REPORT 10

Speculative Design of Cybersickness and the Challenges of System Conflicts

[ANONYMIZED REPORT – NO IDENTIFYING INFORMATION]

Abstract

Immersive technologies have brought innovative possibilities to various fields such as entertainment, sports, education, health, training, and rehabilitation. However, despite the growing popularity and feasibility of these technologies, due to their ability to create a greater sense of presence, a significant challenge remains in the widespread adoption of virtual reality: simulation sickness or cybersickness. This phenomenon causes symptoms such as nausea, dizziness, and fatigue, stemming from factors such as sensory discrepancies between real and virtual movements, latency, graphic quality, and individual susceptibility. This article aims to provide an overview of the utopian or not-so-utopian possibilities that the future may hold regarding the mitigation of cybersickness, through speculative design. By reviewing current literature, exploring its causes, and identifying current methods to mitigate its adverse effects through advances in hardware, software, and usability settings, aiming for a more comfortable and positive virtual experience.

1. Introduction

The emergence of immersive technologies, such as virtual reality headsets, promised major advances in practices across several areas of knowledge, such as education, training, health, communication, tourism, and entertainment [Lindal et al. 2018]. However, high cost presented itself as an obstacle to wider dissemination and application of these possibilities. Over the years, this technology has become more accessible, both in terms of production and commerce, increasing the consumption of virtual reality products [Wu et al. 2021]. With market expansion, another challenge overlapped the safe personal and commercial expansion of virtual reality systems: simulation sickness.

Classified as a subcategory of kinetosis or motion sickness, Simulation Sickness is characterized by a set of symptoms experienced by users during or after exposure to immersion in virtual reality. The symptoms described in the literature are the same as those associated with motion sickness caused by stimuli in the real world, such as nausea, disorientation, fatigue, and vomiting [Porcino et al. 2021]. The causes of simulation sickness are uncertain, but recent research points to conflict among human sensory systems as the main factor [Porcino et al. 2021, Jin et al. 2018].

Many who experience this discomfort abandon the experience prematurely and tend to avoid contact with virtual reality technologies in the future [Wu et al. 2021]. Therefore, important concerns arise regarding accessibility and usability issues capable of mitigating symptoms and their causes, and overcoming the challenges that simulation sickness reveals, so that immersive technologies can continue to be increasingly used in daily life.

This article presents a state of the art that seeks to gather the concepts studied so far regarding the causes and symptoms of simulation sickness, in the context of the use of virtual reality headsets, and from this point, freely speculate on possibilities for technological development and solutions for the future. The article is organized as follows: Section 2 presents the fundamental concepts used throughout the text; Section 3 identifies an overview of how current literature understands the issue; Section 4 presents future possibilities; and Section 5 presents a brief discussion and conclusion of the topics addressed.

2. Fundamental Concepts

For better understanding of the terms discussed in this article, this section addresses the definition of some important concepts for the research area on simulation sickness.

2.1. Virtual Reality

More commonly known by its English term *Virtual Reality*, frequently referred to simply as VR, virtual reality consists of interactive graphics software and hardware systems that create simulated virtual environments, which may be immersive or non-immersive [Lindal et al. 2018].

In non-immersive or desktop virtual reality, users navigate externally or exocentrically in relation to the virtual environment, interacting with it through traditional devices such as monitor, keyboard, and mouse.

Immersive virtual reality provides the user with egocentric navigation within the environment that simulates sensations analogous to those experienced in the real world and can be achieved through multiple screens, projectors, or sets of visualization devices with motion tracking and audio and video displays, such as VR headsets, for example [Wu and Tu 2023].

2.2. Virtual Reality Games

Digital games are interactive experiences accessed through electronic devices and systems such as consoles, computers, and mobile phones [Salen Tekinbas and Zimmerman 2003]. Although primarily directed toward entertainment, games have been present in increasingly diverse areas, such as education and communication, workplace training, physical and psychological rehabilitation, and palliative treatments in health [Lindal et al. 2018, Wu et al. 2021].

Games in immersive virtual reality consist of the implementation of digital game principles adapted to function within simulated virtual environments, providing users with an even greater sense of presence and interactivity [Rosa et al. 2016, Cmentowski et al. 2019, Gonçalves et al. 2020, Maneuvrier et al. 2022]. Generally operating through a VR headset, locomotion mechanics, motion tracking, and audio and video display allow the player to be fully transported into the game environment, experiencing either an exocentric experience, where vision detaches from the character or environment and observes it externally [Cmentowski et al. 2019], or an egocentric one, where the user places themselves as the element with which they are interacting, with a first-person perspective [Kraus 2020].

2.3. Kinetosis and Cybersickness

Kinetosis, also known as motion sickness, is a condition of physiological response of the body when there is a conflict among human sensory systems.

The International Classification of Diseases (ICD), established by the World Health Organization to standardize and catalog diseases and health-related problems, recognized kinetosis as a disease caused by movement under ICD-10 T75.3 [ICD 2019].

The incongruence between stimuli perceived by the visual system (eyes), the proprioceptive system (muscles and joints), and the vestibular system (a set of organs located in the inner ear responsible for bodily balance) is theorized as the main cause of kinetosis [Lindal et al. 2018]. When the movement seen by the eyes, the movement felt by the muscles, and the movement perceived by the vestibular apparatus are incompatible with each other, a conflict occurs among stimuli received by the nervous system, producing a reactive response with main symptoms such as nausea, dizziness, vomiting, headache, pallor, sweating, palpitations, prostration, and malaise [Jin et al. 2018].

The adverse effects of kinetosis are well known in contexts of transportation, such as automobiles and vessels [Porcino et al. 2021]. However, the understanding that virtual environments, such as those produced for virtual reality headsets, can also cause discomfort is still not widespread.

Within virtual environments, this condition receives the subcategory called Simulation Sickness, which is divided into two classifications: VIMS (Visual Induced Motion Sickness), which is motion sickness induced by images, and Cybersickness when generated in immersive virtual reality contexts, the latter being the central theme of this article [Porcino et al. 2021].

2.4. Usability

Usability is a construct that refers to the ease with which people can use a tool or interface to perform a specific task efficiently, effectively, and satisfactorily. According to one of the main usability specialists, Jakob Nielsen, usability is defined by the following components: learnability, efficiency of use, memorability, error rate, and user satisfaction [Nielsen 1994].

Learnability refers to how easy it is for users to perform basic tasks the first time they encounter the design. Efficiency of use concerns how quickly users can perform tasks once they have learned to use the tool. Memorability refers to how easily proficiency can be reestablished when returning to the design after a period of non-use. Error rate concerns how many errors users make, how severe they are, and how easily they can recover from them. Finally, satisfaction refers to how pleasant it is to use the design.

Within the use of VR headsets, an important usability component to consider is user satisfaction: how pleasant the immersive experience is and how comfortable the equipment used to achieve immersion is [Wang et al. 2024, Bedard et al. 2024].

3. State of the Art

This section presents an overview divided into subsections addressing signs and symptoms, possible causes, and mitigation methods.

3.1. Main Signs and Symptoms

The objective of this section is to understand how Simulation Sickness manifests in users and what its adverse effects are, in order to understand what should be offered in terms of accessibility and usability in games or simulations using virtual reality headsets that mitigate cybersickness symptoms.

Kennedy developed a classification method and questionnaire that divides the main signs and symptoms into three categories: Nausea, Oculomotor, and Disorientation [Robert S. Kennedy and Lilienthal 1993]. These categories form the basis of the Simulator Sickness Questionnaire (SSQ), widely used by several studies to measure levels of cybersickness experienced by research participants.

Each category encompasses corresponding signs and symptoms. The nausea group is composed of seven symptoms associated with stomach discomfort sensations, such as increased salivation, burping, nausea, and vomiting. The oculomotor group consists of seven symptoms related to eye fatigue and difficulty focusing. Finally, the disorientation group includes seven symptoms related to dizziness and vertigo. The three categories can occur simultaneously and overlap [Szpak et al. 2019].

However, in addition to Kennedy's general classification, it is also interesting to highlight non-categorized symptoms, such as headache, difficulty with motor coordination, sweating, and pallor [Jin et al. 2018, Cmentowski et al. 2019].

3.2. Possible Causes

To date, the literature does not offer a theoretical basis indicating a single reason for the manifestation of Cybersickness. Current understanding theorizes that the main cause of nausea arises from an incongruence between virtual reality systems and the user's sensory systems [Lindal et al. 2018].

These discrepancies occur when movements perceived in the virtual environment do not correspond to real body movements, causing sensory conflicts that lead to nausea and dizziness. Latency, or delay between user movement and corresponding response in the virtual environment, exacerbates these symptoms.

Postural instability, response delays during the virtual experience (VE lagging), rapid and unexpected optical movements, low-quality graphics or inconsistent frame rates, and a series of factors related to hardware, software, and individual user susceptibility also increase the likelihood of simulation sickness [Beadle 2019].

Aspects of predisposition or susceptibility to cybersickness are discussed in terms of factors such as age, sex, and experience with VR. However, some articles show controversy in discussions of individual predisposition. The results of the cited study were not affected by age, education level, or gaming experience of participants [Rebenitsch and Owen 2014].

3.3. Smoothing Mechanisms

The process of smoothing simulation sickness in virtual reality environments can be significantly improved through a "familiarization process." This process involves exposing users to short sessions, allowing them, over time, to become accustomed to the virtual environment and develop resistance to prolonged use effects [Szpak et al. 2019, Kraus 2020].

During these initial sessions, it is essential that users—especially those with limited computer skills, no gaming experience, or accustomed to different types of game controls—have the opportunity to familiarize themselves with the interface and controls of the applied virtual reality system [Rosa et al. 2016]. This adaptation period can significantly reduce kinetosis symptoms and decrease dropout rates and treatment failures.

Other strategies can be employed to reduce symptom emergence, such as behavioral and cognitive methods, pharmacological and dietary methods, as well as adjustments to environmental factors. For example, reducing the field of view in the virtual environment can reduce sensory discrepancy contributing to discomfort [Beadle 2019, Groth et al. 2022, Wu et al. 2021]. Additionally, it is important to avoid games or applications that previously caused discomfort and identify specific computer system factors that may be exacerbating symptoms [Schuhbauer et al. 2019].

By combining these strategies, users can have a more comfortable and positive virtual reality experience, maximizing the benefits of this technology.

3.4. Challenges

The main challenges of simulation sickness in virtual environments include discovering how to best handle sensory discrepancies, latency, graphic quality, and individual susceptibility, understanding their factors in depth. Effective mitigation methods, such as short exposure sessions and field-of-view reduction, are necessary and can prevent symptom emergence; however, implementing these strategies efficiently for all users is challenging [Rosa et al. 2016, Stoffregen et al. 2017].

Little is objectively addressed regarding the relationship between simulation sickness and the games and simulations market. However, some studies indicate a greater probability of rejection and abandonment of immersive technologies by users who suffer from cybersickness, negatively impacting future use of virtual reality systems [Teixeira et al. 2022, Wu et al. 2021].

To face these challenges, it is essential to combine technological advances with human behavior research and collect continuous user feedback to create more comfortable and accessible virtual reality experiences.

4. Speculative Design

The methodology chosen for speculative design in this article was Speculative Design and the Cone of Possibilities. The practice of speculation began based on three fundamental questions that became the subcategories of this topic: the first question "Where are we?" guided by the state-of-the-art mapping conducted in the previous stage; the second question "Where are we going?" which indicates the plausible and probable future according to the cone; and finally, the last question "Where do we want to go?" which offers interventions focused on leading toward the preferable, desired future.

Mapping and understanding speculative design regarding a theme helps us think systematically about it, gain a clearer view of all possibilities—ideal or not—toward which the theme is heading, thus expanding the intervention capacity of professionals, researchers, and developers involved.

4.1. Where Are We?

The research seeks to better understand the nature of cybersickness through the state of the art and thereby identify effective strategies to reduce its impacts, providing a more pleasant and safe experience for users. Thus, two distinct strands emerge in organizing the speculative process. The first strand refers to the relationship between user and technology, investigating how technology presents itself and interacts with the user. The second strand examines market trends regarding the use of technological resources to improve user immersion.

4.1.1. Investigated Theme

The main theme of this research is to investigate how the literature addresses the occurrence of cybersickness and how to develop actions that mitigate its negative side effects affecting the final user’s sense of presence. At the same time, it seeks to explore how cybersickness manifests in users, considering its signs and symptoms as a crucial element to identify measures that can limit or even completely eliminate its occurrence.

More immersive devices, such as Virtual Reality Headsets, tend to aggravate cybersickness occurrence, which within motion sickness classification falls into the simulation sickness subcategory. Therefore, it is important to highlight that this discomfort is not exclusive to immersive content, also occurring in non-immersive virtual environments, such as through a computer screen.

In this study, we limit analysis to cybersickness classification exclusive to immersive virtual reality systems. This choice is justified by the fact that games are increasingly interactive, with the popularization of VR headsets and content using this type of technology, inside and outside the entertainment field.

Thus, this study not only seeks to contribute to the advancement of academic knowledge about cybersickness but also aims to offer practical ideas for application and development for the gaming industry, helping shape the future of digital entertainment in a way that maximizes pleasure and user safety.

4.1.2. Social Interrelations

Regarding the relationship between the immersive virtual reality industry and users, highlighting the role of constant technological advancement in ensuring greater user retention on platforms, two main ways of realizing this immersion can be identified: the use of Virtual Reality Headsets, which currently provide the best total immersion experience by placing the user directly in the virtual environment; and the use of projection techniques that transform reality into a playful virtual world, especially by shifting adaptation from the person entering virtual reality to the virtual world appropriating reality to mimic first-person vision, increasing the sense of being inside the simulation.

These technologies have been fundamental in improving user experience, making games more attractive and interactive. The immersive virtual reality industry continuously invests in these innovations to maintain and increase its user base, offering increasingly realistic and engaging experiences, whether in exhibitions, entertainment games, sports, education, health, training, or rehabilitation activities.

In the commercial axis, from the companies' perspective, especially in entertainment, it is possible to verify a search to maximize user time spent in the virtual environment. From this longer permanence, the industry expects to increase internal consumption opportunities, through consumables and in-game content, increasing revenue from offered content. In training contexts, the expectation is that users can remain in simulation throughout the entire exercise and learning period.

However, with interference from simulation sickness or cybersickness, the ability to remain in simulations is reduced and often forcibly interrupted due to symptom onset such as nausea, disorientation, visual fatigue, and other oculomotor dysfunctions. For this technology to be used more coherently and meaningfully, more durable and effective solutions must be found for the discomfort experienced by users.

Returning to the market context, it is interesting to highlight that game companies seek to create closer relationships with users through development of physical apparatus interacting with the virtual environment, such as customized controllers with tactile, heat, and cold sensations, extra batteries for longer product use, among others. This strategy aims not only to improve user immersion experience but also to drive the secondary market of related services and products, becoming an additional revenue source.

This scenario raises important questions about the balance between technological innovation and user well-being, as many accessories are produced merely to attract consumers without offering real benefits, especially for those suffering from sickness. Although the gaming industry continually seeks ways to increase immersion and player retention, it is crucial to consider potential negative impacts such as cybersickness. Research into strategies to mitigate these adverse effects thus becomes essential to ensure that technological advancement does not compromise user health and positive experience.

4.1.3. Signals and Trends

The mapping of signals and trends uses the innovation map tool, which proves to be a powerful instrument to identify how technology may be envisioned in the future. This methodology allows projecting different scenarios and anticipating positive or negative changes and, mainly, technological innovations, providing a structured and strategic view of development and adoption of new technologies.

By applying the cone of the future, it is possible to identify emerging trends and potential disruptions, as well as evaluate their implications for the gaming industry and users. Thus, the tool not only assists in understanding the current panorama but also in planning actions and strategies to leverage future opportunities and mitigate possible challenges.

The first observed trend lies in the evolution of immersion techniques in simulations. It is estimated that these techniques will move toward even greater immersion, using not only Virtual Reality Headsets but also other physical devices that favor communication between humans (users) and computers (games). Examples include treadmills that allow players to "walk without leaving the place," chairs that mimic in-game movements, and similar devices, addressing one of the main problems of locomotion, which results in inconsistency between movement perceived by user sensory systems and information sent by the virtual system.

These advances have the potential to completely transform the experience, making it more engaging and realistic. Integration of multiple immersive devices creates an environment where physical and visual sensations are amplified, going beyond simple visualization. By exploring new forms of interaction and physical feedback, the gaming industry can offer more dynamic and captivating experiences, promoting a greater sense of presence, engagement, and user satisfaction.

The final trend identified is the maximum exploitation of field of view, attention, and user interaction. Developers seek to identify maximum limits to explore these elements, aiming to offer the greatest possible amount of information and stimuli, as well as using design techniques that direct player attention to key elements within the simulation, such as strategic lighting, directional sound, and intuitive interfaces, enabling engagement maintenance. According to trends, the greater the interactivity, the greater the attention and involvement. This includes implementation of advanced artificial intelligence that can adapt the product to player behavior and integration of haptic feedback, providing tactile sensation of actions performed during immersion.

4.2. Where Are We Going?

Considering advances perceived in the area, it is estimated that the future five years from now will be appropriate for verifying integration between human and computer contexts, along with their consequences.

4.2.1. Mapping the Probable Future Scenario

The probable future, derived from positive and negative trends of the theme, can be substantiated in the following panorama: the use of multiple physical devices that mimic sensations perceived during immersion, making the user more than a simple character and elevating them to a position of absolute protagonism in the experience. It is estimated that, in this probable future, players will use clothing, helmets, headsets, controllers, and "islands" that allow real-world movements to be translated into the digital world.

Immersion perception will be directly linked to companies' enhanced ability to develop simulations highly connected to user sensations, applying sensations previously limited to virtual environments. This technological advancement will allow deeper integration between player and game, where every real-world movement and action is immediately reflected in the virtual world, creating a more realistic and engaging experience.

Users equipped with devices such as sensory clothing, VR helmets, and motion platforms will be able to experience virtual reality in ways previously unimaginable. These technological innovations not only increase immersion but also enhance interactivity, allowing players to move, touch, and feel the environment in a much more tangible way.

However, observing negative trends, it is estimated that players will become even more contested targets for the gaming industry, conjecturing that they will be bombarded with advertisements, promotions, and advertising intended to increase profit. A dangerous balance between advertisement distribution and retention of player attention and immersion is projected, with this limit tending to favor companies, exposing more advertising content at the expense of player comfort.

Furthermore, focusing on the studied theme, it is estimated that players will be subjected to a plurality of stimuli, both visual and sensory, which may result in neurological overload, causing harm to player health. Currently, few studies focus on these effects, especially in the medium and long term. Maintaining such behavior in the probable future, it is possible to predict that players may suffer medical complications due to prolonged exposure to these stimuli.

This overload of stimuli may lead to a series of health problems, such as visual fatigue, headaches, sleep disorders, and, in extreme cases, adverse psychological effects such as anxiety and stress. The lack of comprehensive studies on these impacts makes the need for research and regulation even more urgent to protect users of immersive virtual realities.

4.2.2. Causality Relationships

In cause-and-effect terms, the focus on cybersickness occurrence lies in stimuli caused by virtual reality in simulation and gaming environments. Its occurrence mainly arises from incompatibility between user physical perception and visual and sensory stimuli to which they are subjected.

Immersive virtual reality games and simulations can lead to a mismatch between what the player sees and physically feels. When visual and sensory stimuli are not perfectly aligned with body perception, the brain may interpret these discrepancies as a sign that something is wrong, possibly even poisoning, resulting in simulation sickness.

This incompatibility may occur due to several factors, such as delays in image updating, inconsistent movements between player and virtual environment, or presence of graphics that do not correspond to real player movements. Such discrepancies can cause nausea, dizziness, and other associated symptoms, negatively affecting user experience.

Cybersickness is theorized to be directly proportional to stimuli offered to the player. Thus, the greater the pursuit of immersion in games (positive trend of the probable future), the greater the probability of simulation sickness occurrence (negative trend of the probable future). Although it cannot be stated that both move in parallel—especially due to the possibility of achieving desired immersion without significant changes in user perception—it is important to highlight that in the probable future, immersion will be achieved through complementary tools. This includes intensification of 3D components and use of physical devices to complete player sensation.

However, it is essential to consider that increased immersion may increase cybersickness incidence, requiring careful balance between stimulus offering and player capacity to process them without discomfort. Research and development of technologies mitigating side effects of use are fundamental to ensure immersive gaming experience is pleasant and safe for all users.

Therefore, while the gaming industry advances toward deeper and more realistic immersion, it must also focus on solutions that minimize associated risks, ensuring increased immersion does not compromise user health and well-being.

4.3. Where Do We Want to Go?

Solutions can work together to provide a more balanced and comfortable gaming experience, ensuring pursuit of immersion does not compromise player health and well-being. With advancement of these technologies, the gaming industry can continue offering innovative and engaging experiences while protecting users from adverse effects of cybersickness. In this section, we discuss some ideal possibilities, still limited at present, to be explored in the future.

4.3.1. IT Solutions

It is estimated that two IT solutions could be developed to mitigate cybersickness symptoms in immersive simulations and games:

1. **Identification of the Balance Point Between Visual and Sensory Stimuli and Player Comfort**
   The first solution consists of identifying the balance point between visual and sensory stimuli and player comfort. In this case, immersion and player attention are not the most relevant observation points, as the entire system should be oriented toward player comfort rather than immersion alone. This can be achieved through continuous monitoring of player physiological responses, such as heart rate, eye movements, and other discomfort indicators, dynamically adjusting stimuli to maintain a comfortable and engaging experience.
2. **Implementation of Real-Time Adaptive Feedback**
   The second solution involves implementing real-time adaptive feedback systems that adjust gameplay experience based on player response. These systems could use machine learning algorithms to analyze physiological and behavioral data, automatically adapting visual, auditory, and tactile stimuli to minimize discomfort. For example, if the system detects early signs of cybersickness, it may smooth camera movements, adjust frame rate, or reduce intensity of sensory stimuli.

This is currently the main bet of studies regarding artificial intelligence, deep learning, virtual, mixed, and augmented reality, and cybersickness.

4.3.2. Other Actions

Another action that can be developed to improve immersion quality and mitigate simulation sickness occurrence is development of **Physical Tools That Provide Adequate Immersion.** This solution lies in creating physical tools that provide adequate player immersion in the system, not merely superficial immersion. Adequate immersion may help mitigate negative symptoms, as the player's entire organism would receive the same visuo-sensory information rather than isolated stimuli.

Devices such as sensory clothing, motion platforms synchronizing player movements with the virtual environment, and dynamic chairs replicating in-game motion sensations can create a more harmonious experience and reduce cybersickness incidence.

However, this is an expensive solution, both for developers and end consumers. Therefore, the IT solution of software adjustment tends to be more popular and practical to apply in the coming years.

5. Conclusion

Current literature indicates that simulation sickness or cybersickness, characterized by symptoms such as nausea, dizziness, and disorientation, is likely an adverse reaction resulting from sensory conflict among visual, vestibular, and proprioceptive systems, where discrepant information received by the brain generates discomfort and malaise during virtual reality immersions, especially through VR headset use.

Additionally, analysis of different studies reveals that intensity and susceptibility to cybersickness vary significantly among individuals, influenced by factors such as age, gender, prior experience with VR or computer games, and individual susceptibility to motion sickness. Configuration of VR content, such as latency, frames per second, field of view, and graphic quality, also plays a crucial role in mitigating or intensifying cybersickness symptoms.

The objective of this research is to understand what improvements can be offered in terms of hardware and software through speculative thinking that smooth cybersickness symptoms.

To face these challenges, two main IT solutions are proposed: identification of balance between visual and sensory stimuli and player comfort, and implementation of real-time adaptive feedback. These solutions aim to dynamically adjust stimuli based on player physiological responses, providing a more comfortable experience and minimizing adverse effects of cybersickness.

The relationship between cybersickness and system conflicts highlights the complexity and relevance of the theme for development and safe use of virtual reality technologies. Thus, we emphasize the need for continuous research to develop more effective prevention and treatment methods for cybersickness, through strategies that reduce negative impact of VR in a personalized way, focusing on usability, considering user characteristics and technical aspects of VR applications, including technological advances to improve precision of motion tracking systems.

In summary, speculative design offers a valuable approach to anticipate future scenarios and plan strategies that promote responsible technological evolution. Through a structured and strategic view, it is possible not only to improve user experience but also to ensure that player health and well-being are not compromised. Continuous advancement of research and technology, combined with deep understanding of human behavior, is essential to create increasingly accessible and comfortable virtual environments for all.

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