



ABSTRACT VS. LITERAL SOUND DESIGN FOR VR

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Graduation Project Creative Technology

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28-02-2024

Abstract

This thesis explores the potential impact of literal and abstract sound design approaches on cognitive load within VR environments, specifically focusing on enhancing user experiences in museum settings. This project stems from the creation of a user-friendly museum exhibition room, where, because it would mostly concern inexperienced users, usability can play a big role. The project's goal is to design and implement sound effects, with the aim of improving usability for users and in doing so the management of their cognitive load. For the sound design, an expert interview was held and from it the idea to research the design of literal and abstract sound effects and their influence on usability and cognitive load was selected. To evaluate the effects of literal versus abstract sound design, a within-subject experimental design is employed where the conditions of literal and abstract sound effects are tested. While statistical analyses did not yield significant differences between conditions, trends in the data suggest a potential preference for literal sound design. However, challenges such as non-normal data distributions and the slightly unsuitable testing method are acknowledged, highlighting the need for further refinement in methodology and analysis. Valuable observations were also made during the experiment, the evaluation of which can help improve further research significantly.

In conclusion, while the findings offer some very tentative support for the hypothesis, additional research with the suggested improvements is essential to draw definitive conclusions. Nonetheless, the study emphasizes the importance of continued investigation into sound design's role in VR environments, emphasizing its implications for usability and the influence on cognitive load.

Table of Contents

Abstract.....	1
Table of Contents.....	2
Chapter 1 – Introduction.....	4
1.1 Context.....	4
1.2 Problem Statement.....	4
Chapter 2 – Related Work.....	6
2.1 Usability and Cognitive Load	6
2.2 Virtual Reality	7
2.3 Sound Design in VR	8
Chapter 3 – Methods and Techniques	11
3.1 The Creative Technology Design Process	11
3.2 Sound Design.....	11
3.3 Virtual Reality Environment	11
3.4 Experimental Design	12
3.5 Analysis	12
Chapter 4 – Sound Design Procedure.....	13
4.1 Expert Interview.....	13
4.2 Literal vs. Abstract Sound Design.....	13
4.3 Technology Used.....	14
4.4 Literal Feedback Sounds	14
4.5 Abstract feedback sounds	17
4.6 Ambient Sound.....	18
4.7 Implementation.....	18
Chapter 5 – Virtual Reality Environment Procedure	19
5.1 Technology Used.....	19
5.2 Design Choices	19
5.3 The Environment	21
Chapter 6 – Experimental Design & Analysis Method	24
6.1 Test Subjects.....	24
6.2 Experimental Set-up	24

6.3 Evaluation Questionnaire.....	26
6.3 Analysis Method	26
Chapter 7 – Results & Statistic Analysis.....	28
7.1 Statistical Analysis.....	28
7.2 Observations and Open-ended Questions	30
7.3 Other Notable Observations	31
Chapter 8 – Discussion & Future Work	32
Chapter 9 – Conclusion.....	34
References	35
Appendices	38
A. Information Letter	38
B. Consent Form	39
C. Instructions Script	41
D. Evaluation Questionnaire	41
Acknowledgements.....	43

Chapter 1 – Introduction

1.1 Context

Virtual reality (VR) has become an increasingly prominent technology, finding applications across various industries, including entertainment and education. Particularly within the domain of museums, VR offers opportunities to create immersive experiences that complement traditional exhibits, catering to a diverse audience in the digital age [1]. This graduation project initially emerged from an exploration of VR's potential within museum contexts, aiming to leverage technology, specifically head-mounted displays (HMDs), to enhance visitor experiences. However, the integration of VR in museums poses design challenges, notably in managing cognitive load for inexperienced users, necessitating user-centered design approaches to ensure usability and inclusiveness [2]. The project's goal is to develop a user-friendly VR exhibition room using sound design as a central component.

To delve deeper into VR interaction design and address the challenge of cognitive load management, this thesis investigates the role of sound design in enhancing usability within VR environments. By synthesizing insights from literature on usability and cognitive load in VR design, along with an evaluation of common VR and sound design techniques, the project seeks to identify strategies for improving usability. Drawing upon this knowledge, the project aims to design, implement, and test a VR museum exhibition environment integrated with sound effects, specifically feedback sounds for interactions, guided by cognitive load theory.

1.2 Problem Statement

Despite the increasing use of VR in museums, the potential of sound design to enhance user experience remains largely unexplored. In particular, the distinction between literal and abstract sound design approaches and their respective impacts on usability and cognitive load has received limited attention. This research aims to fill this gap by investigating how sound design influences usability and cognitive load in VR environments. Given the challenges associated with managing cognitive load for novice users in VR, there is a pressing need to explore effective design strategies that prioritize user experience and engagement.

This research therefore seeks to answer the following research question by addressing the following sub questions:

Research question

To what extent do literal and abstract sound design approaches in a virtual reality environment differ in their impact on user experience and cognitive load?

Sub questions

SQ1: What existing techniques are relevant for sound design and VR design?

SQ2: How can sound effects for a VR environment in Unity be created and implemented?

SQ3: How can the experience and cognitive load of users in a VR environment be evaluated?

SQ4: How do the implemented sound design techniques impact user experience, and cognitive load?

Hypothesis

Based on common practices within the world of sound design for 360 environments, it is tentatively hypothesized that both techniques lead to a reduction in cognitive load, with literal sound design having a larger impact than abstract sound design. This hypothesis is based on the fact that within most 360 environments, think of games and other immersive experiences, most sound design is kept closer to reality with a slight exaggeration.

Chapter 2 – Related Work

The focus of this research lies within the design of feedback sounds for VR and how it influences the users' experience. However, in order to understand how sound design can play a role in developing a VR environment with good usability, two other factors need to be taken into account. First it is discussed what usability and cognitive load are and how the former has influence on the latter. Then it is explained how sound design might tie into this according to previous research and what techniques might be useful or interesting.

2.1 Usability and Cognitive Load

Usability is a critical aspect of user experience design across various fields, encompassing everything from software applications to physical devices. One of the most accepted definitions of usability has been developed by the International Organization for Standardization (ISO) [3, 4]. They defined it as follows [5]: "The degree to which a program may be utilized to achieve measurable objectives with effectiveness, efficiency, and satisfaction in a specific context of usage". This definition depicts effectiveness, efficiency, and satisfaction as the three main categories of factors of influence. Where effectiveness can be described as the ability to complete the relevant goals, efficiency regards to the amount of resources needed to complete them, and satisfaction relates to how satisfied the user is with the experience. This definition of usability is often used within the field of VR and AR as well [6, 7, 8], further proving its general relevance for the development of VR. Thus, this definition is used going forward.

However, usability covers such a wide range of variables and factors that it can prove difficult to address them all within a single study. Therefore, the focus of the present approach is on the cognitive aspects of usability, namely those covered by cognitive load theory. This enables a more focused approach in evaluating the combination of the VR environment and the sound effects.

Cognitive load can be described as the mental effort it takes to process information and perform tasks [9, 10]. Within cognitive load theory, usually three categories are distinguished [9, 10]: intrinsic load, extraneous load, and germane load. Intrinsic load covers the cognitive load that is caused by the difficulty that is inherent to the subject or the task. Extraneous load contains the cognitive load from any distractions or irrelevant elements to the current information or task at hand. Germane load includes the cognitive load that stems from the integration and processing of new information and turn it into longtime memory and skills (schemas). All these types of cognitive load are usually considered when assessing cognitive load.

In order to assess cognitive load, a measurement technique is required. One of the techniques that is mostly used is a subjective method of assessment, where the participant fills in a questionnaire with statements that are related to the experience and a certain type of cognitive load [6, 9, 11, 12, 13, 14]. The multidimensional cognitive load scale by Andersen and Makransky [15] is an example of such a cognitive load. Their scale is one that is specified for

VR testing purposes, and they adapted extraneous load to VR by splitting it up into three categories: instructions, interactions, and environment. This was done because previous studies had identified these three sub-categories to have an influence within VR especially. Due to its relevance, Andersen and Makransky's scale was chosen for the evaluation of this research. However, they did not mention in their paper what kind of Likert scale they used for the assessment of their scale. Most cognitive load assessment scales use a five, seven or nine-point Likert scale. As for the left and right labels on the Likert scale, some use "very low mental effort" to "very high mental effort" and some use labels regarding how much the participant agrees [9, 10, 11, 12, 13, 14]. The nine-point Likert scale was selected because it covered the widest scale of options. Regarding the choice of labels, "totally disagree" and "totally agree" were chosen because they were thought to be more widely used, easier to grasp than the label regarding mental effort, and more easily implemented within the technology used in this studies (Google Forms).

2.2 Virtual Reality

The relevance of thoughtful user centered design and usability testing regarding VR becomes clearer when a main component of VR is considered. A term that often comes up when talking about VR is "immersion". According to Chitescu [16] VR can provide immersion for the user through its inherent characteristics. Jerald [17, p. 48] also states this characteristic has the potential to engage users, increasing their attention. However, to reach this immersion, the VR interface must not be a big obstacle. Something needs to be user-friendly for it not to be an obstacle to the actual content and so the immersion, and design for usability and evaluating its influence on cognitive load can provide the design process for this. In conclusion, design for usability in conjunction with usability testing, or in this case testing with cognitive load, can provide immersion and is key when designing for VR.

Motion sickness is a well-known problem when it comes to interacting with a HMD VR, and because moving around in the 3D environment is such a vital part of VR, this problem needs to be addressed. Luckily, the field has produced a few techniques to counter this issue. One of these techniques is the use of "point and click" teleportation (TP). Langbehn et al. [18] assessed this technique against two other techniques, redirected walking (RDW), and traditional movement with a joystick (JS). The results of the experiment show that JS significantly increases motion sickness, whilst this is not the case with TP and RDW. These results are strengthened by Buttussi and Chittaro [19], who assessed TP against JS and leaning. They emphasized the strength of TP by concluding the following based on their results [19, p. 134]: "(...) teleport allows users to move faster, causes less nausea and is more usable than the other two techniques". However, Bozgeyikli et al. [20] concluded that there was no significant difference between all their tested techniques, including TP, regarding motion sickness. On the other hand, they did suggest that TP is [20, p. 44] "a good candidate for locomotion in room scale VR", scoring good in almost all the usability, presence and user-friendliness categories. Which was also seen in the results of the two aforementioned experiments [18, 19]. Therefore, regarding the current

graduation project regarding a VR exhibition room, it can be said that TP is a valid user-friendly option for locomotion.

The design of VR is a complex field, considering a multitude of factors. The inherent complexity of VR design emphasizes the importance of user-friendly locomotion techniques and effective user attention guidance within expansive 360-degree environments. The research on locomotion techniques, particularly the validation of "point and click" teleportation within the context of the VR exhibition room project, offers a promising option for user-friendly navigation.

The locomotion system is just one of many things that can be done to improve the usability of a VR environment. In chapter 5 more design choices are covered to improve the usability of the environment. However, the topic of focus for this research is sound design and with good reason. From other interactive experiences like games, it could be devised that sound design is crucial to the making of a clear and good game. Take for example the music in adventure games. The music often changes when the user becomes engaged in combat, becoming more intense or increasing in tempo (see for example *The Witcher 3*, *Palworld*, *Hollow Knight*, *Hogwarts Legacy*, *Zelda* games etc.). This signals to the player that they have triggered combat and need to be prepared to act. Similarly, feedback sounds also give off a signal to the user, but in this case, they signal whether an action has been performed well or what kind of interaction has taken place. Take for example fitting a piece to a puzzle, in virtual puzzling games there are often sounds for both moving a piece and fitting it into the puzzle (see for example *Unpacking*, *A Little to the Left*, *Microsoft Jigsaw* etc.). The first is to inform the user that they are interacting with the object successfully and the second is to confirm that the action was successful towards the goal, in this case the puzzle. These are just two examples of the crucial role that sound design can play in the experience of a user.

2.3 Sound Design in VR

As was mentioned in the previous paragraph, it can be concluded that sound design can play a crucial role in enhancing the usability of interactive experiences; it's difficult to envision playing a game without sound, as it serves to guide and immerse the user. Similarly, in the context of virtual reality (VR), sound design plays a key role in managing the disorientation and steep learning curve often experienced by new users. By providing auditory cues to navigate and interact within the virtual environment, sound design has the potential to provide a more seamless and intuitive user experience. This is done by positively influencing the three aforementioned usability factors that tie into cognitive load. Effectiveness could be positively influenced by the addition of feedback sounds, because they help in achieving the goal of understanding the interactions of the environment. Similarly, efficiency could be positively influenced because the sound effects could help with understanding the interactions quicker and with less mental effort, saving resources. Lastly, satisfaction could be improved by the influence sound effects of the past two factors and it could improve satisfaction because usually users find it satisfactory and natural to hear sound when interacting with objects in an environment. These three factors tie into cognitive load, especially efficiency, since it strives to reach goals as efficiently as possible, using as little mental effort as possible to reach goals. This helps with the

management of cognitive load. Effectiveness also plays a role for cognitive load, especially for germane load, because it can help process the information on the actions more effectively so the user can create a permanent skill or memory more easily.

In the following paragraphs, three sound design factors regarding VR are discussed and how they could tie into reducing and optimizing cognitive load is discussed. In the field of VR, sound design encompasses a diverse collection of methods aimed at creating immersive auditory experiences that enhance user engagement and interaction within virtual environments. Essentially, sound design involves manipulating and integrating various audio elements to evoke emotions, convey spatial information, and guide user attention. Three relevant categories for this VR project are defined based on an expert interview and four articles [21, 22, 23, 24]. One common approach is the use of spatial audio, which simulates realistic soundscapes and provides users with directional cues to navigate the virtual space effectively. These directional sound cues help users orient themselves within the virtual environment by guiding their movements and interactions toward specific points of interest [22, 23].

Another important aspect of sound design involves implementing feedback sounds or sound effects, which offer users auditory responses to their actions within the VR environment [21, 24]. These feedback sounds serve to reinforce user interactions, confirm successful actions, and deepen the overall sense of presence and immersion. Moreover, sound design often includes creating ambient audio in the shape of background music or a soundscape, with the purpose of immersing the user more in the experience. This can help with focus possibly enabling the user to grasp the controls quicker [21, 24].

Spatial sound, feedback sounds, and ambient audio represent three fundamental techniques within sound design that may hold promise for managing cognitive load in virtual reality (VR) environments. Spatial audio, with its potential to provide directional cues and simulate realistic soundscapes, could reduce intrinsic load by assisting users in orienting themselves and navigating the virtual space more effectively. Feedback sounds, such as those confirming successful actions or interactions, might enhance germane load by potentially strengthening mental associations between user actions and their outcomes. By providing clear auditory feedback, users may develop better mental models of the virtual environment, leading to potentially more efficient task performance. A study by de la Mora Velasco et al. showed that sound effects and background music had positive effects on user attention and learning retention [14]. As the study also showed, ambient audio, such as background music or environmental sounds, may influence extraneous load. Well-designed ambient audio could contribute to a sense of immersion and focus, potentially reducing extraneous cognitive load by providing a more engaging and coherent virtual experience. However, it's important to note that excessive or poorly designed ambient audio could have the opposite effect, increasing distraction and cognitive load. Therefore, thoughtful implementation of these sound design techniques may be essential for optimizing cognitive load management in VR environments.

For the purpose of this research an expert interview (see appendix A) was held with a professional within the field of sound design. From this interview it became clear that sound design is a very broad and non-specific field. Meaning that all design decisions are very personal and situational. However, this interview also mentioned that feedback sound, guiding sound, spatial sound, and ambient sound are all important and the main factors to design for in

interactive experiences. The inspiration for the focus of this research also originated from the expert interview. One topic of conversation was the design of literal sounds and that of more abstract sounds. The distinction is further described in chapter 4, but a brief description is given here. Literal sound design is the design of sound that is closer to the real sound an object would make and abstract sound is more a sound that is not necessarily close to a literal sound, but more a sound that could be associated with the object or action. This seemed like an interesting topic of research, because usually a combination of the two is used, but what type of sound design is actually more useful when it comes to the usability and cognitive load regarding a VR environment?

Chapter 3 – Methods and Techniques

In this chapter, various research methods and techniques employed in the development and evaluation of the VR environment and sound design are outlined. These methods and techniques guide the systematic approach towards creating an immersive and user-friendly experience. The chapter begins with an overview of the Creative Technology Design Method, followed by descriptions of other methodologies utilized in the research process.

3.1 The Creative Technology Design Process

A technique for development that is often used within the field of Creative Technology is one developed by Mader and Eggink [25]. This technique consists of four phases which are applied to the subjects that need to be designed and developed for, namely sound design and the VR testing environment. Firstly, during the ideation phase, research is done about what is already out there, what techniques could be relevant, and what ideas could be viable. Secondly, the ideas generated are refined during the specification phase. Then they are realized and implemented during the realization phase. Lastly, they are tested and evaluated during the evaluation phase. These phases are key to designing thoughtfully and will therefore be applied in this research.

3.2 Sound Design

The Ideation phase of sound design involves defining common practices and understanding the potential role of sound in enhancing user experiences within the VR environment. Ideas are generated through a combination of literature research and an expert interview, with a focus on meeting user requirements. In the Specification phase, pilot testing is conducted to refine the requirements of the sound design, leading to the specification of appropriate technologies for recording, mixing, and implementing sounds into Unity. The Realization phase involves the further generation of sound assets and their integration into the VR environment. Evaluation of the implemented sounds is carried out through user testing, with the results analyzed to assess their impact on user experience and cognitive load.

3.3 Virtual Reality Environment

Similar to sound design, the development of the VR environment follows the phases of Ideation, Specification, Realization, and Evaluation. Common practices are identified, and user requirements are defined to guide the design process. Pilot testing helps refine the specifications

of the VR environment, leading to the selection of technologies for creation and execution. The Evaluation phase involves assessing the usability and effectiveness of the VR environment through user testing and analysis.

3.4 Experimental Design

The development of the experimental design covers defining the research methodology and selecting appropriate methods to fulfill the study's objectives. Key considerations include establishing experiment requirements based on previous work, identifying user needs and the required technology, and addressing concerns such as privacy, motion sickness, epilepsy, and eyesight. Additionally, the measurement criteria and their methods are selected carefully, partially informed by cognitive load theory as seen in chapter 2, to ensure a comprehensive answer to the research questions.

3.5 Analysis

For the analysis and the evaluation of the research careful selection of suitable methods and tools for processing and interpreting the collected data is needed. The analysis process is informed by previous research on cognitive load theory and usability testing, ensuring that the chosen methods align with the research objectives and experimental design. Technologies for data collection, distribution of surveys, and analysis of results are evaluated and selected to facilitate the analysis process. Evaluation of the analysis methods used is critical to ensure the validity and reliability of the research findings.

Chapter 4 – Sound Design Procedure

The most important part of this thesis is the sound design, because this is what was tested during the user testing. In order to get an idea of how to create the sounds and what would be interesting to look at an expert interview was done. This chapter discusses how sound can be designed and developed for literal and abstract sound design and this is applied to the four sound effects that needed to be developed: picking up and setting down a pedestal and picking up and hanging back a painting. For these sound effects both literal and abstract sounds were created. In addition to those an ambient sound was created, because otherwise the soundscape might feel a bit empty to the user. All of the final sounds that were used can be found via the Google Drive link in the references list.

4.1 Expert Interview

As mentioned before, an expert interview was held to get a feeling for the field of sound design and what factors might be relevant to take into account. The interview was held with Rik Nieuwdorp, an expert in sound design, specifically for interactive projects, which also includes the field of this project. He is also a professor in sound design for Creative Technology and Interactive Technology at the University of Twente. During the interview, which was about 60 minutes, an open discussion was held about what factors might be relevant for the sound design of this research and what might be interesting to research. First the possible functions of sound were discussed, to get a feeling for what could be designed for and what could be tested regarding sound for the VR environment. Some examples were guiding attention with sound, giving feedback with sound, and providing immersion with sound by making use of, among others, ambient sound. Then some possible properties of sounds were discussed, for example: what emotion or information do you want to signal with it, what pitch do you use, what is the level of urgency, how closely do you want to design the sound to the sound it would make in the real world? Lastly, it was discussed what methods for the creation of the sound could be used and what technologies could be used to employ them. The use of synthesizing sounds versus layering existing or recorded sounds was discussed and the use of Reaper and Audacity was determined. The main take-aways of the expert interview included the choice of designing for feedback sounds, the design and testing of literal versus abstract sound design, and the use of the two relevant programs.

4.2 Literal vs. Abstract Sound Design

As mentioned in the previous paragraph, one of the things that stood out during the expert interview was the idea of literal and on the other hand abstract sound design. This is a concept that, to the best of our knowledge, has not been studied before, especially in relation to VR and cognitive load. To understand what is meant by this, both types of sound design will be explained. The following explanation is based on the expert interview and an article by Jonathan Mitchel [26].

The definition used in this research of literal sound design is roughly described by sound design that is closest to the sound an object would make in a real-world setting. So, for example, when the movement of a sword quickly moving through the air is animated and needs sound, literal sound design would match the sound made in the real world as closely as possible. In the real world this movement merely makes a swooshing sound through the air. This sound could be created by recording said movement in the real world or by matching it as closely as possible by combining different sounds and mixing/processing them e.g. by adjusting volume or introducing an equalizer. In short, literal sound design tries to match the real-world sound as much as possible. The power of literal sound design could be that it might speak to the imagination of the user really well, because the sound might sound familiar.

On the other hand, the definition used in this research for abstract sound design is best described as a more subjective and artistically inclined technique. A method that looks more toward association and intuition. Take the previous example of the sword moving quickly through the air, one could associate the sound with a more metallic sounds, because of the material of the object. Therefore, with abstract sound design the sound effect might sound more like the combination of the swish and a metallic ring. This could be made by synthesizing a sound and/or combine it with a recorded sound that is then again mixed and processed. Concluding, abstract sound design is a very subjective, but also a very free method of sound design, with a lot of possibilities and creative freedom. The power of abstract sound design could come from the focus on associative thinking.

4.3 Technology Used

Various technologies were employed throughout the sound design process to create and implement immersive audio experiences within the virtual reality (VR) environment. At first samples from Freesound.org were used to compose sounds. However, as it later turned out, it was more efficient and effective to record the audio. To capture high-quality recordings, a USB microphone was utilized, in an attempt to record audio as clear as possible. In the production stage, Reaper, equipped with a VST effects library, facilitated the design and processing of the sounds. Subsequently, Audacity was employed for sound leveling, ensuring consistency in volume levels across different audio elements. Finally, Unity served as the platform for implementing the finalized sounds into the VR environment, providing the necessary tools and functionalities for seamless integration. For specific details on the implementation process, refer to Chapter 5.

4.4 Literal Feedback Sounds

Please recall that literal sound design intends to create a sound that is as close as possible to the original sound the object would make. At first a layering technique was used for the development of the sounds, so layering multiple samples on top of each other with virtual sound

effects applied to together form one sound. However, in the end this technique proved to be quite difficult to apply and create sounds that are as close to reality as possible. Therefore, a different technique was opted for in the end. But the process of the first technique and the struggles that came with it are still relevant for the design process, therefore they will shortly be explained and mentioned.

For the design of picking up a painting from a wall multiple samples were used during the usage of the first technique. Two different samples of something scraping wood were used. The sample that comes first in the audio represents the friction of the painting across the wall as one pushes the painting up from the hook. To this sound an equalizer (ReaEQ) was applied in Reaper (see Figure 1) and the sound was pitched down 0.1 semitones. The second sample represents a quick scrape as the painting is picked up from the wall. ReaEQ was also applied to this sample (see Figure 2) and it was pitched down 0.2 semitones.

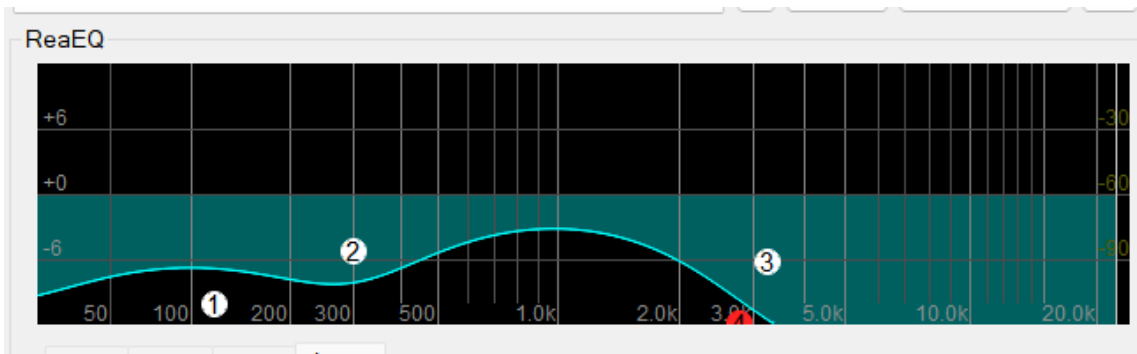


Figure 1: ReaEQ equalizer in Reaper for the first sample used for the realistic picking up sound of a painting

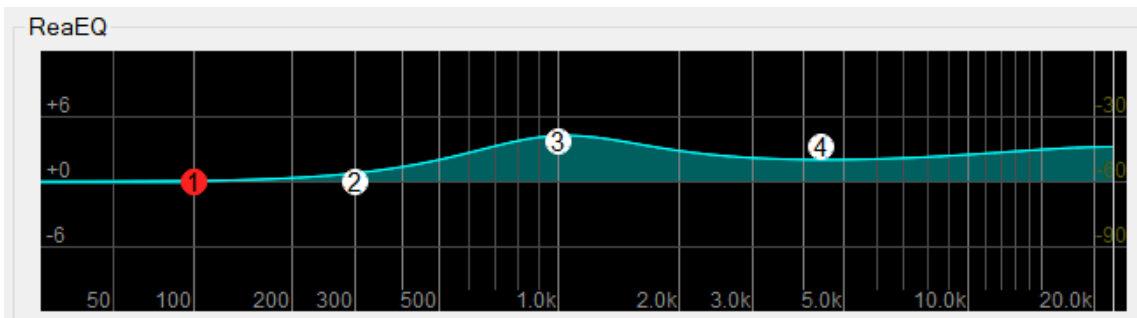


Figure 2: ReaEQ equalizer in Reaper for the second sample used for the realistic picking up sound of a painting

However, as discussed before, this method proved difficult to master. Therefore, a different technique was chosen, where a recording was made of multiple instances of the action that is similar to the action in the environment. In this case a recording was made of someone slowly picking up a small frame from a wall multiple times and the instance that was closest to the desired sound was chosen. This sound was pitched down 0.5 semitones and any noise was removed using the ReaFir effect from the VST library. The removal of the noise is done by first giving ReaFir a sample in the recording where it is “silent”, so this can be removed from the whole recording.

For the sound of hanging a painting on a hook at first the same method was used. Sounds were combined, namely another wood friction sound and the sound of setting down a cup. The first represented the painting scraping against the wall as one slowly lowers it to the height of the hook. To this sound the ReaEQ equalizer was applied as seen in Figure 3 and the volume of the overall sound was also lowered, because the recording was more “heavy scraping” whilst a painting scraping against a wall should not sound that intense. The second sound, putting down a cup, represented the painting making contact with the hook and the bottom of the painting knocking against the wall as it is laid flat. The volume of this sound was also lowered, because again it should not sound very heavy or loud since one usually hangs a painting gently.

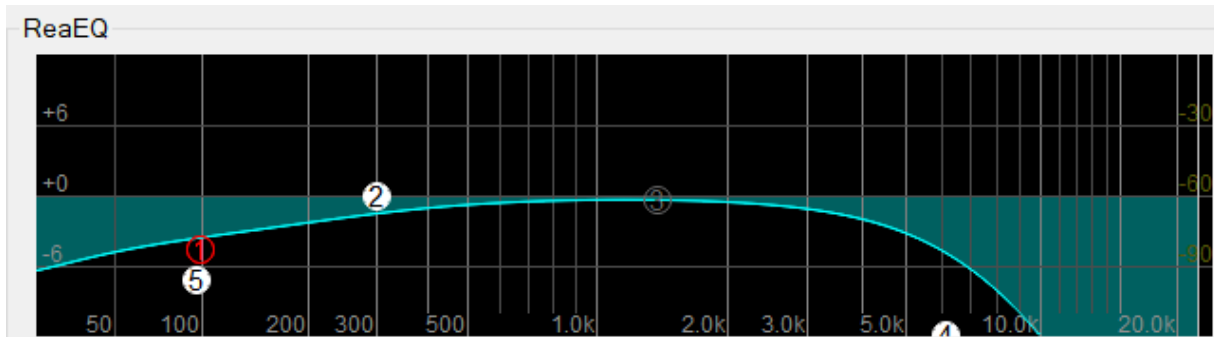


Figure 3: ReaEQ equalizer that was applied to the wood scraping sound used for hanging down a painting

For this sound effect the method gave slightly better results, but again using a recording of the movement was chosen as the better option. So multiple takes were made of the sound after which the best was chosen. This sound included the painting first scraping against the wall and then a small thud for the top of the painting making contact with the hook and the bottom of the painting making contact with the wall. This sound was again pitched down to compensate for the smaller size of the painting used in the recording and was also filtered of noise again using the same method as before.

After the development of the literal sound effects for the paintings was finished, it was time for the literal sound effects of the pedestals. From the design process of the sound effects for the paintings it was already concluded that layering of existing sounds was not an effective method for the purpose of this research. Therefore, the same method was used of recording multiple takes of the action in real life with the USB microphone for both the picking up and the putting down of the pedestal. For both sounds the noise was removed as before using ReaFir.

Regarding the creation of the literal sound effect for picking up a pedestal, multiple recordings were made of a glass jar swiping across a wooden floor and then, with a quick flick of the bottom of the jar against the floor, it being picked up. The best version was chosen and sped up by a factor of 1.2 because the dragging sound felt too slow as well as the flicking sound of picking it up. It was also pitched down by two semitones to compensate for the weight of the jar in comparison to that of the pedestal.

As for the creation of the sound effect of putting down a pedestal a recording was made of putting down a glass jar on a wood floor multiple times. From this recording two snippets were chosen: one for the first side of the pedestal hitting the floor and another “thump” for the complete bottom of the pedestal making contact with the floor. Because the glass jar made a different sound than a solid marble or stone pedestal wood, some effects were applied. First, the sound was once

again pitched down by six semitones to account for the difference in weight between the two objects. Second, the ReaEQ equalizer was employed once more as seen in Figure 4. This was done to eliminate a jingling sound the jar made because it is glass, and this would not be heard when putting down a solid object like the pedestal. This sound is comprised of higher frequencies, so these were filtered out using the equalizer. Last, a slight reverb was added, because setting down something so heavy in a mostly empty exhibition room would echo a bit. This was done by using the Sanford Reverb module. All the sound effects mentioned so far were mastered (adjusted in volume to match each other) in Audacity.

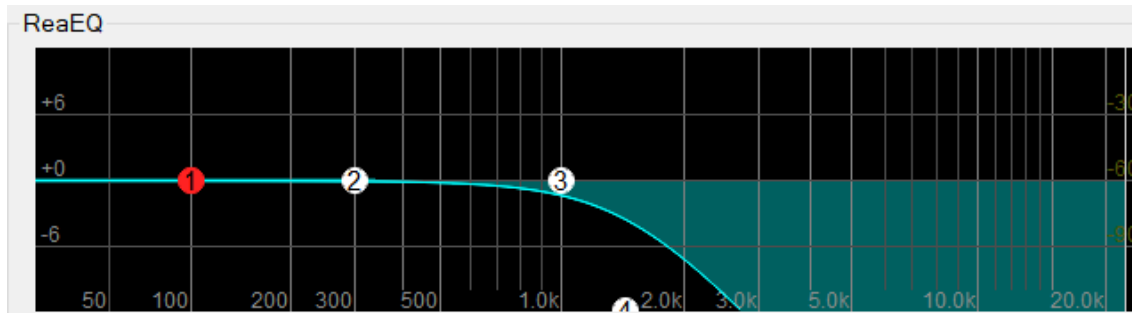


Figure 4: ReaEQ equalizer that was applied to the recording of putting down a jar

4.5 Abstract feedback sounds

The process for the creation of the abstract feedback sounds proved to be a more efficient process after the creation of the literal feedback sounds. Again, the utilization of original recorded material was opted for because synthesizing and manipulating existing sounds from a limited sound library are difficult techniques to master, and the used technique offers more flexibility and creative freedom. For both different objects that can be interacted with the same sound effects were used, since abstract sound design regards a more associative style, so picking something up was associated with the same sound for both objects and putting something down was associated with the same sound for both objects.

The sound effect for picking something up was inspired by the Minecraft “pop” for picking up items. The sound was made by recording someone making a plopping sound with their mouth and finger multiple times. Then, a recording was picked where the plopping sound went up in pitch towards the end, as an analogy to also picking something up. The recording was filtered of any noise by using the same method as before and then mastered in Audacity.

Finally, it came to the development of the sound effect for putting something down. A similar sound to that of picking something up was used, but a different recording was chosen. The recording that was selected was a “pop” sound that went down in pitch at the end. Just like before this is an analogy to the user putting something down. The recording was also filtered of any noise and mastered in Audacity.

4.6 Ambient Sound

Multiple ambient sounds of a museum were sourced from Freesound.org. They were carefully selected, making sure that the base of each ambient recording matched in tone and general sounds to some extent. A seamless loop was created using a common technique in sound design. First a more silent moment in the final ambient sound must be chosen and a cut should be made there. Then the two newly formed samples should be switched around and overlapped in the middle. This overlap with a fadeout from the first sample and a fade in from the second sample creates a seamless connection between the two samples. In addition to that, because the start and end of the loop used to be attached, this creates a seamless loop. In Figure 5 this ambient sound can be seen with the fade in and fade out in the middle.

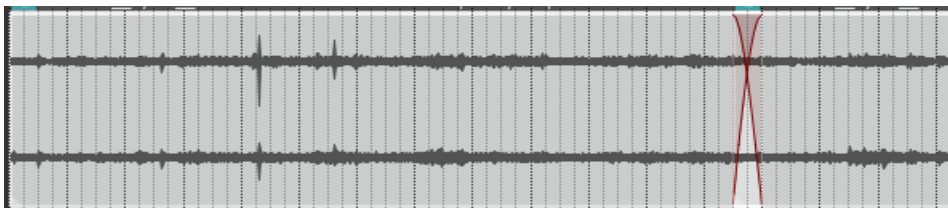


Figure 5: Screenshot of what the ambient loop looks like in Reaper, notice the cross-over in the audio (in red)

4.7 Implementation

In the sound design implementation process, careful consideration was given to how sound effects were attached to objects within the virtual reality (VR) environment. To enhance user immersion and intuitiveness, sound effects were directly linked to the corresponding objects, aligning with the natural expectation that objects generate sounds when interacted with. Similarly, for the ambient soundscape, a stereo sound was attached to the sound-player of the player, replicating the typical experience of central, omnidirectional ambient sounds within VR environments. For more detailed technical information about the implementation, refer to paragraph 5.3.

Chapter 5 – Virtual Reality Environment Procedure

For testing the designed sound effects a platform was needed. As has been discussed before, in chapter one, this research comes from the context of the desire to improve upon VR museums. Therefore, a VR exhibition room was built using Unity and its built in XR library. This chapter talks about the required technology, the design choices made, and the process of creating the environment and implementing the sounds.

5.1 Technology Used

- Unity 2022.3.15f1
- YouTube tutorials
- Unity assets for the paintings and for the hand models and animations
- Custom build computer
- Oculus Quest + controllers

5.2 Design Choices

To maintain immersion and minimize user confusion, various design decisions were implemented. Firstly, users can't rotate their view using a joystick, relying solely on head and body movements. This restriction aims to deepen immersion and simplify interaction by reducing unnecessary options. Secondly, adjustments were made to where the user's virtual hand grasps objects, enhancing the grabbing experience and immersion by not having the placement within the object, but rather outside of it. Moreover, paintings automatically "snap" to nearby hooks when released, also showing up in blue when the user hovers a painting close to a free hook (see Figure 6). This streamlines object interaction and makes it easier for users to hang paintings. These changes aim to reduce user confusion by providing a more intuitive interaction with virtual objects.



Figure 6: A painting is hovered nearby an available hook, showing up in blue

To further lessen the confusion of the user a flexible locomotion system was implemented. This system offers multiple options, including teleportation with the left trigger button (as mentioned in chapter 2) and a pointing laser (see Figure 7), walking within a restricted area, and the use of a joystick. The rationale behind this approach is to prioritize immersion and accommodate different use cases, travelling further (teleportation) and shorter distances (walking around and joystick movement). By providing multiple movement methods users can choose the one that best suits their comfort level and the need for either short- or long-distance movement. One thing of note about the additional option of movement with the joystick is that this was not just a design choice, but also a necessary choice. Sometimes when the player teleported, they ended up stuck in the ground, a bug that was not fixed during time constraints. By using the joystick to move a bit they could get out of the ground again.

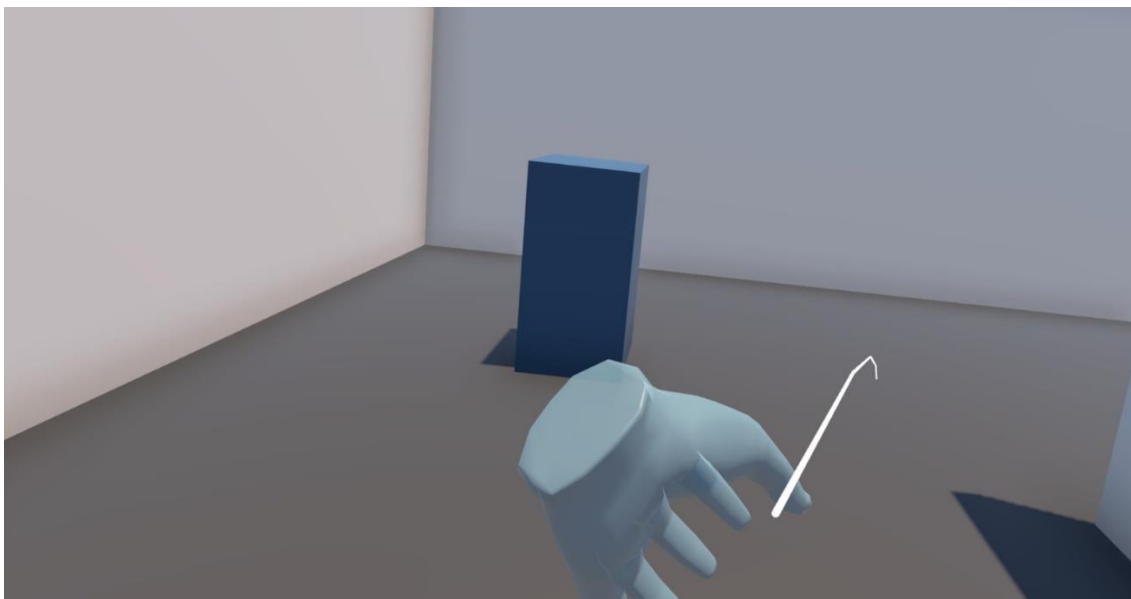


Figure 7: Screenshot of the point of view of the user in the Unity environment pointing their teleport ray

Regarding user engagement, deliberate choices were made to encourage exploration and interaction. There are more hooks than paintings, encouraging users to interact more extensively with the environment. Similarly, pedestals are strategically placed in unconventional locations, such as the middle of the room, prompting users to explore and move them around, fostering discovery and interaction. In addition to that, the environment in general was made more interesting by providing walls or room divider in the middle of the room. These design decisions aim to actively engage users and promote a sense of agency within the virtual environment.

To enhance user engagement and learning, the user starts the VR experience in a tutorial area, or "nook," at the beginning of the experience (see Figure 8). This area introduces users to the virtual environment, familiarizing them with controls and mechanics before freely exploring the exhibition space. The tutorial consists of three steps: first, users navigate around the corner following verbal instructions to understand movement controls. Second, they interact with a painting by moving it to a nearby hook, demonstrating object interaction mechanics. Lastly, users move a pedestal to any location within the vicinity, practicing object manipulation and spatial navigation. By providing users with structured guidance, the tutorial facilitates a smoother transition into the experience, ensuring users have the necessary skills to navigate and interact effectively within the virtual space.

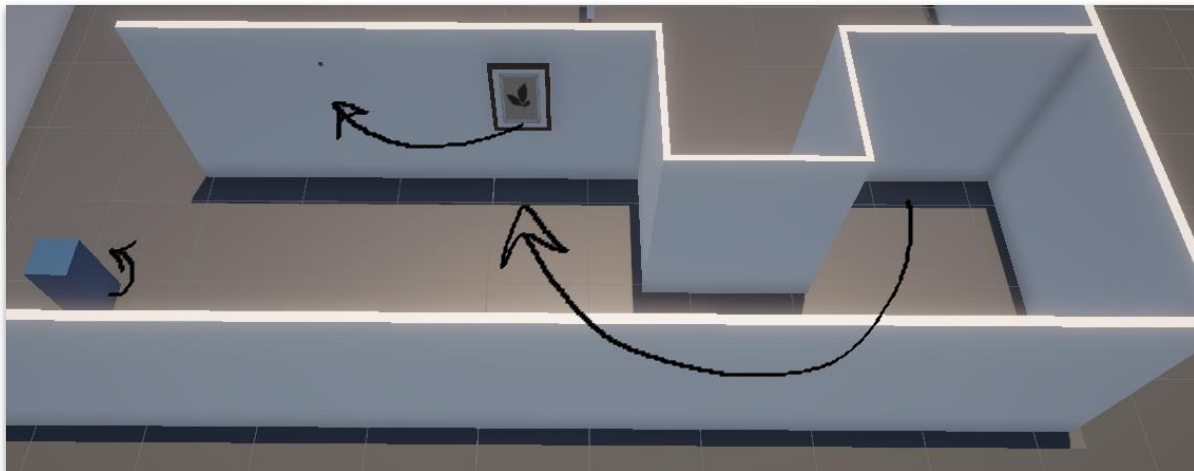


Figure 8: The tutorial area in the Unity environment

5.3 The Environment

The first step in the creation of the environment was adding the physical elements. The floor, walls, hooks, and pedestals are all made by adjusting standard shapes that are available in Unity and assign basic materials in different colors, with a more metallic look for the hooks (see Figure 9). The paintings were imported from an asset by Webcadabra [27]. In addition to the physical elements, a light source was also required, in this case a directional light source. There is either a collider or a collider and a Rigidbody attached to every object in the environment.

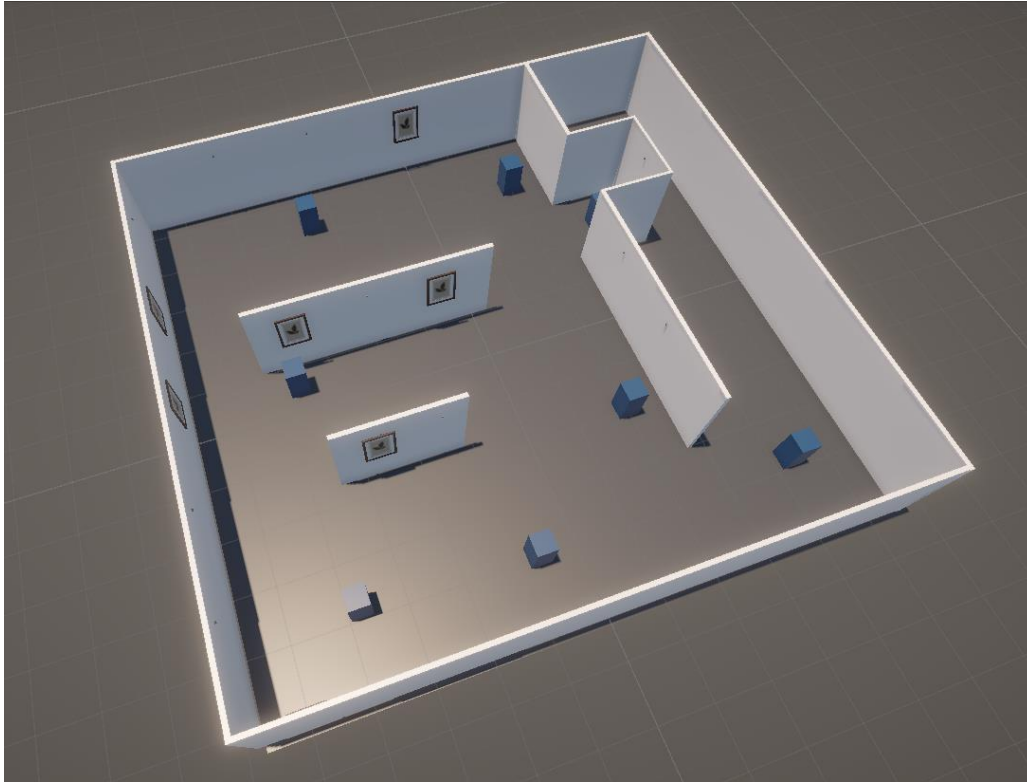


Figure 9: Layout of the final VR environment in Unity

With the basic environment down, it was time to create and implement the VR system. For this purpose the Unity XR library, a public library specifically dedicated to the development of VR, was used. To get an understanding and an idea of how to implement this, multiple YouTube tutorials were utilized [28, 29]. From this it was concluded that the most essential component of the environment is the VR rig. This is an object to which the user camera is attached and which the user can control. There are a few elements attached to such a VR rig:

- The main camera that is fixed to the view of the user.
- A locomotion system which houses standard scripts for the three locomotion methods [28, 30].
- An audio listener so the user can receive and hear the audio that is played from audio sources.
- A left- and right-hand rig and model, for which a YouTube tutorial was used with included hand model assets by Oculus [28].
- An interaction manager, in which the input is managed and connected to certain functions.

The third step in the VR environment was implementing the interactions with the interactable objects, namely the paintings and hooks, and the pedestals. The latter utilized the XR grab interactable component, which is a function from the XR library [28, 31]. This component enables the user to grab the object using the designated grabbing button, in the case of this research the button on the inside of the controller was chosen. For the hook and painting system first an XR grab interactable component was also added to the painting, so the user can move it

around. Then an XR socket interactor component was added to the hook [32, 33, 34]. A socket interactor can allow for an interactable object of a certain layer to “attach” to the socket, in our case a painting attaching to a hook. The physics of the painting get disabled once attached, so the painting will stay floating on the hook and not fall to the ground. The physics are enabled again when the user takes the painting of the hook by hovering within the trigger box of the hook and pressing and holding the “grab” button.

The sound effects were implemented using pre-defined events within the Unity XR interactable and socket components. These components included events that several different functions could be attached to, in this case the playing of the sound effects was added to events. An example can be seen in Figure 10 where a screenshot of the relevant components for the sound implementation of a hook are shown. The realistic sound of the painting being put back is played when the hook has “selected” a painting (Select Entered). The realistic sound of a painting being picked up is played when the hook “deselects” a painting (Select Exited). In order for these sounds to be emitted, an audio player that emits spatial sound was also added. The ambient sound mentioned in chapter 4 was implemented by adding an audio component to the light source where the audio is played in stereo (so not spatialized) continuously in a loop.

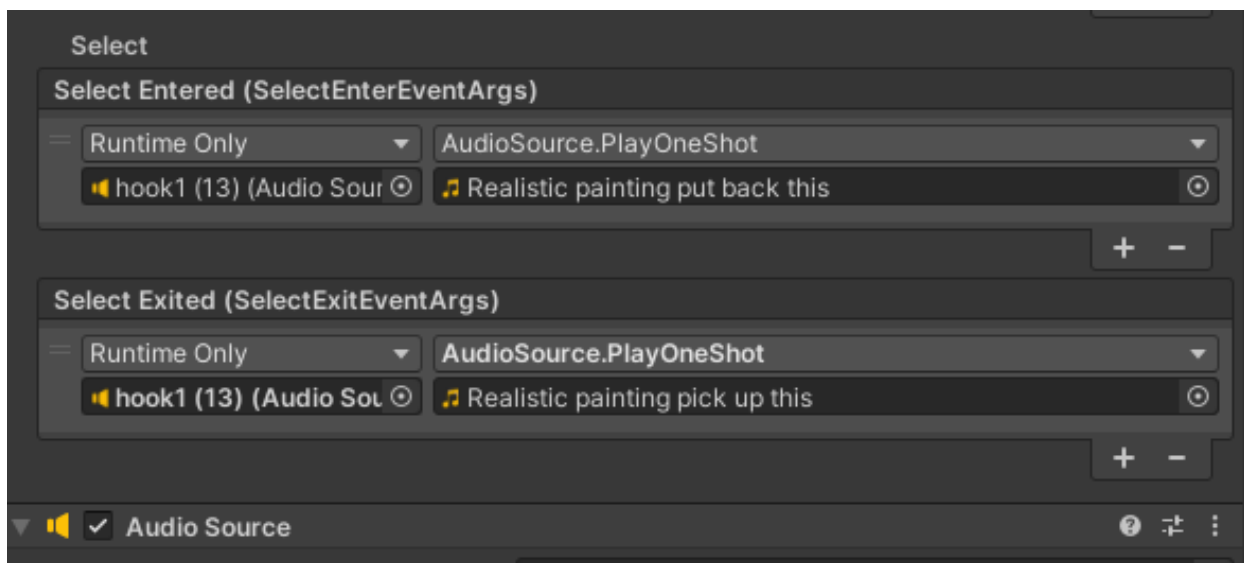


Figure 10: A screenshot of the implementation of the audio for the hooks: two events that play audio and an audio source that emits the sound

This whole design process cumulated to a usable museum exhibition environment as seen in Figure 8. Which formed a solid base for the testing of the sound effects mentioned in chapter 4.

Chapter 6 – Experimental Design & Analysis Method

In order to answer the research question, the virtual reality (VR) environment with the sound effects should be tested. Therefore, an experimental design is needed, together with the method of analyzing the results.

6.1 Test Subjects

As mentioned in chapter 1, the purpose of this research is to find out whether the difference between abstract and literal sound design has any influence on the usability and the cognitive load of the user of a VR environment. However, the research originates from the context of VR museums. Therefore, "the general public of a museum" is considered as the population of this research, so anyone could be a participant, however, some participants will be excluded, because of practicality, the risks involved with VR, and the reliability of test results:

- People under the age of 18
- People with motion-sickness
- People with epilepsy

Sixteen test subjects were recruited via WhatsApp or word of mouth. Most of them were students due to time constraints and availability. Of the sixteen test subjects fourteen provided usable data. At the start of the testing there was a slight hiccup with the Unity environment and therefore the first two subjects could not fully perform the experiment, so their data was excluded. However, their user testing was very helpful for the finetuning of the experiment and made the later experiments go more smoothly.

6.2 Experimental Set-up

There were two locations where the testing took place: across the Interaction Lab inside the Citadel building at the University of Twente (see Figure 11), and in a bedroom. The experimental set-up consisted of:

- a VR head mounted display (HMD), the Oculus Quest 2, and its two controllers
- a computer with the Unity project to which the HMD was wirelessly connected
- a phone for a timer
- a separate laptop used for the evaluation questionnaire



Figure 11: Experimental set-up

There were two different experimental conditions or independent variables: abstract sound effects (A) and literal sound effects (B). Due to the constraints of this research and thus the limited participants, the test-subjects do the experiment two times consecutively with the two conditions, within subject testing. Therefore, learning and repetition could influence the results. In order to minimize this influence, the order of the conditions alternated between AB and BA.

The test-subjects were first briefed and given an information letter (see appendix B) containing all of the necessary details needed for informed consent form (see appendix C). Which they signed after reading the information letter. Then the subjects were told to put on the HMD and hold the controllers. During their experience the experimenter gave the user a set of instructions following a script (see appendix D) to explain to the user what tasks they will have to do and how to perform them. During the first two participants it was observed that participants did not really notice or pay attention to the sound effects. Since this would hinder the results of the experiments it was decided that the experimenter would tell them before they put the HMD on that: “The research is mainly about the sound design of the environment”. The tasks that the participants had to perform were:

- Tutorial: move one painting that is on the hook to the hook next to it and move the pedestal to the left of it to any spot in the vicinity (see figure 7 in chapter 5)
- Move four different paintings to a different point in the room
- Move three pedestals to a different point in the room

Both of these numbers were chosen arbitrarily, to give the subject enough to do to properly experience and test the environment. There were more hooks to put paintings on than pedestals in the room, hence the difference in the tasks. During the experiment the completion time of the tutorial was recorded. However, for this measurement a larger margin of error needs to be taken into account, because even though a script was followed, there will be slight variations in timing.

After the completion of these tasks the subjects were asked to fill in the same questionnaire after both iterations of the experiment with questions regarding the experiment and the experience. The results of this questionnaire amount to, together with the recorded completion times, the dependent variables of this experiment.

6.3 Evaluation Questionnaire

The questionnaire included 23 questions. Firstly, three demographic questions were posed, regarding their age, their gender, and whether they had previous experience with VR and an HMD. These three factors were considered since they possibly influence the results. Secondly, there were ten statements based on different cognitive load types, which were adapted from a study by Andersen and Makransky [18]. In their paper they researched the use of certain evaluation phrases for assessing the three different types of cognitive load, as mentioned in chapter 2. Thirdly, four questions regarding the sound design specifically were developed based on the phrases of Andersen and Makransky. Three of them assessed the extraneous load from the sound design and one assessed the germane load from the sound design. Lastly, three open questions were asked regarding the VR environment, the sound design, and the experiment in general, to gain more insight into the thoughts of the participants.

The phrases used for this research were based on Andersen and Makransky's researched and validated multidimensional cognitive load scale [18, tab. 4] (for the exact phrases and their relation to the phrases of Andersen and Makransky see Appendix E).

As mentioned in chapter 2 it is usual to use a Likert scale when using a subjective assessment of cognitive load using a questionnaire. In this case a 9-point Likert scale was used with on the side of one "strongly disagree" and on the side of the nine "strongly agree". The questionnaire was created using Google Forms, which was connected to a Google Sheets document for easy data collection and analysis.

6.3 Analysis Method

For the evaluation both Excel and SPSS were used. Excel was used for mean calculation and t-tests and SPSS was used for normality testing. The p-value based paired samples t-test was chosen, because this is a method commonly used to test whether the difference between the mean of two groups is significant. However, this test assumes a few properties of the dependent variables namely: the data is continuous, the data is normally distributed, the variance of the two samples is similar, and the population is randomly sampled from a population.

Regarding continuous data, the data from the multi-dimensional cognitive load scale is recorded in a Likert scale, a form of non-continuous data. However, for the first five cognitive load categories that are tested, multiple questions are asked regarding the same category and these values are averaged, resulting in a semi-continuous variable. Therefore, this assumption might be made for the t-tests regarding these five categories. For the last category though, germane

load, this has to be taken into account when analyzing the results. As for the normality of the data, a Shapiro-Wilk test was conducted in SPSS to test whether the data is normally distributed, so $p < 0.05$. When it comes to the similarity of the variance, Levene's test is not needed, since this is not required when the samples are similar in size, which is apparent with paired sample testing. Lastly, there is the assumption of a randomly sampled population. Due to the time constraints and limitations of this research all of the participants were students of various backgrounds. This means that the sample is not randomly sampled and therefore cannot be used to generalize the results for the whole population. However, since all the participants are close to randomly sampled from a population of students, significant results could say something about the population of university students.

Chapter 7 – Results & Statistic Analysis

To gain knowledge from the user testing, the results of the experimental observations and evaluation questionnaire are gathered and analyzed in this chapter. First, quantitative results are discussed, then the qualitative results, observations and answers to the open questions of the questionnaire, and lastly some other notable observations are discussed. These observations could have been relevant to the results of this research, but do not directly relate to the research question. They could also be helpful for future research withing virtual reality (VR) development and user testing.

7.1 Statistical Analysis

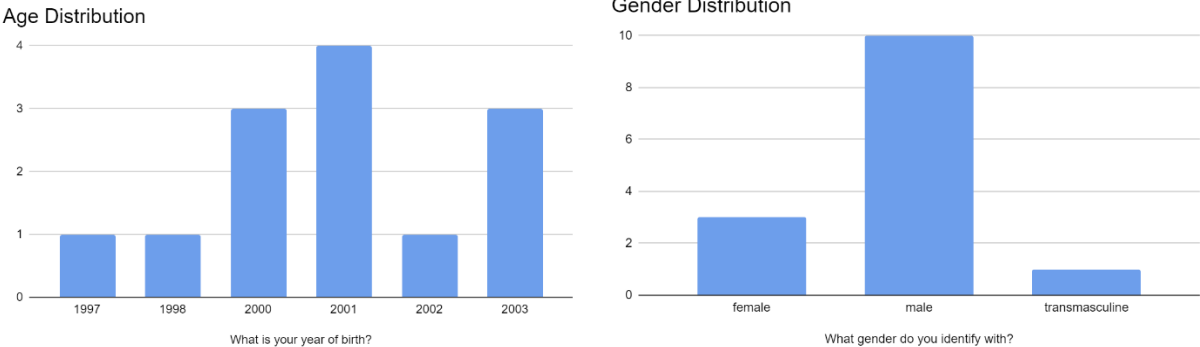


Figure 12: On the left a histogram of the age distribution of the participants and on the right a histogram of the gender distribution of the participants

In the figures above the age and gender distributions are shown. The average year of birth is 2000 and there were three female participants, ten male participants, and one transmasculine participant. Notice that fourteen participants are shown in the demographics, but 28 datapoints have been collected due to the within-subject experimental design.

Previous Experience with VR

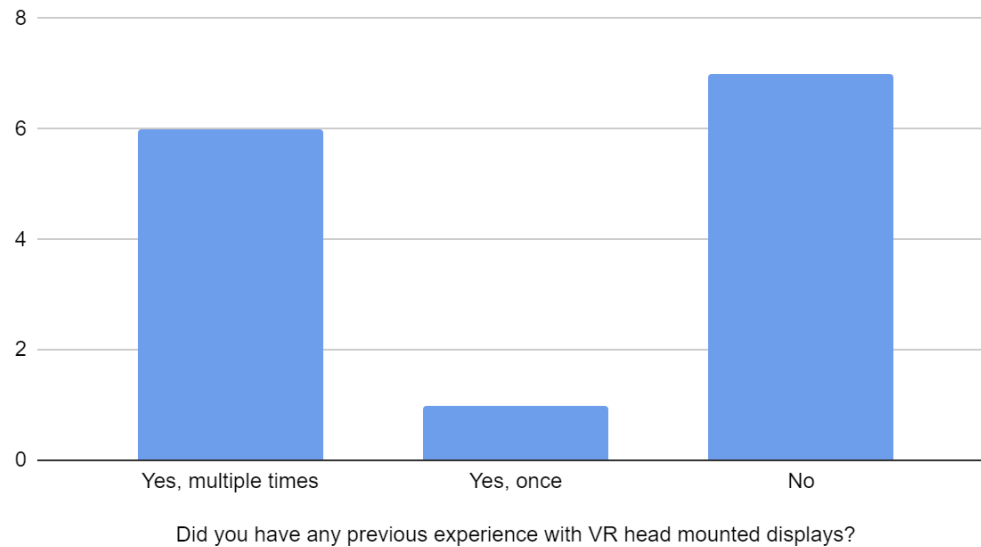


Figure 13: Histogram depicting the participants' previous experience with VR

In the histogram above, the participants' reported previous experience with VR is shown. Seven participants had no previous experience, one participant had only used it once, and six participants had used it multiple times.

Tests of Normality

	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
abstract_intrinsic	,180	14	,200*	,891	14	,084
literal_intrinsic	,218	14	,069	,768	14	,002
abstract_extins	,324	14	,000	,595	14	,000
literal_extins	,290	14	,002	,649	14	,000
abstract_extint	,219	14	,067	,878	14	,055
literal_extint	,206	14	,110	,887	14	,074
abstract_extenv	,317	14	,000	,740	14	,001
literal_extenv	,247	14	,021	,798	14	,005
abstract_extsound	,254	14	,015	,848	14	,021
literal_extsound	,268	14	,008	,826	14	,011

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure 14: SPSS table with the normality tests of the data

In Figure 14 the normality tests of the data are shown. These tests were conducted with the use of SPSS. For this research only the last column was considered: the significance (Sig.) of the Shapiro-Wilk normality test. If the significance is under 0.05, the data is not normally distributed. This is the case for all of the dependent variables except for the intrinsic load regarding the abstract sound design condition and the extraneous load for the instructions regarding both of the sound design conditions. All the significance values are under 0.084, meaning they are all quite low and close to 0.05.

	Abstract sound design mean (SD)	Literal sound design mean (SD)	p-value of t-test
<i>Intrinsic load</i>	1.93 (0.86)	1.6 (0.74)	0.27
<i>Extraneous instructions load</i>	1.71 (1.37)	1.64 (1.11)	0.73
<i>Extraneous interactions load</i>	2.50 (1.32)	2.09 (1.10)	0.31
<i>Extraneous environment load</i>	2.12 (1.50)	2.00 (1.19)	0.57
<i>Extraneous sound design load</i>	2.40 (1.44)	2.05 (1.20)	0.32
<i>Germane load sound design</i>	4.50 (2.38)	5.79 (2.75)	0.08

Figure 15: Table with the means per category per condition including their standard deviations and the p-value of the t-tests

In the figure above the first column lists all the different types and categories of cognitive load that were measured. For the second and third columns, first the mean value of the questions asked in that category were averaged per participant. Afterwards the mean of their means is taken and that is the value per category. The standard deviations are listed next to the means. Recall that these values come from a nine-point Likert scale. The phrases within the first five categories were negatively phrased, so all the means being under 2.50 converts to a positive response. The phrase of the last category was positively phrased, so the mean of 4.50 for the abstract sound design converts to a neutral response and a mean of 5.79 for the literal sound design this converts to a slightly positive response. The last row contains the p-value of the t-test comparing the means of the two conditions per category. All of the p-values are over 0.05, so not significant.

7.2 Observations and Open-ended Questions

During the user testing session, observations were noted and written down. They were not formally recorded or counted, so the following statements are rough estimates. The observations yielded some noteworthy results. Firstly, it was noted that roughly four participants initiated interaction or movement before receiving instructions from the instructor, potentially influencing the results. Secondly, due to the within-subject experimental design, the second

testing session felt somewhat unnatural for participants and instructor during roughly more than half of the user tests. It felt particularly unnatural regarding the repetition of instructions and specific tasks. Participants also appeared to act more quickly and pay less attention during the second session. Additionally, during the first two user tests, it was noted that participants often failed to notice or pay attention to the sound effects, prompting a decision to inform subjects from then on, that the research primarily focused on sound design. This choice is further supported by the notion that well-designed sound effects should blend in seamlessly with the environment, in this case necessitating subtle encouragement for participants to notice them. Lastly, it was also observed that roughly five of the participants bumped into the pedestals or mentioned that they were in the way or in an illogical place, resulting in the desired behavior of the user interacting with the object. As well as about three participants mentioning that it was nice that there were a lot of hooks to put the paintings on, so they had more options and incentive to move them around.

The analysis of open-ended survey responses revealed multiple notable findings. Participants frequently commented on the negative phrasing of many questions, suggesting potential impact on their responses. Regarding the sound effects, participants commonly indicated a lack of awareness or noticeability, although some remarked on their seamless integration with the environment to which they dedicated the lack of awareness. The participants also mentioned that they were often more focused on or distracted by the ambient sound, rather than the sound effects. Furthermore, a significant proportion of participants acknowledged the connection between sound effects and interactions, highlighting an important aspect of their perceived experience.

7.3 Other Notable Observations

Additional observations were made throughout the course of the study, offering insights that, while not directly relevant to the core findings, could prove valuable for future research regarding VR development and testing. Participants frequently attempted to manipulate interactable objects, particularly pedestals, using both hands, occasionally resulting in unintended glitches or irregular interactions. Notably, individuals with prior experience in virtual reality (VR) or gaming demonstrated a swifter acclimatization to the controls and interface, showcasing a more rapid grasp of the available functionalities. Interestingly, some participants overlooked the option of physical movement within the virtual environment, relying solely on joystick controls or teleportation methods for navigation. In response, gentle reminders were provided to encourage the utilization of physical movement as an alternative means of navigation, thereby mitigating potential user struggles.

Chapter 8 – Discussion & Future Work

The analysis of the quantitative data from the study revealed that there were no significant differences between the experimental conditions based on t-tests. However, it's notable that the germane load condition approached significance ($p = 0.08$). Yet, this category had a limitation due to its reliance on a single question, failing to meet the requirement for a continuous variable in a t-test. Regarding the quality of the data, the majority of the collected data exhibited non-normal distributions, posing challenges to the reliability of the results. On the other hand, the demographic distribution among university students was consistent, with an even split between those with and without previous VR experience. However, the gender distribution was skewed, with a predominance of male participants. Moreover, the within-subject experimental design might have influenced the data, as participants performed the same experiment twice under different conditions. Despite attempts to mitigate this by switching conditions, notable differences in participant performance were observed between the two experiments. Furthermore, adapting the cognitive load scale to the experimental context proved challenging, as it was originally designed for educational settings rather than creative or entertainment purposes.

Several observations during the study could have influenced the quality of the data, because they distracted participants from focusing on the sound effects. Participants frequently reported a lack of awareness of the sound effects, attributing this to the immersive nature of the environment. Navigation challenges and ambient sounds further diverted attention from the intended interactions. Participants' comments suggested that the natural integration of sound effects into the environment, while indicative of effective sound design, hindered their noticeability—a critical aspect for testing purposes. So to test them, one might have to go against sound design principles and make them stand out more or make them feel less natural so they will actually be noticed.

Despite the absence of statistically significant findings and the shortcomings of the data as mentioned above, it is important to note that all the measured factors point towards literal sound design. This indicates a trend favoring literal sound design, suggesting a potential alignment with the hypothesis. To finalize, given the established influence of sound design in prior studies, continuing research in this area could be relevant and might still yield a significant difference between literal and abstract sound design. However, to address shortcomings of the experiment, multiple adjustments are necessary.

Firstly, future research should aim to expand the participant demographic to include a wider range of individuals, beyond the predominantly male composition observed in this study. This broader representation would provide a more comprehensive understanding of how different demographics interact with sound design in VR environments. Additionally, adopting a between-subject experimental design rather than a within-subject approach could mitigate the potential influence of repeated exposures to the experimental conditions, ensuring more robust and reliable data.

Furthermore, refining the VR environment to reduce distractions and enhance immersion is essential for future studies. Simplifying the locomotion system and providing clearer instructions integrated seamlessly into the environment would facilitate greater participant engagement and

focus on the intended interactions. For example, streamlining the controls for movement and incorporating intuitive navigation cues could minimize cognitive load for that aspect and maximize mental resources dedicated to aspect of the sound effects.

In terms of the experimental design, future research could employ an experiment where the focus lies more on interaction. For example, the participant is given an animation of the interaction paired with the sound effect, rather than they having to perform the interactions themselves. Employing alternative evaluation approaches such as mean opinion score (MOS) or MUSHRA testing instead of the current cognitive load scale could offer more reliable insights into user perceptions of sound design. These methods provide structured frameworks for participants to evaluate and compare different sound design elements, which might fit better than the adaptation of a cognitive load scale that is meant for the evaluation of educational environments. By incorporating these adjustments, future research endeavors could overcome the challenges encountered in this study and pave the way for a deeper understanding of the impact of sound design on user experience and cognitive load in virtual environments.

Chapter 9 – Conclusion

The primary goal of this study was to investigate whether sound design, specifically literal versus abstract approaches, influenced cognitive load in a virtual reality (VR) environment. This objective directly aligns with the main research question: "To what extent do literal and abstract sound design approaches in a virtual reality environment differ in their impact on user experience and cognitive load?" The findings from the study provided insights into this question, indicating that literal sound design had a more positive effect on cognitive load, with the germane load condition approaching significance ($p = 0.08$). Additionally, all other measured factors pointed towards literal sound design, suggesting a potential alignment with the hypothesis.

However, it's important to acknowledge the extent to which this question can be answered and the reliability of the results. While the study yielded valuable insights, certain limitations and challenges were identified during the data analysis and discussion. For instance, the majority of the collected data exhibited non-normal distributions, posing challenges to result reliability. Additionally, the within-subject experimental design may have influenced participant responses despite the taken precautions, highlighting the need for alternative approaches in future studies.

Regarding the other research questions, the first subquestion regarding relevant techniques for sound design and VR design was partially addressed through background research and observation of the experiment. Valuable insights were gained regarding good VR design and relevant methods for sound design. The second subquestion, concerning the creation and implementation of sound effects in Unity, was fully answered since the sounds were successfully created and implemented, although there is room for improvement in the creation process. The third question, focused on evaluating user experience and cognitive load, was determined in the background research and employed in the experiment, albeit with the limitations of the chosen method, for which other suggestions were given in the discussion. Unfortunately, the fourth question regarding the impact of implemented sound design techniques on user experience and cognitive load was not conclusively answered due to the lack of significant results. However, it could be said that it might be possible that the difference between the abstract and literal sound design does not have an impact on the cognitive load. But further research should be done to determine this further with more reliable results.

In conclusion, while the data provided a slight suggestion that the hypothesis may be correct, further research with improvements in methodology and design is necessary to draw definitive conclusions. The study underlines the relevance of ongoing research in this area, given the established influence of sound effects on user experience, the potential implications for VR design, and the tentative trend. Therefore, future research endeavors should aim to address the identified limitations and build upon the trends observed in this study to deepen our understanding of the impact of sound design on cognitive load in VR environments.

References

Link to the final sounds:

https://drive.google.com/drive/folders/19qyoid0kNExki5W5pFVdncLXLpb8txrG?usp=drive_link

- [1] M. Charr, "How technology is bringing museums back to life," MuseumNext, 2020. [Online]. Available: <https://www.museumnext.com/article/how-technology-is-bringing-museums-back-to-life/#:~:text=The%20likes%20of%20augmented%20reality,innovative%20360%2Ddegree%20immersi ve%20experience> . [Accessed: Sept. 14, 2023]
- [2] J. A. Bueno-Vesga, X. Xu, and H. He, "The effects of cognitive load on engagement in a virtual reality learning environment," IEEE Virtual Reality and 3D User Interfaces (VR), Lisboa, Portugal, 2021, pp. 645-652, doi: 10.1109/VR50410.2021.00090.
- [3] J. L. Campbell, "Towards a pluralistic, dynamic definition of usability," 2021 IEEE International Professional Communication Conference (ProComm), Pittsburgh, PA, USA, 2021, pp. 44-49, doi: 10.1109/ProComm52174.2021.00013.
- [4] F. L. Dutsinma, D. Pal, S. Funilkul, and J. H. Chan, "A systematic review of voice assistant usability: An ISO 9241–11 approach," SN Computer Science, vol. 3, no. 4, May 2022. doi:10.1007/s42979-022-01172-3
- [5] International Organization for Standardization (ISO) (2018) Ergonomics of human-system interaction. doi:10.3403/30464855u.
- [6] P. Albus and T. Seufert, "The modality effect reverses in a virtual reality learning environment and influences cognitive load," Instructional Science, vol. 51, no. 4, pp. 545–570, Feb. 2023. doi:10.1007/s11251-022-09611-7 V. F. Martins, M. de Paiva Guimarães and A. G. Correa, "Usability test for Augmented Reality applications," 2013 XXXIX Latin American Computing Conference (CLEI), Caracas, Venezuela, 2013, pp. 1-10, doi: 10.1109/CLEI.2013.6670668.
- [7] H. Fordell et al. (2011) 'A virtual reality test battery for assessment and screening of spatial neglect', Acta Neurologica Scandinavica, 123(3), pp. 167–174. doi:10.1111/j.1600-0404.2010.01390. x.
- [8] Y. Apaza-Yllachura, A. Paz-Valderrama and C. Corrales-Delgado, "SimpleAR: Augmented Reality high-level content design framework using visual programming," 2019 38th International Conference of the Chilean Computer Science Society (SCCC), Concepcion, Chile, 2019, pp. 1-7, doi: 10.1109/SCCC49216.2019.8966427.
- [9] Y. Huang, E. Richter, T. Kleickmann, K. Scheiter, and D. Richter, "Body in motion, attention in Focus: A virtual reality study on teachers' movement patterns and noticing," Computers & Education, vol. 206, p. 104912, Dec. 2023. doi:10.1016/j.compedu.2023.104912
- [10] G. Orru and L. Longo, "The evolution of cognitive load theory and the measurement of its intrinsic, extraneous and germane loads: A Review," Communications in Computer and Information Science, pp. 23–48, 2019. doi:10.1007/978-3-030-14273-5_3
- [11] G. B. Petersen, V. Stenberdt, R. E. Mayer, and G. Makransky, "Collaborative generative learning activities in immersive virtual reality increase learning," Computers & Education, vol. 207, p. 104931, Dec. 2023. doi:10.1016/j.compedu.2023.104931
- [12] A. Bettelli et al., "Beyond the embankments: Virtual training on human–river interaction for fostering safer behaviors during flood emergencies," Sustainability, vol. 15, no. 20, p.

14855, Oct. 2023. doi:10.3390/su152014855

- [13] G. Gutiérrez-Carreón, J. J. Esteve, and T. Daradoumis, "Integrating learning services in the Cloud: an approach that benefits both systems and learning," *Educational Technology & Society*, vol. 18, pp. 145–157, 2015.
- [14] E. de la Mora Velasco, A. Hirumi, and B. Chen, "Improving instructional videos with background music and sound effects: A design-based research approach," *Journal of Formative Design in Learning*, vol. 5, no. 1, pp. 1–15, Jan. 2021. doi:10.1007/s41686-020-00052-4
- [15] M. S. Andersen and G. Makransky, "The validation and further development of a multidimensional cognitive load scale for virtual environments," *Journal of Computer Assisted Learning*, vol. 37, no. 1, pp. 183–196, Sep. 2020. doi:10.1111/jcal.12478
- [16] C. Chitescu, S. Galland, S. Gomes, & J.C. Sagot, (2003). "Virtual reality within a human-centered design methodology." In 5th International Conference on Virtual Reality (pp. 99–104). Laval.
- [17] J. Jerald, "The VR book: Human-centered design for virtual reality." New York, New York: Association for Computing Machinery, 2016.
- [18] E. Langbehn, P. Lubos, and F Steinicke, "Evaluation of Locomotion Techniques for Room-Scale VR: Joystick, Teleportation, and Redirected Walking," in *Proceedings of the Virtual Reality International Conference - Laval Virtual (VRIC '18)*. Association for Computing Machinery, New York, NY, USA, Article 4, pp. 1–9, 2018. <https://doi.org/10.1145/3234253.3234291>
- [19] F Buttussi and L. Chittaro, "Locomotion in Place in Virtual Reality: A Comparative Evaluation of Joystick, Teleport, and Leaning," in *IEEE Transactions on Visualization and Computer Graphics*, vol. 27, no. 1, pp. 125-136, 1 Jan. 2021, doi:10.1109/TVCG.2019.2928304.
- [20] E. Bozgeyikli, A. Raji, S. Katkooi, R. Dubey, "Locomotion in virtual reality for room scale tracked areas", *International Journal of Human-Computer Studies*, Volume 122, 2019, pp. 38-49, ISSN 1071-5819, <https://doi.org/10.1016/j.ijhcs.2018.08.002>.
- [21] E. de la Mora Velasco, A. Hirumi, and B. Chen, "Improving instructional videos with background music and sound effects: A design-based research approach," *Journal of Formative Design in Learning*, vol. 5, no. 1, pp. 1–15, Jan. 2021. doi:10.1007/s41686-020-00052-4
- [22] S. Poeschl, K. Wall, and N. Doering, "Integration of spatial sound in immersive virtual environments an experimental study on effects of spatial sound on presence," *2013 IEEE Virtual Reality (VR)*, Mar. 2013. doi:10.1109/vr.2013.6549396
- [23] G. Corrêa De Almeida, V. Costa de Souza, L. G. Da Silveira Júnior, and M. R. Veronez, "Spatial Audio in virtual reality: A systematic review," *Symposium on Virtual and Augmented Reality*, Nov. 2023. doi:10.1145/3625008.3625042
- [24] Gulshan Kumar Film & Television Institute of India, "Five basics elements of sound design?," GKFTII, <https://www.gkftii.com/blog/elements-of-sound-design.html#:~:text=Mastering%20the%20five%20basic%20elements,auditory%20environment%20for%20your%20audience>. (accessed Feb. 14, 2024).
- [25] A. Mader, and W. Eggink, "A design process for creative technology", 2014.
- [26] J. Mitchell, "Sound Design: Jonathan Mitchell," Transom.org, <https://transom.org/2018/sound-design-jonathan-mitchell/> (accessed Feb. 2, 2024).
- [27] [Paintings Free | 3D Interior | Unity Asset Store](#)
- [28] [How To Make A VR Game in Unity - Complete BEGINNER Tutorial \(youtube.com\)](#)

- [29] [\(1946\) Introduction to VR in Unity - PART 1 : VR SETUP - YouTube](#)
- [30] [How to Make a VR Game in Unity 2022 - PART 4 - TELEPORTATION \(youtube.com\)](#)
- [31] [How to Make a VR Game in Unity 2022 - PART 5 - Hover, Grab and Use Interactable \(youtube.com\)](#)
- [32] [\(1946\) Unity VR XR Interaction Toolkit - XR Socket Interactor - YouTube](#)
- [33] [Unity VR XR Interaction Toolkit - Schakel het licht uit met stopcontact \(youtube.com\)](#)
- [34] [Unity VR XR Socket Interactor - Wat kan verbinden -Layer Mask \(youtube.com\)](#)

Appendices

A. Information Letter

Information sheet for designing a user-friendly VR-environment using auditory feedback

Purpose of the research

The purpose of this research is to gather information and insight regarding the usability and cognitive load of a virtual reality (VR) environment, which is a museum exhibition room.

Benefits and risks of participating

The research project has been reviewed and approved by the Computer & Information Sciences ethics committee. If the participant has epilepsy or motion sickness, they cannot participate.

Procedures for withdrawal from the study

You can withdraw from the study at any time or refuse to answer any questions.

Personal information

Only the age of the participant and their previous experience with VR will be collected, this information cannot be traced back to the participant.

Usage of the data

The collected data will be anonymized and processed into the user testing component of the bachelor graduation project for the study Creative Technology of Froukje den Brok, supervised by M. Gómez-Maureira and T. Hartmann.

Retention period for the data

The retention period of this data is until the end of the scope of the research project: the end of Feb 2024.

Contact information

See consent form

B. Consent Form

Consent Form for designing a user-friendly VR-environment using auditory feedback

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes

Yes **No**

Taking part in the study

I have read and understood the study information dated 08/11/2023 or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

I understand that taking part in the study involves answering questions from a questionnaire in conjunction with the taking of written notes.

I understand that taking part in the study involves the use of a virtual reality head-mounted display and controllers.

Use of the information in the study

I understand that the results of the experiment and the answers I provide will be used for research regarding the bachelor graduation project of Froukje den Brok.

I agree that my answers can be quoted anonymously in the research.

Future use and reuse of the information by others

I give permission for the results of the experiment to be stored on a personal drive to be possibly used in further research.

Signatures

Name of participant

Signature

Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher name

Signature

Date

Study contact details for further information:

Froukje den Brok, *e-mail of the researcher*

personal phone number of the researcher

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee/domain Computer & Information Sciences of the Faculty of electrical engineering, mathematics and computer science at the University of Twente by ethicscommittee-cis@utwente.nl .

C. Instructions Script

You can put on the headset and hold the controllers.

Take a moment to gather your bearings, please tell me if you start to feel unwell or uncomfortable. I'd like to remind you that you can stop with the experiment at any moment.

When you are ready, move around the corner and look for a painting. You can move both by walking and teleporting by pointing and pressing the left trigger button. Please tell me once you are in front of the painting.

Try to move the painting to the hook next to it. You can use the grabbing buttons for grabbing objects by holding them down, and you can release them by releasing the button.

Start timer

Once they did it

Next, look to your left and notice the blue pedestal, try to move it using the same interaction technique.

Once they did it, stop the timer

Alright, next you will have some freedom in moving around certain objects. Try moving four different paintings to a different location and three different pedestals to a different location. Take your time and arrange them in any way you like.

*Remind them when there's one more object left of an object to move. *

*Tell them when they're done. *

D. Evaluation Questionnaire

1. What is your age?
2. What is your gender?
3. Did you have any previous experience with VR head mounted displays?

Type of cognitive load	Original phrase	Adapted phrase
Intrinsic	The topic covered in the simulation was very complex.	The topic covered during the experience was very complex.
	The simulation covered procedures that I perceived as very complex.	The experience covered tasks that I perceived as very complex.
	The simulation covered concepts and definitions that I perceived as very complex.	The experience covered concepts that I perceived as very complex.
Extraneous instructions	The instructions and/or explanations used in the simulation were very unclear.	The instructions and/or explanations used during the experience were very unclear.
	The instructions and/or explanations used in the simulation were, in terms of learning, very ineffective.	The instructions and/or explanations used during the experience were, in terms of learning, very ineffective.

	The instructions and/or explanations used in the simulation were full of unclear content.	The instructions and/or explanations used during the experience were full of unclear content.
Extraneous load interactions	The interaction technique used in the simulation was, in terms of learning, very ineffective.	The interaction technique used in the virtual environment was very unclear (e.g. the controls, the way the interactions behaved, the way the environment reacted).
	The interaction technique used in the simulation was difficult to master.	The interaction technique used in the virtual environment was difficult to master.
	The interaction technique used in the simulation was, in terms of learning, very ineffective.	The interaction technique used in the virtual environment was, in terms of learning, very ineffective.
	The interaction technique used in the simulation made it harder to learn.	The interaction technique used in the virtual environment made it harder to learn.
Extraneous load environment	The elements in the virtual environment made the learning very unclear.	The elements in the virtual environment made the learning very unclear. (e.g. the arrangement of the physical objects, the amount of objects, the sounds that were included)
	The virtual environment was full of irrelevant content.	The virtual environment was full of irrelevant content.
	The virtual environment was, in terms of learning, very ineffective.	The virtual environment was, in terms of learning, very ineffective.
Extraneous load sound effects	The elements in the virtual environment made the learning very unclear.	The sound effects in the virtual environment were very unclear.
	The virtual environment was, in terms of learning, very ineffective.	The sound effects used in the virtual environment were, in terms of learning, very ineffective.
	The interaction technique used in the simulation made it harder to learn.	The sound effects used in the virtual environment made it harder to learn.
Germane load sound effects	The simulation really enhanced my understanding of the procedures covered	The sound effects in the virtual environment really enhanced my understanding of the interactions.

22. What did you notice about the sound effects used in the study?

23. What did you notice about the VR environment?

24. What comments or thoughts about the experiment in general would you like to share?

Acknowledgements

Generative AI in the form of ChatGPT was utilized in the making of this report. All content was critically reviewed and/or rephrased.

Link to the chat: <https://chat.openai.com/share/51b00530-98b9-40c1-a8d0-91856a92e5e2>