UTILIZING MULTI-SENSORY CUES TO ENHANCE ART GALLERY EXPERIENCE

by

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Declaration

We, S.A.A.D. Maithripala (2019/IS/043), W.R.G. Menike (2019/IS/047), W.M.H.P .B Weerasinghe (2019/IS/089) hereby certify that this dissertation entitled Utilizing Multi-Sensory Cues to Enhance Art Gallery Experience is entirely our own work and it has never been submitted nor is currently being submitted for any other degree.

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I, Dr.K.T Karunanayake, certify that I supervised this dissertation entitled Utilizing Multi-Sensory Cues to Enhance Art Gallery Experience conducted by S.A.A.D. Maithripala, W.R.G. Menike, W.M.H.P.B Weerasinghe in partial fulfillment of the requirements for the degree of Bachelor of Science Honours in Information Systems.

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Abstract

Assistive technologies play a major role in bridging the accessibility gap in the arts. Despite constant advancements, people with visual impairments (VI) still face challenges in independently experiencing and interpreting paintings. This study aimed to evaluate the effectiveness of conveying the contents of a painting to people with VI using selected multi-sensory stimuli (tactile, auditory, and somatosensory) to compensate for the loss of sight. A prototype, named SEMA (Specially Enhanced Multi-sensory Art), was designed around a simple painting, incorporating actuators for the aforementioned stimuli. SEMA was developed and refined iteratively with visually impaired students at the University of Colombo, Sri Lanka. We analyzed and evaluated all the sensations individually and as a whole system, utilizing several quantitative and qualitative measures. The final user study, conducted with 22 visually impaired participants, showed a strong preference (92.6%) for the prototype over traditional painting experiences, highlighting its potential to enhance how VI individuals experience art. The findings of this study contribute to further exploration of multi-sensory integration in entertainment and its impact on the visually impaired community.

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List of Abbreviations

ANOVA Analysis of Variance

AR Augmented Reality

CEDREP Centre for Disability Research, Education, and Practice

EEG Electroencephalogram

FMRI Functional magnetic resonance imaging

GPS Global Positioning System

HCI Human-Computer Interaction

HMD Head-Mounted Display

MMD Magic Music Desk

MR Mixed Reality

SD Standard Deviation

SEMA Specially Enhanced Multi-sensory Art

VR Virtual Reality

Chapter 1

Introduction

1.1 Introduction

Entertainment is a significant part of the everyday life of human society. The earliest forms of entertainment date back to the very first civilizations (Moss 2010). Many forms of entertainment include a visual component as humans greatly rely on the sense of sight to consume information on a regular basis. This was exploited by artists throughout history to create visual masterpieces that convey many themes and messages at once, evident by the Renaissance art era (Panofsky 2018). However, the human brain is not so simplistic that it 'just' relies on sight as a method of processing the environment, or in this case, art. As referred by some researchers it is obvious that in the natural environment, people perceive events through multiple senses (Stevenson et al. 2014). Then the brain decides the kind of information to group together and the kind of information to segregate.

According to researchers, over the years entertainment has evolved to combine different stimuli elements and provide the audience with a richer experience (Kuhns 2005).

Sensory alignment is a concept that is critical when discussing sensory stimulation since it aims to find the perfect alignment between different stimuli Marshall et al. (2019). Since a perfect alignment is not always ideal for the overall experience, it is important to have a good understanding of the different ways in which senses work, as this can explain how different sensory cues are processed and integrated into the brain.

Even though this trend to 'associate more than one sense to enjoy a work of art' is adopted by the entertainment industry to attract a larger audience, it is still not widespread. Only a handful of institutes of entertainment like museums seem to be displaying multi-sensory art. Currently, the world population sits on a number of 237 million people with moderate to severe visually impairments (*Visual Impairment & Blindness: Global Data & Statistics* n.d.). This audience is mostly deprived of good entertainment that does not heavily rely on sight. Even the technologies tackling these problems like Virtual Reality have not yet addressed this problem in a meaningful way.

Even the audience that does not suffer from any impairment is not given many chances to enjoy or interact with a multi-sensory art often and without sensory overload due to the lack of understanding of how several stimuli inputs work (Obrist et al. 2017). Therefore, it is important to give more attention to multi-sensory art as an area of research.

1.2 Problem Statement

The visually impaired community is often lacks the opportunity to get an art gallery experience. It always follows a more traditional method where a description of a painting is played to the visually impaired individuals, rendering any other methods of them experiencing that painting incapacitated. There is a growing need to address the issue of entertainment for the visually impaired with the assistive technologies rearing in the technological community.

1.2.1 Research Questions

How can we enhance accessibility in visual art forms for visually impaired persons?

Our study intends to address the issue of limited accessibility in visual art forms, especially for those with visual impairments. Traditional visual art relies heavily on the sense of sight, creating barriers for those who are visually impaired. By exploring innovative techniques and technologies, such as visual, audio, and haptic feedback, we seek to enhance the accessibility and inclusivity of visual art. This research is significant as it strives to ensure that individuals of all abilities can experience and appreciate art, fostering a more inclusive and diverse art culture.

How can a traditional painting be enhanced to provide a multi-sensory artistic experience for the visually impaired?

The traditional paintings focused primarily on visual stimuli, limiting the overall sensory experience for art viewers. Our research caters to the human need for multi-sensory experiences by integrating haptic, audio, and visual elements in the art-viewing process of visually impaired individuals. By combining tactile feedback and visual representations, we attempt to create a more immersive and engaging art encounter. This research is justified by the understanding that engaging multiple senses simultaneously can enhance the viewer's connection with art, evoke emotions, and provide a more comprehensive and enriching understanding of the artwork's intended message.

How to overcome the challenge of limited engagement in art viewing?

In the art world, limited engagement and the ability for only one person to view art at a time pose significant challenges. Our research seeks to overcome this limitation by creating a compact booth set-up that only accommodates one viewer at a time. While the setup may accommodate only one person, it enables a more intimate and focused art-viewing experience. By implementing this approach, we try to create a balance between individual engagement and broader accessibility.

This research is significant as it offers an alternative solution to enhance the art-viewing experience while accommodating the constraints of limited engagement and the number of people who can enjoy art simultaneously.

1.3 Aims and Objectives

1.3.1 Aim

The research project's primary aim is to implement a solution that enables a wider range of participants to enjoy the artwork. This goal is driven by a set of specific objectives to remove obstacles and enhance the entertainment value of a painting.

1.3.2 Objectives

First and foremost, Inclusiveness is a key objective of the study. The project aims to ensure that art is accessible to a larger range of people by emphasizing inclusiveness. This includes addressing barriers faced by people with disabilities or impairments, such as visual impairments. Through the research, we develop techniques and technologies that give individuals with diverse abilities equal access to engage with and appreciate art.

Another objective of the research is to explore the effectiveness of multi-sensory entertainment in painting. Traditional painting primarily relies on visual perception, but this project looks to go beyond that by incorporating additional sensory stimuli. By integrating haptic feedback and audio cues, the research seeks to create a more immersive and engaging art experience. The objective is to enhance the viewer's emotional connection and understanding of artistic expressions by stimulating multiple senses simultaneously.

The research also seeks to investigate the best senses to adopt by the paintings in order to stimulate a broader audience. By exploring how different senses can be effectively incorporated into the art viewing experience, the project intends to provide more insight into the art industry. Understanding which sensory cues have the greatest influence can help to create new artistic methods and approaches that appeal to a wider range of audiences. By doing so, the research aims to break down barriers and create art that resonates with diverse audiences.

Finally, this research study will provide a framework for artists to create and recreate art in more effective and stimulating ways. By analyzing the findings and outcomes of the research, the project seeks to develop guidelines and recommendations for artists to create art that incorporates multi-sensory elements, promotes inclusiveness, and maximizes viewer engagement. The framework will serve as a practical resource, helping artists explore new possibilities, push creative boundaries, and connect with audiences on a deeper level.

In conclusion, the research project's aim is to implement a solution that allows more participants to enjoy an artwork. The objectives include reducing barriers to entertainment in painting, promoting inclusiveness, exploring the effectiveness of multi-sensory entertainment, identifying the best senses to adopt into paintings, and providing a framework for artists to create art in more effective and stimulating ways. Through these objectives, the research project aims to enhance the accessibility, engagement, and enjoyment of art, creating a more inclusive and immersive art culture.

1.4 Significance of the research

With inclusivity being a rapidly growing concern in every aspect of the world, it is important to address the ways where entertainment and art can be inclusive. Specially for institutes like museums and art galleries where sense of sight plays the primary role of supplying information, the visually impaired demographic is directly excluded from experiencing the artefacts that are displayed in those places.

Additionally, the way different sensory cues should be aligned to give a bigger impact for the visitors is also a concern that should be focused on. This research addresses both these issues by developing a method to identify if other senses can be stimulated to compensate for the loss of vision. Moreover, it focuses on sensory alignment, the hows and ideals of the sensory stimulants. As an example, if we are to indicate a 'fire' in a painting for an visually impaired person, this research focuses on how to represent fire and which stimuli to use, as well as what are the ideal parameters for those stimuli such as the ideal temperature.

This approach will not only serve as a way of creating inclusive artwork, it will provide the artists basic parameters to work with when creating said artworks, furthering the ability of visually impaired people to enjoy paintings in a novel way.

1.5 Research Scope

1.5.1 In Scope

The scope of this research project focuses on the evaluation of a multi-sensory apparatus designed to enhance the viewer's experience of a single painting, as the stimulus for the multi-sensory experience. The findings may be specific to the characteristics and context of this particular artwork, and may not be applicable to other artworks or genres. The research will initially involve the development of a prototype apparatus that provides sensory cues such as music, temperature variations, and possibly other available sensory modalities. The evaluation will be conducted with a limited number of participants who will have the opportunity to experience the painting in a multi-sensory way.

1.5.2 Out Scope

- **Sample Size:** Due to resource constraints and time limitations, the study will involve a relatively small sample size of participants. This may limit the statistical power and generalizability of the findings to a larger population.

- **Accessibility:** Initially, the multi-sensory apparatus or booth will be designed to accommodate one person at a time. This limits the scalability and broader accessibility of the experience, as it may not be feasible for large groups or simultaneous viewers.

- **Sensory Cues:** The inclusion of sensory cues in the apparatus will depend on factors such as budget, technical feasibility, and usability considerations. As a result, the available sensory cues may be limited, and certain sensory modalities may not be included in the initial implementation.

- **The subjectivity of Experience:** The perception and interpretation of art and the multi-sensory experience are subjective in nature. Individual preferences, cultural backgrounds, and personal biases may influence participants' responses and affect the generalizability of the findings

1.6 Research Methodology

The research design for this study involves the development and implementation of a customized apparatus to provide a multi-sensory experience while viewing a painting. This method will enhance the viewer's perception and engagement by incorporating additional sensory stimuli beyond visual perception.

The study will follow an experimental design, allowing for the manipulation and control of the multi-sensory components in the apparatus. This design will enable investigation of the impact of different sensory modalities (e.g., music, heat or air projections, tactile elements) on the viewer's overall experience of the painting.

1.6.1 Identifying the Problem

How to make paintings accessible for the visually impaired community?

1.6.2 Analyzing the Problem

Analyzing the problem, we are able to identify approaches to address the problem, the main one being the use of assistive technologies. Conducting a user study to gather their input on the problem would also assist with narrowing down the problem to a digestible and addressable problem.

1.6.3 Systematic Literature Review

Doing a systematic literature review by using a filtering criteria to learn about the domain and if there are alternatives available to address the problem and how the researchers have approached similar problems.

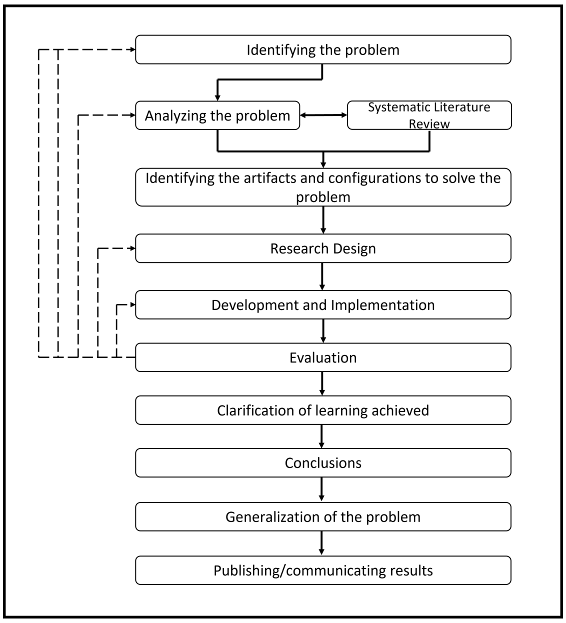

Figure 1.1: Overview of the Methodology of the Research

1.6.4 Identifying the artifacts and configurations to solve the problem

Through the literature review and conversations with the experts, different assistive technologies and approaches to solve the problem should be identified. If there are configurations and parameter changes to achieve ideal performance, they should also be identified.

1.6.5 Research Design

In this stage, designing the overall architecture and the initial hardware and program logics is done. Pretests are also conducted to get the users involved early in the process to do a user-centric design and development. Equipment designs for identified stimuli are proposed. An apparatus will be designed to serve as the vessel to integrate these equipment.

1.6.6 Development and Implementation

Designed hardware, equipment and programs are developed and improved with the user inputs to for the integration. The designed apparatus will be built, integrating all the hardware with it.

1.6.7 Evaluation

Evaluation done for each stimuli as well as for the overall experience.

Sample Size and Data Collection

The sample size will be determined based on the principle of saturation, aiming to achieve a sufficient number of participants to capture a diverse range of perspectives and experiences.

Data collection will involve two primary components: the multi-sensory viewing experience and participant feedback. During the viewing experience, participants will be exposed to the customized apparatus while observing a selected painting. Their reactions, behaviours, and physiological responses will be observed and recorded.

Following the viewing experience, participants will be invited to provide feedback through structured interviews and questionnaires. The feedback will encompass their subjective impressions, emotional responses, perceived quality of the multi-sensory elements, and overall satisfaction with the experience.

Data Analysis

The collected data will be analyzed using a mixed-methods approach. The qualitative data obtained from interviews will be thematically analyzed to identify recurring themes, patterns, and insights related to the multi-sensory experience. The quantitative data from the questionnaires will be subjected to statistical analysis after a word-to-vector process to identify any significant differences or correlations between the sensory stimuli and participant feedback.

1.6.8 Clarification of Learning Achieved

After the evaluation, the gained results will be discussed with the prior knowledge to gain insights and clarify the learning outcomes of the study.

1.6.9 Conclusions

Through the insights gained from evaluations and clarifications, conclusions will be reached.

1.6.10 Generalization of the problem

With the help of the above-gained conclusions, our idea or the final design will be generalized for visually impaired people. It will have the potential of serving as a basic framework for future researcher or developers that are tackling similar problems.

1.6.11 Publishing/communicating results

The literature review and the final research paper will be published in journals/conferences. By the day of the submission of this thesis, an abstract of this research is published in the '23rd International Conference of ICT for Emerging Regions (ICTer 2023)' under the topic of 'Utilizing Multi-sensory Cues to Enhance Art Gallery Experience: Focus on Entertainment for the Visually Impaired.'

1.6.12 Ethical Considerations

Ethical guidelines will be followed throughout the study. Informed consent will be obtained from all participants, emphasizing their voluntary participation and the confidentiality of their data. Measures will be taken to ensure the well-being and comfort of participants during the multi-sensory viewing experience.

1.7 Evaluation Plan

1.7.1 Objective

To evaluate the effectiveness of the multi-sensory painting (SEMA) in providing a comparable experience for visually impaired individuals.

1.7.2 Methodology

Evaluation plan integrates both qualitative and quantitative methods to assess the cross-modal experience of the multi-sensory painting, with a focus on leveraging word embedding techniques for in-depth analysis of textual feedback.

Participant Recruitment

1. Recruit visually impaired participants and sighted participants separately

   The LogMAR and Snellen scales are used to measure the Acuity of the human eye. These charts are internationally accepted and used by the World Health Organization to define visual impairment. For this research, subjects will be chosen with 'Severe visual impairment' or 'Blindness' in the WHO visual impairment category. (Solebo & Rahi 2013) The measurements in the LogMAR and Snellen scales for the above categories are as follows.

	LogMAR	Snellen
Severe Visual Impairment	1.1, 1.2, 1.3	5/60, 4/60, 3/60
Blindness	1.4	2/60

   Table 1.1: Selection criteria for visually impaired participants

2. Ensure diversity in gender for a comprehensive assessment.

3. Obtain informed consent from all participants.

Preparation

1. Familiarize participants with the multi-sensory painting and its components.

2. Clearly explain the purpose of the evaluation and the type of feedback desired.

Experiencing the Painting

1. For visually impaired participants:
   (a) Provide a guided tour of the painting, emphasizing the tactile, auditory, and heat elements.
   (b) Encourage participants to explore and engage with the multi-sensory features.
2. For sighted participants:
   (a) Allow participants to view the painting without interacting with the tactile, auditory, or heat elements.

Data Collection

1. Administer a questionnaire to both groups immediately after the painting experience.
   (a) Include open-ended questions to capture qualitative feedback.
   (b) Ask participants to describe their emotional responses and overall experience.
2. Collect demographic information to account for variations in responses.

Feedback Analysis

1. Utilize natural language processing techniques to convert textual feedback into word vectors (e.g., Word2Vec, Open AI Models etc).
2. Create vector representations for feedback from both groups separately.
3. Apply cosine similarity, clustering or other similarity metrics to measure the similarity between the vectors of visually impaired and sighted groups. Here, measurements such as Cluster size and inter-cluster and intra-cluster distances will be used.
4. Identify commonalities and differences in the vector space.

Statistical Analysis

1. Conduct statistical tests (e.g., t-tests, ANOVA) to compare mean scores of specific aspects of the experience between the two groups.
2. Analyze correlations between demographic factors and feedback to identify potential influencing variables.

Feedback Integration

1. Use the findings to make adjustments to the multi-sensory painting if necessary. One parameter will be changed at a time. Example: Only change the temperature while keeping the other conditions the same thus allowing the analysis of how a change in a certain parameter affects the interpretation of stimuli.

2. Aim to increase the number of visually impaired subjects that fall into the chosen cluster in the vector space.

1.8 Overview of the Report

Chapter 2 (Literature Review) will dive into the background and related work that forms the foundation of this study. The literature review will discuss the history of multi-sensory entertainment, neurological aspects of multi-sensory processing, assistive technologies in multi-sensory entertainment and contemporary research and developments in the domain.

Chapter 3 (Research Design) will provide a detailed description of the overall architecture and design components used in this study. The high-level architecture will outline the different components of the proposed system to stimulate different senses. The design of hardware and program for each stimuli will be discussed in this chapter, highlighting the functionalities of each of those equipment.

The implementation of the study will be described in Chapter 4. First, we will go through the apparatus implementation specifics, including the software and hardware components utilized in its creation in all their final versions.

Chapter 5 (Evaluation and Results) will present the final results of this research. A detailed description of the evaluation process will be provided in this chapter, including the methodology used and the feedback received from participants. We will analyze the data collected during the evaluation process and present the results in a comprehensive manner.

Chapter 6 (Conclusion) will give an overview of the research work, including a summary of the contributions of this research to the field of Information Systems and Human Computer Interaction. We will also discuss the limitations of this study and provide suggestions for future research in this area. Finally, we will conclude with a discussion of the implications of this research for the broader society and the potential impact it could have on the lives of visually impaired individuals.

Chapter 2

Literature Review

2.1 Introduction: Definition of Multi-Sensory Experience in Entertainment

Many methods of entertainment are now evolved towards variety as some researchers mention (Malia 2023). Although traditional art, music, and drama remain true to their roots, they have also developed in to suit different personal tastes and cultures. Different forms of entertainment are blended to provide a richer experience for the audience. As an example, drama is usually enhanced by music, and music is now enhanced by a matching video clip. There are many similar instances where one form of experience is coupled with another to provide a more equipped experience than one form.

As referred by some researchers it is obvious that in the natural environment, people perceive events through multiple senses (Velasco & Obrist 2021). Then the brain decides the kind of information to group together and the kind of information to segregate. In recent research, the focus has been devoted to finding ways to control the sensory stimuli to give a relevant, to-the-point experience to the user, rather than just integrating different sensory stimuli together (Chou et al. 2020).

Lately, an ideal approach to sensory stimulation is provided by Marshall et al.(Marshall et al. 2019). That is by aiming for the perfect alignment between the senses. But the research also states that not having a perfect alignment can sometimes have some feasible effects on the audience. So it is important to have a good understanding of the different ways in which senses work, as this can explain how different sensory cues are processed and integrated into the brain. Marshall has also researched on the likelihood of separating different levels of sense alignments within the brain.

Research on art has discovered that physical mechanisms of awareness encourage consumers to create their own phenomenal worlds (Joy & Sherry Jr 2003). Hence, understanding the physical ways of consumption is essential in developing a holistic experience for the audience whether it is material or ethereal.

Therefore in this context, multi-sensory integration is considered a key factor in the design of successful and memorable entertainment experiences. The ability to combine different sensory stimuli in a meaningful and engaging way is being appreciated by audiences and this can lead to a positive impression (Solves et al. 2022).

By focusing on the multi-sensory integration for everyday art and entertainment, we examine views and practices in providing an inclusive experience for everyone. Our findings showcase several novel use cases in this context, including multi-sensory museum and gallery experiences, as well as methods to enhance the existing perception of everyday entertainment methods. We discuss limitations and challenges in this form and propose future studies that can be done through increased collaboration for promoting inclusive tourism.

When conducting this literature review, we established some guidelines for selecting articles that align with our primary research question. One of our main objectives was to uncover how multi-sensory experiences can enhance entertainment for individuals with visual impairments. A key criterion for choosing papers was their involvement in comparing different treatments. We intentionally included some older papers that introduced certain concepts, to highlight foundational ideas that underlie certain theoretical frameworks on which most of the present-day applications are built. For research papers, we mostly made sure the study was published in the last 5 to 6 years. Furthermore, our language inclusion criteria restricted our selection to studies published in English, to ensure linguistic consistency. In terms of methodology, both qualitative and quantitative research approaches are assessed to the merits of each method.

2.2 Understanding the neural mechanisms behind multi-sensory integration

In the past, the research on sensory processing and perception was focused more on one sensory modality at a time. But it's a known fact that humans stimulate multiple senses at the same time. The field of neuroscience describes many regions of the brain as multi-sensory regions. These are kind of merging zones in the brain where neurons receive inputs from multiple senses. The types of multi-sensory influences are mostly pervasive and can affect brain regions as well as neural responses and judgments, making them considered modality-specific in the field. Another finding in this area is the multi-sensory interplay; which refers to the Situations in which one sense influences another without necessarily resulting in a combined perception.

NeuroImage (Mercier & Cappe 2020*a*) also goes on to mention that decisions about a property that pertains to one modality can be influenced by multi-sensory inputs from other modalities. For example, a simple touch at a given place can improve the person's judgment of visual colour nearby, even though it's not proven that touch can convey colour to the brain. The concept being proposed suggests that information in one sense can affect how another sense perceives a specific space or time. This can facilitate the processing of parts of the brain that are specific to one modality. Another good instance is the "auditory-flash illusion" mentioned by Shams et al.(Shams et al. 2001) which illustrates how a single flash can be incorrectly perceived as two flashes when coupled with two beeps. Similar to this, Driver et al.(Driver & Noesselt 2008) describes how the brain can perceive more visual movements than what is actually present due to the perception of multiple sounds, hence improving the ability to detect "visual orientation". This phenomenon refers to the ability of our visual system to sense and distinguish the orientation of visual stimuli like lines, edges and shapes. It is an example of how multi-sensory interplay can affect judgements in our brain specific to the senses we take.

2.2.1 Multi-sensory Convergence in the Brain

Since the 1990s, researchers have found evidence that the human brain contains many multi-sensory convergence zones (Mesulam 1998). These regions get sensory inputs from multiple sensory organs. The main identified parts of having these multi-sensory organs are the cortical and sub-cortical regions of the brain. They are located in the cerebral cortex (the outer layer of the brain). Truszkowski et al. suggest that cellular-level multi-sensory interplay can be the maximum when every single sensory input induces a weak neural discharge (Truszkowski et al. 2017). The concept of inverse effectiveness, as discussed by Stein et al.(Stein & Meredith 1990), has illustrated this phenomenon. Van de Rijt et al.(Van de Rijt et al. 2019) revealed that similar to the principle outlined by Truszkowski et al.(Truszkowski et al. 2017), the application of inverse effectiveness in audiovisual speech stimuli manifests when stronger audiovisual benefits coincide with weaker unimodal stimuli, particularly evident in the recognition of spoken words, signifying a nuanced cognitive strategy involving attention division between listening and lipreading.

With the latest technological advancements, scans like FMRI and EEG have aided researchers in finding that multi-sensory interplay affects both established multi-sensory convergence zones and also sensory-specific brain areas and responses. Recent studies suggest that information from one sensory modality can impact the judgments made specifically for another sensory modality (Mercier & Cappe 2020*b*). For example, the perceived sweetness of food can be influenced by colour, and the same food will appear sweeter when presented on a red plate, compared to a white plate.

2.2.2 Multi-sensory Phenomena and Brain Processing: Theories and Findings

Various theories, as well as models, have been proposed to explain newly discovered multi-sensory phenomena. One instance is the concept that all brain areas may be naturally Multi-sensory or might contain some Multi-sensory inter-neurons (Allman & Meredith 2007). A variety of explanations and structures have been proposed to clarify these newly found phenomena. One theory is that all regions of the brain might be capable of processing information from multiple senses, or they may contain some cells that can integrate information from different senses to varying degrees. In addition to this, feedback from higher-level regions in the brain that integrate multiple senses can contribute to the multi-sensory effects in regions of the brain that process information from a specific sense (Allman & Meredith 2007).

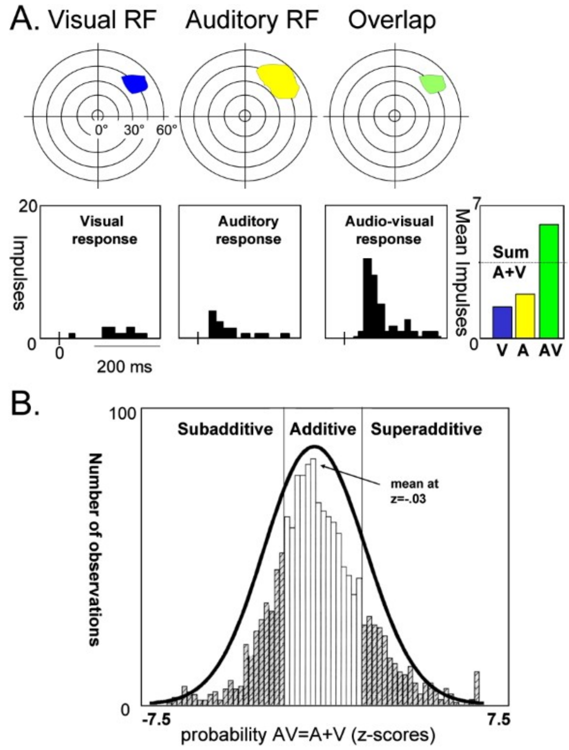

Figure 2.1: Response Properties of Multi-sensory Neurons
Source: https://www.sciencedirect.com/science/article/pii/S0896627307010197

An interesting area for future multi-sensory researchers is the identification of the roles of feed-forward, lateral, and feedback connections in specific multi-sensory phenomena and to determine whether different types of neurons are mixed together in certain areas of the brain. This may potentially lead to a jump from sensory-specific research (which is the dominant field in medical research as of now) to multi-sensory processing research. Another interesting find of these researches is that the timing of when the senses are combined can be important for how the brain processes them (Lakatos et al. 2007). It means that when we hear and see something at the same time, the timing of when we see it and when we hear it can affect the way the brain integrates the information received from those senses.

Recent studies have shown that the ability of the human brain to process receptions from different senses is not limited to specific areas. Therefore rather than being limited to processing information from just one sense, many regions in the brain can receive information from multiple senses. This can enhance the processing of the primary modality in that area. However, when a given sense is deprived, such as during blindness or blindfolding, the brain may depend more heavily on input from other senses. For example, in visually impaired people, the visual cortex may become responsive to touch or sound. This area of research is rapidly growing and provides suggestions to understand the brain's plasticity and the way it adapts to the changes in sensory inputs received.

Research shows that many multi-sensory experiences involve interactions between different areas of the brain, rather than just one specific region (Vuilleumier

& Driver 2007). To understand how these areas work together in a proper manner, researchers are developing new methods that involve studying the effects of temporarily shutting down or else, stimulating specific regions of the brain, while measuring how the other regions respond to that. These studies are conducted while people perform tasks to see how different areas of the brain work together to complete them. To fully understand how the brain processes multi-sensory information, future researchers are going to need many different methods to study the connections and interactions between different regions of the brain.

2.2.3 Advancements in Understanding Multi-sensory Processing

Recent findings have challenged the traditional belief that multi-sensory processing occurs after uni-sensory processing. Studies using behavioural, neurophysiological, and neuroimaging methods suggest that multi-sensory integration can occur earlier than previously thought. For instance, research Calvert et al.(Calvert et al. 2004) have mentioned that cortical area V1, which was previously believed to be exclusively visual, is activated by both auditory and somatosensory inputs. Studies show that there is evidence to support the idea that sensory information from different senses can interact and integrate with each other, even in the primary sensory areas of the brain (such as the auditory and visual cortices). These regions handle the skilled movement of our body, including tactile identification of objects and pain intensity etc.

This indicates that the brain has a highly interconnected and complex processing system that integrates inputs from multiple sensory modalities. These findings have important implications for understanding how the brain processes sensory information and can accelerate the development of new approaches to sensory integration in numerous fields.

The rise in research on multi-sensory processing is said to be the result of two key factors. The first one is the advancements in the understanding of cortical function ease the exploration of how different senses are combined and integrated with the brain. Secondly, the identification of principles associated with sensory integration, which integrates visual, auditory, and somatosensory (relating to or denoting a sensation) inputs. One of the key findings of researchers, known as superadditivity, became a defining feature of multi-sensory integration and informed investigations in cortical areas of the brain. This principle also had clear implications for behaviour and perception, which fueled cognitive studies in the multi-sensory domain (Stein & Meredith 1993). These studies also indicate that behaviour and perception have caused a rise in cognitive studies in the multi-sensory domain (Wallace et al. 2020).

2.2.4 Attention Across Modalities

Attention is a cognitive process that enables focus on certain sensory stimuli while ignoring others Alais et al. (2010). While early attention research focused on the auditory modality, recent decades have seen an emphasis on visual attention. More recently, researchers have explored attention in cross-modal contexts, which offers new questions to be asked about attention processes. Some of these questions include whether attention can be selectively directed to one modality, whether attention can be focused on a visual object in the presence of auditory and visual distractors, and whether there are separate resources for attention in each modality. These investigations have expanded our knowledge of attention processes. Recent findings from Lunghi et al. (Lunghi et al. 2017) highlight attention across modalities, demonstrating that congruent haptic signals reduce suppression durations of visually suppressed stimuli, revealing automatic cross-modal interactions in attention processes.

2.2.5 Modeling multi-sensory Texture Perception

The "Modality Appropriateness" hypothesis suggests that observers weigh different sensory inputs based on their individual performance capabilities for a given task (form, size, texture, etc.). Measures of relative performance include accuracy, response time, and precision/variability. The hypothesis contrasts with earlier research arguing for the dominance of vision in perception, as it suggests that vision should strongly dominate touch and audition on spatial tasks, while audition should strongly dominate vision on temporal tasks. The basis for this weighting is the relative strengths and weaknesses of each modality for the given task (e.g., vision is spatially best, while audition is temporally best).

In 1979, Lederman et al.(Lederman 1979) demonstrated that people tend to disregard touch-produced sounds during haptic exploration as they are typically low in amplitude and often overshadowed by other environmental sounds. Conversely, Lederman et al. (Lederman et al. 2002) found that when texture-related sound cues were generated using a rigid probe, participants relied more on these cues in their perception of roughness. These findings suggest that the appropriateness of sensory modality depends on the shot term characteristics of the input rather than its general utility.

2.3 History of Multi-Sensory Entertainment

Multi-sensory cues have always been utilized as a method of entertainment by the entertainment industry. Even before technology became a major part of human life, entertainers used different techniques to address the different senses of the audience.

One of the earliest noticeable multi-sensory art in the entertainment industry is Phantasmagoria."Phantasmagoria" is a ghost lantern show that happened in France 18th century (Spence 2022).It uses shadows and lights and their contrasting qualities to tell a story. Since then, it has evolved and is used in the multi-sensory sensoriums often found in theme parks. This was embedded in the theme parks as a multi-sensory overloading experience, probably to leave a lasting impression on the visitors about the experience. Spence et al.(Spence 2022) and Kasson et al.(Kasson 1978) refer to phantasmagoria in theme parks as a way of enhancing the experience of a photograph by adding the "total body experience of pleasure". Both auditory and visual outputs are given in these shows, sometimes incorporated with olfactory sensations to heighten the impact the show has on the audience (Casetti 2022).

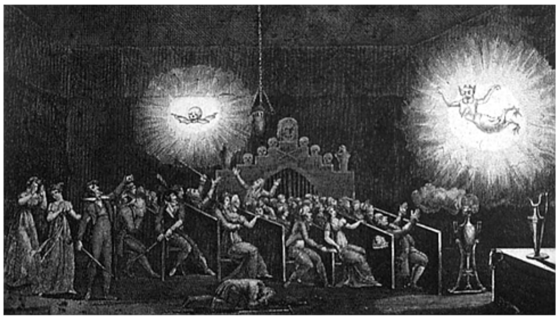

Figure 2.2: Early Phantasmagoria
Source: http://www.acmi.net.au/AIC/PHANTASMAGORIE.html

In the 17th and 18th centuries, museums were more open to letting visitors touch and feel the displayed objects (Christidou & Pierroux 2019). This allowed the visitors to experience the artefacts intimately. As an example, by touching and putting on jewellery, visitors could feel and understand the cultural status of the wearer of that piece.

Matos et al. (Matos et al. 2015) researched multi-sensory storytelling which was mainly developed as a way of approaching people with intellectual disabilities and motivating them to learn. The study had two approaches, one with just two stimuli (audio and visual) and the other with multi-sensory stimuli (audio, video, smells, tactile). A smell machine, audio track, video track and fruits were utilized as stimulants for this research. The multi-sensory approach returned 69% of correct answers from the participants, while just the audio-visual approach returned 49% of correct answers in the study conducted by Matos et al. (Matos et al. 2015).

A scenario-based experimental study was conducted by Guo et al.(Guo et al. 2021) in a controlled environment, where participants were given a link to access a video clip and the associated questionnaire. The video was hoped to provide multi-sensory cues to replicate a digital museum experience. There were 3 video clips based on 3 scenarios incorporating different combinations of multi-sensory cues as follows.

- Cue 1: Visual, Auditory
- Cue 2: Visual, Auditory, and Haptic
- Cue 3: Visual, Auditory, and Taste

While studying multi-sensory interaction with art and entertainment, it is also essential to study how different stimuli react to and complement each other in the process of generating artistic output. Verma et al. (Verma et al. 2020) conducted a study to translate brush strokes of live painting into music with the collaboration of two artists; a painter and a composer. The study also trained an AI model with an intensive library of music and paintings, serving as a cross-model stimulus. Several scenarios were carried out to study this process. In the first scenario, the painter and the composer are separated, so they cannot see or hear each other. The AI system is fed with the earlier works from the two artists. While the two artists perform live, the AI system offers the most matching content from its existing library. For example, if the composer is performing a particular melodic piece of music, a painting that matches the tone of that music is displayed to the composer and vice versa. The two artists use each others' work displayed as material to develop their art further. In the second scenario, the two artists compose art together, and the AI system compares their performances and generates congruity between them. Consequently, the artists can choose to align or stray from the other.

The cinema industry also started different trends to incorporate multi-sensory aspects into the industry. Drive-in cinema culture is one of the earliest signs of this phenomenon. Some researchers (Atkinson & Kennedy 2016) (Atkinson & Kennedy 2015*a*) states that it is not a certain teleological model of cinematic developments that nudges the industry towards these shifts and trends, but rather it is the audience that proposes them.

A live augmented reality cinematic experience was carried out in the UK called "Summer of Live." This event focuses on replaying critically and commercially successful movies with added sensory layers and presenting some immersive experiences (Atkinson & Kennedy 2016). Some of the immersive and multi-sensory experiences presented in this are as follows.

- Star Wars Episode V: The Empire Strikes Back presented by Secret Cinema
- Alice's Adventures Underground Screening
- Against Captain's Orders: an immersive play by PunchDrunk under the subtitle of 'A Journey into the Uncharted', performed at The London National Maritime Museum

After analyzing the events at Summer of Live, Atkinson et al. (Atkinson & Kennedy 2016) proposes a spectrum to classify the creative interventions.

1. **Enhanced** - Physical experience of the spectator is enhanced, but it does not relate to the art's (movie's) thematic aspects. Ex: Screening drive-in movies
2. **Augmented** - Screening a film in a place or context relevant to the story or theme of that movie. This uses sensory enhancements like smell-o-vision and taste-a-longs or elements of a non-interactive performance. Ex: Harry Potter at Kirkstall Abbey. This category again divides into two parts.
   (a) Live Scored - the original soundtrack of the film remains completely audible, and the film is played as its originally intended
   (b) Re-Scored - dubbing over the original soundtrack or mixing it in with new elements
3. **Participatory** - The audience has direct involvement in the original art. This category has a spectrum for the intensity of the immersive experience. Ex: Rocky Horror Picture Show (dance-along, sing-along)

2.4 The Rise of Multi-sensory Technologies

The human experience is largely shaped by the way we perceive and interact with the universe around us. Since the dawn of time, humans have been utilizing their senses to explore their surroundings, learn new things, and communicate with each other. For example, ancient humans used their tactile senses to navigate their environments; their visual senses to identify their food sources and potential predators; their gustatory senses to enjoy their food sources; and their olfactory senses to detect danger and locate their food. Therefore, it is evident that human senses function together to comprehensively understand the world around them.

With rapid technological advancements, people have moved towards utilizing multi-sensory technologies to create immersive experiences in various fields. By combining visual, auditory, haptic, and olfactory feedback, the creators produce more opportunities for the users to expand the multi-sensory experience.

2.4.1 Immersive Realities

Virtual reality (VR) is a rapidly growing technology that provides an immersive experience by simulating a virtual environment. The history of VR dates back to the 1950s, when Morton Heilig invented the Sensorama, which used 3D visual, audio, haptic, olfactory, and even wind stimuli to provide an immersive experience to the users (Uruthiralingam & Rea 2020). In 1968, Ivan Sutherland invented the first ever successful head-mounted display (HMD) , which was named “Sword of Damocles" (Sutherland 1970) and later became a crucial milestone in VR technology as it helped to inspire the development of modern-day HMDs. These HMDs continue to be utilized in VR technology to transport users into a simulated world, giving a sense of immersion and presence.

VR technology has come a long way since the 1950s, and as the technology continues to improve and evolve, it has opened up new opportunities for other related technologies such as augmented reality (AR) and mixed reality (MR). Although VR has encountered a problem with a lack of connection to the real world, AR addressed this issue and presented a new way of displaying computer-generated materials in the actual world. This technology has created an augmented space that can be accessed by the user (Rokhsaritalemi et al. 2020). The British Computer Society defines AR as a technology that combines physical and simulated views by adding graphics and sounds to what the user is experiencing *Augmented reality learning* (2021). AR technology can be accessed using smartphones, tablets, and glasses. These devices use their sensors, such as cameras, GPS, and accelerometer, to monitor the user’s location and orientation and deliver content within their field of vision (Gillis 2022).

Mixed reality goes a step further by merging the real and the digital world. MR blends the components of virtual reality and augmented reality. Microsoft HoloLens, which first appeared in 2016, is one of the best examples of a mixed-reality application and it allows users to experience a blended reality consisting of virtual elements in the physical world Park et al. (2021). All three realities are characterized by similar features; however, they differ in their objectives and underlying technologies.

2.4.2 The Influence of Immersive Technologies in Entertainment

The development of VR, AR, and MR technology has had a significant influence on the art and culture sectors. It has opened a new realm of possibilities to provide new and creative ways to experience art for viewers. These technological advancements undoubtedly made it possible to improve the sensory experience of the viewer, immersing them in the work of art and enabling a deeper connection and comprehension. The utilization of VR, AR, and MR has transformed how we view art and prepared the path for a new era of art entertainment.

In 2017, Zumoko, an AR/VR solution-providing company, released a virtual gallery curator app called "Feel the Art", compatible with the Microsoft HoloLens 2 headset, and it allows the users to experience a 3D prototype of the art with a detailed introduction to that particular art (Zumoko n.d.). As the app is intended to be used inside the real gallery, the users can experience a mixed-reality engagement with the art in the real gallery(Zumoko n.d.).

Gong et al. (Gong et al. 2022) examined the use of augmented reality (AR) to enhance the museum experience for visitors. This project focuses on Chinese art pieces, including the famous artwork, “Along the River During the Qingming Festival" (Gong et al. 2022). The study found that using AR technology to present an art piece has had a positive impact on visitor satisfaction with the art museum.

Van Gogh: The Immersive Experience is an experimental art exhibition that has been held all around the world. The exhibition uses VR, touch, sound, and other immersive mediums to successfully introduce art viewers to Van Gogh’s world. The viewers could experience the arts with high-definition digital replicas of Van Gogh’s paintings in a 360-degree virtual space (Yu 2022).

“Claude Monet: The Immersive Experience" is another display of art that offers an immersive and interactive experience to visitors. The exhibition is designed to take visitors on a journey through Monet’s life. For this, over 300 paintings and sketches were digitized with 360° view to showcase them to visitors through immersive mediums (*Claude Monet: The immersive experience* 2022).

2.4.3 Haptic Technology in Human-Computer Interaction

The term “haptic" refers to using the sense of touch to manually sense and manipulate surrounding elements and environment (Giachritsis 2020). Simply put, it is the sense of touch that allows people to feel sensations in the environment. The first commercial haptic devices were introduced in the 1990s. Before that, haptic technological devices were used for space and military purposes in the 1950s (Stone

2001).

Haptic technology is a way humans can communicate and interact with computers using their sense of touch and movement. Traditional interfaces generate visual and auditory signals, but haptic interfaces produce pulses that evoke a sense of touch and movement. They allow for the bi-directional exchange of information between the real and digital worlds (Kern et al. 2023). For example, you might use a traditional mouse to click on a button. The feedback for that particular task would either be visual or auditory, but if a haptic mouse is used, the users will receive vibration or resistance as the feedback that makes them aware of what is happening on the computer screen. Using computers or machines with this technology may feel more intuitive and natural.

According to Culbertson et al. (Culbertson et al. 2018), to understand the scope of haptic devices, mainly three categories have been taken into consideration: graspable devices, wearable devices, and touchable devices. Graspable devices allow users to hold physically and interact with digital elements using gestures and movements. Wearable devices are usually attached to the hands to give a direct sensation to the skin through vibration. Touchable devices allow users to interact with the entire surface. These devices can have several location-based tactile qualities, such as different levels of friction on the device's surface (Culbertson et al. 2018).

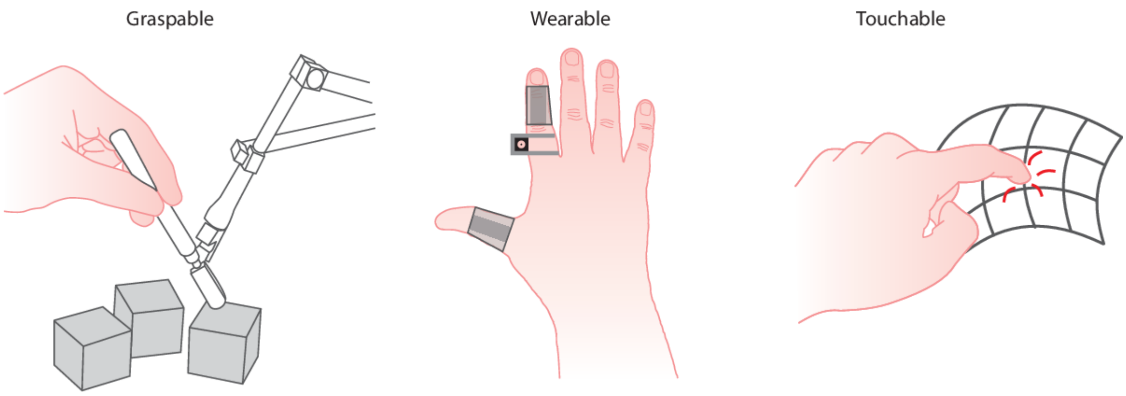

Figure 2.3: Examples of Graspable, Wearable, Touchable Haptic Systems
Source: https://vrscout.com/news/how-ai-and-haptics-could-revolutionize-vr

2.4.4 The Advancements of Ultrasound Haptic Technology in Entertainment

Ultrasound haptics is a fast-moving field that involves creating haptic sensations using ultrasound waves. Ultrasound waves are a form of sound wave that is typically above 20 kHz, exceeding the range of human hearing. This is an example of mid-air haptic technology, which enables the delivery of a haptic sensation without any direct connection between the user and the haptic interface.

Haptic technology has revolutionized the way people experience art in the past few years. Ultrasound haptics can create a broader range of sensations, including pressure, vibration, and texture. It has been used to give viewers an enhanced immersive experience in museum art exhibitions. In addition to traditional art, this technology has been used in applications merged with different technologies such as audiovisual, augmented reality, virtual reality, and mixed reality to give a better entertainment experience to the viewers. One such example is "Neurodigital: Touching Masterpieces" (Lannan 2019). This study uses ultrasound haptic feedback with virtual reality to create sensations for users interacting with famous museum artworks like statues, enabling individuals with visual impairments to experience the artworks. Instead of a VR headset, they use a pair of gloves that use ultrasounds to simulate the texture and 3D shape of the selected statues (Lannan 2019).

Combining 3D technology with haptic feedback creates an immersive experience by allowing viewers to physically touch the 3D representation of the object while feeling it with haptic mapping of the object. 3D Photowork is a company that works with these two technologies to provide their service for museums, art galleries, libraries, science centres, etc. First, they create 3D sculptures that are used as tactile prints, and then they use sensors in the 3D art to activate sensory sounds (Gabry 2018).

The Tate Sensorium, a project initiated by the company "Flying Object", was a groundbreaking experience for art viewers. It featured four different paintings, each of which was enhanced by a mix of sensory stimuli, to investigate the possibilities of multi-sensory experiences. The exhibits allowed the viewers to interact with the art pieces in novel and fascinating ways. For example, "Full Stop" by John Latham used mid-air haptic sensations with synchronized sounds to simulate a feeling of a dry rain and a blow through a straw on the skin using mid-air haptics. Those haptic inputs were synced with a soundtrack that amplified the artwork's interaction of positive and negative space (Pursey & Lomas 2018).

2.4.5 Spatial Presence with Audio-Visual Technology

Audio-visual technology is a form of media that blends audio and visual elements to produce a multimedia experience for the user. Audio-visual technology stimulates the human senses by creating a fully immersive experience that triggers feelings and emotions. The visual element is accountable for the images that the user perceives. It grabs the attention of the user and sets the context for auditory elements. The auditory system is accountable for the sounds that human beings perceive. It establishes an emotional connection and develops the story with visual elements. Such senses work together to deliver a fully immersive experience that stimulates the human senses and enhances understanding.

Dolby Atmos is a cutting-edge audio technology system that delivers an immersive experience by directing sounds in any direction based on the speaker position and the number of speakers. Dolby Atmos creates a three-dimensional space around the listener by placing sound objects above, below, and around the listener(Cabanillas 2020). The concept of Dolby Atmos technology was first introduced with Disney's Pixar movie "Brave", where the overhead speakers were positioned hanging from the ceiling above the audience to give them a more immersive experience (Cabanillas 2020). Now it is widely used everywhere to improve spatial presence, and its impact on the entertainment industry cannot be underestimated. Its ability to create a three-dimensional space around the listener has made it a popular choice for the music streaming industry, audio engineering industry, movie industry, etc. Dolby Atmos is an innovative audio technology that has revolutionized the entertainment industry.

2.4.6 The Advancements of Audio-Visual Technology in Entertainment

Audio-visual technology is now an essential component of the entertainment industry. It has revolutionized the way humans perceive art. This technology gives these visual arts a new dimension by bringing the artwork to life. This approach creates an immersive experience that enhances the viewer's senses and emotions.

The Rain Room is an artwork hosted in an art exhibition in 2012 and 2013 at the Barbican Museum and MoMA (Museum of Modern Arts), created by Random International in collaboration with Hyundai Art and Technology (Yuan et al. 2020). The artwork uses 3D motion sensors to track the viewers and prevent rainwater from falling on them. The exhibit uses recycled water, and spotlights illuminate the rain room to reflect the water droplets, creating a surreal experience. The Rain Room relies heavily on audio. The sound of rain falling is played throughout the exhibition. The audio is carefully calibrated to match the flow of water to create an immersive experience (Yuan et al. 2020).

The Tate Sensorium exhibition is worth highlighting again as an example of the effective use of multi-sensory experiences blended with technology in art entertainment. For example, the scents and sounds used in the "Interior II" display were chosen to enhance the experience of viewing Richard Hamilton's painting, which portrayed a late 1940s interior. It used four speakers to deliver quadrophonic sounds to create a surround-sound experience for the viewers. Three Olfactive Pro perfume diffusers were used to spray the fragrances, and each of them had a distinct scent to represent different elements in the artwork and shift the viewer to that time and place, creating a more enhanced experience. Similarly, all four paintings were presented by merging different sensations and technologies with audio-visual technology. John Latham's "Full Stop" was experienced using haptic sensations with synchronized audio. David Bomberg's "In the Hold" was experienced using scent stimuli in 3D-printed objects along with directional sounds. Finally, "Figure in a Landscape" by Francis Bacon was experienced through taste, scent, and auditory stimuli. Audio-visual technology plays a vital role in an art exhibition, and the Tate Sensorium exhibits were able to successfully merge various sensory inputs to create a fascinating art experience for the viewers along with audio-visual technology (Pursey & Lomas 2018).

Figure 2.4: Rain Room at the Museum of Modern Arts
Source: https://www.moma.org/calendar/exhibitions/1352

2.5 Adopting Multi-sensory Entertainment for Contemporary Art

Contemporary artists seem to adopt different technologies to create multi-sensory art for the audience. Several types of research have been done on this subject. As an area of focus within this domain, researchers try to create inclusive art for people with disability by inventing novel ways for them to enjoy art (Rieger & Chamorro-Koc 2022).

Christidou el al.(Christidou & Pierroux 2019) recently conducted research in association with an exhibition that was touring in Norway named "The Form of Eternity." The exhibits were designed and sculpted by Norwegian modernist artist and sculptor Aase Texmon Rygh. She has tried to embed geometrical and mathematical concepts of eternity and infinity into his sculptures. The exhibition mainly relied upon visitors interacting with the artefacts by seeing and touching them. During the aforementioned research, researchers gathered some findings about using touch as an interpretive device: touch has an interactional communicative function, interpersonal function, and ideational function.

Digital museums are another pathway of multi-sensory entertainment experience in contemporary society. The Museum of Pure Form allows its visitors to wear a device on their index, letting them receive haptic sensations of the 3D artworks they are looking at (Vaz et al. 2020).

Figure 2.5: Eternity's Form Sculpture by Aase Texmon Rygh
Source:
https://www.altamuseum.no/en/events/aase-texmon-rygh-evighetens-form

A six-week exhibition held by the Tate Britain art gallery that is situated in London, United Kingdom, integrated paintings with other sensory stimuli to create a multi-sensory user experience. The paintings presented in this exhibition were: Interior II painted by Richard Hamilton, Full Stop painted by John Latham, In the Hold painted by David Bomberg, and Figure in a Landscape painted by Francis Bacon. Full Stop painting combines visuals with touch and sound features to make a strong impression on the viewer (Vi et al. 2017). Researchers asked the visitors to place their palms on a haptic sensory device that outputs tactile sensations. Parallelly, sounds were used to invoke different motions in the painting. The sound file created by collecting audio parts from invoking motions is the final sound file then used to synchronize with the haptic device to give a comprehensive experience. Different haptic patterns were utilized in different stages to increase the effectiveness of the study.

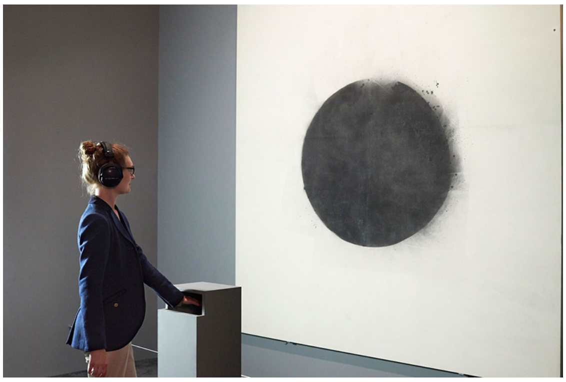

Figure 2.6: Visitor experiencing Full Stop by John Latham displayed in Tate Sensorium
Source:
https://www.widewalls.ch/magazine/multisensory-exhibition-tate-sensorium

Flavor and taste can be utilized as utensils for conveying things like class, race, and culture. It is not often regarded as such, but it could be a great cinematic tool (Velasco et al. 2018). Edible cinema brings together audio, visual, and gustatory stimuli to create a rich cinematic experience that compliments the narrative of the movie (Velasco et al. 2018). Edible Cinema collaborates with other institutions to add more value to the multi-sensory cinematic experience.

More inventions and novel ideas exist in the contemporary entertainment industry, which will be briefly described in the following paragraph.

Faustino et al. (Faustino et al. 2017) have created a wearable device called the SensArt. It stimulates the auditory sense, Mechanoreceptors, and Thermoreceptors to give a fuller and richer experience. The Cultural Survival Gallery uses moving images and audio-visual media to create an 'imaginary sensory environment' (Morgan et al. 2012). The vibrotactile augmented garment created by Giordano et al. Giordano et al. (2015) is used in the sensory art installation called 'Ilinx'. This installation blends together sound, visuals, and whole-body vibrations. Visitors are guided through two phases, the first one choreographed to present a planned-out experience while the second phase lets them move around freely and feel the art at their own pace. Sound Forest is another instalment that is introduced as an extensive Musical Instrument of Digital properties. There are five optic strings set from the floor to the roof of a room while each pole sits on a platform that produces vibrations when something interacts with the pole. The fibre optic strings emit different colours and intensities depending on the input they get from the visitors plucking the strings. Three speakers connected to each string output the sounds the strings generate. It is a cross-modal interaction that uses several senses at once to produce music, and five different people can collaborate in the same time to create an intuitive musical experience. Visitors can feel the vibrations through their feet in addition to hearing the music and seeing different colours of light (Frid et al. 2019).

Bumble Bumble is a musical system that is developed by Zhou et al. (Zhou et al. 2004). The same developers created the Magic Music Desk (MMD) . Both of those systems offer a unique experience to music enthusiasts. With Bumble Bumble, users can create chaotic, non-linear music using an Augmented Reality game while the users can manipulate VR visual metaphors of musical instruments in the physical environment. Input for MMD is taken through natural, intuitive hand and speech commands to produce music. MMD translates speech commands into visual imagery. EXTRACT/INSERT is an exhibition curated by the Herbert Museum in Coventry, England. It merges the real and virtual worlds using a series of sensory cues. As a result, visitors can see avatars from a virtual world enter into the physical space (Kawashima 2006). The "Touch Art" exhibition used Didu technology. They reproduced five paintings that are under the possession of the Fine Arts Museum, Bilbao. This technology emerged from Estudios Durero company in Spain. Didu is a technology that carves and etches a design into a block. The audience can touch the paintings while an audio track guides them through the interpretation of each piece of art (McMillen 2015).

2.6 Adoptable Aspects of Multi-sensory Entertainment Literature

Looking through an overview of the literature, multi-sensory entertainment-based research has received primarily positive feedback from the participants of the study. Researchers rely on methods like audio and video recordings to collect data when conducting research, and it seems that they return accurate results for analyzing purposes (Christidou & Pierroux 2019). Researchers recognize the importance of understanding how an exhibition plays a huge part as a resource centre for expert knowledge and providing historical and artistic context to the exhibits presented when doing a study (Christidou & Pierroux 2019). This research further establishes that while interaction and multi-sensory engagement are crucial, it is also necessary to provide resources such as interpretive texts to strengthen the experience.

The study done by the Tate Sensorium resulted in mostly positive feedback from the participants. Multi-sensory sensations layered upon the visuals help create a deeper emotional reaction Vi et al. (2017). The degree of arousal experienced by a user depends on the type of haptic sensations they feel. As an example, a Circle haptic motion has a much higher arousal level than a Line haptic pattern. Faustino et al. (Faustino et al. 2017) write that emotions felt by the audience while going through a multi-sensory experience are affected by the length and intensity of haptic perception as well as the body part the sensation is pointed at.

Edible cinema provides an interesting point of adding new layers to the cinematic experience by providing elements to arouse taste, smell, sensations in the mouth, and Thermoreceptors (Velasco et al. 2018). Using movies that the audience is familiar with helps them connect with it more as well. The element of nostalgia seems to be an effective tool when adopting a cinematic piece into a multi-sensory experience (Bugaj 2019).

Temperature changes the arousal(alertness) and dominance(intensity) of an emotional experience. Studies show that usually, the participants incorporate warmth with pleasant feelings and coldness with fear (Faustino et al. 2017).

Apart from some minor negative feedback from a few participants, 'Ilinx' by West et al. (West et al. 2019) resulted in an engaging and surprising installation. Well-planned accurate placement for tactile enhancement in the body suite is the key factor of that success.

2.7 Limitations and Challenges

In limitations, it can be seen that the lack of understanding about the multi-sensory cues and how people would react to them is hindering the applications of multi-sensory entertainment. However, It creates the opportunity for experimenting and learning, ultimately leading to more advanced entertainment. Research also shows that timing, intensity, and method of delivery can significantly affect the entertaining or overwhelming qualities of a multi-sensory cue.

Moreover, most contemporary multi-sensory art can only be experienced by one person at a time. The full Stop art piece in the Tate Sensorium can be taken as an example (Pursey & Lomas 2018). Tate Sensorium is regarded as one of the most memorable multi-sensory exhibitions. However, each art piece in the exhibition can be experienced by one person at a time because they are utilizing equipment like headphones, and a haptic touchpad to present the experience. Researchers have a substantial gap to focus on creating a multi-sensory experience that can be enjoyed by several people at once.

Several limitations were identified in the study conducted by Guo et al. (Guo et al. 2021) using video clips from Mori Digital Art Museum to stimulate mental imagery and perceived feelings. Video stimuli often have limited field-of-view, low resolution of reality, and user disorientation.

In retrospect, researchers have realized that every multi-sensory experience does not leave the audience satisfied and entertained. According to Velasco et al. (Velasco et al. 2018), screening of Iron Man 3 caused the audience to be exhausted. This was because of the researchers' lack of knowledge and understanding of the link between multi-sensory stimulation and experience (Obrist et al. 2017). It is still hard to determine how people experience multi-sensory cues. Specific design frameworks that exploit touch, taste, and other novel multi-sensory modalities are also scarce (Obrist et al. 2017). When several multi-sensory cues are enticed together and fed to a person, there is a chance that it would produce unexpected results such as sensory overload or depression. Incongruous stimuli can create perceptual effects and illusions. Therefore, a researcher must always resort for choosing which sensory cues to merge together to compose a comprehensive, enriching, and effective immersive multi-sensory experience (Frid et al. 2019).

Vi et al. (Vi et al. 2017) state that their study, though mostly received positive feedback, received some negative feedback due to the lack of fulfilment of the participants' expectations. The participants expect full body stimulation. Even though, in theory, this idea seems rather effective, executing a study of that scale can be exhausting. Further, because of the points mentioned earlier in this section, it could result in an overwhelming and unenjoyable experience for the participants. Visitors also did not prefer the limited individual journey and self-discovery. Each visitor was guided through the museum space on a defined path. Though this was a conscious decision taken by the researchers, it limited the free interaction between the art and the visitor.

The method of edible cinema, which is to distribute trays of food to visitors manually, does not utilize technology. It relies on a series of signals to communicate to the audience when to open and consume the different food items they are given (Velasco et al. 2018).

In the 'Ilinx' installation, participants criticized the body suit for being too loose, resulting in inaccurate tactile sensations (West et al. 2019).

Sound Forest successfully tackles one of the findings in the musical research, which is that there should be proper nurturing and development through education and listening exercises for one to be able to create meaningful music (Frid et al. 2019). To address this point, Frid et al. (Frid et al. 2019) studied children starting from age 2 who visited Sound Forest. The results found that young children are in fact capable of associating music with emotional attributes with consistency.

Speech is not often recognized as an intuitive interaction in HCI. Zhou et al. (Zhou et al. 2004) mentioned that in some contexts, it is not the user's tactile actions that determine the output of a multi-sensory interactive device. Instead, it depends on the system's interpretation of those actions. Improvements must be made when designing a system to overcome these challenges.

2.8 The Impact of Multi-Sensory Experience on Entertainment

Escapism and entertainment are key objectives museums, and such entertainment-providing institutions should aspire to provide to their audience. A combination of this objective and a few other objectives subsequently provides the experiencescape model; Education, entertainment, aesthetics, escapism, serendipity, localness, communitas, and personalization (Guo et al. 2021). Even though fields like neuroscience, art, and aesthetics have adopted the concepts of multi-sensory perspective, naturally occurring interactions with visitors and displayed art or artefacts are rarely seen and studied (Christidou & Pierroux 2019). However, the literature indicates that visitors to museums, art galleries, etc., are actively looking for an immersive experience (Lunardo & Ponsignon 2020). It is obvious that such experiences merged with cutting-edge technologies can increase enjoyment and satisfaction (Chung et al. 2018).

Research and development in the multi-sensory field give artists novel ways to compose art and perform as well as make them more interactive using the methods they are familiar with. For example, the conducted by Verma et al.(Verma et al. 2020) allows painters to compose music by manipulating brush strokes. One of the objectives of this research is to allow musicians to generate album cover art through clips of their respective music.

In the last few years, there seems to be a trend within museums to adopt different multi-sensory cues to provide a different and more memorable experience to visitors (Mirghadr et al. 2018).

Exploiting nostalgia and the power of fan engagement have become trends in the entertainment industry, which makes most of the material used for these multi-sensory experiments, research, and studies that involve an audience old and well-loved (Atkinson & Kennedy 2015*b*). This factor acts as a catalyst to create a deeper emotional engagement along with the multi-sensory experience. There is a visible growth in live cinema exhibitions and distribution (Atkinson & Kennedy 2016).

While physical engagement plays a significant part in the multi-sensory entertainment industry, establishments like The 'Cultural Survival' Gallery demonstrate how interaction can be manifested through passive and still experiences. In addition, sensorial-political ideas like access and inclusion are vastly considered when experimenting with multi-sensory entertainment. The goal of such studies is to motivate more diverse audiences to engage in entertainment experiences (Fartan 2022). Though accessibility is utterly important, it should also be mentioned that it is not enough. A person with impairment should also be able to have opportunities to meaningfully engage with the art and receive a rewarding experience. Any program, installation, or exhibition should strive to be easily accessible for everyone, provide educational insights, and be inclusive to a much larger audience (Kawashima 2006). Sound Forest provides a great example of a platform that practices this point. This installation has wheelchair accessibility and even the hearing-impaired visitors could use other sensory outputs present like vibrations and visuals to enjoy the experience. The EXTRACT/INSERT exhibition which combines virtual elements with the physical space, is accessible through the internet, taking accessibility into a more meaningful avenue. Spanish company Estudios Durero developed a relief printing technique that allows designers to etch digital images into a block. The painting therefore will contain different volumes, textures, and shapes in different areas. It allows people to feel an image with their touch and experience that image more intimately than just seeing it (Kawashima 2006).

2.9 Discussion: Strengths and Weaknesses of Multi-sensory Entertainment

Looking at the literature, domain-specific research and the contemporary state of multi-sensory integration in the entertainment industry, many strengths and weaknesses can be identified, which are summarized below.

Strengths	**Weaknesses**
Multi-sensory integration helps effective information communication with a greater inclusion rate (people with learning disabilities, etc.) (Matos et al. 2015).	Some technologies can have physical manifestations of discomfort like simulator sickness caused by the Microsoft HoloLens (Vovk et al. 2018).

New technologies can be adopted to further strengthen the ideas and products of the domain. Technologies like FMRI and EEG are giving a new point of view into the inside of the human brain, allowing researchers to study not only how multi-sensory applications affect a person's arousal but also how effective different multi-sensory cues are. Also, Artificial Intelligence and Machine Learning are used by researchers in their multi-sensory entertainment related research (Verma et al. 2020).	Limitations of the visual stimuli (specifically video) such as limited field-of-view, low resolution, user disorientation (Guo et al. 2021).
Multi-sensory integration for entertainment. It increases the user experience, involvement and engagement (Atkinson & Kennedy 2016). The collaboration between the users can be enhanced (Frid et al. 2019). User satisfaction with such an experience is recorded as higher than a traditional experience (Gong et al. 2022).	Because of the researchers' lack of understanding of the sensory alignment and how to effectively integrate several stimuli together, the audience sometimes get exhausted or overwhelmed from the constant flow of information they are getting (Velasco et al. 2018) (Vi et al. 2017).
It creates a broader range of sensations with different stimuli (Lannan 2019).	The users develop psychological effects such as sensory overload, depression, perceptual effects and illusions (Frid et al. 2019).
It builds a three dimensional space around the listener, especially with the auditory related integration and improves spatial presence (Cabanillas 2020) (Velasco et al. 2018).	Some sensory cues are easy to miss if not communicated properly, especially if there are certain instructions that the audience have to follow simultaneously with the experience (Velasco et al. 2018).
Adds value to the traditional entertainment (Velasco et al. 2018).	Inaccuracies in identifying tactile sensations are also an occurrence (West et al. 2019).
Creates deeper emotional reactions in the visitors (Vi et al. 2017).	

Table 2.1: Strengths vs Weaknesses of Multi-sensory Entertainment

2.10 Conclusion and Future Work

In conclusion, we can see that throughout history, many researchers have tackled different aspects of multi-sensory cues and how they can be practically applied to numerous fields. Advancements in cutting-edge technologies help researchers navigate through their research into novel areas, including entertainment.

Moreover, technologies like VR, AR, Ultrasonic Haptic technologies, and audio-visual technologies are taking a great stance in the multi-sensory entertainment industry. This has helped appeal to a larger audience and include people with certain impairments or disabilities to enjoy art. A trend can be seen in the entertainment industry, where entertainers have started to adopt different methods to create multi-sensory art. Artists with different expertise can often be observed collaborating to achieve this end. Museums have also started to pave the way for more enriched visitor experiences using multi-sensory art.

With the increasing technological advancements, the demand for multi-sensory entertainment is dramatically increasing. However, research done to understand how to implement multi-sensory cues effectively is a rarity. It can often be observed from the participants of multi-sensory entertainment studies claim that they were overwhelmed by the experience more than entertained. It is not a reason to be discouraged but rather an opportunity to explore how to implement several multi-sensory cues in the same piece of art. There is a gap in the research area to find how to combine several sensory stimuli effectively to create an art piece that leaves a lasting positive impression on the audience. This research gap is further fed by the fact that researchers mostly focus on studying how one particular sensory stimulus affects a person. But as humans, we perceive the environment with many senses at once. Though there are several studies done on studying the effects of combined sensory stimulus, this is an area where many more studies are needed.

Novel ways of utilizing multi-sensory entertainment to introduce enhanced experiences to people with an impairment are also a dire necessity in the entertainment field. Especially the visually impaired population suffers immensely when it comes to enjoying art (paintings) because the entertainment industry greatly relies on the sense of sight. This is another area where not enough studies are done but can be benefited through multi-sensory entertainment. Multi-sensory entertainment can be a great asset in a forwarding world where the demand for escapism is rising every day.

Chapter 3

Research Design

3.1 High Level Architecture

This research attempts to create a means for visually impaired individuals to use other sensory stimuli to experience a painting. For this purpose, we designed a prototype called SEMA: Specially Enhanced Multi-sensory Art which encompasses stimulating three main senses; Tactile, Auditory, and Somatosensory. By integrating these different sensory stimuli, we hoped to understand how multi-sensory integration contributes to understanding a scenario of a painting better when the assistance of the sense of sight is limited. To stimulate each sense we chose three elements a River, a Campfire (bonfire) and a Tent. A combination of different stimuli represents each of these elements.

	Tactile	Somatosensory		Auditory
		Cold	Hot	
River	x	x	-	x
Campfire	x	-	x	x
Tent	x	-	-	

Table 3.1: How three stimuli are represented in different elements

The high-level architecture of this system is represented in Figure 3.1 below. When the user approaches the proposed system SEMA, they can start with either of the elements and work their way to the other elements and experience the SEMA fully.

To accommodate to the above architecture, several hardware and programs are built. Each hardware component will focus solely on providing one stimulus for the purpose of easy modification and integration purposes. To elaborate, the thermal actuator component only provides heat and no tactile or auditory stimuli. Separate components will be built for the other two components.

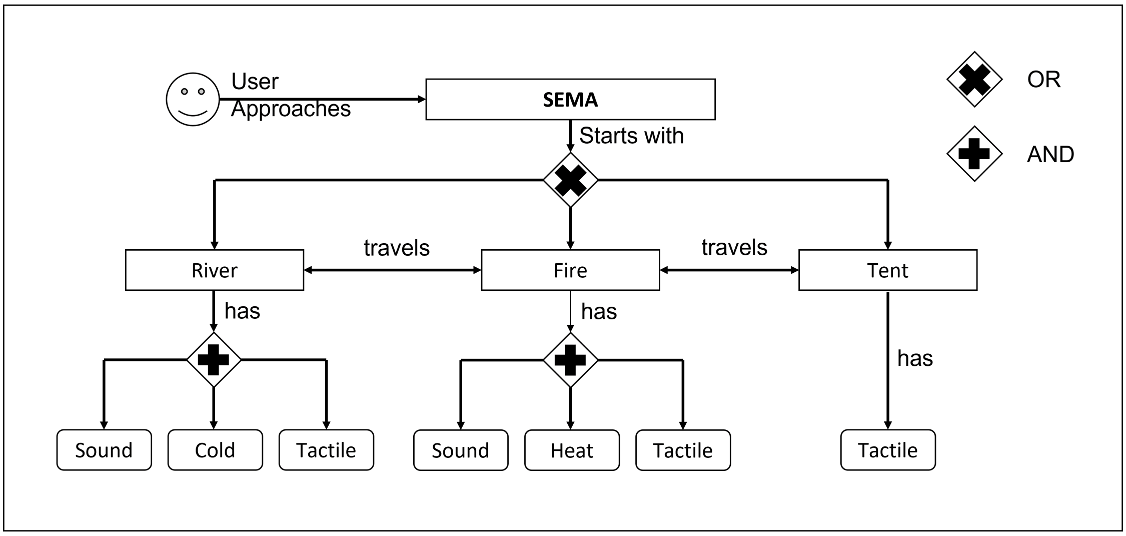

Figure 3.1: High-level architecture of SEMA

3.2 User Study

A user study was conducted to investigate how visually impaired individuals engage with multi-sensory augmented paintings. Seventeen participants, ranging in age from 18 to 60, were recruited. The visual acuity distribution (Dandona & Dandona 2006) included ten participants categorized as "Severely Blind," two as "Blind," four with "Moderate Visual Impairment," and one with "Mild Visual Impairment". This study was held to observe participants interacting with a prototype designed to enhance a painting through multi-sensory stimuli and assess their engagement.

The user study consisted of two phases. The first phase focused on gathering feedback from visually impaired participants regarding their fundamental tactile experiences. This feedback informed the development of the Specially Enhanced Multi-sensory Art (SEMA) prototype. Second phase focused on evaluating the prototype, with respect to how would a visually impaired person would normally experience a painting (i.e. by listening to a description of the painting). The SEMA prototype facilitates active engagement with a painting, allowing visually impaired individuals to grasp its core content. A combination of quantitative and qualitative methods was employed to collect data. These methods included participatory observations, informal discussions, and Likert-scale questionnaires (Beeli et al. 2005). Additionally, semi-structured interviews were conducted, utilizing open-ended questions to encourage participants to elaborate on the challenges they encounter when experiencing paintings and similar art forms as visually impaired individuals.

Phase one of the user study aimed to enrich the participatory design process. Informal discussions were conducted with visually impaired participants to explore their early experiences with shape recognition and historical art appreciation (e.g., Sigiriya paintings). Additionally, discussions centered on their general approach to experiencing paintings and their perspectives on using touch and vision in tandem to create a mental map of a painting.

Analysis of the first phase revealed that identifying object boundaries within paintings posed a significant challenge for visually impaired individuals. Participants described using strings to delineate object boundaries in educational settings (e.g., maps of Sri Lanka) to create a tactile representation in their minds. Furthermore, they expressed that their exposure to paintings was primarily limited to verbal descriptions provided by sighted individuals. This presented difficulties in comprehending objects they had never experienced through touch (e.g., fireplaces, Sigiriya rock). Consequently, their mental image of such objects remained abstract.

Based on this feedback, the research team prioritized object boundary identification within the prototype painting. Additionally, the incorporation of multi-sensory elements (heat, cold, and sound) aimed to further enhance the experience. It is important to clarify that the prototype's focus was on facilitating object identification, not on conveying the deeper meaning or artistic intent behind the painting.

Given the visually impaired nature of the study population, the initial phases prioritized qualitative methods. Participatory observations and unstructured interviews were employed to examine how participants interacted with tactile sensations to identify objects within a painting. This approach allowed researchers to observe overall engagement strategies and gather participant perceptions through informal discussions. Below image how participants interacted with the initial test prototype. They were presented with various embossed lines crafted from plaster of Paris in different thicknesses and lengths to assess their interaction with such materials. This methodology fostered rapport with participants and yielded a deeper understanding of their experiences. Additionally, the casual approach contributed to a positive and engaging user study for all participants.

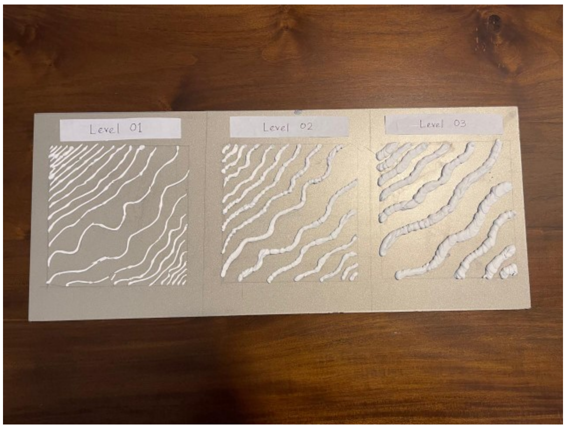

Figure 3.2: Embossed lines with various width and thickness were presented

The Faculty of Arts at the University of Colombo was selected as the primary research site due to its accessibility features catering to visually impaired individuals. This selection was further justified by the Faculty's distinction as the sole government university faculty offering specialized admissions for students with disabilities, as documented in *Centre for Disability Research, Education and Practice (CEDREP) — arts.cmb.ac.lk* (n.d.). The initial visit to the Faculty was facilitated by a Computer Instructor specializing in Special Needs Education (Grade 2) employed by the institution.

To ensure ethical conduct and adherence to research protocols, we were advised to obtain prior approval from the University of Colombo's Ethics Board before commencing the study. A participatory design approach was implemented, fostering engagement with participants and allowing them to provide feedback on the overall prototype design. This approach was further extended by empowering participants to determine the optimal boundary thickness for the prototype. By actively involving participants in the design process, we aimed to guarantee that the final solution aligned with their specific needs and preferences.

The following section, "Research Design," delves into the decision-making process for constructing the apparatus, integrating multi-sensory stimuli into the painting, and designing the evaluation methodology. This section provides a detailed account of the factors influencing these decisions and the methods employed to arrive at the final design.

3.3 Research Design

This section outlines the design of the proposed study, including the design specifics of the proposed prototype. The proposed research design will mainly focus on two main components.

3.3.1 The painting

This study adopted a single-painting approach to explore the potential of multi-sensory experiences for visually impaired individuals. The selection of the painting itself necessitated careful consideration. While popular works like Van Gogh's "Starry Night" or Vermeer's "Girl with a Pearl Earring" possess artistic merit, their deeper meanings transcend literal interpretation. These paintings, even for sighted viewers, require contextual understanding to fully grasp the artist's intent. The focus of this research, however, was not on conveying complex emotions or narratives, but rather on evaluating the effectiveness of multi-sensory augmentation in conveying basic visual information through touch and sound.

Therefore, we opted for a painting that could be deconstructed into fundamental visual components comprehensible through tactile and auditory means. Simple geometric shapes, while readily understood through touch, wouldn't necessitate a painting in the first place. Visually impaired individuals often navigate the world by tactically exploring objects, forming mental maps of their surroundings. This research, however, hope to address challenges associated with comprehending entities they cannot physically touch, such as a fireplace or a river. The goal wasn't to convey knowledge about the exact shapes of these objects in the real world, but rather to assess how such entities are typically depicted in paintings and how multi-sensory augmentation could enhance this representation. Given these considerations, we identified the need for a painting that could incorporate elements characterized by distinct thermal sensations: coldness, warmth, and a neutrally textured, easily traceable element. Consequently, a simple campsite scene featuring a stream (coldness), a bonfire (warmth), and a tent (tactile exploration) was chosen as the artistic foundation for the study. The first digital design for the painting is shown in the following figure.

Figure 3.3: Digitally designed initial image for the painting.

To optimize cost-effectiveness, the painting's foundation was planned to be constructed from a basic hardboard supported by a wooden frame. This minimalist design approach was adopted to prioritize functionality while minimizing expenses associated with elaborate frames and canvases.

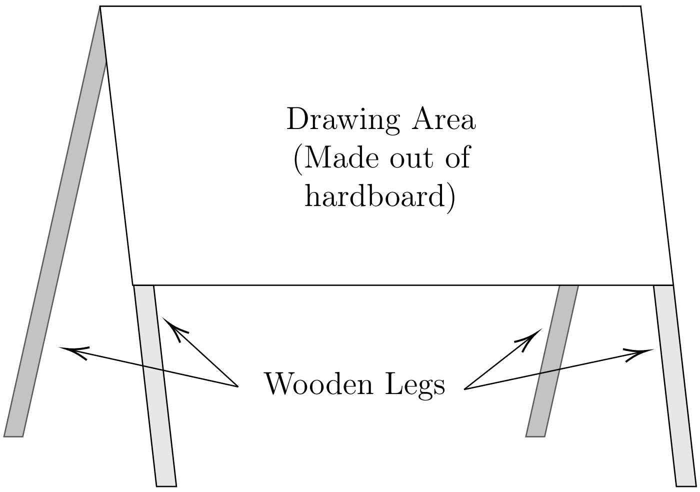

Figure 3.4: Initial Design of the canvas - Front view of SEMA

Now, after the painting was selected, we designed the specific augmentation methods to enhance the content of the painting. our intention was to give out cold sensation when the river was touched by a participant, a heat sensation when the fire was touched, and all these experience will enhanced by a constant audio stream that's playing ambient sounds. all in all the goal was to create an immersive experience to enjoy the painting to its maximum capacity.

3.3.2 Contour Line Design

One of the most well-established methods for tactile letter recognition is Braille. Beyond Braille, tactility is essential for object identification in everyday situations. Visually impaired individuals rely on the sense of touch to explore the texture, shape, and size of objects. This exploration process allows them to build mental representations of objects and categorize them based on their tactile properties. For instance, differentiating between a cup and a book is achieved through a combination of grasping the object and feeling its unique surface contours. Studies by Heller & Gentaz (2013) have shown that haptic exploration strategies are systematic and efficient, enabling rapid object recognition through touch. Embossed surfaces take the concept of tactile perception a step further. Embossing refers to the process of creating raised designs on a surface. In the education context, embossed materials are frequently used to teach visually impaired children about letters, shapes, and geographical features. By feeling the raised lines and bumps, children can learn to associate these tactile experiences with visual representations. Kamei-Hannan & Lawson (2012) investigated the effectiveness of embossed materials in learning Braille, demonstrating their positive impact on developing literacy skills.

Based on the insights gleaned from both the current study and the Sri Lanka Council for the Blind user study, we determined the optimal thickness for the contour lines demarcating object boundaries within the painting. Participants were presented with lines of varying spatial intervals (1mm to 30mm, measured using callipers), for them to identify a preference for an optimal difference between two lines. Afterwards, we identified the objects within the painting that would benefit most from the application of these contour lines. Plaster of Paris was chosen as the material due to its ease of use and application; it could be readily applied to the painting using a standard syringe.

3.3.3 Design of the Heat and Cold modules

While touch remains the primary sense for object identification among visually impaired individuals, the potential of incorporating other sensory modalities is actively explored in the field of multi-sensory integration. One major case is utilizing thermal cues, specifically controlled heat sensations, to enhance object recognition. By incorporating a mild heat source behind the area depicting the fireplace, the individual would receive an additional layer of information. The idea is that this thermal signature could strengthen the mental picture of the object and create a more holistic understanding of the painting.

The practical implementation of thermal cues presents exciting possibilities. Peltier modules offer a promising solution. These solid-state devices can generate heat or cold depending on the direction of the current. Compact size and low power consumption make them ideal for integration into tactile displays or interactive environments. By placing Peltier modules behind specific elements within a tactile representation, heat could be used to highlight objects associated with warmth, in the context of this research, the fireplace. Commercially available Peltier modules within the study's geographic scope (Colombo and surrounding suburbs, Sri Lanka) fell into four primary categories. The following table outlines the key differentiating factors between these commonly available modules, focusing on current draw and cooling times. It is important to note that while the initial intention was to utilise Peltier modules for both hot and cold sensations, feedback from participants as well as some major technical challenges necessitated an alternative approach. Ceramic resistors were ultimately employed to generate heat on designated areas of the painting, while Peltier modules were reserved solely for producing the cold sensation.

	Current (at 12V)	**Time to 0°C**	**Temp after 30 min**	**Temp after 60 min**
TEC1-12706	3.47 A	1 min 3 sec	-4.5 'C	-3.6 'C
TEC1-12705	2.57 A	53 sec	-7.5 'C	-8.8 'C
TEC1-12704	2.73 A	35 sec	-14.8 'C	-15.5 'C
TEC1-12703	3.18 A	30 sec	-18.8 'C	-19.6 'C

Table 3.2: Specification of Different Peltier Modules

Figure 3.5: A TEC1-12706 DC12V 60W Peltier Module

Although the initial design envisioned Peltier modules for generating both heat and cold sensations, during the research process, it became evident that Peltier modules were not ideal for heat generation. Further details regarding participant feedback on this issue are presented in the evaluation chapter. A significant factor influencing this change was the technical difficulty associated with precisely controlling heat output using Peltier modules.

Figure 3.6: A 10 Ohm 10W Resistor used for the heating array

Consequently, an array of resistors ranging from 10 Ohm 10W to 5W resistors connected in series was implemented as the heat source. The challenge of heat control remained. The initial plan involved utilizing a temperature sensor to provide temperature feedback for control by an Arduino UNO module. However, due to the predictable nature of heat emission from the resistors, a temperature sensor was deemed unnecessary. Instead, a mechanical relay was employed to regulate heat delivery based on a predetermined time frame corresponding to peak heating. It is noteworthy that the inherent properties of wire-wound resistors provided an additional benefit. These resistors exhibited a slower ramp-up time to reach desired temperatures but also displayed a slower cooling rate, enabling a more gradual reduction in heat and a more stable temperature throughout the research.

3.3.4 Sound Design

Similar to thermal cues, sound can enrich object recognition for visually impaired individuals. Imagine a tactile painting of a river that plays flowing water sounds when touched, or a tactile map with chirping birds for parks and chimes for doorways. This auditory information complements touch, creating a more holistic understanding of the surroundings and art.

The intention was to incorporate ambient sounds that complemented the thermal sensations delivered by the artwork, without introducing distractions for the viewer. Initially, two 5W speakers facing downward were positioned on either side of the prototype. However, participant feedback during an initial iteration indicated that this configuration produced overwhelming sound levels, particularly in the center – the most common viewing location. The overlapping audio streams from both speakers detracted from the desired subtle, complementary soundscape.

In response to this feedback, a single speaker configuration was adopted. Subject tracking technology was then explored as a means to determine participant position and adjust the audio accordingly. While this approach addressed the issue of distracting audio overlap, it presented a new challenge: unnatural sound transitions. Dividing the camera feed into two sections and triggering distinct audio tracks based on the viewer's location resulted in abrupt shifts in sound as they moved. To achieve a smoother and more natural audio experience, the design shifted towards utilizing multiple audio tracks and dividing the camera feed into corresponding zones. By identifying the viewer's location within these zones, the appropriate audio track could be played, creating smoother transitions and enhancing the overall experience.

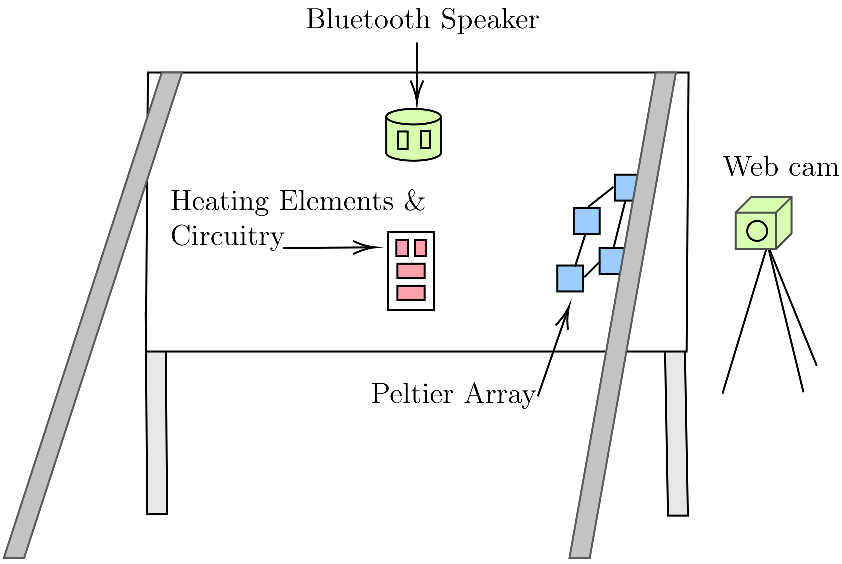

Figure 3.7: Initial Design of the eletronic circuitry - Back view of SEMA

The conducted user study proved to be a cornerstone in our investigation to answer the research questions guiding this project. By directly engaging with seventeen visually impaired participants, we gained invaluable firsthand knowledge regarding their art appreciation experiences. The diverse range of participants and varying degrees of visual acuity, offered a comprehensive perspective on the challenges they face. This user-centered approach informed the development of the SEMA prototype, as potential solution for enhancing accessibility and inclusivity in the visual art world (research question 1). The exploration of multi-sensory integration within the prototype addressed the potential for a more immersive and engaging art experience (research question 2). Finally, the study's single-viewer booth design offered a potential solution to the challenge of balancing individual engagement with broader accessibility (research question 3). By providing a platform for direct interaction with participants, the user study served as a bridge between the initial research questions and the development of potential solutions embodied in the SEMA prototype.

Chapter 4

Implementation

The implementation involved the development and integration of mechanics to stimulate tactile, somatosensory, and auditory stimuli. These stimulation mechanics were integrated into a base painting of a simple camping scenario.

Figure 4.1: Basic Painting Created on the Wooden Frame

This painting was created on a portable wooden frame. The painting itself is 6 feet long and 4 feet tall. The board of the painting (on which the drawing was done) was 2.5mm thick. Each of the hardware, and programs that layered the above painting were developed in an iterative process and the evolution of each of these are described under the next few sub topics.

4.1 Tactile Stimuli – Acrylic Relief

4.1.1 First Iteration

After drawing the painting on the board, tactile sensory stimuli were embedded on top of it. To create the basic patterns of the painting, a technique called the Acrylic Relief was used. We conducted a pretest with the participants from Sri Lanka Council for the Blind to identify the thickness and the spatial distance between the plaster of Paris lines we were going to use for the final painting. There were 3 main levels of the pretests.

- Level 1: Contour line thickness: 1mm
- Level 2: Contour line thickness: 3mm

- Level 3: Contour line thickness: 5mm

Additionally, in each level the contour lines were embedded with the spatial intervals varying from 1mm to 30mm to identify how sensitive a visually impaired person's touch to the contour lines that are closely huddled together.

Figure 4.2: Pretest conducted at Sri Lanka Council for the Blind

In the pretest, the participants gave their feedback on how well they can identify contour lines. According to them, "as long as they have enough space between them, we [visually impaired individuals] can differentiate between contour lines." We later clarified with them that the space had to be more than 1mm for them to identify two contour lines separately. They did not indicate any preference towards using one thickness over the other, and therefore, for our design, we decided to use the level 2 option with 3mm thickness.

We had three main components of the base painting: the river, the campfire, and the tent. The river and the campfire were also coupled with the somatosensory stimuli while the tent was just embedded with plaster of Paris to serve as a controlled substance. The objective was to understand whether touching would provide enough information without the additive of other sensory stimuli, much like braille as shown in figure 4.3.

Figure 4.3: Acrylic Relief Technique to Embed Tend and River and mark their boundaries

For all the components, only the outlines were embedded with the plaster of Paris as a way of highlighting the boundaries and the shape of elements.

4.1.2 Second Iteration

After the first experiment that involved the subjects, we were given some suggestions to improve the sensibility of the tactile stimuli by the participants. Therefore, some rocks were moulded and embedded into the campfire element to give it a realistic feel. They were made of plaster of Paris and given a 3D feel as depicted by the figure 4.4.

Figure 4.4: Acrylic Relief Technique to create 3D rocks on the painting

4.2 Somatosensory Stimuli – Thermal Actuators

Two sensory stimuli actuators were developed to appeal to the somatosensory sense. The heat actuator went through two iterations of development.

4.2.1 Actuator for Heat Stimulation

First Iteration

For the first iteration, a Peltier module was used as the heat emitter assisted by circuitry consisting of an Arduino Uno microcontroller board, a temperature sensor, a mechanical relay and a transformer. Figure 4.5 is initial this hardware system where a relatively small heat sink was paired with the Peltier module.

A program was developed using C language to keep the temperature on a certain level. From the pretest, we found that participants prefer the temperature to be around 55 - 60 °C for the campfire. Following is a step-by-step process of how this actuator functions.

1. 12V DC electricity is supplied to the circuit through the transformer and the mechanical relay.

2. Peltier module is heated.

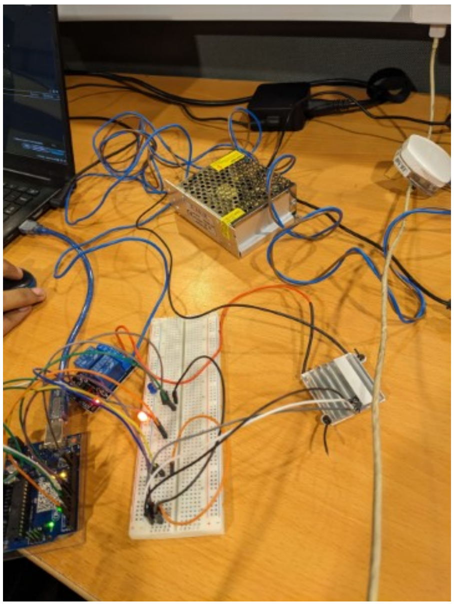

Figure 4.5: Actuator for heat stimulation using a Peltier Module as the Heat Emitter

3. Temperature sensor measures the temperature of the Peltier module and track it.
4. Once the temperature exceeds the upper end specified limit, the program sends a signal to the relay.
5. Relay cuts off the electricity to the circuit and lets the Peltier module cool down.
6. Once the temperature drops below the lower end of the specified limit, the program sends a signal to the relay.
7. Relay re-supply electricity to the circuit. We attached the Peltier module to the campfire element from behind for iteration one.

Though we used this approach for the first iteration of the experiment, we identified some weaknesses.

- Relay cannot control the heat well.
  - Since our temperature limit was quite small (5°C), the relay could not successfully cut off and turn on the power to the circuitry fast enough.
- The area coverage of the Peltier module is not enough. It only covers 2 x 2 square inches.
  - We used Nichrome wires to distribute the heat without much success.

Second Iteration

Since the main issue we faced was distributing consistent heat, we changed from the Peltier modules to a resistor array. Using the same transformer, 9 resistors that were connected parallelly were powered. This circuit shown in figure 4.6 was then pasted on top of the campfire element and covered with heat-conductive aluminium foil for even distribution in the shape of the fire. We used a thermal compound on the resistors before applying the aluminium foil to control additional heat. We supplied power to the resistor circuit for 3 minutes in 2 minute intervals to keep the temperature between 55 – 60 °C.

Figure 4.6: Actuator for Heat Stimulation Using 9 Parallelly Powered Resistors Covered with Heat Conductive Aluminum to Distribute Heat in the Shape of the Fire

Hardware	**Quantity**	**Specifications**
Circuit Board	1	not-printed
Resistor	9	10K Ohm and 5K 5% 5W Watt Fixed Cement Power Resistors: 4 each
Thermal Paste		Heat Sink Compound - HT510 Silicone Thermal Paste
Aluminum Foil		

Table 4.1: Specification for the Actuator for Heat Stimulation Using Resistors

4.2.2 Actuator for Cold Stimulation

To create the cold stimuli, we used a Peltier module along with a case fan to control the heating of the unused side of the module. A thermal compound was used to glue the case fan into the module. Both the Peltier module and the case fan were supplied electricity with a transformer.

The temperature limit we used was between 13 – 16 °C.

After creating this piece of hardware, we installed it to the painting from behind. Since our budget only allowed us to cover an area of 4 x 4 square centimeters, only a part of the river component was cooled. The ideal scenario for this approach would be to cover the whole river area with several Peltier modules, with a large heat sink to absorb the excess heat as distributed in the figure 4.7.

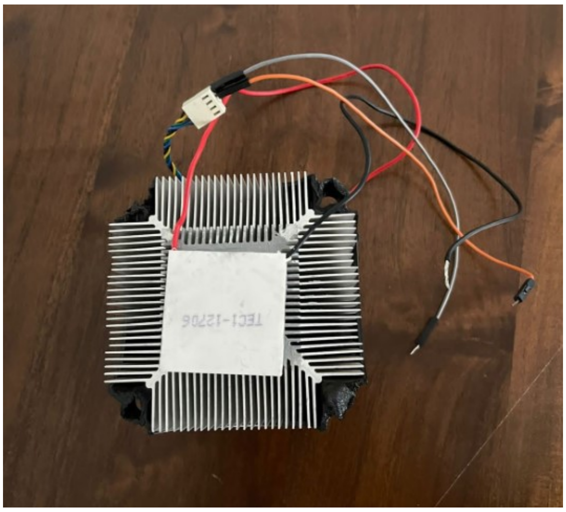

Figure 4.7: Actuator for Cold Stimulation Using a Peltier Module and a Case Fan

The humidity that was collecting over the painting due to the cool temperature of the module was used as an additional sensory stimulant; conveying the area is supposed to represent a body of water.

Following are the hardware specifications of the cold stimuli actuator.

Hardware	**Quantity**	**Specifications**
Peltier Module	1	TEC1-12706 DC12V 60W Peltier Thermoelectric Cooler (MD0318)
Case Fan	1	12V Cooling Cooler Fan IDE 120mm 2-4Pins
Thermal Paste		Heat Sink Compound - HT510 Silicone Thermal Paste

Table 4.2: Specification for the Actuator for Cold Stimulation Using Peltier Module

4.3 Auditory Stimuli

We provided two different ambient sounds for the participants depending on the place they were at while experiencing the painting.

4.3.1 First Iteration - Two Speakers

Two speakers were installed on the two sides of the painting. The painting was mainly divided into two main zones as Fire and Water and as the names suggest, the fire song was assigned a fire ambient sound track and the water ambient sound track. In the first iteration, two sound tracks were played simultaneously through the two speakers.

When doing the experiments, through the feedback of the participants we identified a main area that should be improved.

- Participants mentioned that the sounds were "bit cluttered" because they were overlapping rather "harshly."

4.3.2 Second Iteration

For the second iteration, we decided to keep one speaker so that there would not be sound cluttering. A program was developed using Python language to track the face of the subject with the assistance of a web camera that was placed above the painting. When the subject's face enters the 1st grid (fire) the fire ambient soundtrack was played on the speaker we had also placed above the painting. When the subject's face enters the 2nd grid (water), the soundtrack changes into the water ambient soundtrack.

However, when we conducted the pretest, several shortcomings were identified.

- The soundtrack change is abrupt and it disturbs the immersive experience of the participants.
- Having two separate soundtracks created a disorientation regarding the distance of the elements and one pretest participant stated that "It's like the campfire was completely removed when I go near the river. So I didn't feel like I was at a campsite, it felt like two separate scenes of a river and a fire."
- Sometimes the camera does not pick up the faces of the participants since it is set at an angle, in front of the painting.

These shortcomings were addressed next.

To improve the design, the grid was divided into 4 instead of the main 2 to address the issue of the soundtracks shifting abruptly and disorienting the participants. Our objective was to highlight the property of distance without completely shutting off one sound to spotlight the other sound.

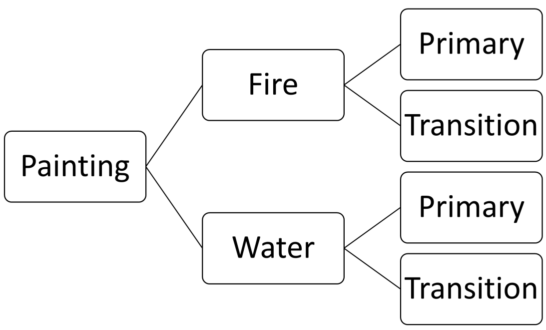

Figure 4.8: Grid zone division for audio tracks

Primary zones had more prominent sounds of either Fire or Water and the transitioning zones were a mix of both so they can act as in-between areas.

We mixed different compositions of the two tracks together to give a more immersive and put-together ambient sounds for the subjects. Audacity Recording and Editing software was used for sound mixing.

Main Zone	Divisions	Fire Sound Track	Water Sound Track
Fire	G1: Primary	25%	75%
	G2: Transition	40%	60%
Water	G3: Primary	60%	40%
	G4: Transition	75%	25%

Table 4.3: Composition of Ambient Sound Tracks for each grid zone

This approach was positively received by the participants because it created a "rather smooth transition."

To address the issue of the web camera and the program not picking up the participant's face, we changed the identifier to the whole body of the participants and placed the web camera in front of the painting, facing the painting.

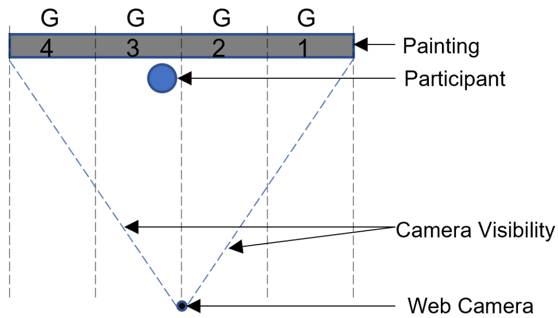

Figure 4.9: User tracking system and web camera placement

As it is shown in the figure 2 the camera is placed in front of the painting so that the entire painting is included in the visible area of the camera.

Since the visually impaired subjects tent to walk towards the element that they are exploring, their whole body usually ends up in the particular zone, therefore using the body as the target parameter for sound track program was successful.

Hardware	**Quantity**	**Specifications**
Speaker	1	Portable Wireless Bluetooth Speaker
Web Camera	1	1080p HD USB Web Camera and the Tripod

Table 4.4: Specification for the Actuator for Cold Stimulation Using Peltier Module

4.4 Integration

After each component was individually developed and tested in the pre-testing process, the integration took place. The cold stimulation actuator was installed in the back of the painting with the Peltier module directly contacting the board the painting was drawn on as demostrated by the figure 4.10. The cold sensation transferred through the thin board and started humidifying using the vapor in the atmosphere as planned. However, as mentioned earlier, the cold sensation was only provided for a small area of 4 x 4 square centimeters due to the budgetary concerns. We developed a wooden frame to hold the equipment in place so that it would be removable and installed in a different place.

Figure 4.10: Actuator for Cold Stimulation Using a Peltier Module and a Case Fan Integrated into the Painting

The heat stimulation actuator was installed on top of the painting. After installation, it was covered with heat conductive aluminum foil in the shape of the fire and the plaster of Paris outlines were applied in the same shapes to contain the heat in the boundaries of the fire as shown in figure 4.11. The board we chose for the painting was not a heat conductor and therefore did not spread the heat further in the painting.

The speaker was installed on the top middle of the painting frame. It was connected to the computer through Bluetooth where the program to choose the relevant sound track by tracking user's location in the grid with the assistance of the web camera.

4.5 Chapter Overview

This chapter describes the different types of hardware and programs that were developed for SEMA and the evolution of them depending on the input we got from

Figure 4.11: Actuator for Heat Stimulation being Integrated into the Painting and Tested by the Subjects

pretests and experiments. Three main senses were stimulated; Tactile, Auditory and Somatosensory. After 2 iterations SEMA final version of this research included Plaster of Paris contour lines, a resistor based heat actuator, a Peltier module based cold actuator, and a web camera and speaker system for ambient sounds along with a python program. The code-bases for the programs are attached in the appendix.

Chapter 5

Evaluation

This section details the evaluation methodology employed in our research. We utilize both quantitative and qualitative methods to assess participant reactions to the prototype and explore the insights gleaned from their feedback. The participants, students from the Centre for Disability Research, Education, and Practice (CEDREP) at the University of Colombo, interacted with the multi-sensory installation. We detail the methods used to capture their experiences, including questionnaires and interviews. Furthermore, we discuss the distinctions between these methods, the rationale behind employing different participant groups, and the improvements made based on participant feedback. Finally, we address the statistical significance of the findings and provide a qualitative evaluation of both the improvements and the chosen methodologies.

5.1 Usability Test (Pre-Test)

To gain insight into the interaction between visually impaired individuals and tactile sensations (Iranzo Bartolomé et al. 2020), a usability test was conducted at the Sri Lanka Council for the Blind in Colombo, Sri Lanka. Informed consent was obtained on-site, and the evaluation was overseen by the Director of CEDREP and the Director of the Sri Lanka Council for the Blind.

5.1.1 Pre-Test Plan

Our goal was to identify how the differences in thickness of a contour line affect the understanding of a visually impaired individual to trace out a territory by hand. This was essential information to know as, it was the way of differentiating between the object boundaries in the painting. For example differentiating a stone from the background (land). So we let them interact with different types of lines each having slight differences in thickness and space between lines. The material we used for constructing the lines was the same, a plaster of paris compound.

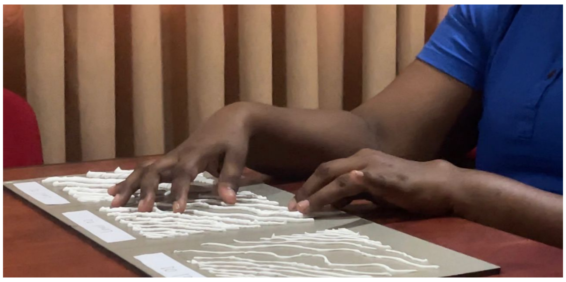

Figure 5.1: Participant engaging with different combinations of contour lines

5.1.2 Followed Procedure for the Pre-Test

We opted not to provide a structured questionnaire to participants, instead we conducted open-ended interviews to explore their firsthand experiences with various line sizes. Remarkably, all participants expressed a preference for lines within the range of 2 to 4 centimetres. These dimensions were found to be particularly effective in terms of sensory perception, ease of differentiation, and overall understanding of the painting. The insights gleaned from our usability tests played a major role in shaping the final prototype, especially with regard to defining traceable lines for object differentiation.

5.2 Evaluation 1

The finished SEMA prototype incorporated heat, cold, and sound emitters alongside embossed lines to differentiate objects within the painting.

5.2.1 Evaluation Plan

Prior to the evaluation, participants were informed about the research objectives and the evaluation process. Random assignment was employed to divide participants into two groups. The prototype group experienced the multi-sensory painting augmentation, while the control group received only a verbal description of the painting.

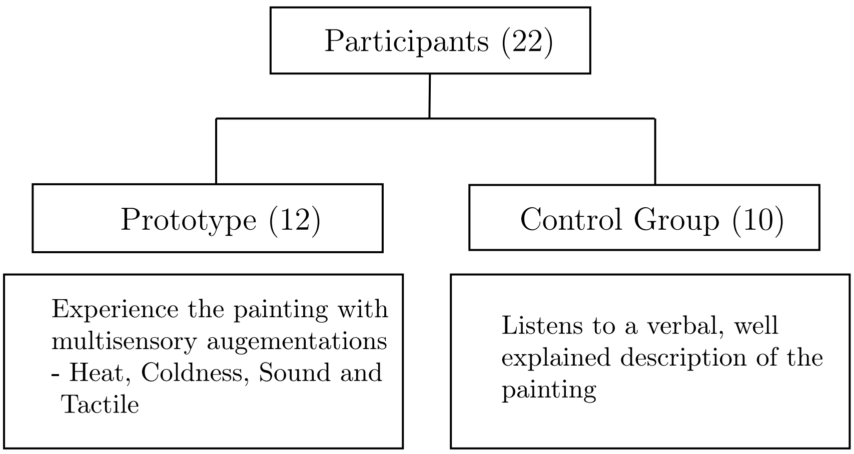

Figure 5.2: User Evaluation Breakdown

Prototype Group: Participants in the prototype group were allocated ample time to interact with the painting (SEMA). They were given a description of the painting first, and then were asked to interact with the painting as they want. A verbal guide was given when it was seemed necessary or as per their inquire. They used their hands to feel the embossing, warmth, coldness and, an ambient sound that matches the enviornment depicted in the picture was accompanying the whole session. Usually the experiencing lasted around five minutes. Upon completion, each participant was asked to sit with a researcher and complete a brief questionnaire regarding their experience. This questionnaire included seven questions designed to gather quantitative data and eight questions for qualitative data collection. Additionally, demographic information such as participant age, sex, and type of visual impairment (using WHO criteria) (Solebo & Rahi 2013) was recorded individually.

Control group: The control group experienced the painting description in a manner simulating a visually impaired person's encounter with a painting at a museum which supports accessibility guidelines. Each participant was seated individually with a researcher who provided a plain language explanation of the painting in English, based on the participants' unanimous agreement. The script used for this explanation can be found in the appendix section.

5.2.2 Followed Procedure of Evaluation 1

The following questions were asked to gain quantitative insights into the participant experience. Participants answered using a 5-point Likert scale (where 5 is the highest rating) (Beeli et al. 2005)

1. How do you like the overall experience
2. How much did you like the multi-sensory experience
3. How intense was the mult-sensory experience
4. How intense was the texture?
5. Importance of auditory stimulators in this experience
6. Importance of heat emulators in this experience
7. Important of coldness emulators in this experience

These questions were used to quantify the added values of the designed sensory augmentation to the experience of the paintings. In addition to the questionnaire data, we collected qualitative data from 12 participants through conducting interviews on right after their experience with the prototype. All the interviews were transcribed and analysed by the researchers (who conducted the interviews) based on the main areas of interest defined above. Based on repeated readings of the transcripts and discussions in the group, we clustered the findings into three main themes, which we present in the following sections after the quantitative results gained from the questionnaire.

The following collection of open-ended questions were asked during the interviews to gain feedback in their own words. These were entirely informal questions, carried out as discussions.

1. How would you describe the overall experience?
2. How would you describe the tactile experience?
3. How would you describe the heat sensation?
4. How would you describe the sensation of coldness?
5. How would you describe the auditory experience?
6. Contrary to how you would normally experience a painting, how was SEMA?
7. Anything else you would like to share or say about the experience of this art?
8. How can we improve this experience?

From the feedback we collected, we could extrapolate the following points about participants' perception of the sensory augmentation of the painting.

Overall, we observed that the participants enjoyed experiencing the prototype, many stating it as engaging and realistic. They provided many insights in the first iteration, which we were able to correct and fine tune. Before the final prototype, another pre-test was carried out to have an understanding of the heat and coldness levels, and the thickness of the contour lines used for the painting by asking them to test various levels of temperature actuators, and embossed lines.

Quantitative Evaluation Method

This study investigates the potential improvement recorded by the prototype group compared to the control group by analyzing data collected from the two sample groups. Both studies employed a Likert scale, and the processed data aims to determine which group performed better. Analysis of Variance (ANOVA) is a statistical technique well-suited to assess the differences in means between multiple groups (montgomery2017design). This approach allows us to statistically evaluate whether the observed difference in performance between the groups is likely due to chance or reflects a genuine effect of the intervention.

The result sections will detail the application of ANOVA to the data collected from the two sample groups. We will explore whether SEMA demonstrably improves performance compared to the traditional method and also if the improvements made to SEMA actually performed better than it did before, based on the processed Likert scale data. The z-test formula used for this purpose is:

$$Z = \frac{P1 - P0}{\sqrt{(P0(1 - P0)/n}}$$

- Z: The calculated z-statistic.

- P1: Sample proportion of the whole population
- P0: Assumed proportion for the result to occur
- n: The size of the population

By calculating the z-statistic and its corresponding p-value for the comparison between the two groups, whether the observed improvement in performance with SEMA is statistically significant or not is determined.

Qualitative Evaluation using Word Vectoring

To analyze the qualitative feedback obtained through open-ended interview questions, a word vectoring program was employed. This program, built using ReactJS for the frontend and Python for the backend, using the BERT Language model. Participants' responses from both the prototype and control groups were analyzed. The program functioned by vectorizing keywords extracted from the responses. This process assigns a mathematical value to each word based on its semantic meaning. These vectorized keywords were then plotted on a Cartesian plane according to predetermined criteria. The x-axis represented the intensity conveyed by the keywords, while the y-axis reflected the overall sentiment (positive or negative) expressed in the feedback. By analyzing the resulting graphs, we were able to assess the improvements achieved by the prototype relative to the control methodology. Keywords were extracted from participant responses to the open-ended questions: "How do you like the overall experience?" and "How do you describe the overall experience?". By analyzing the resulting graphs, we were able to assess the improvements achieved by the prototype relative to the control methodology.

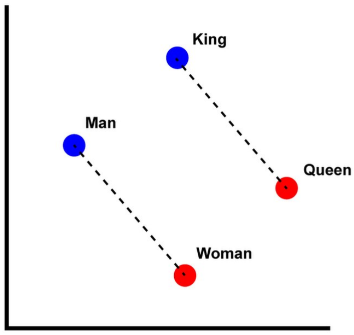

Figure 5.3: Visual illustration of word embeddings

Control Group: To compare with the prototype, only two questions were asked from the participants of the control group, who only listened to the description of the painting.

1. How do you like the overall experience

2. How do you describe the overall experience

First question is answered on a likert scale, and the latter was taken as a verbal response, so they can freely express their thoughts, and later the keywords of their responses was analysed through word vectorization.

5.2.3 Results of the Evaluation 1

Overall, participants enjoyed experiencing the protoype, many stating it as engaging and realistic. They provided many insights in the first iteration, which we were able to correct and fine tune. Before the final prototype, a pre-test was carried out to have an understanding of the heat and coldness levels, and the thickness of the contour lines used for the painting by asking them to test various levels of temperature actuators, as well as embossed lines, made of different materials and thicknesses.

Contour Lines
Purpose: Added contour lines around objects in the painting so visitors could feel their way around and understand what's depicted.
Feedback: Participants suggested making these lines thicker and more noticeable. They also recommended adding different textures to help identify each object better.

Heat
Purpose: Used a Peltier module to create heat where the bonfire is in the painting, trying to make the bonfire feel real through temperature. (Sensory Alignment Theory)
Feedback: Participants liked the idea but said it would be better if the warmth could cover a larger area around the bonfire in the painting, not just the small spot where the Peltier module is.

Audio
Implementation: Placed two speakers at the sides of the painting, one playing fire sounds and the other playing river sounds.
Feedback: Some participants found it confusing to hear both sounds at the same time, especially when standing in the middle of the painting. They suggested adjusting the sound setup so it's easier to tell the sounds apart and not feel overwhelmed.

In The first evaluation, researchers examined the primary hypothesis that multisensory augmentation of a painting would enhance the experience for visually impaired participants. A secondary question explored how different senses contribute to this experience. Interestingly, participants liked a warm feeling created by a temperature increase of around 15°C, but a similar decrease for coolness wasn't as pleasing, according to the feedback received.

The primary hypothesis was evaluated statistically using a Likert-scale question asking participants from both groups, "How do you like the overall experience?"

The prototype group's average response was 4.24 (Standard Deviation = 0.97) based on data from twelve participants. The control group's average response was 2.71 (SD = 0.99). While these averages suggest an improvement in experience with the prototype, no statistical significance was found (p = 0.739). This lack of significance is likely due to the impact of sample size and data variability on p-values.

Multiple-way ANOVAs were also conducted to assess any influence of gender or level of visual impairment on the relative importance of different senses in participants' experiences. These analyses revealed no significant effects (p greater than 0.05 in all cases), indicating that participants with varying genders and levels of visual impairment rated the added multi-sensory experiences similarly.

Word vectorization yielded similar results (Figure 5.4). The initial evaluation revealed a clear distinction between the feedback from participants in the control group and those who experienced the SEMA prototype. Red dots represent feedback from the control group, while blue dots represent feedback from the SEMA group. As evident in the results screenshot below, the majority of control group feedback (red dots) leans towards the positive side of the spectrum, but with lower intensity. Conversely, feedback from the SEMA group (blue dots) clusters in the upper right quadrant, indicating both positive sentiment and high intensity. However, a small number of blue dots are located near the red dot cluster, suggesting that a few participants did not find the SEMA experience to be particularly positive or intense.

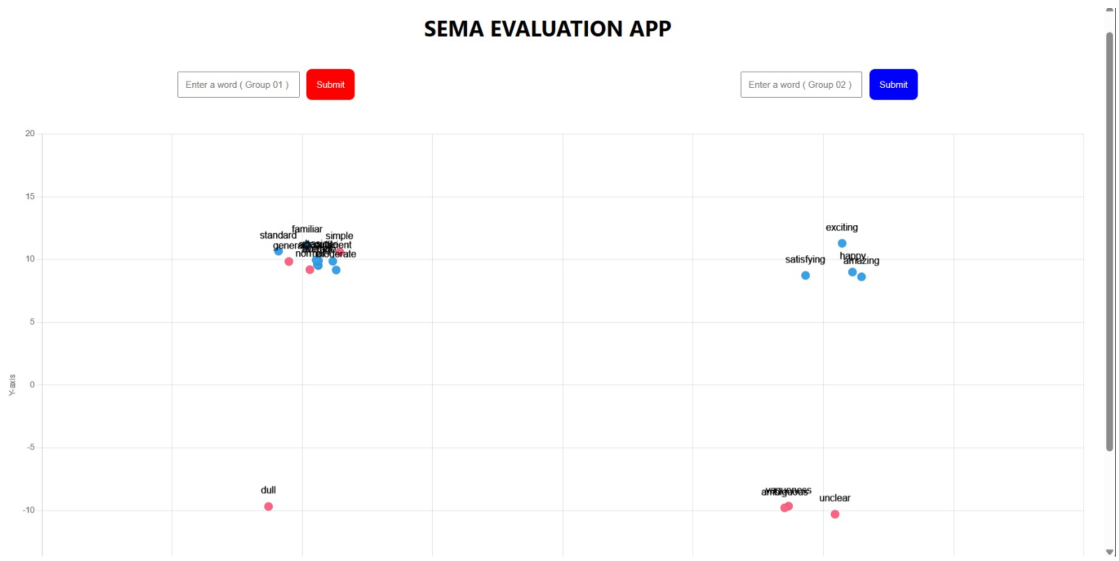

Figure 5.4: Results of the first word embedding run (Evaluation 1)

Despite the overall positive sentiment towards SEMA, participant feedback was used to identify areas for improvement. Subsequently, a second evaluation was conducted following the implementation of these refinements to the SEMA prototype.

5.3 Evaluation 2

In the second iteration of the evaluation, a refined prototype of the multi-sensory painting was employed. While maintaining the core structure, hardware and software upgrades were implemented based on feedback from the prior evaluation. As before, participants engaged with the painting for approximately five minutes, followed by a questionnaire and open-ended interview to gather feedback.

5.3.1 Evaluation Plan

This iteration aimed to assess the impact of the new features on participants' multi-sensory experience. Researchers provided a brief description of the painting to each participant and instructed them to explore the tactile elements by running their hand(s) along the surface. The sensations were explained individually (e.g., a river depicted on the left with a border signifying its edge, and a cool sensation in the center representing the water's coldness or wetness). Participants were also informed about the new tracking device that curates sound based on their position. Finally, the evaluation sought to determine if each improvement contributed to a more positive response from participants. Analysis of variance (ANOVA) and related methods were employed to compare the results of evaluations 1 and 2, enabling a conclusion on whether the new prototype represented a significant improvement over the first version.

5.3.2 Followed Procedure for Evaluation 2

Mirroring evaluation 1, after interacting with the painting, participants completed a short questionnaire assessing all sensations and their overall experience in both qualitative and quantitative formats. The questionnaire content remained unchanged.

The control group was not involved here as no changes were made to that experiment.

5.3.3 Results of the Evaluation 2

The anticipated participant preferences included a gradient heat sensation emanating from the bonfire (replacing the single heat source used previously), variations in sound responsive to their position relative to the painting, and an embossed texture for the stones instead of a boundary line.

Therefore, evaluation 2 served to test two hypotheses to answer the original research questions:

1. Does multi-sensory integration enhance the experience of a painting?
2. Do the implemented improvements on the new prototype lead to increased overall participant satisfaction?

To address these hypotheses, two multi-way ANOVAs were conducted to analyse multi-sensory experience liking and sensory stimulation ratings, with the age and visual impairment level of each participant serving as independent variables.

	Intensity of the texture	Intensity of auditory stimulators	Intensity of heat emulators	Intensity of coldness emulators
Average	4.22	4.33	4.33	4.00
Standard Deviation	0.83	0.71	0.71	0.71
Variance	0.69	0.50	0.50	0.50
ANOVA (using the VAR.A Function)	1.07	0.59	0.71	0.48
F-Statistic Formula	0.3663	0.9262	0.4984	0.9451
p-value Formula	0.9584	0.5760	0.8877	0.5632

Table 5.1: Significance measures of the results in Evaluation 2 compared to the Evaluation 1

The results indicated a clear improvement compared to the evaluation of the prototype's first iteration. Participants in the prototype group provided an impressive average rating of 4.24 (SD = 0.66) to the question "How do you like the overall experience?" Heat sensation and the Auditory sensations received an average score of 4.33 (SD = 0.71), followed closely by texture with an average of 4.22 (SD = 0.83), while the coldness scored an average rating of 4.00 (SD = 0.71). Overall, these scores represent a marked improvement over the feedback received during evaluation 1. While statistical significance was not achieved (p-values higher than 0.05) likely due to a limited sample size, qualitative feedback analysis demonstrably revealed an enhancement in all sensory stimulations with the new prototype.

A comparison of the new feedback scores with the control group's evaluation revealed a clear distinction. The prototype group significantly outperformed the control group in terms of Likert scale responses. As a reminder, the primary hypothesis was assessed statistically using a Likert-scale question posed to participants from both groups: "How do you like the overall experience?" The new prototype group's average response was 4.24 (SD = 0.97) based on data from twelve participants, whereas the control group's average response was 2.71 (SD = 0.99).

As can be seen in the chart 5.5, participant feedback on the Likert scale (the numbers represent the mean value of the feedback) showed significant improvement in evaluation 2.

Participant feedback regarding texture intensity increased from a mean of 3.78 (SD=0.83) in evaluation 1 to 4.22 (SD=0.83) in evaluation 2. This improvement can be attributed to the implementation of stone textured emobings, directly addressing a potential shortcoming identified in the first evaluation. Additionally, feedback on the contribution of auditory stimulators rose from 3.44 (SD=0.73) to 4.33 (SD=0.71). This enhancement likely stems from the use of newly designed subject tracking software, facilitating smoother audio transitions and potentially creating a more immersive experience.

Evaluation 1 feedback indicated areas for improvement regarding heat distribution. In evaluation 2, the incorporation of an array of porcelain wire-wound resistors facilitated a more gradual heat emission. This resulted in better heat control and a temperature gradient, evident from the higher feedback for the "contribution of heat emulators" (4.33/SD=0.71 compared to 3.56/SD-0.88). This improved temperature variation likely contributed to a more realistic and engaging tactile experience for participants.

Overall, the changes implemented in evaluation 2 directly addressed the feedback received from participants in evaluation 1. The positive shift in participant perception across all categories of the Likert scale shows the success of these improvements.

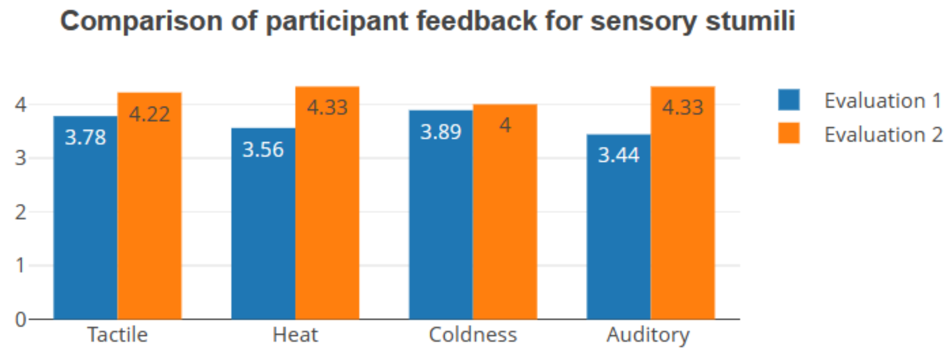

Figure 5.5: Comparison between the feedback from two evaluations

Word vectorization again provided valuable insights. Compared to the initial evaluation, a clear improvement was observed in the feedback from participants who experienced the refined SEMA prototype in evaluation 2. Previously, a small cluster of blue dots (SEMA group) overlapped with the red dots (control group), indicating a neutral or negative experience for some participants in evaluation 1. However, in evaluation 2, the blue dots are predominantly located in the upper right quadrant, signifying a significant shift towards positive and high-intensity feedback for the improved SEMA prototype. This suggests that the majority of participants in evaluation 2 found the SEMA experience to be both positive and impactful.

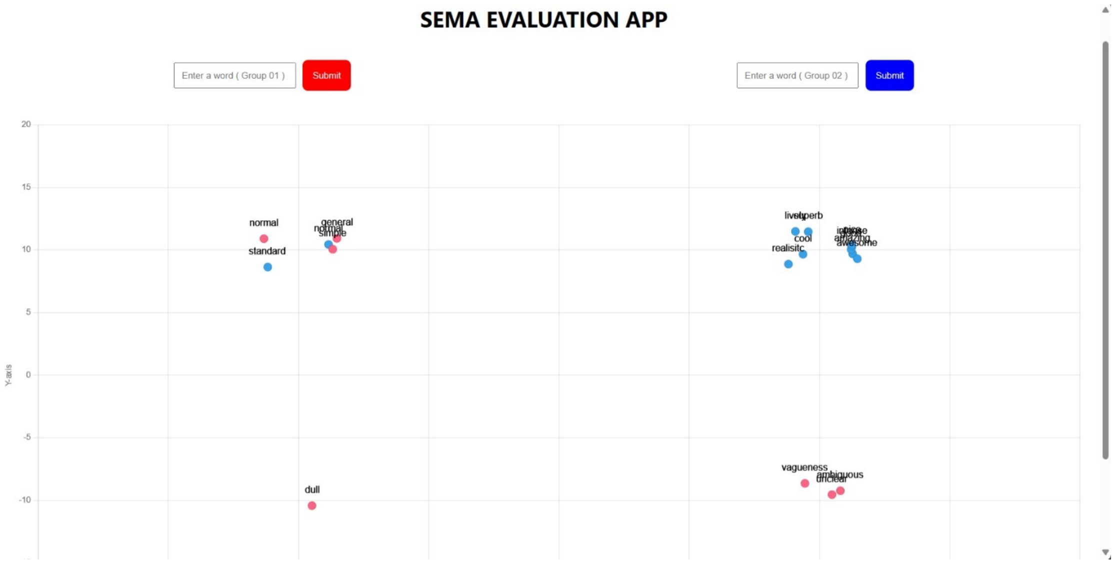

Figure 5.6: Results of the second wrod embedding run (Evaluation 2)

5.3.4 Chapter Overview

The evaluation, combining both qualitative and quantitative methods, proved to be successful. By iteratively refining the SEMA prototype based on participant feedback and conducting parellel evaluations, we were able to identify and address shortcomings, ultimately leading to a more optimized and user-friendly experience. This iterative approach played a crucial role in perfecting the prototype, minimizing errors, and ensuring a positive experience for participants.

Chapter 6

Conclusion

6.1 Introduction

Multi-sensory integration is being researched as a way of promoting inclusively and richer experiences in many sectors including entertainment. However, understanding sensory alignment and how it contributes to the overall experience of the users is a research gap the researchers are barely scratching the surface of. Proven by the scenarios such as the unsuccessful attempt of multi-sensory screening of Iron Man 3, it is shown that the researchers' lack of knowledge and understanding of the link between multi-sensory stimulation and experience (Obrist et al. 2017).

Even though, studies such as Tate Sensorium (Pursey & Lomas 2018) are conducted to address these issues, the particular combination of Somatosensory (Heat and Cold), Auditory, and Tactile stimuli is a rarely addressed subject in the entertainment industry. This puts the visually impaired demographic at a disadvantage because institutions like art galleries and museums heavily rely on the sense of sight, and the visually impaired people use touch and audio as their main sources of information gathering.

It is not only the visually impaired people who could benefit from the integration of other stimuli into a painting. As many researchers suggest, human brain is capable of processing several sensory stimuli at once which results in a richer experience which is why the "auditory flash illusion" is such an effective method of tricking a person's brain. (Shams et al. 2001) Therefore, a normal viewer will also have an enhanced experience if a painting or an artwork is integrated with other sensory stimuli that match the painting.

By enhancing their displayed artefacts using multi-sensory integration, museums and art galleries can increase their clientele, be inclusive to a larger demographic and offer their customers a novel and unique experience in entertainment.

6.2 Conclusions about research questions, aim and objectives

The present study aims to enhance the art gallery experience for a wider audience by integrating paintings with tactile, somatosensory, and auditory stimuli with a focus on aiding visually impaired people to experience an artwork better than the traditional method of listening to a description of the said artwork. To accomplish this, three research questions were formulated.

The first research question focuses on what techniques we can use to enhance the accessibility of a visual art form. As the first step for this, we studied the available assistive technologies and research that can be used to enhance visual art. There are many different underlying theories on integrating different stimuli together such as 'sensory alignment' which we focused on to design a solution that would work in being more accessible to the visually impaired audience.

The second research question was framed to identify how the painting industry can provide a multi-sensory artistic experience for viewers. Since traditional art (especially in museums or art galleries) focuses on the sense of sight to convey information and themes of the artwork to the public, it is hard for an audience lacking the sense of sight to grasp the ideas that are being presented. This issue is further fueled by the fact that the paintings or artefacts are prohibited from touching, and even if allowed to touch, they do not provide any additional information because most of the time paintings are just 2 Dimensional. When we conducted our user study, this problem was especially highlighted that the visually impaired people are very much ignorant of how real-world objects are represented in the 2-dimensional canvas because there is nothing to touch.

This was why all our elements added in SEMA were embedded with plaster of Paris contour lines to highlight the shapes they are usually drawn on a painting. Other than that, we explored the ways to combine Heat, Cold, and Sounds to enhance the accessibility of experience in an artwork rather than an audio description of the painting that most people with moderate to severe visual impairments will fail to grasp.

The results showed significant improvements in SEMA over the traditional method, proving that additional stimuli do play a role in increasing entertainment for the visually impaired. They were able to correctly identify that the heat and wood chirping sounds were attached to fire and that coldness and humidity with the water running sound were attached to a river. To strengthen this point, we had moulded a tent without adding any other stimuli and they were not able to identify it which proves that several stimuli contribute better to provide meaningful information to visually impaired people.

As the third research question we focused on how to overcome the challenge of limited engagement in art viewing, which was a recurring theme in similar contemporary research. Traditionally, an artwork does not encourage engagement. The artefact is just kept in its place and the user views it and moves on, which creates a certain monotonousness to the experience. Given the fact that visually impaired people cannot experience even that limited engagement, it is absolutely necessary to address that issue when we are finding ways to be inclusive in the art and entertainment industry.

To improve engagement, SEMA has several features. The auditory component tracks the visitors' movements and plays the relevant ambient soundtrack that matches their location creating a more immersive experience. There are also somatosensory stimuli, user can touch and experience the sensations at their own phase. In the museum, if a user is listening to the provided audio track, they cannot engage with it as well. Users commented positively on the freedom they had in the free-paced engagement of SEMA.

Overall, the finding of this study suggests that the three sensory stimuli somatosensory, audio, and tactile can work together to create a more comprehensive experience for the user and it does somewhat compensate for the loss of vision when they are experiencing an artwork.

6.3 Contribution

This research contributes to the Information Systems field, specifically the Human-Computer Interaction domain in a significant way. It offers insights into the way users interact with different assistive technologies when they are integrated together.

This study is the first study that uses the combination of Somatosensory, Tactile, and Auditory stimuli to provide an artistic experience to the users. It is also one of the first research in studying the sensory alignment of these mentioned stimuli and how to increase the effectiveness of integrating those stimuli. Through this, we were able to identify some data for parameters that are not found in the literature so far, such as the pattern that while people usually are satisfied with heat that is around 15 degrees Celsius more than their body temperature to represent the heat of the fire, they are not satisfied with the coldness that is 15 degrees of Celsius less than their body temperature to represent the coldness of the water.

We also developed several programs that can be accessed and used by researchers or artists to use this framework to create inclusive paintings and artworks. The programs are in a public GitHub repository and will be published with any document this research might release in the future. There are hardware equipment we have also developed which are low cost and can be used along with the aforementioned programs. The schematics for these hardware equipment are also available in the GitHub repository.

Further, SEMA offers a unique opportunity for visually impaired people to experience art and artists to explore how to use other stimuli to enhance their paintings. It blends technology with art to allow a larger audience to access entertainment.

6.4 Limitations

Though SEMA was tested using the same age and education level demographic, it disregarded the gender of the visually impaired subjects. This may cause some information to go unnoticed, given that some studies have found that women and men feel temperature differently. (Karjalainen 2007) It might be the same for the other stimuli we integrated as well. Therefore, during future research, this aspect should also be addressed.

The user study was carried out in a semi-controlled environment, where the users were allowed to freely interact with the system but we tried to minimize any distractions and noise which may not hold true in an actual gallery or museum environment. Therefore, how SEMA would work in a public setting was not fully accounted in this study.

Due to budgetary concerns, only 2cm x 2cm square was assigned for cold sensation. The ideal scenario should cover the whole area of the river, which might contribute to the changing of the results.

The parameters set for this study such as the temperature limits could change depending on the place where the experiments are conducted. These parameters were identified with tests and pretests done with Sri Lankan users at a room temperature of 30°C. However, if users from a rather colder country were to experience SEMA, these parameters might not prove to be ideal.

6.5 Future Work

To address the limitation of the limited generalizability of the findings to other contexts and populations, future studies can consider recruiting a more diverse sample from multiple locations. This will be able to help to increase the representativeness of the study and enhance the external validity of the findings.

For the limitation regarding the controlled environment of the user study, future work could involve conducting field studies in various real-world scenarios to assess the usability and effectiveness of SEMA. This could involve studying its performance in different settings such as galleries and museums in environments with varying levels of background noise and other distractions.

Enhancing the area coverage of stimuli is also an objective we aspire to achieve in the future.

In addition, integrating other stimuli and experimenting with different combinations of stimuli should also be perceived as a future objective.

6.6 Final Remarks

The authors are confident that the proposed solution holds promise for improving the accessibility of entertainment and art gallery experience for the visually impaired community. However, several limitations and areas for future research were identified, including the need for broader user testing in more real-world scenarios and consideration of alternative solutions for individuals who are physically impaired. Despite these limitations, this research contributes to the field of human-computer interaction and has the potential to benefit individuals with disabilities and the wider user population. The proposed approach can be further developed and refined to provide more inclusive and engaging experiences in various domains. It is hoped that the findings of this study serve as a foundation for future research that is able to explore the full potential of multi-sensory integration in entertainment and its impact on user experiences.

Appendix A

Script - Control Group

This description will cover the sections Size, Composition, and Details respectively.

A.1 Size

The painting is 6 feet long and 4 feet wide. It is divided into 3 equal pieces vertically, each section consisting of one dominant element. The painting represents a camping site.

A.2 Composition and Layout

Overall, the painting has three major elements. From left to right, the first section is a river, the second or the middle section is a campfire, and the third, right-most section is a tent used for camping. There is a slightly straight line running across the painting horizontally one foot below the top boundary of the painting. This line signifies the division between the sky and land, or, the horizon.

A.3 Detailed explanation

The scenario is set in the nighttime, the sky is dark and the ground is brown. Going basck to the first, or the leftmost section, consists of a river that starts from the horizon and runs to the bottom left corner of the painting. The river is wavy and coloured blue. Both banks of the river are covered in green bushes.

Moving on to the middle section, there is a bonfire or a campfire. It has flames that are coloured in yellow. The fire is surrounded by rocks. The campfire is set directly on the ground.

Next, the last section has a red tent that is set up on the ground. The tent is made of a material similar to polyester and has a door that opens from the middle. The door is slightly opened but the inside is dark. There are a couple of crumples on the top of the tent. The tent is facing the campfire. The front left tent peg also known as the stake which is driven into the ground is visible. Only a part of the tent is visible due to the rest being out of the frame.

Appendix B

Software

This code builds a web API that takes a word as input and predicts its category. It uses BERT (a pre-trained language model) for converting words into numerical representations and a Logistic Regression classifier to predict the category based on those representations. The code first loads a dataset with words and their categories, then uses BERT to encode each word into a vector to capture its meaning. These vectors are used to train a Logistic Regression model that can then predict the category of a new word based on its encoded representation. Finally, the code creates a web API that allows users to submit words and receive their predicted categories.

B.1 Back End

```
from fastapi import FastAPI  # Import FastAPI to create the web API
from pydantic import BaseModel  # Import BaseModel to define data models for request and response
import pandas as pd  # Import pandas to read data from excel file
from sklearn.linear_model import LogisticRegression  # Import LogisticRegression for classification
from transformers import BertTokenizer, BertModel  # Import BertTokenizer and BertModel from transformers library
from fastapi.middleware.cors import CORSMiddleware  # Import CORSMiddleware to handle CORS requests
import torch
import numpy as np  # Import torch and numpy libraries for tensor operations

# Create a FastAPI application instance
app = FastAPI()

# Configure CORS middleware to allow all origins, methods, and headers for development purposes (adjust for production)
app.add_middleware(
    CORSMiddleware,
    allow_origins=["*"],  # Allow requests from any origin
    allow_methods=["*"],  # Allow any HTTP method (GET, POST, etc.)
    allow_headers=["*"],  # Allow any header in the request
)

```

```python
# Define a BaseModel class named WordInput to represent the expected input data for the API endpoint
class WordInput(BaseModel):
    word: str  # This field expects a string value representing the word to be categorized

# Load the pre-trained tokenizer for the BERT model (vocabulary for converting words to numerical representations)
tokenizer = BertTokenizer.from_pretrained('bert-base-uncased')

# Load the pre-trained model (BERT base uncased)
model = BertModel.from_pretrained('bert-base-uncased')

# Read the dataset from a file named "words.xlsx" using pandas
df = pd.read_excel("words.xlsx")

# Extract features (words) and labels (category) from the dataframe
X = df['Word'].tolist()  # List of words
y = df['Category']  # List of categories

# Function to encode text using BERT tokenizer and model
def encode_texts(texts):
    # Tokenize the text with padding and truncation, and return tensors suitable for PyTorch
    encoded = tokenizer(texts, padding=True, truncation=True, return_tensors='pt')
    # Disable gradient calculation for efficiency as we're not updating the model here
    with torch.no_grad():
        # Get the model outputs from the encoded text
        outputs = model(**encoded)
    # Extract the embeddings from the pooler layer (represents the overall sentence meaning)
    embeddings = outputs.last_hidden_state[:, 0, :].numpy()  # Convert to numpy array for further processing
    return embeddings

# Encode the entire dataset using the encode_texts function
X_vectorized = encode_texts(X)

# Train a Logistic Regression classifier to predict category based on the encoded word vectors
classifier = LogisticRegression()
classifier.fit(X_vectorized, y)  # Train the classifier on the encoded features and labels

# Define a function to handle POST requests to the "/predict-category" endpoint
@app.post("/predict-category")
async def predict_category(input: WordInput):
    # Encode the input word using the BERT model
    input_vector = encode_texts([input.word])
    # Predict the category using the trained classifier
    category_pred = classifier.predict(input_vector)
    # Return the predicted category as a dictionary response
    return {"category": category_pred[0]}  # Get the first element from the prediction array

```

```python
# Check if the script is run directly (not imported as a module)
if __name__ == "__main__":
    # Import uvicorn library to run the FastAPI application
    import uvicorn
    # Start the server on localhost port 8000 (adjust as needed)
    uvicorn.run(app, host="127.0.0.1", port=8000)
```

B.2 Fron End (React JS)

```javascript
import React, { useState } from 'react';
import axios from 'axios';
import { Scatter } from 'react-chartjs-2';
import 'chart.js/auto';
import ChartDataLabels from 'chartjs-plugin-datalabels';

// Define a mapping from category to coordinates
const categoryToCoords = {
  'TR': { x: 10, y: 10 },
  'TL': { x: -10, y: 10 },
  'BR': { x: 10, y: -10 },
  'BL': { x: -10, y: -10 },
};

const getRandomOffset = (scale = 5) => (Math.random() - 0.5) * scale;

const mapCategoryToPosition = (category) => {
  if (categoryToCoords[category]) {
    return {
      x: categoryToCoords[category].x + getRandomOffset(3),
      y: categoryToCoords[category].y + getRandomOffset(3),
    };
  }
  return { x: 0, y: 0 };
};

function App() {
  const [word1, setWord1] = useState('');
  const [word2, setWord2] = useState('');
  const [data, setData] = useState({
    datasets: [
      {
        label: 'Words1',
        data: [],
        backgroundColor: 'rgba(255, 99, 132, 1)',
        pointRadius: 6,
        pointHoverRadius: 8,
      },
      {
        label: 'Words2',
        data: [],
        backgroundColor: 'rgba(54, 162, 235, 1)',
        pointRadius: 6,
        pointHoverRadius: 8,
      },
    ],
```

```
});

const addDataPoint = async (word, datasetIndex) => {
  try {
    const response = await axios.post('http://localhost:8000/predict-category', { word });
    const newCategory = response.data.category;
    const coordinates = mapCategoryToPosition(newCategory);
    setData((prevData) => {
      const newDatasets = prevData.datasets.slice();
      newDatasets[datasetIndex].data.push({ x: coordinates.x, y: coordinates.y, label: word });
      return { datasets: newDatasets };
    });
  } catch (error) {
    console.error('Error predicting category:', error);
  }
};

const handleSubmit1 = (e) => {
  e.preventDefault();
  addDataPoint(word1, 0);
  setWord1('');
};

const handleSubmit2 = (e) => {
  e.preventDefault();
  addDataPoint(word2, 1);
  setWord2('');
};

const options = {
  scales: {
    x: {
      min: -20,
      max: 20,
      title: {
        display: true,
        text: 'X-axis',
      },
    },
    y: {
      min: -20,
      max: 20,
      title: {
        display: true,
        text: 'Y-axis',
      },
    },
  },
  plugins: {
    datalabels: {
      color: '#000000',
      anchor: 'end',
      align: 'top',
      offset: 4,
      font: {
        size: 14,
```

```
        },
        formatter: (value, context) => context.chart.data.datasets[context.datasetIndex].data[context.dataIndex].label,
      },
      legend: {
        display: false,
      },
      tooltip: {
        enabled: false,
      },
    },
  };

  return (
    <div style={{ textAlign: 'center', marginTop: '50px' }}>
      <h1 style={{ margin: '20px 0' }}>SEMA EVALUATION APP</h1>
      <div style={{ display: 'flex', justifyContent: 'center', gap: '20px' }}>
        <form onSubmit={handleSubmit1} style={{ margin: '20px auto', maxWidth: '300px' }}>
          <input
            type="text"
            value={word1}
            onChange={(e) => setWord1(e.target.value)}
            placeholder="Enter a word ( Group 01 )"
            style={{ marginRight: '10px', padding: '10px', width: 'calc(100% - 120px)' }}
          />
          <button
            type="submit"
            style={{ padding: '15px', backgroundColor: 'red', borderRadius: '8px', color: 'white', border: 'none', cursor: 'pointer' }}
          >
            Submit
          </button>
        </form>
        <form onSubmit={handleSubmit2} style={{ margin: '20px auto', maxWidth: '300px' }}>
          <input
            type="text"
            value={word2}
            onChange={(e) => setWord2(e.target.value)}
            placeholder="Enter a word ( Group 02 )"
            style={{ marginRight: '10px', padding: '10px', width: 'calc(100% - 120px)' }}
          />
          <button
            type="submit"
            style={{ padding: '15px', backgroundColor: 'blue', borderRadius: '8px', color: 'white', border: 'none', cursor: 'pointer' }}
          >
            Submit
          </button>
        </form>
      </div>
      <div style={{ margin: '20px' }}>
```

```
        <Scatter data={data} options={options} plugins={[
           ChartDataLabels]} />
      </div>
    </div>
  );
}

export default App;
```

Listing B.1: Front end code

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