel authentic, be engaging, and captivate the participants' interest (O'Brien and Toms 2008, De la Peña, Weil et al. 2010).

Virtual arts have the ability to enhance the viewing experience of great art by improving engagement with the artwork. As a result, virtual reality is being utilized in a wide variety of applications, and there is a growing amount of study being done on how virtual reality may be used to improve the visitor experience at art galleries and museums. A number of studies comparing virtual museums/ art galleries with real versions were performed in order to determine the efficacy of virtual representations in terms of the user experience they provided. Some users have found that virtual rendering is more effective than physical rendering, while others have concluded that opposites and mixed reactions (Carrozzino and Bergamasco 2010, Brida, Disegna et al. 2014, Ivancic, Schofield et al. 2016).

5.4 The potential role of EHVR and STHR in improving VR experience

The use of EHVR in this study was driven by theories of cognitive development and prior research, which showed that emotions impacted the VR experience and vice versa. Art viewing is known to elicit a range of feelings, meanings, and judgments in the viewer, depending on the characteristics of the artwork and the psychophysiological condition of the user (Tröndle and Tschacher 2012, Tschacher, Greenwood et al. 2012, Healey 2014). Art can also have an effect on one's physiology, such as heart rate and skin conductivity, for example. In a way, physiological and psychological changes are intertwined and interdependent. However, despite the abundance of evidence supporting the positive effect of emotional stimulation on virtual reality experience, such effects are not well understood in the context of virtual art, and there is a scarcity of practical tools that

can be used to stimulate a specific emotion relevant to the theme of the virtual art gallery. Because of this, VR design must consider the participant's emotional state both inside the experience and between repeated experiences with the same artwork. Once the emotional state is determined, the emotional hacking techniques shown in this research can be used as a tool for emotional stimulation during VR.

Moreover, when spectators' engagement time with an artwork grows, their impression of the artwork may shift; for example, an artwork may first be dull and later fascinating, or it may require a while for a spectator to acquire an understanding of it. This phenomenon is termed as “second-order outputs” or executive consequences of viewing (Pelowski, Markey et al. 2016). The STHR concept, which was established in this study, offers a conceptual and practical framework for increasing user involvement and overall VR realism by increasing the fidelity of the environment. Aside from that, the usage of a 3D printed model to give haptic feedback may be a flexible and cost-effective technique for increasing engagement because of its adaptability. This kind of feedback can help improve the quality of art-specific or distinctive encounter output (Pelowski, Markey et al. 2017). Furthermore, in the event of a mismatch between the actual space and the virtual space, it is possible to create memories that are inconsistent with the VR experience and lead to poor immersion (Mania and Chalmers 2001). The same is true for certain pictures, which connect immediately with a viewer by recalling memories or thoughts. To solve these problems, the VR setup design should first describe and arrange the processing of the formal elements of the artwork. For example, we may notice our reactions to symmetry, lines, and colors in a piece of art and how these elements are combined to form more complicated scenes and patterns. The concept of "smooth transitioning," as described in this thesis, attempts to reduce such inconsistencies.

5.5 Theoretical framework

Though the theoretical framework for virtual representation of art is not fully established, Mayer's cognitive theory model of multimedia learning and subsequent information processing models can shed some light on the general factors that may affect human perception in a simulated or virtual environment (Mayer and Moreno 1998). Mayer's hypothesis assigns visual and auditory functions as the primary senses engaged in the simulated settings. However, since auditory information is not usually provided in virtual artwork representations, the emphasis on visual impressions increases considerably. Mayer's approach also emphasized information selection, organization, and integration. As a result, it was discovered that Mayer limited the cognitive learning process to two modalities, auditory and visual, with no mention of the touch modality. However, in the case of VR, tactile stimulation, as shown in the study, is critical. On the other hand, the human information processing model, the cognitive processor component, and the motor processor component receive special attention (Coles, Gratton et al. 1985). Sensory inputs (eyes and ears) engage the cognitive processor component, whereas hand motions in reaction to the cognitive processor component activate the motor processor component. Hand motions are recognized as an input tactile modality in the computer by devices such as a keyboard, mouse, joystick, touch displays, and wands. According to the hypothesis of human information processing, this motor processor is critical in the cognitive learning process (Proctor and Vu 2006).

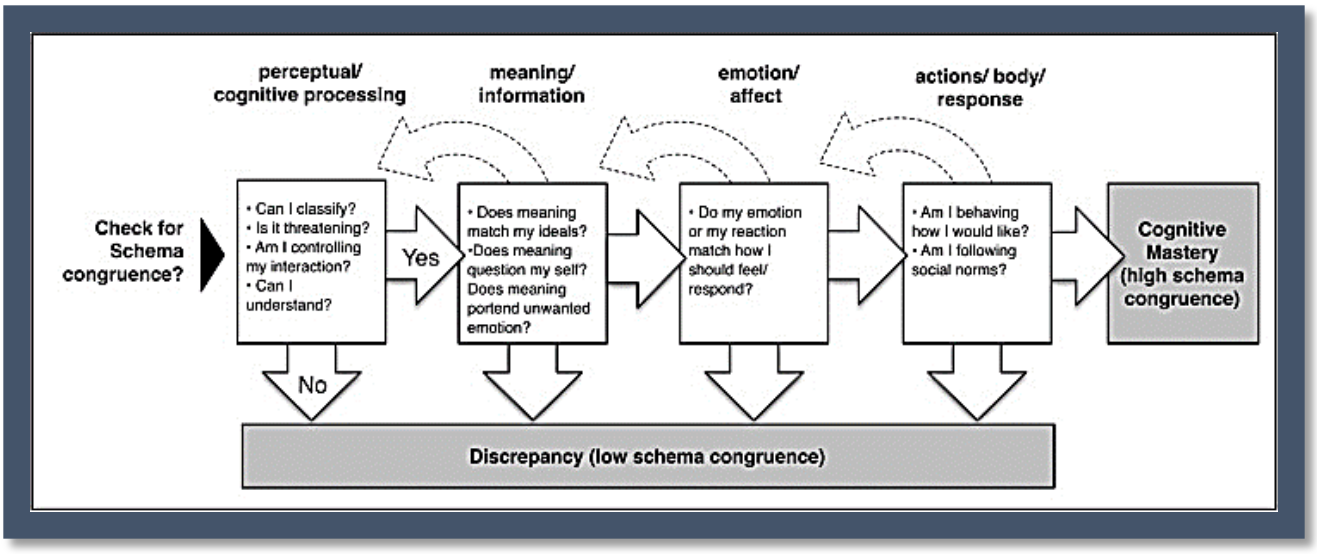

Figure 5.1 Cognition is influenced by the interdependence of emotion and behavior (Pelowski, Markey et al. 2017)

It has also been suggested that a person self-evaluates the wider consequences of information processing (Pelowski, Markey et al. 2017). According to Silvia, this would involve an acknowledgment or assessment of the relative personal importance of the work, its meaning/content, and task/context, as established through the previous stages of the process. An audience member may assess, on a subconscious level, whether they really care about the outcome of their viewing or whether they truly are interested in or need time to absorb the work.

Many characteristics characterize realistic cognition, the most significant of which are self-relevance, congruency, coping, and emotion assessments. Therefore, understanding and appreciating a work of art entails multiprocess cognitive and emotional correlations that are complex in nature (Zaidel 2010). We have used vibrotactile feedback to induce emotional hacking and enhance the VR experience. Psychological alterations that occur when one is in an emotionally stimulated state are the foundation of the notion of emotional hacking. Several types of research have looked at monitoring physiological markers while using virtual reality (Kuriakose and Lahiri

2015, Peterson, Furuichi et al. 2018, Weibel, Grübel et al. 2018, Liu, Clements et al. 2021). In fact, advanced multisensory display systems, such as virtual reality (VR) headsets, provide a level of immersion that may allow for more reliable elicitation of emotional experiences than less immersive displays. These systems can also provide a powerful yet relatively safe platform to induce negative emotions such as fear and anger. However, utilizing a stimulus that causes a physiological response that is often generated during strong emotions has never been tried previously to improve the realism of virtual reality experiences.

In virtual reality, the design of the environment and the method used to enter virtual reality have a significant effect on the overall experience (Coburn, Salmon et al. 2020, Valori, McKenna-Plumley et al. 2020). Findings of this work suggested that establishing a smooth transition from the actual world into the virtual world and back into the real world may be a great option for increasing the realism of virtual reality experiences. The experience of users in virtual environments may be assessed by the notion of presence, which is defined as the subjective sensation of 'being there' (Heeter 1992). A substantial improvement in the VR experience of users was discovered to be achieved by blocking out the actual world and using just modest haptic interactions. Users' prior understanding of real-world space substantially affects the decisions they make during their virtual reality experiences. According to the findings of this study, the use of STHR may improve the VR experience. Our results also demonstrate that inconsistent information between the real world and virtual reality impairs the VR experience.

Moreover, immersion in the VR system can be enhanced by providing more realistic sensations that are more closely related to the physical interaction process (Ryan 1999, Grau 2003). As a result, haptic feedback is essential for enhancing the level of immersion, interaction, and imagination provided by virtual environments. When haptics may provide extra signals for users

to mentally construct an imagined virtual world that is not constrained by space and/or time limitations, users' imaginations may be sparked and intensified (Rostami, Arastoo et al. 2012). Compared to physical touch, the haptic sensation obtained through virtual engagement is much poorer. It is widely used in our daily life for a variety of tasks, such as perception of stiffness, roughness, and warmth of objects in the external environment, manipulation of these objects, and motion or force control activities such as grasping, touching, or walking, to name a few (Azmandian, Hancock et al. 2016). Tactile experiences, on the other hand, are in short supply in the virtual world, both in terms of quantity and quality. The majority of commercial virtual reality headsets only provide visual and auditory input, with just a small number of them providing rudimentary haptic sensation. It is essential to develop techniques that provide sensations that are comparable to those experienced through physical contact. In addition to relying only on visual information, they are deficient in haptic feedback, which enables people to interact with their physical surroundings via a range of tactile qualities. As shown in our research, 3D-printed models may be a helpful tool in developing effective haptic feedback systems in this context.

In this study, we integrated smooth transitioning and haptic feedback to present the concept of Smooth Transition Coupled Hybrid Reality (STHR), in which the participants were first deliberately introduced to a physical object that was a replica of one of the virtual objects that they would see during virtual reality. This step was intended to offer haptic feedback that was consistent with both the real world and virtual reality (Hoffman 1998, Lee, Kravitz et al. 2012). Furthermore, the arrangement was created to allow for a seamless transition from the actual world to the virtual world and vice versa. This process included making the real-world subject as relevant to the virtual environment as feasible while limiting any superfluous information to the greatest degree possible. We were able to enhance consumers' VR experiences by shutting off real-world space and using

limited haptic inputs. Prior knowledge of real-world space has a significant impact on the choices made by users throughout the VR experience. This result indicates that the use of STHR may enhance the VR experience. As mentioned previously, our results also demonstrate that conflicting information between the real world and VR reduces the quality of the VR experience.

It is difficult to design the optimal arrangement for each VR experience; but, by applying the approach described in this study, it is possible to build a semi-unified covered space that can accommodate a variety of conditions. In addition to that, the corresponding items from many other experiences and places, such as fence barriers and glass boxes seen in galleries, may be utilized to facilitate physical interactions with the user. The technical framework described in this study provides many opportunities for increasing the user's immersion in virtual reality by carefully smoothing the transition to the VR world and by including a perceptual stimulus into the experience. As demonstrated in our work by the example of a real-world VR art gallery, STHR is particularly useful in museums and art galleries. We believe that the use of STHR in VR art galleries will significantly impact the way patrons connect with art, as the interaction with artworks involves advanced cognitive function and substantial processing of visual information. In future studies, we believe that some targeted emotions can be amplified by deliberately exposing the VR user to specific visual or auditory information while blocking the extraneous information. Using this approach, the believability of VR can be further manipulated. As the use of VR is going to increase in the near future, STHR could play a key role in improving the quality of the VR experience.

Considering the current state of VR technology, VR experiences cannot realistically simulate a virtual space with high precision. We believe that the space setup and the method to transition to VR significantly influence immersion, but there is little research on it. A standard approach to ensure a smooth transition to VR is to create a controlled environment with replica 3D models of

the actual space to reduce the differences between the natural and VR areas. Slater et al. (2002). stated that creating a gentle transition from the real world into the virtual and back into the natural environment could be a good solution, at least in their experiment. However, the factors that led to this ease of transition are poorly understood.

From video capture, task completion time, and interviews, we noticed that people who saw the real space before wearing the headset had more freedom of movement and were faster in completing the task. We believe that the addition of a barrier/mask increased VR realism. We surveyed the participants about anticipation and hybrid reality after introducing them to a virtual reality environment where there is a mismatch between the real world and the virtual world, and an additional VR object was introduced during the experiment. The experiment revealed that almost half of the participants relied on the real space's prior knowledge even when different visual information was delivered through VR. In addition, participants who did not remember the real space during the experiment became aware of it after the physical interaction, suggesting that physical interactions resulted in a more intense experience. The experiences of the visitors to VAG, which was based on the key concepts of STHR, i.e., providing haptic feedback in the initial phase of the VR experience and maintaining a smooth transition from RW space to VR space, corroborated the above-mentioned results. The average time spent in the gallery was good, suggesting a high level of engagement. The feedback of visitors was generally positive, supporting the use of VAG. More than 80% of visitors rated the experience 4 or 5 on a scale of 5. Notably, there was no negative feedback. Surprisingly, all of them were shocked and did not expect that it was an empty space. Their response ranged from "I was tricked!", "It is an empty gallery," "No way!", "I fell into your plan!" to "There is nothing!" One person laughed and commented, 'You are a good liar!' As mentioned before, we had used a 3D-printed artwork to which visitors could

interact. This 3D-printed artwork was made of plastic; however, the corresponding VR artwork had some metal parts. The participant asked us how we made the art piece and, knowing that it was a 3D printed object, the visitor claimed that '. . did not know you can 3D print with metal! ' Notably, 12 visitors commented that it was an exciting experience to touch a sculptured artwork, which is usually not allowed in conventional galleries. These reactions suggest that the VAG successfully met its objectives.

Overall, incorporating EHVR and STHR concepts into a virtual reality exhibition had good results, with participants seeming to think that the majority of what they saw in VR really existed in real life. In our opinion, this would lead to a greater appreciation of art by the general public.

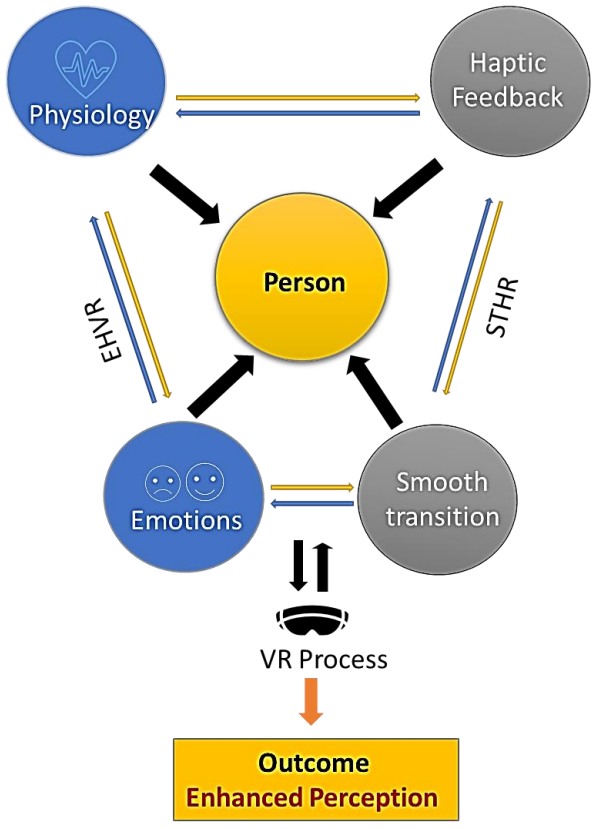

Figure 5.2: Elements of EHVR and STHR in the context of overall VR experience

The above schematic places the concepts of EHVR and STHR in the overall framework of factors that influence VR realism. Emotions, physiology, the mismatch between the real-world setting and the virtual world (smooth transition)(Valkov and Flagge 2017, Okeda, Takehara et al. 2018, Lin 2020, Horst, Naraghi-Taghi-Off et al. 2021), and sensory stimulus by haptic feedback can influence the immersion and perception of the VR (Zenner and Krüger 2017, Lontschar, Deegan et al. 2020). Emotions are an integral part of human existence; in the virtual world, if emotions are not elicited as per the rendered virtual presentations, it may weaken the VR realism. The physiological consequences of emotions are known; for example, an increase in heart rate is known to be associated with several emotions and thus can be used to heighten the realism of VR. Likewise, a smooth transition from the real world to the virtual world is essential to increase the immersion of observers in VR. Haptic feedback may further increase the realism by providing sensory stimulus.

5.6 Relation with the overall research

We established two primary objectives at the outset of the research:

- To investigate practical methods and approaches for improving the virtual representation of artworks and the engagement of participants.

- To use commercially available technologies to provide a framework for an engaging experience with a virtual art gallery.

However, the methodologies and tools necessary to achieve these objectives were not available at the time the research was initiated. Building the EHVR technology was our effort to improve the VR experience. However, when applied to artwork, it became evident that the solution cannot be

applied to all types of artworks. However, showcasing the EHVR system as a solution in real-world public settings provided us with valuable feedback from users, which played a key role in the development of STHR. In other words, EHVR directed us to STHR.

The STHR is a blend of two principles that work together to improve the effects of immersion produced by each other. The concept of a seamless transition is based on minimizing the information of the real area by restricting the VR user's gaze. This helps prevent any contradictory information between the actual world and the VR work, which diminishes the VR content's credibility. As a result, it prevents the formation of a mental representation of the real space. As demonstrated in the third experiment described in Chapter 4, the memory of the actual world always takes precedence in mind. We put up a barrier to do this (wall or curtain). Knowing that the observer has no idea what the actual world consists of makes it easy for them to believe in the rendered virtual art. Notably, observers cannot see the actual environment while wearing the VR headset, which may aid in the application of illusion-like notions. The idea of hybrid reality is created by using proxy objects that correspond to both VR and the real world. We utilized 3D-printed artwork as well as traditional elements such as seats and museum fences. The STHR system might be extended and coupled to be utilized with haptic feedback technologies like the Baxter robot and will increase its efficacy (Devine, Rafferty et al. 2017).

Taking a look at the overall utility of the concepts reported in this work. Our different concepts can be applied at various stages of the VR experience to enhance immersion. The smooth transition (ST) is used before the start and into the VR world (Fig. 5.3). Hybrid-reality (HR) should be applied at the start to trick the user into believing in the virtual objects. Emotion hacking (EHVR) is used in the middle of the experience to increase engagement with VR content. Combining all of this should result in a highly engaging VR experience.

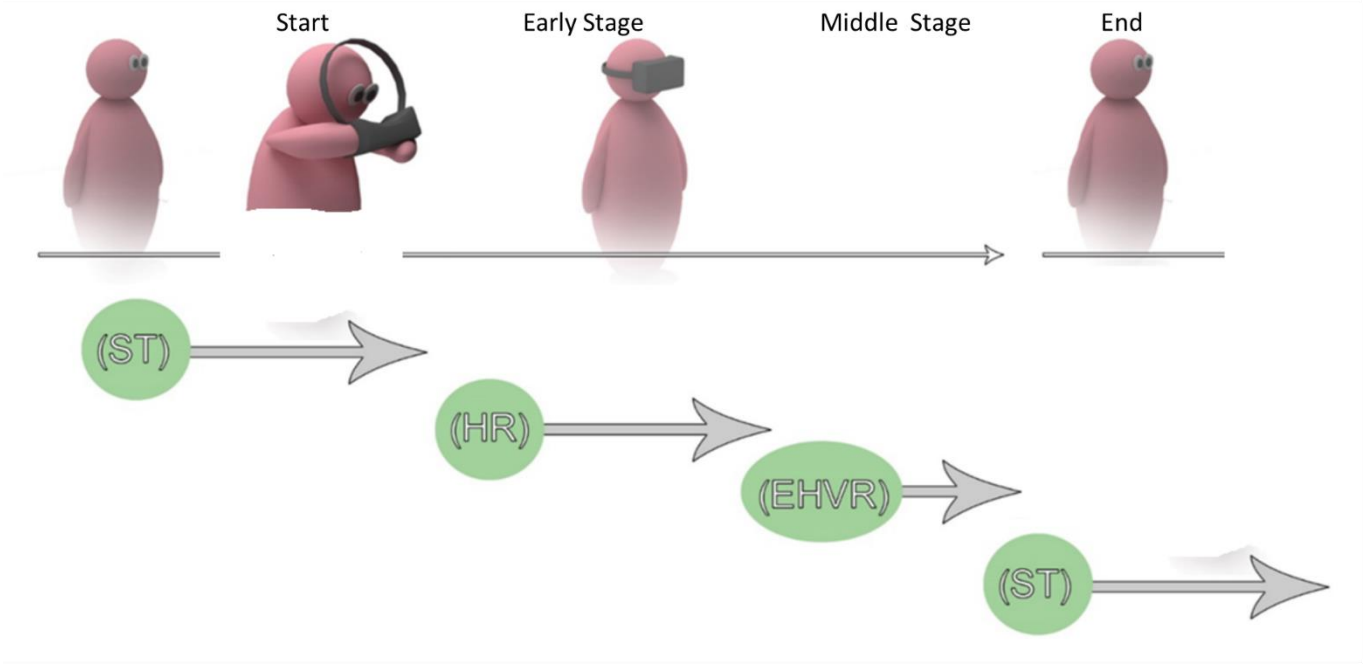

Figure 5.3: Implantation of EHVR and STHR in the different stages of VR experience

Chapter 6

6 Conclusions

In recent years, a growing community of academics has been paying close attention to virtual reality technology, and the technology has made considerable strides. However, creating a realistic experience in virtual representations of things continues to be a significant challenge, even as virtual reality has finally started to move away from its purely theoretical roots and toward its more practical applications. In this thesis, two novel techniques, EHVR and STHR, were introduced, which can be utilized to create a more realistic virtual representation of the artwork. These approaches are simple, cost-effective, versatile, and scalable. Furthermore, this research has conducted several controlled experiments which have documented participants' perceived realism in different settings, providing fundamental insights into the immersive virtual art.

The foundation of EHVR was laid by conducting controlled experiments and real-world validation. In controlled experiments, first, an experimental protocol for adding vibrotactile feedback, which was as a stimulator of the feeling of fear, was established, then the response 40 participants were examined. During the real-world validation, ETHR was applied to random participants in an Art event. Our study demonstrated many important aspects of how these features can be applied, the most notable being the finding that synchronous feedback elicits a more favorable emotional reaction than asynchronous input. The findings of this study demonstrate that emotional hacking has a major impact on the perceived realism of virtual art. Controlled trials and real-world validation were also carried out in the second study, which centered on the idea of STHR. In fact, three different controlled experiments were performed to investigate the impact of spatial awareness and generating physical interaction during VR experience in ways to construct a technical and conceptual framework for STHR. A virtual art exhibition was established for the general public for real-world validation, and tactile interaction was facilitated utilizing a 3D

printed object. STHR results show that spatial awareness has a major effect on the perceived reality of virtual art, and the inclusion of 3D printed items improves the believability of art and expands the possibilities in which artworks are typically presented in a variety of ways.

When used with virtual reality systems, haptic displays, such as 3D printed replicas of artwork, may substantially enhance the degree of immersion and engagement between the user and computer by allowing bilateral signal exchanges between the user and the object. It enables the use of tactile senses that are not accessible in conventional art galleries. Recent research has shown the use of haptic feedback and interaction, both from an evolutionary perspective of providing a better user interface and from a revolutionary viewpoint of allowing applications previously unimaginably difficult to perform (Reeves, Benford et al. 2004, Hall and Bannon 2005). Over the past few decades, haptic technology has undergone a paradigm shift that may be split into three stages: desktop haptics, surface haptics, and wearable haptics. Our study is one of the first to utilize 3D printed objects to offer haptic feedback in order to improve the VR art exhibition experience. The reaction was very favorable, and the vast majority of those who participated expressed a high degree of realism. Based on these findings, it can be concluded that 3D printed items can enhance human haptic perception and can be utilized in the creation of effective haptic devices (Wang, Guo et al. 2019). In the near future, with the advent of advanced additive manufacturing techniques, high-fidelity virtual reality interaction, portable haptic devices, multimodal haptic devices, and high-fidelity haptic rendering will all become more widely available and effective.

Making professional virtual reality applications for art galleries is an unavoidably difficult job because it requires developing a software system that must adhere to stringent quality and time restrictions imposed by human factors. The formation of different setups that may allow for a smooth transition from the real world to virtual reality and vice versa appears to be the primary

constraint for applying the concept of STHR because no single system can provide all aspects required for user satisfaction in different application areas, as has been demonstrated. Diverse packages must be merged, and ad-hoc solutions must be created to combine them into working software in order to successfully use the ideas of emotional hacking and STHR in various situations. Construction of a semi-unified covered area that can handle a variety of circumstances is, nevertheless, a viable option. Beyond that, physical interactions with the user may be enabled by sharing items from various experiences and places. Examples include fence barriers and glass boxes in art galleries, among others.

While there are many options for visual, tracking, and user input interfaces for virtual reality, audio and haptic interface technologies are mainly reserved for research purposes (Giri, Maddahi et al. 2021). In a similar vein, full-body motion interfaces are currently limited to specialized entertainment systems, with support for more general types of movement still being investigated (Aoyagi, Wen et al. 2021, Macchini, Lortkipanidze et al. 2021). This indicates that, although the technology is ready for professional use, it is still in the early phases of developing defined standards and reference points in all areas, including prospective leading manufacturers, compatibility criteria, performance levels, affordable pricing, and human expertise. This is not due to a lack of confidence in the technology's potential results but rather to the fast development and growth of VR, which is perhaps more visible than in other information technology industries.

Our findings on replicating the sensation of a heartbeat and its impact on participants' emotional states open up a new area of research in integrating physiological signals to enhance VR realism. Similarly, the concept of haptic feedback with a 3D printed item offers up new avenues for advanced haptic technology design. However, all of these elements of VR technology would

benefit from a study focused on better understanding the role of sensory cues and human perception issues and further research and development on real hardware and software concerns. This enhanced knowledge is needed to understand how sensory signals are supplied or mimicked and to identify when and how they should be utilized. The following discussion focuses on the specific contributions and limitations of this research.

6.1 Goals, hypothesis, and outcome

As stated in Chapter 1 (section 1.6), the goal of this research was to investigate practical methods and strategies for improving the virtual portrayal of artworks, hence improving the overall virtual reality experience. EHVR (presented in Chapter 3) and STHR (presented in Chapter 4) were the key concepts developed in this work. The following is a summary of the underlying hypothesis and the result obtained.

6.1.1 EHVR

6.1.1.1 Goal

To improve the quality of the VR experience by altering the emotional state of the participants during a VR encounter via the use of physiological feedback.

6.1.1.2 Hypothesis

Providing physiological feedback associated with a certain emotion may improve VR realism.

6.1.1.3 Outcome

In this work, the EH-VR system was built as an interactive system that hacks and regulates a person's pulse to speed up a scary VR experience. The EH-VR technology provided vibrotactile biofeedback through the footrest, simulating the feeling of a heartbeat. The technology was tested

in more than 100 individuals, and all participants' heart rates increased due to feedback. Several further tests confirmed that the EH-VR might have produced this effect by displaying a synthetic pulse to the subject. When asked how genuine they thought the experience was, the vast majority of participants said they thought it was "feeling real" This indicates that a significant number of participants were frightened during the VR event.

6.1.2 STHR

6.1.2.1 Goal

To reduce the divergence between the virtual and real environments and offer haptic input corresponding to the themes of virtually rendered art.

6.1.2.2 Hypothesis

A seamless transition from real-world to virtual reality experience may improve the VR experience; moreover, smooth transitioning combined with haptic compatible feedback can boost VR realism.

6.1.2.3 Outcomes

By introducing STHR, where a mix of real-world and virtual objects was presented during the VR experience, a smooth transition could be made from real to virtual. According to our findings, this strategy greatly increased the time required to complete VR activities and had an impact on the overall attention of the participants. Furthermore, in STHR based virtual art gallery made for the public, the visitors' overall feedback was highly positive. It found that by introducing minimal haptic feedback by felicitating physical matching interactions, the users' perception inside the VR environment could be altered.

6.2 Contributions of the current work

Our endeavor to share the virtual reality framework, from concept to real-world execution, is a significant contribution to the complex field of virtual art production and to increase participation in art galleries and museums in general. Several new contributions were made as a consequence of the research presented in this thesis, including the following:

- Physiological stimulation of dread feelings has been successfully demonstrated, and vibrotactile feedback has been shown to correlate with the actual heartbeats of participants while immersed in a virtual reality experience.
- An EH-VR system was developed and demonstrated in a real-world environment, demonstrating the effectiveness of the approach. Although the present study focused on 'fear,' the idea may be expanded to include other emotions related to the subject of an art museum.
- It was possible to get a complete understanding of the impact of spatial awareness on perceived involvement, realism, and interaction.
- A 3D replica of the artwork was utilized effectively to provide extremely relevant haptic feedback. This concept has been extensively utilized in the context of virtual art galleries and is expected to expand the art experience. This method (the use of haptic feedback by 3D printed objects) will enhance engagement, particularly since visitors are not allowed to touch the object in traditional art galleries, and tactile sensations are virtually non-existent in the experience.
- Participants generally measure presence as a feeling of 'being there,' the degree to which they saw virtual environments as reality rather than a mere picture on a screen, and the degree to which they thought of virtual environments as places to visit (Slater, Usoh et al. 1994). We examine the presence and immersion during the virtual reality experience by examining four key parameters: expectations, realism, attention, and engagement. Our research revealed a statistically

significant and favorable relationship between haptic feedback, emotional hacking, and seamless transitions with the realism of virtual reality. These findings will be helpful in developing a better understanding of perceived VR realism.

- Finally, the technique's feasibility is shown through a real-world virtual art display and overwhelmingly positive feedback. The space design of this work and the 3D printed components are inexpensive and may be utilized in a number of scenarios.

Although these concepts are mainly developed in the context of an art gallery, they can be fairly generalized to other application areas. For example, the notion of emotional hacking described in this thesis may find applications in the treatment and counseling of people suffering from mental and psychological problems. The EHVR technology provides vibrotactile biofeedback from the footrest, which mimics the feeling of a heartbeat. The technology calculates a fake heartbeat frequency by continuously monitoring the user's heart rate. A total of approximately 100 individuals were introduced to the system, and their reactions revealed the success of this approach. Marn-Morales has published a comprehensive review of 42 articles on emotion recognition research that combine physiological and behavioral measurements with head-mounted displays as elicitation devices (Marín-Morales, Llinares et al. 2020). These virtual reality characteristics have proven to be especially attractive for studying pathological processes in mental disorders, and this technology has steadily gained momentum since its introduction in the early 1990s. The main use of virtual reality scenarios in this field is the investigation of the processes that underlie anxiety disorders and their treatment. This area has seen the rise of virtual reality (VR), which has proven itself as a viable tool for investigating threat perception, fear, and exposure treatment. As a consequence, it is expected that the concept of emotional hacking would be used in a number of fields, especially in the healthcare and entertainment industries.

6.3 Limitations of the current work

There are several important limitations of this study. The research is restricted to the setting of virtual representations of artwork; extending the ideas described in the thesis to other contexts may require rigorous re-optimization and situation-specific modifications. Although the concept of EV-HR can theoretically be extended to all emotions, the feasibility of getting suitable feedback for additional emotions that can be utilized in real-world situations without increasing the cost and complexity of the process has to be explored further. Furthermore, since emotions, physiology, and art interpretation entail a variety of subjective assessments, choosing emotional stimulation should be done with caution. Individuals who are hypersensitive, as well as those who have cardiac or mental problems, maybe unfit for intense emotional stimulation.

Additionally, emotional stimulation must be consistent with the subject of virtual art. If several pieces of art or abstract art are exhibited, these methods must be recalibrated or may have practical limits. Haptic feedback utilizing a 3D printed item seems to be a cost-effective and flexible option. However, it only offers tactile input; furthermore, given the limitations of the materials and technology available for additive printing, making a 3D copy of a matching art object, such as a painting, may be challenging. A seamless transition between the virtual and real worlds may have certain practical constraints. Finally, in this study, we focused on the technical side and practical solutions; more research is required to explore the psychological elements of perception of the artwork. In addition to the artwork, there are many surrounding elements that influence the experience. These include the viewer's general background, culture, or memories, as well as expertise and art-related knowledge. The impact of these factors on the realism of virtual artwork requires further investigation.

6.4 Future Work

This study establishes that spatial awareness and emotional stimulation can both significantly improve the VR experience. However, more research is needed to determine how to design virtual reality systems with the greatest positive impact on perceived realism for different artworks. Further development of the EHVR would include a variety of emotions and their combinations according to the theme of virtual art. A more refined version of the EVHR will be created when neurologists and psychologists improve human cognition of the perception of the artwork. Furthermore, additive manufacturing is developing quickly, and 3D printing of large objects with varying textures and depth will be available shortly. The availability of technology such as artificial skin and artificial muscles will broaden the scope of these ideas, greatly expanding the range of haptic feedback that may be given.

While virtual reality technology continues to grow and improve, it is critical that we take the time to evaluate the dangers and opportunities it offers. In particular, there is a lack of understanding about how virtual reality impacts users, particularly young people. Considering that your prefrontal cortex, which is related to emotion and behavior control, is not fully formed in children, many VR device makers include age restrictions and caution about the use (Bailenson 2018). Simulation sickness, which results from a disconnect between one's actual body and the virtual world in which the mind is engaged, is another problem that should be thoroughly investigated and handled effectively.

From the deployment perspective, the high cost and fragility of VR setups impede the widespread use of VR in museums and art galleries. Museums should consider additional maintenance expenses when planning a VR display. Another potential area of future research is the development of the spectrum of possible emotions that may be elicited during a virtual reality (VR) session. It

is critical to avoid becoming fixated on the design and to restrict the scope of research to techniques that are modest modifications. Other considerations include personal hygiene; over the course of a day, a number of people will use headsets. To improve hygiene, it is necessary to develop cost-effective cleaning solutions or disposable masks.

In essence, virtual reality just represents another innovative technology with great potential. (Fox, Arena et al. 2009, Bailenson 2018). The many applications of this technology have the potential to improve various aspects of our lives, but also the ability to bring out unforeseen or unintended effects. The key to success with this technology, as with any other, is to maintain a delicate balance. Whatever its potential for artistic expression, virtual reality seems to be here to stay for the foreseeable future, making it imperative to understand both the benefits and disadvantages of the technology. The results of the current research, as well as its potential ramifications, are yet another testament to the potential that virtual reality has in the field of virtual rendering of artwork.

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