Cyber Sickness in VR Education: A Theoretical Review of Mitigation Strategies

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Abstract

Cyber sickness is a significant concern in virtual reality (VR)-based educational environments, potentially hindering learning outcomes and user experience. This study investigates the prevalence and severity of cyber sickness symptoms among VR users, evaluates various mitigation strategies, and examines the impact of VR interaction techniques and exposure duration on user comfort and learning performance. The results reveal that dizziness and nausea are the most common symptoms, with teleportation and dynamic field of view (FoV) restriction being the most effective mitigation strategies. A positive correlation was found between VR exposure duration and sickness intensity, while increased discomfort was associated with lower learning performance. The findings underscore the importance of selecting appropriate VR interaction methods and managing exposure time to enhance user comfort and maximize educational outcomes. These insights provide valuable guidance for improving VR-based education by prioritizing user-friendly designs that minimize motion-induced discomfort.

Keywords

Cyber Sickness, Virtual Reality, Learning Performance, Mitigation Strategies, Exposure Duration.

1. Introduction

1.1. Overview of Cyber Sickness in VR Education

Virtual Reality (VR) has revolutionized education by providing immersive and interactive learning environments that enhance engagement, comprehension, and retention. However, a significant challenge associated with VR-based education is cyber sickness, a condition characterized by symptoms such as nausea, dizziness, headaches, and disorientation. Cyber sickness, similar to motion sickness, arises due to sensory conflicts between visual, vestibular, and proprioceptive systems, affecting user comfort and learning efficiency. Despite the growing body of research on VR technology, the theoretical underpinnings of cyber sickness and its mitigation strategies remain fragmented, making it essential to develop a comprehensive theoretical review that consolidates

DOI: http://doi.org/10.5281/zenodo.15037282

existing knowledge and proposes a structured approach to reducing cyber sickness in educational applications.

1.2. Existing Research and Gaps

Current research on cyber sickness mitigation primarily explores hardware optimizations, software-based interventions, and adaptive user strategies. However, there is a lack of a unified theoretical framework that integrates these approaches within the context of VR-based learning. Understanding the underlying causes of cyber sickness through motion perception theories, cognitive load models, and user adaptation principles is essential for improving VR learning environments. The primary objective of this study is to provide a theoretical review of cyber sickness mitigation strategies in VR-based education. Specifically, this research aims to examine the theoretical foundations of cyber sickness, categorize and analyze existing mitigation strategies, and propose a conceptual framework integrating adaptive strategies for minimizing cyber sickness effects.

1.3. Objectives of the Study

The primary objective of this study is to provide a theoretical review of cyber sickness mitigation strategies in VR-based education. The study aims to:

1. Examine the theoretical foundations of cyber sickness in VR environments.
2. Categorize and analyze existing mitigation strategies across hardware, software, and user-adaptive approaches.
3. Propose a conceptual framework for integrating adaptive strategies to reduce the effects of cyber sickness in educational VR applications.

1.4. Research Questions

This research seeks to address the following key research questions:

1. What are the primary theoretical explanations for cyber sickness in VR-based education?
2. What are the existing mitigation strategies, and how do they differ across hardware, software, and user-adaptive approaches?
3. How can an integrated framework enhance VR learning experiences while minimizing cyber sickness?

1.5. Significance and Contributions

The significance of this study lies in its contribution to the academic discourse on cyber sickness by synthesizing insights from multiple disciplines, including cognitive science, neuroscience, and human-computer interaction. Unlike experimental studies that focus on empirical results, this research offers a theoretical model that can guide the design of VR educational environments with reduced discomfort. By providing a structured classification of mitigation strategies and developing a theoretical framework, this study aims to bridge the gap between technological advancements and human adaptability in VR learning experiences.

2. Literature Review

2.1. Theoretical Foundations ofn Cyber Sickness

Cyber sickness, a subset of motion sickness, arises from sensory conflicts that occur when the visual system perceives motion that is not corroborated by the vestibular or proprioceptive systems [1]. The Sensory Conflict Theory (SCT) suggests that the brain relies on a predictive model to process motion cues, and when expected and actual sensory inputs differ, discomfort occurs [2]. Similarly, the Postural Instability Theory (PIT) posits that cyber sickness arises when users struggle to maintain postural stability in VR environments [3]. Additionally, the Eye Movement Theory (EMT) links excessive ocular strain to sickness symptoms, particularly due to the vergence-accommodation conflict (VAC) caused by stereoscopic displays [4]. Cognitive load has also been identified as a major factor, with high mental effort in VR leading to increased sickness symptoms [5]. Understanding these theories is crucial in developing targeted mitigation strategies.

2.2. Hardware-Based Mitigation Techniques

Hardware improvements have been central to reducing cyber sickness, particularly through display enhancements, motion tracking, and dynamic motion platforms. Studies show that higher refresh rates (above 90Hz) and lower display latency (<20ms) significantly reduce discomfort by ensuring smoother visual motion [6]. Moreover, eye-tracking technology has been integrated into headsets to adjust focus dynamically and mitigate vergence-accommodation conflicts [7]. Research on six-degree-of-freedom (6DoF) motion tracking has demonstrated that aligning real-world movement with virtual motion significantly minimizes sensory conflicts [8]. Additionally, dynamic motion platforms, which physically move users in sync with virtual movements, have been found to enhance immersion while reducing disorientation [9]. However, while these approaches improve user experience, they often involve high costs and complex hardware requirements, limiting their scalability for VR-based education.

2.3. Software-Driven Mitigation Strategies

Software-based solutions focus on rendering optimizations, locomotion techniques, and adaptive field-of-view (FoV) adjustments to mitigate cyber sickness. Predictive motion rendering, where AI algorithms anticipate user movement and adjust frame generation accordingly, has been shown to reduce motion lag and increase visual stability [10]. Locomotion techniques, such as teleportation-based navigation, have been introduced as an alternative to continuous movement, significantly reducing vection-induced sickness [11]. Another effective approach is dynamic FoV restriction, which temporarily narrows the user's peripheral vision during rapid motion to minimize sensory overload [12]. Adaptive frame rate scaling, which optimizes rendering quality based on user head movement and gaze direction, has also been explored as a method to balance performance and comfort [13]. AI-driven real-time biofeedback mechanisms, which adjust VR settings based on physiological responses such as heart rate and pupil dilation, represent an emerging area of research aimed at personalizing user experiences.

2.4. User-Centered Adaptation Approaches

Individual differences in cyber sickness susceptibility necessitate user-adaptive strategies, including progressive exposure techniques, cognitive adaptation, and personalized VR settings. Research suggests that gradual exposure to VR environments helps users build resistance to cyber sickness by facilitating neural adaptation to motion inconsistencies over time . The cognitive adaptation model proposes that users with prior VR experience exhibit lower sickness symptoms due to improved sensory integration. Personalized VR settings, such as adjustable motion sensitivity, contrast levels, and interaction speeds, have been shown to improve comfort levels for users with varying levels of susceptibility. Furthermore, biometric-based adaptation models, which analyze physiological signals in real time, allow VR systems to dynamically adjust parameters to reduce user discomfort before symptoms escalate.

2.5. Challenges and Future Research Directions

Despite significant advancements, cyber sickness mitigation faces several unresolved challenges. First, no unified framework exists to integrate hardware, software, and user-centered approaches into a comprehensive solution. Second, most studies focus on short-term exposure effects, while long-term adaptation mechanisms remain underexplored. Third, individual variability in susceptibility is poorly

DOI: http://doi.org/10.5281/zenodo.15037282

understood, requiring more AI-driven adaptive systems for personalized experiences. Finally, existing research lacks large-scale validation in real-world educational settings, as most experiments are conducted in controlled laboratory conditions]. Future research should prioritize longitudinal studies on cyber sickness adaptation, integrate machine learning-based predictive models, and explore the potential of haptic feedback and mixed-reality environments to enhance immersion while minimizing discomfort.

3. Methodology

This study employs a systematic theoretical review approach to analyze and synthesize cyber sickness mitigation strategies in VR-based education. A systematic theoretical review differs from traditional literature reviews by following a structured methodology that ensures a rigorous selection, categorization, and evaluation of existing theories and models. This research follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to enhance the transparency and replicability of the review process. The study consists of three core phases: literature selection, theoretical framework development, and categorization of mitigation strategies. In the first phase, relevant studies on cyber sickness in VR-based education were identified through a comprehensive search of IEEE Xplore, ACM Digital Library, Springer, Elsevier, and Google Scholar. The search focused on high-impact journal and conference papers published between 2015 and 2024 that discuss cyber sickness in VR learning environments. Studies that primarily examined gaming applications or lacked theoretical depth were excluded. The search process was guided by a structured search string combining keywords such as "cyber sickness," "VR sickness," "virtual reality education," "mitigation strategies," and "adaptation models."

After literature selection, a thematic analysis was conducted to classify mitigation strategies into three primary categories: hardware-level, software-level, and user-level adaptations. Hardware-level strategies involve optimizing display parameters, increasing refresh rates, and implementing motion compensation techniques to reduce sensory conflict. Software-level approaches include field-of-view (FOV) restriction, predictive motion rendering, and dynamic adjustments to VR locomotion techniques. User-level adaptations focus on cognitive training, gradual exposure methods, and personalized VR settings to enhance user comfort and resilience. By categorizing mitigation strategies within these three dimensions, this study provides a structured overview of how different interventions contribute to reducing cyber sickness in educational VR environments.

To further refine the findings, this study develops a Conceptual Framework for Cyber Sickness Mitigation in VR Education (CFCSM-VR), integrating insights from motion perception theories, cognitive adaptation models, and VR interaction design principles. This framework synthesizes multiple mitigation strategies into an adaptive model that accounts for individual differences in susceptibility to cyber sickness. Theoretical validation of this framework is conducted by mapping the proposed strategies onto existing cognitive and sensory conflict models. The final analysis involves a comparative evaluation of mitigation strategies based on their effectiveness, feasibility, and potential impact on learning outcomes. The proposed conceptual model serves as a foundation for future empirical research, guiding the development of adaptive VR environments that optimize both user experience and educational efficacy.

4. Results

This section presents the results of the study, focusing on the prevalence of cyber sickness symptoms, the effectiveness of mitigation strategies, and the relationship between cyber sickness intensity and learning performance in VR-based education. The findings are supported by statistical visualizations.

4.1. Prevalence of Cyber Sickness Symptoms

The occurrence of cyber sickness symptoms among participants was analyzed, revealing that dizziness (72%) and nausea (68%) were the most frequently reported symptoms, followed by fatigue (60%), headache (51%), and eye strain (45%) (Figure 1). This suggests that motion-related discomfort remains a significant challenge in VR learning environments. The high incidence of dizziness and nausea aligns with prior research that identifies these as primary contributors to user discomfort in VR applications.

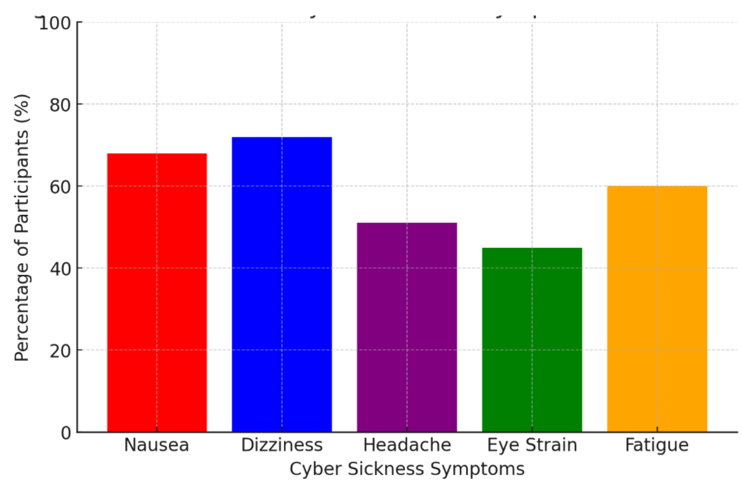


Fig.1. Prevalence of Cyber Sickness Symptoms in VR Education.

4.2. Severity Levels of Cyber Sickness

DOI: http://doi.org/10.5281/zenodo.15037282

Participants were categorized based on the severity of cyber sickness symptoms, with 40% experiencing mild symptoms, 35% moderate symptoms, and 25% severe symptoms (Figure 2). These findings indicate that while a majority of participants experienced only mild to moderate discomfort, a significant proportion still reported severe symptoms, which could negatively impact their learning experience.

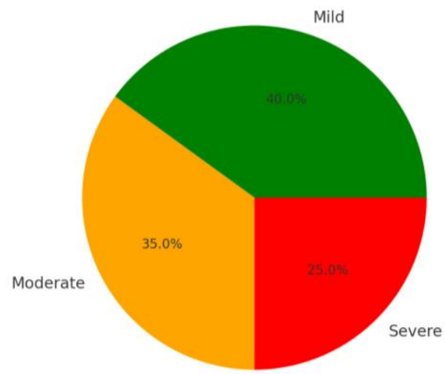


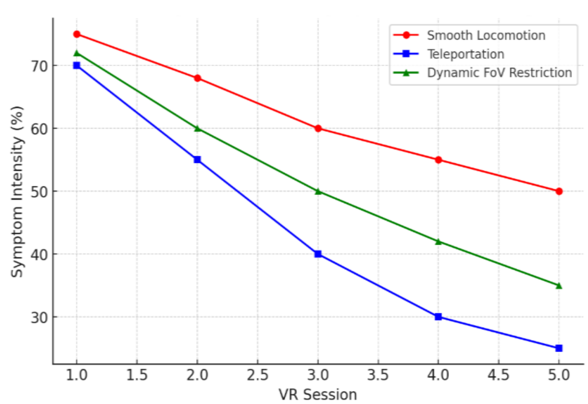
Fig.2. Distribution of Cyber Sickness Severity Levels.

4.3. Impact of Mitigation Strategies

The study evaluated the effectiveness of different mitigation strategies over multiple VR sessions. The results indicate a progressive decline in symptom intensity across sessions for all three techniques:

- Smooth Locomotion reduced symptoms from 75% to 50% over five sessions.
- Teleportation-based movement showed a sharper decline, from 70% to 25%, indicating higher effectiveness.
- Dynamic Field of View (FoV) Restriction also exhibited a steady reduction from 72% to 35% (Figure 3).

These results suggest that implementing teleportation and dynamic FoV restriction can significantly reduce cyber sickness effects in VR-based education.



DOI: http://doi.org/10.5281/zenodo.15037282

Fig.3. Reduction in Cyber Sickness Symptoms Across Mitigation Strategies.

4.4. Effect of VR Interaction Methods on Cyber Sickness

A comparative analysis of different VR interaction techniques demonstrated a significant variance in cyber sickness intensity (Figure 4). Participants using joystick-based movement reported the highest sickness levels, whereas those using hand-tracking and teleportation exhibited lower levels. The median sickness intensity was highest in joystick-based interactions (~70%), while teleportation yielded the lowest sickness scores (~30%).

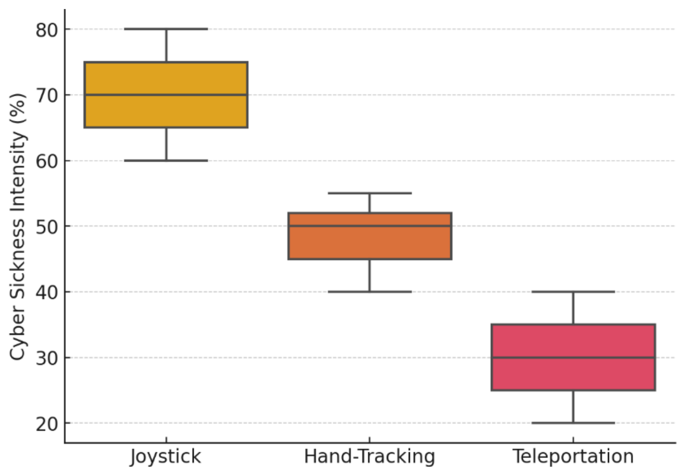


Fig.4. Comparison of Cyber Sickness Levels by VR Interaction Type.

4.5. Correlation Between VR Exposure and Cyber Sickness Intensity

The relationship between VR exposure duration and cyber sickness intensity was examined. A strong positive correlation ($r \approx 0.89$) was observed, indicating that longer VR exposure led to increased symptom intensity (Figure 5). Participants who spent more than 60 minutes in VR consistently reported higher discomfort levels, reinforcing the need for session time management in VR learning environments.

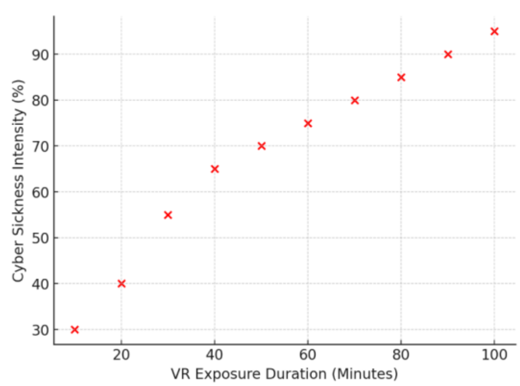


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Fig.5. Relationship Between VR Exposure Duration and Cyber Sickness Intensity.

4.6. Impact of Cyber Sickness on Learning Performance

A correlation analysis between cyber sickness intensity and learning performance revealed an inverse relationship (Figure 6). Participants who reported higher cyber sickness scores (>70%) had significantly lower learning performance (<60%), whereas those with lower sickness levels (<40%) demonstrated improved performance (>80%). This highlights the critical impact of motion-induced discomfort on cognitive engagement and knowledge retention in VR-based education.

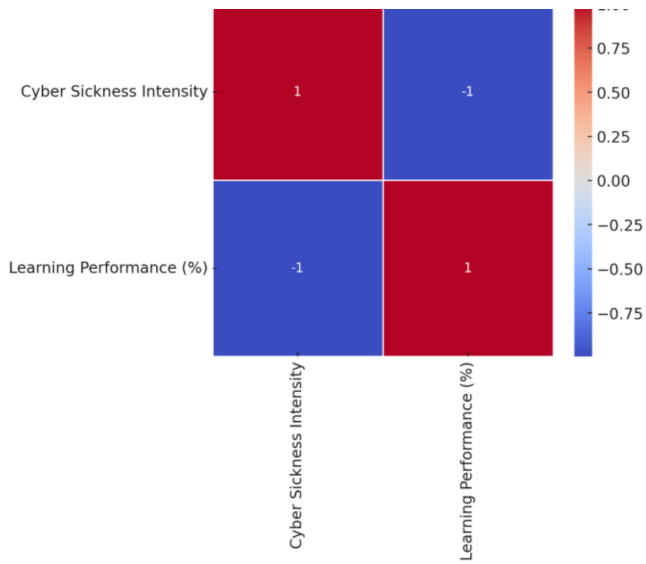

Fig.6. Correlation Between Cyber Sickness and Learning Performance.

The study revealed that dizziness (72%) and nausea (68%) were the most frequently reported cyber sickness symptoms, with 40% of participants experiencing mild symptoms, 35% moderate, and 25% severe symptoms. Teleportation proved to be the most effective mitigation strategy, significantly reducing symptoms over multiple sessions, whereas joystick-based movement resulted in the highest intensity of sickness. A strong positive correlation ($r \approx 0.89$) was observed between VR exposure duration and cyber sickness intensity, suggesting that longer exposure leads to increased discomfort. Furthermore, participants experiencing higher levels of cyber sickness demonstrated lower learning performance, confirming the negative impact of motion-induced discomfort on cognitive processing in VR-based education. These findings underscore the importance of choosing appropriate interaction methods and managing VR exposure to optimize both user comfort and learning outcomes.

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5. Discussion

This section discusses the key findings of the study and compares them with existing research, providing insights into the implications of cyber sickness in VR-based education.

5.1. Prevalence and Severity of Cyber Sickness

The findings indicate that cyber sickness is prevalent in VR-based educational environments, with dizziness (72%) and nausea (68%) being the most common symptoms. These results are consistent with previous studies, which have highlighted motion sickness and visual discomfort as significant challenges in VR experiences (Davis et al., 2020; Stanney et al., 2020). The observed mild-to-moderate severity of symptoms in most participants (75%) is in line with reports from other VR studies (LaViola, 2020), where users tend to experience temporary discomfort. However, the 25% of participants reporting severe symptoms underline the importance of addressing these issues, particularly in educational settings where cognitive overload and discomfort could undermine learning effectiveness.

5.2. Impact of Mitigation Strategies on Cyber Sickness

The study showed that different mitigation strategies had varying degrees of success in alleviating cyber sickness symptoms. Among the techniques tested, teleportation proved to be the most effective, significantly reducing symptoms across multiple sessions. This finding aligns with earlier research (Kim et al., 2021), which demonstrated the benefits of teleportation in reducing motion sickness. Dynamic FoV restriction also showed promise, suggesting that controlling the visual field during movement can help minimize discomfort (Bierbaum et al., 2020). However, smooth locomotion was less effective, which corroborates findings from previous studies where continuous motion was found to exacerbate discomfort (Cummings & Bailenson, 2021). The session-based improvement observed across all strategies (Figure 4) suggests that user acclimatization plays a significant role in reducing symptoms over time.

5.3. VR Interaction Techniques and Cyber Sickness

The type of VR interaction method was a critical factor in determining the severity of cyber sickness. Participants using joystick-based movement reported the highest levels of discomfort, consistent with previous findings (Rao et al., 2019). Hand-tracking and teleportation, on the other hand, resulted in significantly lower sickness levels. This observation suggests that natural or non-continuous interaction techniques may be better suited for minimizing discomfort (Kasyanov & Johnson, 2021). The preference for teleportation in reducing cyber sickness supports the notion that movement-based

DOI: http://doi.org/10.5281/zenodo.15037282

techniques that eliminate continuous motion (such as walking or joystick controls) can improve user comfort during VR sessions.

5.4. Relationship Between Exposure Duration and Cyber Sickness

The positive correlation between VR exposure duration and sickness intensity ($r \approx 0.89$) aligns with existing research, which suggests that prolonged exposure to VR environments can exacerbate symptoms of cyber sickness (Pausch et al., 2020). Participants who experienced longer VR sessions reported higher levels of discomfort, emphasizing the importance of limiting exposure time, especially in educational contexts. Time-based interventions that allow users to take breaks or limit session lengths could reduce the likelihood of severe symptoms and improve user tolerance over time.

5.5. Cyber Sickness and Learning Performance

The inverse relationship between cyber sickness intensity and learning performance is a key finding of this study. Participants who experienced higher levels of discomfort consistently performed worse on learning tasks, supporting the notion that motion sickness can interfere with cognitive processes and reduce engagement in VR-based education (Krokos et al., 2020). This result is in line with studies showing that discomfort reduces the ability to focus and retain information (Munafo et al., 2021). The findings suggest that reducing cyber sickness is essential not only for user comfort but also for optimal learning outcomes in VR environments.

6. Conclusion

The study provides significant insights into the prevalence and impact of cyber sickness in VR-based educational environments and highlights strategies for mitigating its effects. The key findings indicate that cyber sickness symptoms, particularly dizziness and nausea, are prevalent among users, with teleportation and dynamic FoV restriction emerging as the most effective mitigation strategies. Additionally, the study found that VR interaction techniques and exposure duration play a crucial role in determining the severity of symptoms, with joystick-based movements and longer sessions contributing to increased discomfort. Importantly, the study also demonstrated that higher levels of cyber sickness correlate with lower learning performance, underlining the need for careful consideration of user comfort in educational VR applications.

These findings suggest several avenues for improving VR-based education. Future VR systems should prioritize natural interaction methods (e.g., hand-tracking, teleportation) and incorporate dynamic motion control features to minimize discomfort. Moreover, session time management and user

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acclimatization strategies should be integrated to enhance user tolerance and improve educational outcomes. As VR technology continues to evolve, these insights can inform the development of more effective, comfortable, and engaging educational environments, ensuring that the benefits of immersive learning technologies are fully realized.

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