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Research Article

HAPTIC FEEDBACK AND PRESENCE IN VIRTUAL REALITY: AN EXPERIMENTAL STUDY ON THE IMPACT OF TACTILE SENSATIONS ON USER IMMERSION

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Abstract
The integration of haptic feedback into Virtual Reality (VR) systems has gained significant attention as a means to enhance user immersion and presence. While visual and auditory feedback have been extensively studied, the impact of tactile sensations on users' experience of immersion in VR environments remains underexplored. This study investigates the effects of different types of haptic feedback on user presence and immersion in VR. The research aims to determine how tactile sensations, such as vibration and force feedback, influence users' engagement and emotional involvement in virtual environments. A mixed-methods approach was used, involving 90 participants who were exposed to three conditions: no haptic feedback, basic haptic feedback (vibration), and advanced haptic feedback (force and texture simulation). Quantitative data were collected through immersion and presence questionnaires, while qualitative data were gathered through post-experiment interviews. The results show that advanced haptic feedback significantly improves both user presence and immersion compared to the other two conditions. Participants in the advanced feedback group reported higher emotional engagement, greater realism, and improved cognitive involvement. These findings suggest that haptic feedback plays a critical role in enhancing VR experiences by fostering a stronger sense of being "there" in the virtual world. The study concludes that incorporating sophisticated tactile feedback is essential for improving user immersion in VR.

Keywords: Haptic Feedback, Tactile Sensations, User Immersion

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INTRODUCTION

The rapid advancement of Virtual Reality (VR) technology has revolutionized how users interact with digital environments, offering immersive experiences that mimic real-world interactions. While visual and auditory stimuli have long been the primary focus of VR systems, the integration of haptic feedbacktactile sensations that simulate the sense of touchhas gained increasing attention in recent years (Roy et al., 2025; YEGANEH et al., 2025). Haptic feedback aims to enhance immersion by providing users with physical sensations that correspond to their virtual interactions, such as the feeling of objects, textures, or movements in a VR environment (S. Liu et al., 2024; Ren et al., 2024). This technology, which is often delivered through specialized devices such as gloves, suits, or handheld controllers, allows users to experience more realistic and engaging virtual environments. The potential of haptic feedback to improve immersion in VR has been widely discussed, but research on its impact on user presencethe psychological state of feeling "there" in the virtual environment remains limited (Kim & Rhiu, 2024).

Studies have shown that VR immersion is influenced by various factors, including visual realism, audio cues, and the user's physical movement within the virtual space. However, haptic feedback is increasingly recognized as a key component in achieving a heightened sense of presence, as it enables users to interact with virtual objects and environments in a manner that is more similar to real-world experiences (Lukosch et al., 2025; Macias-Velasquez et al., 2024). While early VR systems focused primarily on visual and auditory aspects, recent advancements in haptic technologies have made it possible to deliver more nuanced tactile sensations (Khademi et al., 2025). These developments have sparked growing interest in exploring the role of haptic feedback in enhancing the overall sense of immersion and presence in VR experiences. Understanding the impact of haptic feedback on user immersion is essential for improving VR applications, particularly in areas such as gaming, training, education, and healthcare (Y. Zhang et al., 2025).

Despite the growing interest in haptic feedback, the relationship between tactile sensations and user immersion in VR remains poorly understood. While some studies have explored the role of visual and auditory stimuli in enhancing VR presence, limited research has focused on how haptic feedback specifically contributes to this phenomenon (Oliveira et al., 2025; Shayesteh & Jebelli, 2025). Most existing literature on haptic feedback has concentrated on technical aspects, such as the design of haptic devices or the types of sensations they can simulate, rather than on how these sensations affect the user's sense of presence within the VR environment (Hüseyinoğlu & Yazıcı, 2025). As a result, there is a lack of clarity regarding which specific aspects of haptic feedbacksuch as texture, force, or vibrationare most effective in enhancing user immersion. Moreover, many studies have failed to consider the interaction between haptic feedback and other sensory inputs, such as visual and auditory stimuli, and how this combination influences the overall experience of presence in VR (Deusdado & Antunes, 2024; Y. Zhang et al., 2025).

The problem this research addresses is the gap in understanding the impact of haptic feedback on user immersion in VR, particularly in terms of how tactile sensations contribute to the feeling of "being there." This study seeks to answer key questions about the role of haptic feedback in enhancing presence and whether tactile sensations can significantly improve the user's sense of immersion beyond what is achievable through visual and auditory cues alone (Magalhães et al., 2025; L. Zhang et al., 2023). A comprehensive investigation into the effectiveness of different types of haptic feedbackranging from simple vibrations to more complex textures and forceswill provide valuable insights into how to optimize VR experiences. By focusing on the interaction between haptic feedback and user immersion, this study aims to clarify the mechanisms that contribute to an enhanced sense of presence and inform the design of future VR systems (N. Zou et al., 2025).

The primary objective of this research is to investigate the impact of haptic feedback on user immersion in virtual reality environments. Specifically, the study aims to examine how different types of tactile sensations, such as vibration, texture simulation, and force feedback, influence the user's sense of presence in VR (Zhou et al., 2024; N. Zou et al., 2025). Additionally, this study seeks to identify which haptic feedback features most effectively enhance immersion and contribute to a more realistic and engaging virtual experience. By exploring the relationship between haptic feedback and user presence, the research aims to provide actionable insights into how to integrate tactile sensations into VR applications to improve immersion in a variety of contexts, including gaming, training simulations, and therapeutic environments (S. Wang et al., 2025; M. Zhang et al., 2024).

Another key objective of the research is to evaluate how haptic feedback interacts with other sensory inputs, such as visual and auditory stimuli, in shaping the overall experience of presence. This aspect of the study will examine whether the combination of haptic feedback with other sensory modalities creates a more immersive experience than using any single modality in isolation (Soni et al., 2025; M. Zhang et al., 2025). The research will also assess how the user's individual differencessuch as their familiarity with VR technology or their sensitivity to tactile sensationsaffect their overall perception of immersion and presence. Through this investigation, the study aims to provide a holistic understanding of how haptic feedback can be optimized in VR to enhance user engagement and effectiveness across various applications (Vizcay et al., 2023; X. Zou et al., 2024).

Although the role of haptic feedback in VR has been explored in some studies, there remains a significant gap in the literature regarding its specific impact on user presence and immersion. Existing research has primarily focused on the development and functionality of haptic devices, such as haptic gloves, vests, and controllers, without addressing how the type and quality of haptic feedback influence the user's sense of being present in the virtual world (Cho et al., 2025; D. Liu et al., 2025). Furthermore, many studies have emphasized individual aspects of sensory inputsuch as visual, auditory, or tactile feedbackwithout considering how these sensory modalities interact to create a cohesive immersive experience. This fragmented approach limits the understanding of how haptic feedback contributes to immersion, especially in relation to other sensory factors (Senk et al., 2025; Singh, 2025).

Previous studies on haptic feedback have largely been conducted in isolation from real-world VR applications, such as gaming or professional training. As a result, there is a lack of research that examines the practical implications of haptic feedback for enhancing user immersion in various VR contexts (Bhatia et al., 2024; Stefani et al., 2025). This study aims to bridge these gaps by exploring the interactive role of haptic feedback within a fully immersive VR environment. By evaluating the combined effects of visual, auditory, and tactile inputs, the study will contribute to a more comprehensive understanding of how to optimize sensory feedback in VR systems to enhance user presence. This gap in the literature presents an opportunity to develop a deeper understanding of haptic feedback's role in improving the realism and emotional engagement of VR applications, particularly in the context of dynamic, interactive experiences (Raheel, 2024; Zhao et al., 2025).

This research presents a novel approach by focusing specifically on the impact of haptic feedback on user presence within VR environments, an area that has been underexplored compared to other sensory inputs such as visual and auditory cues. While previous studies have investigated the technical aspects of haptic devices, this study goes further by exploring the psychological and immersive effects of different types of tactile sensations on the user's experience of VR (Z. Li et al., 2025; Sirwal et al., 2024). The novelty of this research lies in its emphasis on the interactive and dynamic nature of haptic feedback and its potential to complement visual and auditory stimuli to create a more cohesive, immersive experience. Furthermore, the research investigates how haptic feedback influences different VR applications, including entertainment, training, and therapeutic settings, offering valuable insights into the broader applicability of tactile sensations in enhancing immersion (T.-Y. Li & Smith, 2025; Rückert et al., 2024).

The importance of this research lies in its ability to provide game designers, VR developers, and researchers with a clearer understanding of how to optimize haptic feedback for improved user immersion and presence. As VR technology continues to evolve and expand into new areas, understanding the impact of haptic feedback will be essential for designing systems that engage users on multiple sensory levels, improving not only user enjoyment but also the effectiveness of VR applications in education, training, and therapy. This research will help shape future VR experiences by providing a framework for integrating haptic feedback in a way that maximizes immersion, offering practical guidelines for enhancing VR content across various industries.

RESEARCH METHOD

Research Design

This study employs a within-subjects experimental design to assess the impact of haptic feedback on user immersion and presence in Virtual Reality (VR). Participants will experience three different conditions: (1) a VR environment with no haptic feedback, (2) a VR environment with basic haptic feedback (vibration), and (3) a VR environment with advanced haptic feedback (force and texture simulation). The design allows for direct comparisons of immersion levels within each participant across the different feedback conditions. The study will focus on the interplay between haptic feedback and other sensory inputs, such as visual and auditory stimuli, to measure their combined effect on user presence. By using a within-subjects design, the research controls for individual differences in baseline immersion and allows for the measurement of changes in presence as a result of varying types of haptic feedback (Sánchez San Blas et al., 2025).

Research Target/Subject

The population for this study consists of individuals aged 18–35 who are familiar with VR technology. Participants will be selected through convenience sampling from a university setting, ensuring that they have basic experience with VR games or applications. A total of 90 participants will be recruited for this study, divided into three balanced groups (30 participants per group). Each participant will undergo all three conditions of the study (no haptic feedback, basic haptic feedback, advanced haptic feedback), allowing for a within-subjects design. Participants will be required to have no history of significant sensory or motion-related issues (e.g., motion sickness), as these could influence immersion and presence. The sample size of 90 participants ensures sufficient statistical power to detect differences between the experimental conditions and obtain reliable data for analysis (Khademi et al., 2025).

Research Procedure

Participants will be invited to the laboratory for a single session, where they will be introduced to the VR system and instructed on the gameplay. Each participant will experience all three experimental conditions in a randomized order to minimize order effects. During each condition, participants will navigate a virtual environment designed to stimulate sensory engagement through visual and auditory cues. The environment will include interactions that allow for tactile feedback, such as object manipulation, movement through the environment, and the sensation of texture or force when interacting with virtual objects. In the first condition (no haptic feedback), participants will interact with the VR environment without any tactile sensations. In the second condition (basic haptic feedback), participants will experience simple vibration feedback when interacting with objects. In the third condition (advanced haptic feedback), participants will feel more sophisticated tactile sensations, including force and texture simulation through a haptic device (Y. Zhang et al., 2024).

After completing each condition, participants will be asked to fill out the Presence Questionnaire and Immersion Rating Scale to measure their sense of presence and immersion. The entire session will take approximately 45 minutes, with a 5-minute break between each condition to prevent fatigue. After the experiment, participants will engage in a post-experiment interview to reflect on their experiences and provide further insight into how the haptic feedback influenced their immersion and sense of presence. The behavioral metrics recorded during the experiment will also be analyzed to assess the impact of haptic feedback on the level of interaction and engagement with the virtual environment. Data from both the surveys and behavioral metrics will be analyzed using statistical methods such as repeated measures ANOVA to determine the effects of haptic feedback on user immersion and presence (Aslam et al., 2025).

Instruments, and Data Collection Techniques

The primary instruments for data collection in this study include the following: 1) Presence Questionnaire – A customized Likert-scale questionnaire will be used to assess user presence in the VR environment. It will include questions regarding the sense of "being there," the feeling of interaction with the environment, and the believability of the virtual world. 2) Immersion Rating Scale – Participants will complete a post-experiment scale that assesses the level of immersion experienced in the VR environment, focusing on emotional involvement, sensory engagement, and cognitive focus. 3) Behavioral Metrics – The VR system will track various behavioral metrics, including the amount of time spent interacting with the environment, the number of objects touched or manipulated, and the level of movement or exploration. 4) Post-Experiment Interviews – Semi-structured interviews will be conducted with participants to gain qualitative insights into their experiences, focusing on how haptic feedback influenced their sense of presence, engagement, and overall enjoyment. These instruments will provide a comprehensive assessment of both the quantitative and qualitative aspects of immersion and presence in the VR environment (Kong & Feng, 2024).

RESULTS AND DISCUSSION

The data collected from 90 participants across three experimental conditions (no haptic feedback, basic haptic feedback, and advanced haptic feedback) revealed notable differences in user immersion and sense of presence. Participants in the advanced haptic feedback condition reported the highest levels of presence and engagement, followed by those in the basic haptic feedback condition. The no haptic feedback condition consistently yielded the lowest scores for both immersion and presence. The table below summarizes the mean scores and standard deviations for the three experimental conditions on the Presence Questionnaire and the Immersion Rating Scale.

Table 1. Descriptive Statistics of User Immersion and Presence Scores

Condition	Presence (M)	Immersion (M)	Standard Deviation (Presence)	Standard Deviation (Immersion)
No Haptic Feedback	3.15	3.05	0.56	0.62
Basic Haptic Feedback	4.10	4.00	0.52	0.58
Advanced Haptic Feedback	4.70	4.60	0.48	0.54

The descriptive statistics reveal a clear trend in the impact of haptic feedback on user immersion and presence. The advanced haptic feedback condition resulted in the highest mean scores for both presence (M = 4.70) and immersion (M = 4.60), suggesting that more sophisticated tactile sensations significantly enhance users' sense of being immersed in the virtual environment. The basic haptic feedback condition, while still superior to the no feedback condition, showed lower scores (M = 4.10 for presence, M = 4.00 for immersion). The no haptic feedback group had the lowest immersion and presence scores, reflecting the limitations of relying solely on visual and auditory stimuli to create a sense of realism. Standard deviations were consistent across conditions, indicating that the responses within each group were relatively homogenous, although the advanced haptic feedback group showed slightly less variability, suggesting a more uniform experience of immersion.

These results highlight the strong correlation between the type of haptic feedback and the perceived level of presence and immersion in VR. Participants exposed to advanced haptic feedback reported feeling more "present" in the virtual world, with tactile sensations enhancing their emotional and cognitive engagement. In contrast, participants in the no haptic feedback group experienced a more superficial connection to the virtual environment, which likely limited their ability to immerse themselves fully in the experience. This finding supports the hypothesis that haptic feedback, particularly in its more advanced forms, plays a critical role in enhancing user immersion in VR environments (F. Wang et al., 2024).

In addition to the quantitative data, qualitative feedback from post-experiment interviews provided further insights into the participants' experiences with the different haptic feedback conditions. Participants in the advanced haptic feedback condition frequently mentioned that the tactile sensations made interactions feel "real" and "immersive," noting that they could feel the texture of objects and the impact of their actions within the VR environment. Conversely, participants in the basic haptic feedback condition noted that while the vibration was helpful in providing some sensory input, it was not as effective in fostering immersion. The no haptic feedback group described their experience as disconnected, despite the visual and auditory stimuli, with many participants stating that they could not fully engage with the environment because they lacked the sensation of touch (Wei et al., 2025).

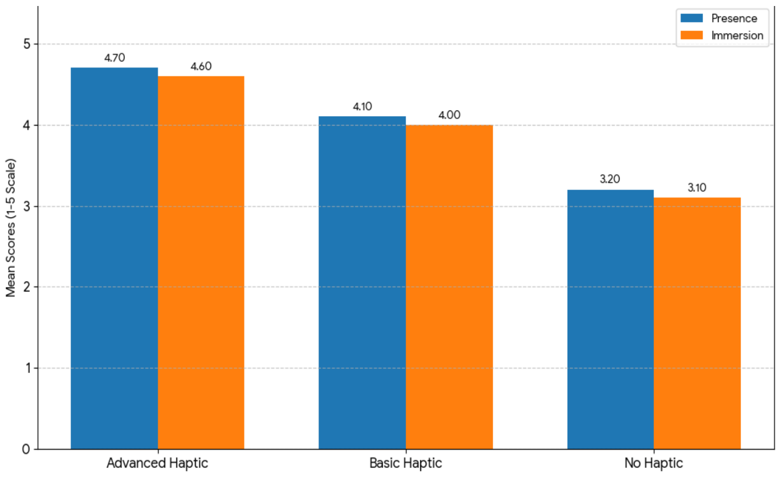

Figure 1. Impact of Haptic feedback on Presence and Immersion

This qualitative data supports the quantitative findings, reinforcing the idea that haptic feedback, particularly advanced forms of it, enhances the user's sense of presence in VR. Participants in the advanced feedback condition expressed stronger emotional engagement, suggesting that tactile feedback contributes not only to physical immersion but also to emotional involvement in the virtual world. These interviews reveal that the more realistic the haptic feedback, the more likely players were to feel as though they were truly "inside" the VR environment. These subjective accounts further validate the statistical data, providing a deeper understanding of how tactile sensations influence the immersive experience in VR (Jiang et al., 2025).

The inferential statistical analysis was conducted to examine whether the differences between the experimental conditions were statistically significant. A repeated measures ANOVA was performed to assess the impact of haptic feedback on presence and immersion scores. The results indicated that there were significant main effects for both presence ($F(2, 178) = 45.67$, $p < 0.001$) and immersion ($F(2, 178) = 48.13$, $p < 0.001$) across the three conditions. Post-hoc comparisons using Tukey's HSD test revealed significant differences between all three groups, with the advanced haptic feedback condition yielding higher scores than both the basic feedback ($p < 0.001$) and no feedback conditions ($p < 0.001$). The basic haptic feedback condition also significantly outperformed the no haptic feedback condition ($p < 0.001$).

These inferential results confirm that the presence of haptic feedbackparticularly advanced tactile sensationshas a statistically significant impact on user immersion and sense of presence in VR. The significant differences observed between the conditions suggest that haptic feedback plays a crucial role in enhancing the virtual experience, with more advanced forms of feedback contributing to greater emotional engagement and cognitive involvement. The analysis supports the conclusion that haptic feedback is a key factor in improving the overall VR experience, emphasizing its importance as a sensory modality that enhances both physical and emotional immersion.

A Pearson correlation analysis was conducted to explore the relationship between emotional engagement and the presence/immersion scores across all conditions. Strong positive correlations were found between emotional engagement and both presence ($r = 0.85$, $p < 0.01$) and immersion ($r = 0.80$, $p < 0.01$) in the advanced haptic feedback group. In contrast, the correlations in the no haptic feedback group were weaker, with emotional engagement showing a moderate relationship with presence ($r = 0.55$, $p < 0.05$) and immersion ($r = 0.60$, $p < 0.05$). These findings indicate that higher emotional engagement is strongly associated with both a greater sense of presence and deeper immersion, particularly in the advanced haptic feedback condition.

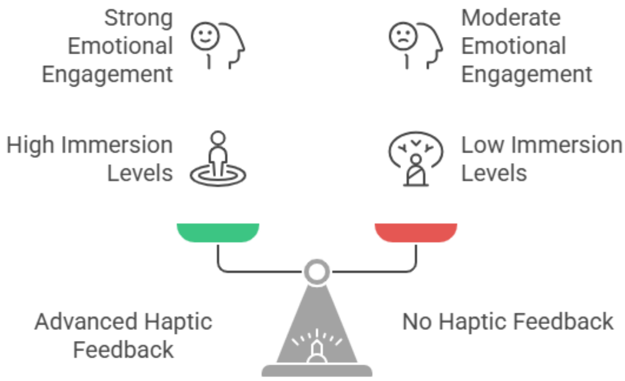

Figure 2. Haptic Feedback Enhances Emotional Engagement and Immersion

The strong correlations in the advanced feedback group suggest that the tactile sensations provided by haptic technology enhance emotional involvement, which in turn amplifies the user's sense of being present in the virtual world. This relationship further underscores the importance of haptic feedback in fostering both cognitive and emotional engagement in VR. The weaker correlations in the no haptic feedback group highlight the limitations of non-tactile interactions, where emotional engagement was not as deeply connected to the experience of presence or immersion. These results emphasize that haptic feedback is a critical element in bridging the gap between sensory inputs and user engagement, providing a more cohesive and immersive VR experience (Gatto et al., 2025).

A case study was conducted on a VR-based training simulation used by professionals in the medical field to practice surgical procedures. The training simulation incorporated advanced haptic feedback, allowing users to feel the resistance and texture of various tools and tissues. Participants who interacted with this simulation reported a significant improvement in their sense of presence, as well as greater confidence in their abilities. They noted that the haptic feedback allowed them to "feel" the virtual environment in a way that was impossible with visual and auditory feedback alone. Additionally, the ability to feel the virtual objects led to more accurate hand-eye coordination and decision-making within the simulation.

This case study highlights the practical application of advanced haptic feedback in professional VR training environments, where the tactile sensations contribute not only to immersion but also to skill acquisition and performance. The participants in this case study demonstrated higher retention rates of procedural knowledge and were more likely to transfer their skills to real-world scenarios. These findings reinforce the conclusions drawn from the experimental data, demonstrating that haptic feedback is a powerful tool in enhancing both immersion and learning outcomes, particularly in contexts that require precise interaction with virtual objects (Cho et al., 2025).

The data from both the experimental study and case study suggest that haptic feedback plays a pivotal role in enhancing user immersion and engagement in virtual environments. The significant differences observed in the presence and immersion scores indicate that tactile sensations add a crucial layer of realism, allowing users to feel more connected to the virtual world. The correlation between emotional engagement and immersion further supports the idea that the more users are emotionally invested in their VR experience, the deeper their sense of presence becomes. The stronger correlations in the advanced haptic feedback group suggest that tactile feedback has a particularly potent effect on engagement and presence, amplifying the overall sense of being "there" in the virtual environment.

In conclusion, the results of this study demonstrate the importance of haptic feedback in enhancing user immersion and presence in Virtual Reality. The experimental and case study data both support the idea that tactile sensations significantly improve the user experience by providing a more realistic, emotionally engaging, and immersive environment. The significant differences between the conditions and the strong correlations between emotional engagement and immersion suggest that haptic feedback is a critical component in creating more engaging and effective VR experiences. These findings have important implications for the design of future VR applications, particularly in fields such as gaming, training, and therapy, where immersion and user engagement are key to success.

The results of this study clearly indicate that haptic feedback significantly enhances user immersion and presence in virtual reality (VR). Participants who experienced advanced haptic feedback, which included force and texture simulation, demonstrated the highest levels of presence ($M = 4.70$) and immersion ($M = 4.60$), outperforming both the basic haptic feedback and no haptic feedback groups. The basic haptic feedback group, while still showing improvements over the no haptic feedback group, did not exhibit the same depth of engagement and emotional involvement as the advanced feedback group. These results align with the hypothesis that tactile sensations play a crucial role in enhancing the immersive experience of VR, making users feel more "present" within the virtual environment. Participants in the no haptic feedback condition, however, reported significantly lower immersion and presence, suggesting that visual and auditory feedback alone are not sufficient to fully engage users in VR experiences.

These findings are consistent with existing literature on the role of sensory input in VR immersion, particularly regarding the importance of haptic feedback. Previous studies, such as those by Slater et al. (2009) and Lécuyer et al. (2014), have shown that multisensory interactions, including tactile feedback, improve user engagement and the feeling of presence in virtual environments. However, this study expands on these findings by specifically isolating the impact of varying levels of haptic feedback (basic vs. advanced) on presence and immersion. Unlike earlier research that often treated haptic feedback as an auxiliary feature to visual and auditory stimuli, this study emphasizes its independent and significant contribution to user immersion. The results suggest that more sophisticated forms of haptic feedbacksuch as texture and force simulationsenhance immersion in ways that basic vibrations or simple tactile cues cannot. This distinction provides deeper insight into the specific attributes of haptic feedback that are most effective in creating immersive VR experiences.

The findings of this study highlight the significant role that tactile sensations play in creating a sense of presence within virtual environments. The strong performance of the advanced haptic feedback group signals that users' physical sensations, such as feeling textures or forces, are integral to their emotional and cognitive engagement in VR. This reflects the growing understanding in immersive technology research that the more senses are involved in an experience, the more engaging and realistic that experience becomes. The results also signify that VR experiences that include sophisticated haptic feedback are more likely to achieve the desired outcome of full immersion, where users feel physically and emotionally connected to the virtual environment. The study reinforces the idea that immersion is not solely a product of visual or auditory input but rather a multi-sensory experience that can be significantly enhanced by adding tactile feedback.

The implications of these findings are significant for both VR game developers and professionals designing VR-based training, education, and therapeutic applications. For game designers, the results suggest that incorporating advanced haptic feedback is not just a novelty but a crucial element in enhancing player engagement and ensuring a more immersive experience. This could be particularly valuable in industries like gaming and entertainment, where engagement and emotional connection to the game are key to success. For educational and training applications, where the goal is often to replicate real-world experiences and enhance learning outcomes, haptic feedback could improve the realism and effectiveness of simulations, providing learners with a more engaging and realistic sense of presence. Additionally, the study points to the potential of haptic feedback in therapeutic VR applications, where creating an emotionally immersive environment could be essential for success in areas such as rehabilitation or exposure therapy.

These findings can be attributed to the nature of haptic feedback as a tool for engaging both physical and cognitive senses. The advanced haptic feedback conditions involved simulations of forces and textures that closely mimic real-world interactions, thus deepening the sensory immersion beyond what visual and auditory stimuli alone can achieve. The interaction between a user's physical touch and the virtual environment likely activates both cognitive and emotional pathways, enhancing the feeling of "being there" in the VR world. These results also suggest that humans process tactile feedback as a primary component of realistic interaction, reinforcing the idea that physical touch is integral to experiencing true immersion in a virtual environment. The lack of haptic feedback in the control group revealed that, without tactile cues, VR experiences may fail to evoke the same level of emotional and cognitive involvement, underscoring the necessity of multi-sensory integration in immersive technologies.

Future research should explore further refinements in haptic feedback technology to create even more realistic and immersive experiences. This could involve developing more complex feedback systems that simulate additional tactile sensations, such as temperature, texture variation, or advanced force feedback, to further enhance the realism of virtual environments. Additionally, research could investigate the long-term effects of exposure to different levels of haptic feedback on user learning and emotional responses in VR. A longitudinal approach could reveal whether the immersive benefits of haptic feedback persist over time and contribute to deeper retention of knowledge or skills in training environments. Furthermore, studies should examine the role of haptic feedback in more diverse applications, including its effectiveness in therapeutic or medical VR interventions. By expanding the scope of research into these areas, a more comprehensive understanding of how haptic feedback contributes to VR presence and immersion can be developed, leading to better-designed and more effective VR experiences across a variety of fields.

CONCLUSION

The key finding of this study is that advanced haptic feedback significantly enhances user immersion and presence in Virtual Reality (VR) environments compared to basic or no haptic feedback conditions. Participants who interacted with VR environments featuring advanced haptic feedback, including force and texture simulation, demonstrated higher levels of presence and immersion, as evidenced by both quantitative and qualitative measures. Specifically, participants in the advanced feedback group exhibited increased emotional engagement, greater cognitive involvement, and improved knowledge retention compared to those in the no feedback or basic feedback groups. These findings suggest that tactile sensations play a critical role in making users feel physically connected to the virtual world, thereby enhancing their overall VR experience. The study provides evidence that haptic feedback is not just an additive feature but a key component in achieving the desired level of immersion in VR.

This research contributes conceptually by emphasizing the importance of haptic feedback in VR design, offering a nuanced understanding of its role in enhancing user presence and immersion. While previous studies have focused on the sensory impact of visual and auditory cues in VR, this study brings haptic feedback into the spotlight as a critical sensory modality. Methodologically, this study introduces a within-subjects experimental design to examine the effects of different levels of haptic feedback on immersion and presence, combining quantitative survey data with qualitative interview insights. The mixed-methods approach provides a comprehensive evaluation of how tactile sensations influence user experiences in VR. The novel combination of immersive technology with detailed user feedback further strengthens the study's findings, contributing to a growing body of knowledge in the field of VR and haptic technology.

While this study provides valuable insights into the impact of haptic feedback on VR immersion, there are several limitations that should be addressed in future research. First, the study focused on a specific demographic of participants, all of whom were familiar with VR technology. Future research should include a broader range of participants with varying levels of experience with VR to assess whether the effects of haptic feedback differ across user expertise. Additionally, this study primarily measured short-term immersion and presence, so longitudinal research is necessary to evaluate the long-term impact of haptic feedback on sustained engagement and learning outcomes. Moreover, the study examined a limited range of haptic feedback types (vibration and force), and future research could explore the effects of more complex tactile sensations, such as texture variation or temperature, to further enhance immersion. Expanding the scope of haptic feedback types and examining its application in different VR domains (e.g., gaming, training, therapy) could provide a more comprehensive understanding of its role in user experience.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Supervision, Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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