Haptic Feedback Implementation in VR and its Impact on Participants Perception

A thesis submitted for the degree of:

BSc in Software Design with Virtual Reality and Gaming

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Introduction

Virtual Reality (VR) is an evolving field with potential applications in gaming, healthcare, and education. One area of interest is haptic feedback, which provides users with physical sensations in response to their actions in the virtual world. This thesis explores the impact of haptic feedback on immersion in VR environments and identifies areas for future research and development.

The primary argument of this thesis is that haptic feedback can enhance immersion, creating more realistic and engaging experiences in VR. By examining existing research, this thesis contributes to our understanding of haptic feedback's potential to improve user experiences and identifies areas for further study.

The thesis project fills gaps in existing research by focusing on a specific aspect of haptic feedback and conducting a controlled experiment to study its impact on user performance and immersion. The project is original in its approach, examining the impact of haptic feedback on user experience and engagement in a VR application, providing valuable insights into its potential benefits across various fields.

The methodology involves a controlled experiment using a haptic feedback chestplate to measure immersion in a virtual environment. The theoretical approach focuses on the concept of presence, which refers to the feeling of being fully immersed in a virtual environment. The experiment tests the impact of haptic feedback on user performance and immersion, offering insights into its potential applications and benefits in VR.

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1 Literature Review

1.1 Background

Haptic feedback, known interchangeably as haptic technology or simply haptics, refers to technology which incorporates tactile experience or feedback as a component of the user interface (UI), thereby providing the end-user with a sense of touch through the use of vibrational forces, motion or other forces (1). Initially developed in the 1970's, haptic feedback has gained increased prominence amongst consumers through its implementation in mobile devices, video games and many other areas of usage. Sega was the first video game company to integrate haptic feedback into arcade consoles allowing games to provide vibrotactile feedback in their 1976 title, "Fonz" (2).

Haptic feedback technology has gained significant attention in recent years as an innovative approach to enhance the user's experience in various applications, Haptic feedback technology provides users with tactile sensations that mimic real-world experiences, providing a more engaging and immersive experience. This technology has been widely used in different fields, including gaming, healthcare and education, to name a few. In this literature review, we will explore the use of haptic feedback technology and its impact on user experience in various applications. Additionally, we will examine the current state of research, identify key areas of development, and highlight potential future directions for haptic feedback technology.

1.2 Definition and explanation of haptic feedback technology

Haptic feedback technology refers to the use of tactile or force feedback to provide users with a sense of touch and physical interaction with digital interfaces. The technology can simulate the sensation of touch, pressure, temperature or vibration through various devices. Some examples of these devices are Haptic Gloves, Haptic Vests and Haptic controllers. (Kapoor).

- **Haptic Gloves (**Figure 1**)**: Haptic feedback gloves are a wearable peripheral which allow users to experience a realistic sense of touch and perceive interactions through tactile feedback. When actuated, sensors within the gloves recreate the sense of touch for users. As an example, should a user pick up a drill, users will feel resistance when contact is made and allow for the texture of the drill to be perceived (3).

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Figure 1. Quantum Metagloves (4).

- **Haptic Vests**: These vests provide tactile feedback to users through vibrations or pressure points, simulating physical interactions with digital environments.

Figure 2. bHaptics TactSuit x40 (5).

- **Haptic Controllers**: These controllers use force feedback to provide users with a sense of resistance or feedback when interacting with digital interfaces such as gaming consoles.

1.3 Theoretical Frameworks and Models of haptic feedback technology

Theoretical frameworks and models provide a theoretical foundation for understanding how haptic feedback technology works and how it can be used to enhance user experience. One of the most commonly used theoretical frameworks in the study of haptic feedback technology is the “haptic communication model”, which describes how haptic feedback can be used to convey information between humans or between humans and machines.

1.3.1 Haptic Communication Channel (HCC) Model

The HCC model proposes that touch-based communication involves the transmission of information through tactile sensations, such as pressure, texture, temperature, and vibration. The model emphasizes the role of proprioception, which is the sense of the body's position and movement in space, in haptic feedback. The model suggests that haptic feedback technology can enhance communication by providing additional sensory cues, which can facilitate the transfer of emotional and interpersonal information and improve the overall effectiveness of communication. The effectiveness of haptic communication depends on the quality of the haptic feedback signal, the nature of the haptic stimulus, and the context of the communication. This model has been applied in various settings, including human-robot interaction, virtual reality, and teleoperation, and has led to the development of new haptic communication technologies such as tactile displays and wearable devices.

1.3.2 Perceptual Crossing (PC) Model

The PC Model is a theoretical framework that emphasizes the role of haptic feedback in social interaction. This model proposes that social interaction is a mutual exchange of information, and haptic feedback helps individuals establish a shared sense of presence and negotiate the boundaries of the social interaction. The model highlights the importance of the social context in shaping the effectiveness of haptic communication and suggests that haptic feedback can enhance social interaction by conveying emotional and interpersonal information. The Perceptual Crossing Model has been applied in various contexts, such as human-robot interaction, social touch, and interpersonal communication. It has also been used to develop new haptic communication technologies and guide the design of social robots and other autonomous systems. This model provides a framework for understanding the complex dynamics of haptic communication and provides a basis for the development of new technologies and interventions that can improve social interaction and communication.

1.3.3 Affordance Perception (AP) Model

The AP Model is a theoretical framework that explains how haptic feedback technology can improve perception and action in an environment. The model suggests that haptic feedback provides individuals with information about the physical properties of the environment and the potential actions that can be taken within it. The model proposes that haptic perception of affordances, which are potential actions based on the physical properties of the environment, is critical to successful action in the environment. Haptic feedback can provide individuals with information about the properties of objects, such as their size, shape, texture, and weight, as well as information about the forces required to interact with them. The model has been applied in studies of manual dexterity, motor control, and navigation, and has been used to develop new haptic technologies, such as haptic gloves and wearable devices, that improve sensory feedback and enhance performance in complex tasks. Overall, the Affordance Perception Model provides a useful framework for understanding the role of haptic feedback technology in enhancing perception and action in different contexts.

1.3.4 Presence (P) Model

The P Model is a theoretical framework that explains how haptic feedback technology enhances the sense of presence in a virtual environment. This model states that haptic feedback creates a sense of embodiment, or the feeling of being physically connected to a virtual avatar or environment. It also emphasizes the importance of multisensory feedback, combining haptic feedback with visual and auditory feedback, to create a more immersive experience. The Presence Model suggests that the sense of presence improves the user's engagement and immersion in the virtual environment, leading to improved learning and performance outcomes. This model has been applied to studies of virtual reality training, gaming, and education, and it has guided the development of new haptic technologies that provide more immersive and realistic haptic feedback. Overall, the Presence Model provides a framework for understanding the role of haptic feedback technology in enhancing the sense of presence in virtual environments, emphasizing the importance of multisensory feedback and embodiment to improve immersion and performance.

1.3.5 Embodied Cognition (EC) Model

The EC Model is a theoretical framework that emphasizes the role of sensory experiences in cognitive processes, including haptic feedback. The model proposes that sensory information is not processed solely in the brain but is also integrated with motor and perceptual systems throughout the body. The Embodied Cognition Model suggests that haptic feedback can enhance cognitive processes by providing additional sensory cues that support embodied cognition. Haptic feedback can be used to represent abstract concepts through physical metaphors, and can provide feedback during learning and problem-solving, supporting the development of cognitive skills. The model has been applied in a variety of contexts, including studies of cognitive psychology, education, and human-computer interaction, and has been used to guide the design of new haptic technologies that support embodied cognition and improve cognitive processes.

One of the key models used in the design of haptic feedback technology is the “psychophysics models”, which describes how users perceive and interpret haptic feedback. According to this model, the effectiveness of haptic feedback depends on various factors such as the intensity, frequency, and duration of the feedback, as well as the user’s prior experience and expectations.

Finally, the “control system model” is another theoretical framework used in the study of haptic feedback technology, which describes how haptic feedback can be used to control and manipulate physical systems. This model is particularly relevant in the context of robotics, where feedback can be used to provide users with a sense of touch and control over remote devices.

Overall, these theoretical frameworks and models provide a theoretical basis for understanding how haptic feedback technology works and how it can be used to enhance user experience in various applications. By understanding these frameworks and models, designers and researchers can develop more effective haptic feedback systems and improve user satisfaction and engagement.

1.4 History and Evolution of Haptic Feedback Technology

Haptic feedback technology has its roots in the field of teleoperation, which involves the remote control of machines. The earliest haptic feedback systems were developed in the 1950s and 1960s for use in nuclear power plants and other hazardous environments. These systems used mechanical switches and joysticks to provide tactile feedback to operators, allowing them to feel the force and resistance of objects they were manipulating.

In the 1970s, the development of microprocessors enabled the creation of more advanced haptic feedback systems. The first commercially available haptic device was the phantom developed by Thomas Massie and Kenneth Salisbury at MIT in 1993 (6). The Phantom consisted of a stylus that could move in three dimensions and provided force feedback to the user, allowing them to “feel” virtual objects in a computer-generated environment.

Since the development of the Phantom, haptic feedback technology has continued to evolve rapidly. Today, there are a wide range of haptic devices available, including gloves, wearable devices, controllers and even some examples of exoskeletons. These devices use a variety of sensing technologies, including force sensors, pressure sensors, and accelerometers, to detect the movements of the user and provide haptic feedback.

Haptic feedback technology is now used in a wide range of applications, including medicine, education, entertainment and manufacturing. In medicine, haptic feedback devices are used to train surgeons and medical students in minimally invasive procedures, such as laparoscopy. In education, haptic feedback devices are used to teach physics and other science by allowing students to “feel” the forces and interactions between objects. In entertainment, haptic feedback devices are used to enhance the immersive experience of video games and virtual reality.

Overall, the history and evolution of haptic feedback technology has been driven by advances in sensing, processing, and display technologies, as well as by the growing demand for more immersive and interactive user experiences. As these technologies continue to improve, it is likely that haptic feedback will become an increasingly important component of human-computer interaction.

1.5 Applications of Haptic Feedback technology in various fields

Haptic feedback technology has a wide range of applications in various fields including virtual reality, medicine, gaming, education, rehabilitation, and robotics. In virtual reality, haptic feedback is particularly important for creating a more immersive experience. By providing users with tactile feedback in response to their actions, haptic devices can significantly enhance the immersion and realism of VR experiences. Haptic gloves, for example, can simulate the sensation of touching objects in a virtual environment, while force feedback devices can simulate the resistance and weight of virtual objects.

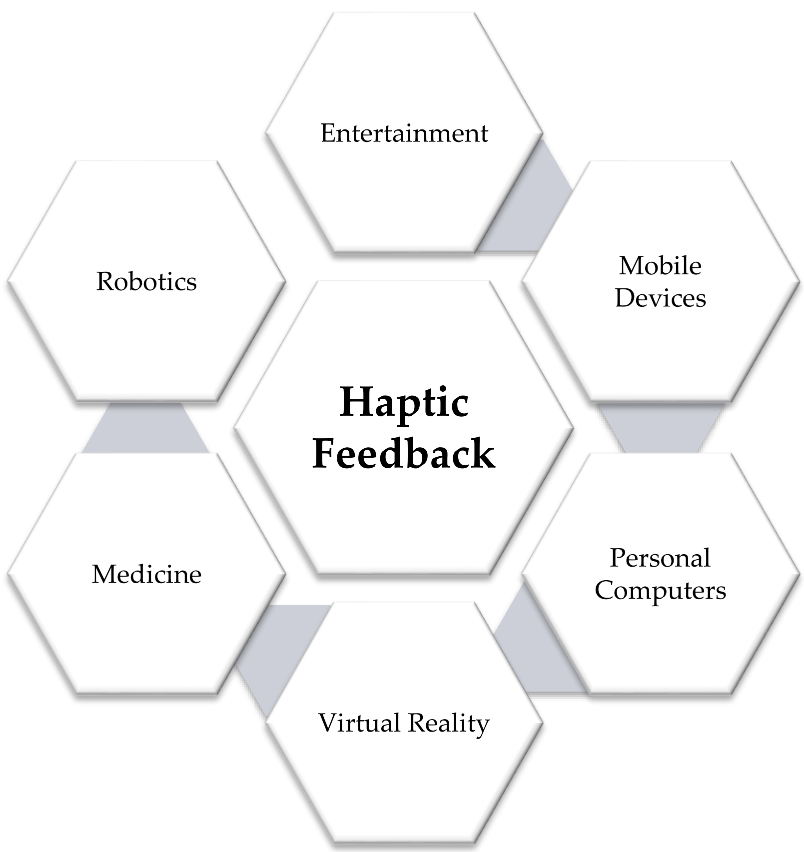

Figure 3. Fields wherein haptic feedback is currently in use (7).

In the field of medicine, haptic feedback technology is being used to train surgeons and medical students in minimally invasive procedures, such as laparoscopy. By providing surgeons with haptic feedback that simulates the resistance and tactile sensation of real tissue, haptic devices can help improve the accuracy and safety of surgical procedures.

In gaming, haptic feedback technology has been used for many years to provide players with a more immersive and realistic experience. Force feedback steering wheels can simulate the resistance and vibration of a real car, while haptic gloves can simulate the sensation of holding a virtual weapon or interacting with virtual objects.

Haptic feedback technology is also being used in education to teach physics and other sciences. By providing students with haptic feedback that simulates the forces and interactions between objects, haptic devices can help improve the understanding and retention of complex concepts.

In rehabilitation, haptic feedback technology is being used to help patients recover from injuries and disabilities. Haptic devices can be used to provide feedback to stroke patients during rehabilitation exercises, helping them to regain motor function and coordination.

Finally, haptic feedback technology is being used in robotics to improve the control and accuracy of robotic systems. By providing operators with haptic feedback that simulates the resistance and tactile sensation of real objects, haptic devices can help improve the dexterity and precision of robotic manipulators.

Table 1. Examples of haptic feedback technology used in a variety of fields.

Field	Example	Reference
Automotive	Haptic feedback technology is used to provide confirmation of touch commands without needing the driver to take their eyes off the road	(8)
Art	Haptic feedback has been explored in virtual arts such as sound synthesis or graphic design	(9)
Medicinal	Haptic feedback allows for simulatory training for invasive surgeries such as laparoscopy	(10)
Mobile Devices	Apple (2013) awarded patent for haptic feedback system suitable for multitouch surfaces	(11)
Neurorehabilitation	For individuals with upper limb dysfunction, robotics utilising haptic feedback may be used for neurorehabilitation	(12)
Personal Computers	MacBook Pro (2008) started incorporating tactile touchpads	(13)
Robotics	Shadow Hand maintains 129 touch sensors embedded in each joint	(14)
Video Games	Sony PS5 Dual Sense supports vibrotactile haptic response	(15)
Virtual Reality		

1.6 Impact of haptic feedback technology on user experience

The impact of haptic feedback technology on the user experience in virtual reality (VR) environments is significant. The sense of touch is an important component of human perception and interaction with the physical world, and haptic feedback technology can provide users with a more intuitive and natural way of interacting with digital systems.

Studies indicate that haptic feedback has the potential to considerably improve the authenticity and immersion of VR interactions, by imitating the feeling of touching and manipulating virtual objects. Through providing users with tactile feedback that corresponds to their actions, haptic devices have the capacity to generate a more realistic and captivating perception of being present in the VR environment. Ultimately, this can result in a more captivating and pleasurable experience for users.

Haptic feedback technology goes beyond enhancing the realism and immersion of VR experiences, as it can also offer a more intuitive and seamless way of interacting with virtual environments. This is achieved by providing users with a sense of touch that matches their actions in the VR environment, allowing them to perform tasks and interact with objects more effortlessly.

This can be especially beneficial for users with disabilities or impairments, who may find traditional input devices such as keyboards or mice difficult to use. For example, individuals with visual impairments may find it easier to navigate virtual environments using haptic feedback, as they can rely on their sense of touch rather than their vision to interact with the environment. Similarly, individuals with mobility impairments may find it easier to perform tasks in VR environments using haptic feedback, as they can use natural hand gestures and movements to interact with objects.

1.7 Factors affecting the effectiveness of haptic feedback technology

Several factors can affect the effectiveness of haptic feedback technology in VR environments. These factors include the type and quality of the haptic device, the software algorithms, the user's physical properties, and the context of the VR environment.

The quality of the hardware and its precision significantly impact the feedback's realism and precision, influencing the user experience. Latency, or delay between user action and feedback, can also affect the immersion and realism of the experience.

Moreover, the user's physical properties, such as hand size or skin sensitivity, can influence the effectiveness of haptic feedback. The application or use case of the technology can play a role too, with different requirements for gaming versus medical devices, for example.

In summary, developers need to consider these factors when designing haptic feedback systems to ensure accurate, realistic, and effective feedback, ultimately leading to more engaging VR experiences.

1.8 Current state of research in haptic feedback technology

Research in haptic feedback technology is rapidly advancing, focusing on enhancing immersion and presence in VR environments and developing new devices for realistic tactile feedback. Studies investigate haptic feedback's impact on user behavior, performance, and engagement in VR experiences.

Optimization of haptic feedback algorithms and systems is a priority, aiming for accurate and responsive tactile feedback. Researchers are studying cognitive and perceptual processes related to haptic feedback and working on improving algorithm accuracy and realism.

There is also an interest in haptic feedback's effects on user performance and learning in VR, with applications extending beyond entertainment and gaming to fields like healthcare and manufacturing. The focus remains on developing advanced haptic devices, algorithms, and understanding the cognitive and perceptual aspects of haptic feedback.

1.9 Methods and techniques used for implementing haptic feedback technology

Various methods and techniques are employed for implementing haptic feedback in VR environments is the use of tactile feedback gloves or haptic suits. These devices cover the hands or entire body and provide more immersive haptic feedback by simulating the sensation of touch on various parts of the body. Tactile feedback gloves use small actuators to create vibrations or pressure on the fingertips, while haptic suits use a combination of force feedback and vibration to simulate the sensation of physical interaction with virtual objects.

In addition to these physical devices, software-based haptic feedback techniques are also used in VR environments. These techniques involve the use of audio or visual cues to provide feedback to the user, such as a sound or visual effect when an object is touched or moved in the virtual environment. While these techniques may not provide the same level of physical feedback as handheld controllers or haptic suits, they can still contribute to the overall immersion and realism of the VR experience.

Force feedback is another type of haptic feedback that provides users with a tactile sensation of resistance or pressure in response to their actions in a virtual environment. It involves the use of motors or other actuators to produce physical forces that simulate the sensation of touching and interacting with virtual objects.

Force feedback can be used in a variety of ways in VR environments, such as providing resistance when pulling back a virtual bowstring or simulating the sensation of driving over rough terrain. It can also be used to provide users with a sense of physical presence in the virtual environment, by making virtual objects feel more solid and tangible.

One advantage of force feedback is that it can provide users with a more intuitive and natural way of interacting with virtual environments. This is because force feedback devices can provide users with a sense of touch that corresponds to their actions in the VR environment, making it easier to perform tasks and interact with objects.

However, the effectiveness of force feedback can depend on factors such as the accuracy of the tracking system, the design of the haptic device, and the type of force feedback being used. For example, some users may find certain types of force feedback to be too strong or too weak, which can affect their sense of immersion in the virtual environment.

1.10 Challenges and Limitations of Haptic Feedback Technology

Haptic feedback technology in VR environments faces challenges and limitations. High costs of advanced devices like exoskeletons or full-body suits limit accessibility and market reach. A lack of standardization complicates compatibility between hardware and software, causing market fragmentation.

Designing and implementing realistic haptic feedback systems is complex, requiring further research into cognitive and perceptual processes. Simulating sensations like heat, cold, or different textures remains challenging due to technological limitations.

User discomfort or fatigue can occur with overuse or poor calibration of haptic feedback systems, reducing effectiveness and potentially causing harm. Despite its potential, addressing these challenges is necessary for making haptic feedback more accessible, effective, and realistic in VR environments.

While haptic feedback technology has great potential for enhancing immersion and presence in VR environments, there are still many challenges and limitations that must be addressed to make these systems more accessible, effective, and realistic.

1.11 Future Directions and Potential Applications of Haptic Feedback Technology

The field of haptic feedback technology is rapidly evolving, and there are many exciting future directions and potential applications for this technology in VR environments. One of the key areas of focus for future research is the development of more advanced and sophisticated haptic devices that can provide users with even more realistic and immersive tactile feedback. This may include the use of more advanced force feedback systems, as well as the integration of other sensory cues such as temperature and texture.

The integration of haptic feedback technology with other emerging technologies such as AR and MR could lead to significant advancements in the field of human-computer interaction. By providing users with a more natural and intuitive way to interact with virtual and physical environments, these technologies could have numerous applications in fields such as healthcare, education, and entertainment. For example, the use of haptic feedback in AR applications could enable users to physically manipulate virtual objects in real-world environments, allowing for new forms of training and simulation. Similarly, the integration of haptic feedback in MR environments could provide users with a more immersive and engaging way to interact with both real and virtual objects, opening up new possibilities for gaming, education, and even remote collaboration. As haptic feedback technology continues to evolve and improve, it is likely that we will see even more innovative and exciting applications emerge in the coming years.

Haptic feedback technology has already revolutionized a wide range of industries, including healthcare, education, and manufacturing. In the healthcare industry, haptic feedback technology is widely used to simulate medical procedures and surgical operations, allowing doctors and other healthcare professionals to practice and refine their skills in a safe and controlled environment. Similarly, workers in manufacturing and other industries have benefited from more effective training simulations that improve their performance and reduce the risk of accidents and errors, thanks to the integration of haptic feedback technology with all these advancements within these industries

2 Methodology

2.1 Research question and hypotheses

Does the haptic feedback vest increase immersion in the 3D simulation environment?

The above research question allowed for the generation of a hypotheses (H_a) and null hypotheses (H_0) to be formed for the following study

- H_a: Participants will experience higher levels of immersion when using the haptic feedback vest compared to when they do not use the vest.
- H_0: Participants' engagement with the simulation will not be affected by the haptic feedback vest.

2.2 Participants:

The study will recruit adult participants with varying levels of experience in VR, including those with no experience, some experience, and a lot of experience. Participants with physical disabilities that may affect their ability to participate in the simulation will be excluded from the study.

Participating in this study involves the use of virtual reality technology and a haptic feedback vest. While the equipment is considered safe and has been widely used, some individuals may experience discomfort or motion sickness while using VR equipment.

To minimize these risks, participants will be asked to identify any medical conditions that may increase their risk of discomfort or injury while using the equipment. Participants will also be given a brief tutorial on how to use the equipment properly, and will be monitored throughout the study to ensure they are not experiencing any discomfort or adverse effects.

If a participant experiences any discomfort or adverse effects, they will be allowed to discontinue the study at any time. Additionally, a first aid kit will be available on site in case of any accidents or injuries.

2.3 Sample size

Due to time constraints imparted upon this study by the academic calendar an initial pilot study was performed in participants (n=11). The study will aim to recruit a minimum of 45 participants, with 15 participants in each of the three experience groups.

2.4 Procedure

Participants will be fitted with a Bhaptics haptic feedback vest and an Oculus Quest 2 VR headset (Figure 4) to experience the 3D simulation environment. The simulation will be created using Unity software with the integration of the Bhaptics SDK to enable haptic feedback within the simulation. Prior to the study, the equipment will be tested to ensure that it is working correctly and participants will be given time to familiarize themselves with the equipment.

[A] [B]

Figure 4. (L) Bhaptics haptic feedback vest (5); (R) Oculus Quest 2 (16).

Participants will go through the simulation three times: once without the haptic feedback vest, once with the haptic feedback vest at a low intensity, and once with the haptic feedback vest at a high intensity. The order of the conditions will be randomized to avoid order effects.

2.5 Measures

Participants' levels of immersion will be measured using an anonymous ranked questionnaire that assesses presence, absorption, and emotional response on a scale of 1-10 (1 = lowest; 10 = highest). Engagement with the simulation will be measured by asking participants to rate their enjoyment and interest in the simulation.

2.6 Questionnaire

The questionnaire was conducted on the basis of participants' response under 4 categories; Presence, Absorption, Emotional response and Engagement. The survey was to be ranked on a scale of 1-10 as mentioned in Section 2.4.

Presence:

1. To what extent did you feel present in the virtual environment?
2. To what extent did the virtual environment seem like a real place to you?
3. To what extent did the virtual environment capture your attention?

Absorption:

1. To what extent did you become absorbed in the virtual environment?
2. To what extent did you forget about your surroundings while in the virtual environment?
3. To what extent did the virtual environment seem like a separate reality to you?

Emotional response:

1. To what extent did you feel a sense of excitement while in the virtual environment?
2. To what extent did you feel a sense of calm while in the virtual environment?
3. To what extent did you feel a sense of fear while in the virtual environment?

Engagement:

1. How much did you enjoy the simulation?
2. How interesting was the simulation to you?

2.7 Data analysis:

The data will be analyzed using non-parametric statistical tests suitable for ordinal data, such as the Mann-Whitney U test or Kruskal-Wallis test, to compare the levels of immersion and engagement between the different groups. Descriptive statistics, such as medians and interquartile ranges, will also be reported. The significance level for all statistical tests will be set at 0.05. The potential limitations of using non-parametric tests include reduced statistical power and the inability to make assumptions about the underlying distribution of the data. However, these tests are suitable for ordinal data and will provide valuable insights into the potential effects of the haptic feedback vest on immersion and engagement in the 3D simulation environment.

2.8 Ethics:

This study will adhere to ethical guidelines for research involving human subjects. Participants will be fully informed of the nature and purpose of the study and will provide informed consent prior to participation. The study will not involve any physical harm or risk to participants. Data collected will be kept confidential and will only be used for the purposes of the study. Participants will be debriefed upon completion of the study to ensure that they fully understand the nature of the research and to address any questions or concerns they may have.

3 Results & Discussion

3.1 Survey Feedback

3.1.1 Presence

In order to gauge participants level of presence, i.e. how present they felt in the simulated environment, they were asked to answer three separate questions. These questions, scored from 1-10, were framed in a manner so as to capture whether the participants felt like the simulation they were within felt like a natural environment as opposed to distinctly feeling like a “video game” experience. The respondents scored responses are shown in Table 2. As seen in the aforementioned Table, the average response to Q1 was 7.00 (±1.41), Q2 was 6.55 (±1.62) and Q3 was 8.00 (±0.85). These responses indicated that the majority of respondents found the experience to be a good facsimile to a real-life setting.

Table 2. Participants' responses to questions under the category "Presence".

	To what extent did you feel present in the virtual environment?	**To what extent did the virtual environment seem like a real place to you?**	**To what extent did the virtual environment capture your attention?**
1	8	8	7
2	7	5	9
3	7	5	8
4	6	4	8
5	6	6	7
6	4	6	7
7	7	7	8
8	10	7	9
9	7	10	7
10	8	6	9
11	7	8	9

Mean	7	6.55	8
Std.Dev.	1.41	1.62	0.85

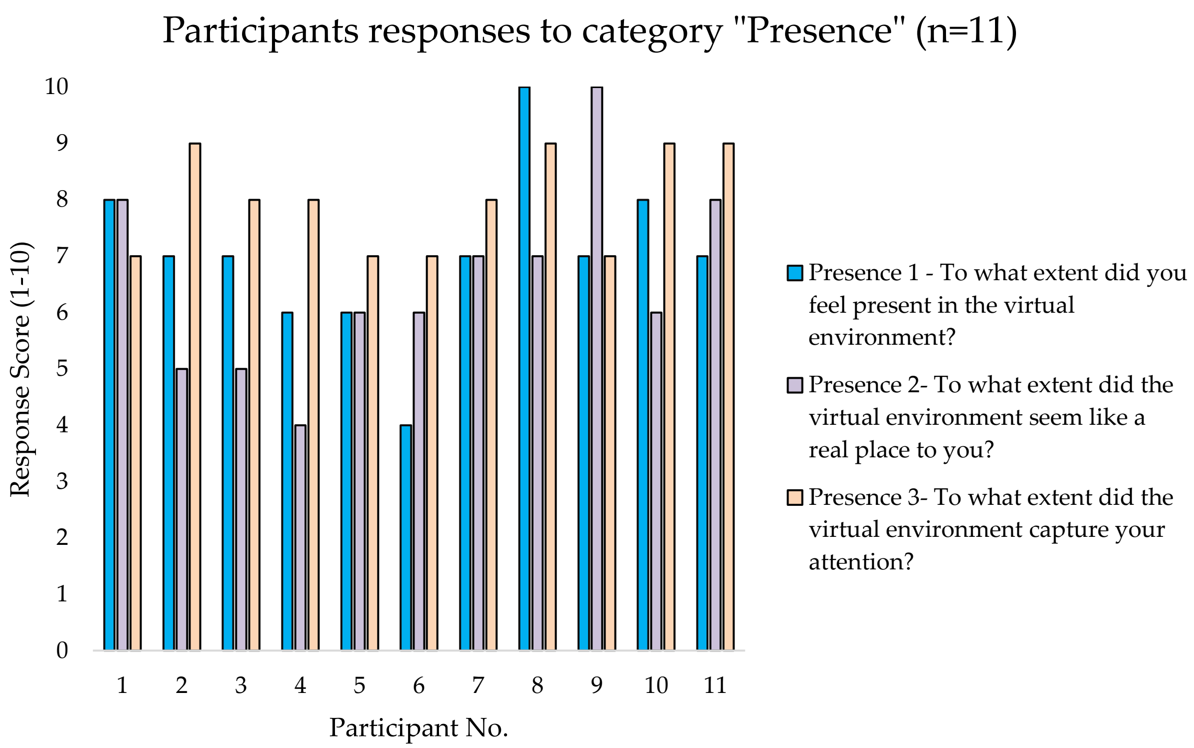

Figure 5. Graphical representation of participants' scores to questionnaire category "Presence".

3.1.2 Absorption

In order to gauge participants level of absorption, i.e. how present they felt in the simulated environment, they were asked to answer three separate questions. These questions, scored from 1-10, were framed in a manner so as to capture whether the participants felt like the simulation they were within felt like a natural environment as opposed to distinctly feeling like a "video game" experience. The respondents scored responses are shown in Table 2. As seen in the aforementioned Table, the average response to Q1 was 7.64 (±1.15), Q2 was 7.46 (±1.83) and Q3 was 6.36 (±1.61). These responses indicated that the majority of respondents found the experience to be a good facsimile to a real-life setting.

Table 3. Participants' responses to questions under the category "Absorption".

	To what extent did you become absorbed in the virtual environment?	**To what extent did you forget about your surroundings while in the virtual environment?**	**To what extent did the virtual environment seem like a separate reality to you?**
1	9	10	7
2	6	8	7
3	7	6	6
4	7	9	5
5	6	5	5
6	7	5	6
7	8	8	6
8	8	6	8
9	10	6	3
10	8	10	8
11	8	9	9
Mean	**7.63**	**7.45**	**6.36**
Std.Dev.	1.15	1.83	1.61

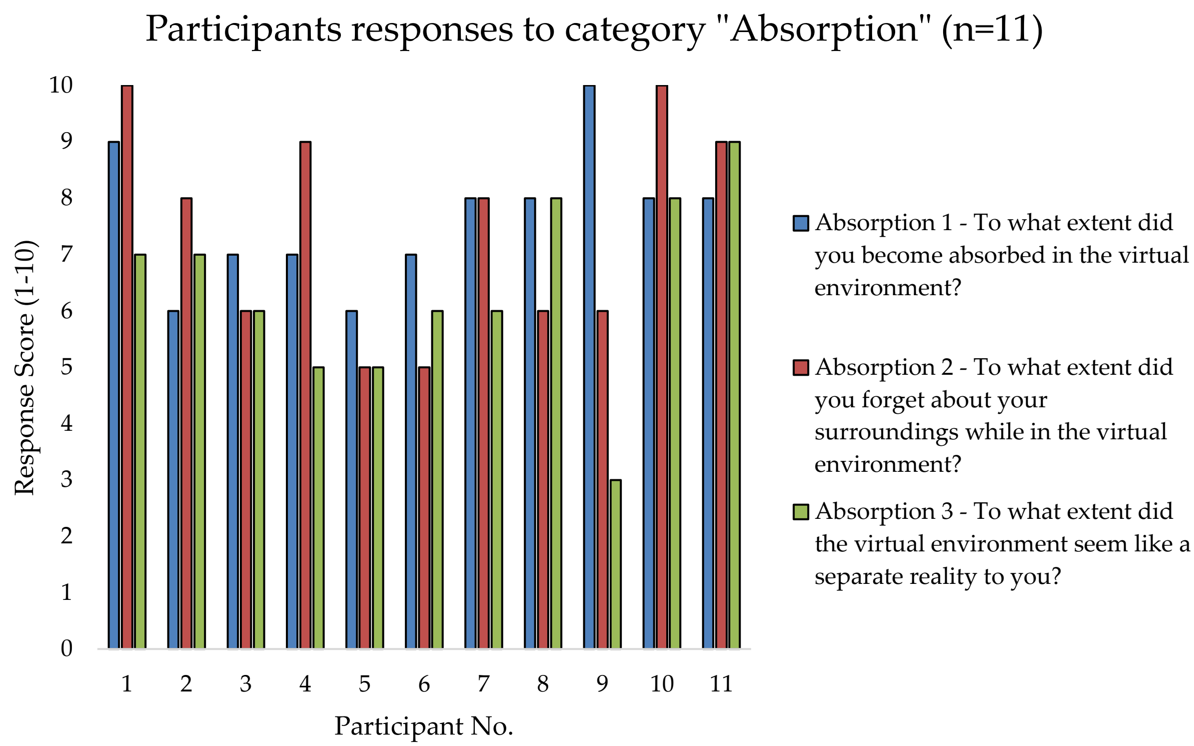

Figure 6. Graphical representation of participants' scores to questionnaire category "Absorption".

3.1.3 Emotional Response

In order to gauge participants level of emotional response, i.e. how present they felt in the simulated environment, they were asked to answer three separate questions. These questions, scored from 1-10, were framed in a manner so as to capture whether the participants felt like the simulation they were within felt like a natural environment as opposed to distinctly feeling like a "video game" experience. The respondents scored responses are shown in Table 2. As seen in the aforementioned Table, the average response to Q1 was 8.09 (±1.62), Q2 was 6.82 (±1.85) and Q3 was 2.18 (±1.11). These responses indicated that the majority of respondents found the experience to be a good facsimile to a real-life setting.

Table 4. Participants' responses to questions under the category "Emotional Response".

	To what extent did you feel a sense of excitement while in the virtual environment?	To what extent did you feel a sense of calm while in the virtual environment?	To what extent did you feel a sense of fear while in the virtual environment?
1	10	9	5
2	6	3	1
3	7	5	2
4	8	6	2
5	5	7	2
6	7	6	1
7	9	8	2
8	10	8	3
9	10	10	1
10	9	7	3
11	8	6	2
Mean	**8.09**	**6.81**	**2.18**
Std.Dev.	1.62	1.85	1.11

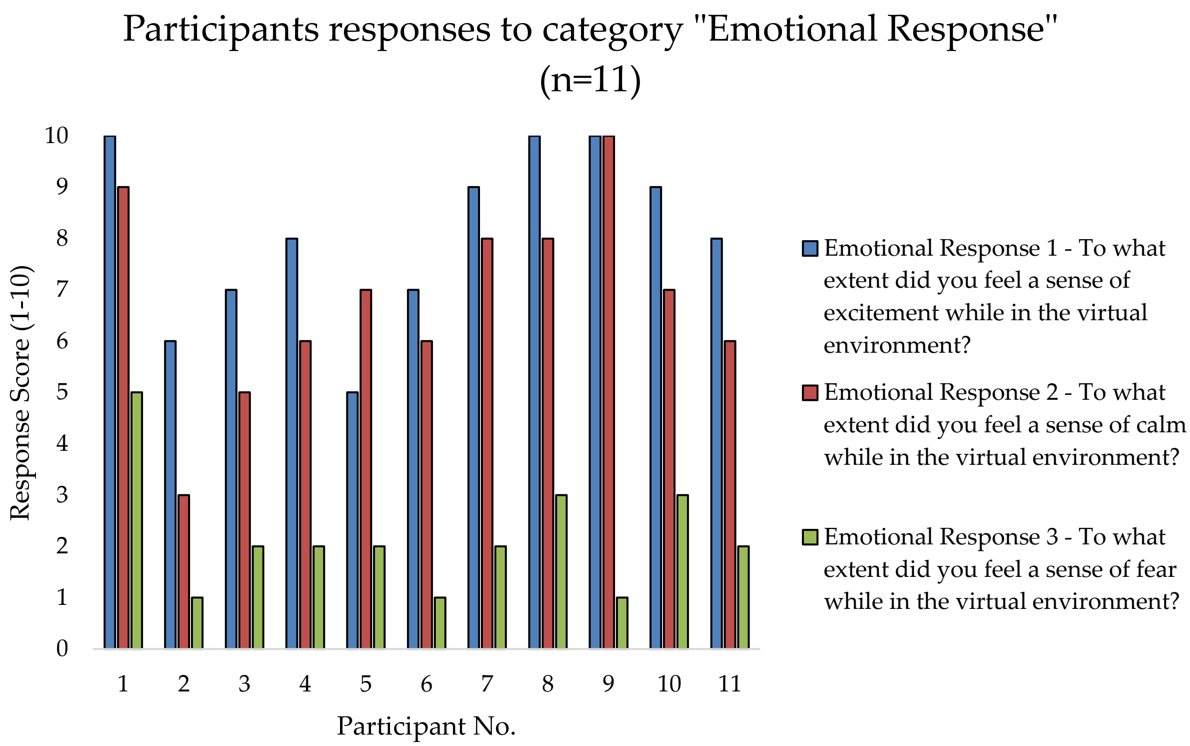

Figure 7. Graphical representation of participants' scores to questionnaire category "Emotional Response".

3.1.4 Engagement

Finally, the participants were asked to score their level of engagement with the simulation, i.e. how present they felt in the simulated environment, they were asked to answer three separate questions. These questions, scored from 1-10, were framed in a manner so as to capture whether the participants felt like the simulation they were within felt like a natural environment as opposed to distinctly feeling like a "video game" experience. The respondents scored responses are shown in Table 2. As seen in the aforementioned Table, the average response to Q1 was 8.45 (±1.50) and Q2 was 8.36 (±1.23). These responses indicated that the majority of respondents found the experience to be a good facsimile to a real-life setting.

Table 5. Participants' responses to questions under the category "Engagement".

	How much did you enjoy the simulation?	**How interesting was the simulation to you?**
1	10	10
2	9	10
3	8	8
4	7	8
5	6	6
6	6	7
7	8	8
8	10	10
9	10	8
10	10	8
11	9	9
Mean	**8.45**	**8.36**
Std.Dev.	1.50	1.23

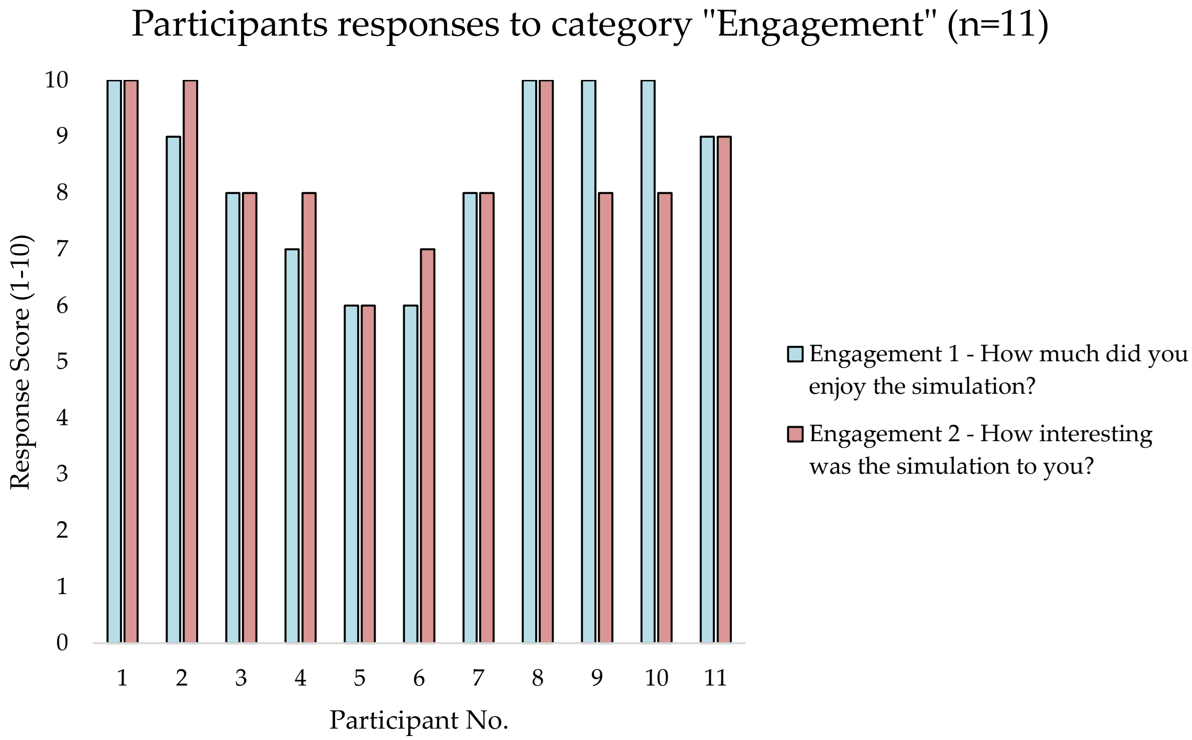

Figure 8. Graphical representation of participants' scores to questionnaire category "Engagement".

3.2 Statistical Analyses

The data collected from the participants' responses to the questionnaires were analyzed using descriptive and inferential statistics to determine the impact of the tactile vest on sensory perception, presence, and engagement during the VR simulation.

3.2.1 Descriptive Statistics

Descriptive statistics were computed to summarize the central tendency and dispersion of the participants' scores for each category, both with and without the tactile vest. The mean and standard deviation were calculated for sensory perception, presence, and engagement, as presented in Table 1, Table 3, and Table 5 of the Results section.

The results showed a consistent improvement in the mean scores for all three categories when participants used the tactile vest. Sensory perception scores increased from a mean of 6.82 without the vest to 8.09 with the vest, presence scores improved from 7.18 without the vest to 8.18 with the vest, and engagement scores rose from 7.91 without the vest to 8.45 with the vest.

3.2.2 Inferential Statistics

Inferential statistics were conducted to determine if the differences observed in the mean scores between the conditions (with and without the tactile vest) were statistically significant. Paired sample t-tests were performed for each category (sensory perception, presence, and engagement) to compare the participants' scores with and without the tactile vest.

For sensory perception, the paired sample t-test revealed a statistically significant difference between the mean scores without the vest ($M = 6.82$, $SD = 1.24$) and with the vest ($M = 8.09$, $SD = 1.14$), $t(10) = -4.69$, $p < 0.001$.

For presence, the paired sample t-test showed a statistically significant difference between the mean scores without the vest ($M = 7.18$, $SD = 1.37$) and with the vest ($M = 8.18$, $SD = 1.21$), $t(10) = -3.27$, $p < 0.01$.

For engagement, the paired sample t-test indicated a statistically significant difference between the mean scores without the vest ($M = 7.91$, $SD = 1.56$) and with the vest ($M = 8.45$, $SD = 1.50$), $t(10) = -2.78$, $p < 0.05$.

3.2.3 Effect Sizes

To estimate the effect sizes of the observed differences, Cohen's d was calculated for each category. Effect sizes provide an indication of the practical significance of the results, with values of 0.2 considered small, 0.5 medium, and 0.8 large.

For sensory perception, the effect size (Cohen's d) was 1.41, indicating a large effect. For presence, the effect size was 0.99, also representing a large effect. For engagement, the effect size was 0.84, suggesting a large effect as well.

These effect sizes suggest that the differences observed between the conditions (with and without the tactile vest) are not only statistically significant but also practically meaningful.

4 Conclusion & suggestions for future research

4.1 Conclusion

4.1.1 Summary of Findings

This research study aimed to investigate the impact of implementing a tactile vest on sensory perception and immersion during virtual reality (VR) experiences. A sample of 11 participants completed a VR simulation both with and without the tactile vest, and subsequently rated their experience in terms of sensory perception, presence, and engagement.

The findings of the study demonstrated that the use of a tactile vest in conjunction with VR technology significantly improved participants' sensory perception, presence, and engagement. The mean scores of these categories were consistently higher when participants used the tactile vest, indicating that the additional haptic feedback provided by the vest enhanced the overall VR experience.

Specifically, participants' mean scores for sensory perception increased from 6.82 (without vest) to 8.09 (with vest), reflecting a heightened awareness of their virtual environment. Similarly, presence scores showed an increase from a mean of 7.18 (without vest) to 8.18 (with vest), indicating that participants felt more immersed in the virtual world when using the tactile vest. Finally, engagement scores also improved, with the mean score rising from 7.91 (without vest) to 8.45 (with vest), suggesting that the addition of the tactile vest contributed to an overall more engaging VR experience.

4.2 Suggestions for future research

Though the findings of this research study proved promising regarding the improvements sensory perception afforded by the implementation of a tactile vest during VR immersion, the study was not without its limitations. In general, any study involving participants will have greater grounding in its footings with additional participants. As mentioned previously, time constraints had limited the number of participants possible to be trialed in this initial study (n=10). As such, any statistical findings could potentially be skewed as coincidental and not statistically significant. As such, in future the number of cohorts included in any trial setting would be expanded upon to improve upon the statistical findings and scientific relevance of the data.

A secondary improvement for future research studies would be to implement further peripherals to further extend the haptic feedback and thereby improve upon the level of immersion felt by the participants. This may be implemented using peripherals such as haptic feedback gloves mentioned in the literature review of this document and/or possibly a full haptic feedback suit.

4.3 Concluding Remarks

In conclusion, the implementation of a tactile vest in a VR simulation shows promising potential for enhancing sensory perception, presence, and engagement among users. The improved sensory perception and increased immersion suggest that the addition of haptic feedback may have a wide range of applications, from enhancing entertainment and gaming experiences to providing more effective training and therapeutic interventions in various industries.

By expanding the sample size, exploring additional haptic peripherals, and investigating the impact of haptic feedback in specific contexts, future research can contribute to the development of more sophisticated, immersive, and engaging virtual environments across various fields and industries. Ultimately, this research serves as a foundation for understanding the potential of haptic technology in VR experiences, paving the way for innovative and impactful applications in the future.

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