

VR Motion Sickness: Causal Mechanism and Prevention Based on Visual Generation Principle

Anan Yang

*Faculty of Science and Technology, Beijing Normal-Hong Kong Baptist University, Zhuhai, China
1125568980@qq.com*

Abstract. Virtual Reality (VR) motion sickness is a physiological discomfort that users experience when using virtual reality devices, and it is one of the main reasons that limit the development and application scenarios of virtual reality technology. To enhance user experience and broaden the application prospects of VR technology, it is crucial to study the causes and preventive measures of motion sickness. This article primarily examines the causes and manifestations of VR motion sickness by integrating the visual generation principle of VR. Understand subjective assessment indicators such as Simulator Sickness Questionnaire (SSQ) and Vestibular Function Measurement (FMS), as well as objective indicators, and discuss the relief methods of related symptoms from multiple aspects including technical optimization, content design, and user adaptation. Future research can further integrate physiological signal monitoring and behavioral data analysis to build a more comprehensive assessment and intervention system for motion sickness, thereby promoting the wider application of virtual reality technology in fields such as education, healthcare, and entertainment.

Keywords: VR Motion Sickness, SSQ, FMS

1. Introduction

As an emerging human-computer interaction technology, Virtual Reality(VR) technology can provide users with immersive interaction experiences by simulating senses. It has huge application potential in various fields such as training, education, healthcare, and the military. With the development of VR technology, the experience of VR devices has gradually upgraded, supporting the all-round construction of virtual worlds through senses such as vision, hearing and touch, bringing users an unprecedented experience.

However, VR technology has not been widely applied, as users may experience physiological discomfort when using VR devices, mainly dizziness, headache, nausea, and eye fatigue—with an underlying complex mechanism. This phenomenon is called VR motion sickness. Research shows that VR motion sickness not only affects users' comfort and experience, raises people's concerns about whether VR technology will be harmful to human health. Additionally, it restricts the promotion of VR in long-term application scenarios, such as education and healthcare. For instance, in an educational environment, excessive discomfort may impair students' concentration and

learning efficiency. In surgical simulation training, the trainees' operations may be affected, resulting in the inability to simulate real surgical scenarios.

Therefore, accurately understanding the mechanism of VR motion sickness, establishing scientific assessment methods, and proposing effective mitigation strategies have become an important research topics in the field of virtual reality. This essay will systematically review the current research status, cause mechanisms, assessment methods and intervention measures of VR motion sickness based on the visual generation principle of virtual reality, providing a reference for subsequent academic exploration and application practice.

2. The causes and mechanisms of VR motion sickness

2.1. Sensory conflict theory

Currently, there are three mainstream theories explaining the causes of motion sickness: sensory conflict theory, posture instability theory, and individual differences and psychological factors. Among the three causes, the sensory conflict theory is the most classic theoretical model. When users use a fixed base simulator, the motion signals transmitted by the visual system are inconsistent with the information transmitted by the vestibular system or proprioception, causing confusion in the brain and triggering an uncomfortable response. For instance, in a VR scenario, when a user performs "virtual movement" through a controller, visual feedback indicates that the body is accelerating. However, vestibular system of the inner ear fails to detect the corresponding movement signal, thereby causing symptoms such as nausea and dizziness. Research shows that both rendering delay and overly rapid picture rotation can significantly exacerbate this conflict [1].

2.2. Posture instability theory

Another explanation for the mechanism of motion sickness is the posture instability theory. This theory posits that the fundamental cause of motion sickness lies in the inability of users to maintain stable posture control when using VR devices [2]. During the VR visual generation process, slight delays in head tracking and image feedback can interfere with the body balance system, enabling users to continuously adjust their postures in the virtual environment. A prolonged state of unstable posture can cause physiological stress and fatigue, which in turn can trigger motion sickness symptoms. Compared with the sensory conflict theory, this theory places more emphasis on the significant role of "dynamic balance" in VR experiences.

2.3. Individual differences and psychological factors

In addition to the above two theories, individual differences such as gender and age are also important variables in the causes of motion sickness [3]. Some researchers used nausea and eye movement as indicators to assess the degree of motion sickness response in different genders [4]. The study found that compared to the male group, the female group had a higher probability of experiencing a motion sickness. Meanwhile, research has confirmed that as age increases, users' sensitivity to VR will decline that is, teenagers are more likely to be affected by motion sickness [5]. VR users with more extensive experience have also been shown to generally have stronger adaptability compared to those with short-term exposure to VR. Additionally, psychological factors can also affect the severity of motion sickness symptoms. Negative emotions such as anxiety and fear can greatly trigger motion sickness [6]. Moreover, if users have a psychological predisposition to feeling dizzy before using the product, their symptoms tend to be more severe.

3. The impact of VR visual generation on sickness

According to statistics, 75% to 80% of human perception of objective information comes from vision. Therefore, the visual channel is the most important interface for perception in VR systems. VR devices generate and present visual information by simulating the human visual system's working mode, creating a virtual environment that is remarkably close to reality. However, in this process, the technical features and limitations of the visual generation mechanism also pose hidden dangers for the occurrence of VR motion sickness. The following elaborates on aspects such as stereoscopic imaging, dynamic tracking, rendering delay and refresh rate, field of view and immersion.

3.1. Parallax imaging

Human vision relies on binocular parallax to create a sense of depth. VR headsets, however, present slightly different images for the left and right eyes, respectively, through the display screen, reconstructing a three-dimensional visual effect and thus creating an immersive spatial sense, such as constructing image size differences, and texture gradient differences, etc. However, this artificially created stereoscopic parallax does not always align with the vestibular system or body movements; that is, the parameters for obtaining stereoscopic images do not match the parameters perceived by the human eye [7]. For instance, when the movement direction or speed of objects in the virtual image does not match the actual perception of the body, it causes distortion in the perception of the virtual space, leading to a decrease in the visual comfort for the human eye. This can thereby induce VR motion sickness.

3.2. Field of View in virtual environments

The Field of View (FOV) determines the range that a user can see in a virtual environment. It is generally believed that in an ideal situation, immersion is proportional to the viewing angle, provided that the quality of visual perception is guaranteed. However, a careful balance is needed between "immersion" and "comfort" in visual generation. A larger FOV helps enhance the sense of presence, but it also amplifies the illusion of displacement and rotation, intensifying sensory conflicts, increasing visual load and the probability of motion sickness [8]. Research shows that the FOV is positively correlated with the impact of motion sickness, and moderately reducing the FOV can effectively alleviate motion sickness [9].

3.3. Rendering delay and refresh rate

Motion-to-Photon Latency, which is the total delay required from the occurrence of user actions to the update of the visual display, is a key parameter affecting the VR experience. Studies show that if the delay exceeds 20 milliseconds, users will perceive it as significantly unnatural and thus be more prone to motion sickness [10]. At the same time, an insufficient refresh rate (for example, below 60Hz) can cause the picture to be blurry or have trailing, further increasing the eye movement load. Therefore, mainstream VR devices often require a refresh rate of at least 90Hz to reduce the risk of motion sickness.

3.4. Head tracking and image update

The immersion of VR also relies on the precise tracking of head movements. Stand technologies include inertial measurement units (IMUs) and external positioning systems (such as optical tracking and Inside-out tracking). Ideally, the slightest rotation of the user's head should be fed back to the image update in real time within the millisecond level. Disabling head tracking will comprise the user experience and potentially cause motion sickness [11]. Additionally, if there is a delay or jitter during the tracking process, users may experience a temporal dislocation between vision and movement, leading to dizziness and discomfort.

3.5. Optical distortion and dynamic blurring

The lenses used in VR headsets inevitably introduce geometric distortion or dispersion distortion [12]. Although pre-correction is usually carried out during the rendering process, residual distortion may still cause additional load on the eyes. In addition, when users move quickly in a virtual environment, if there is not enough dynamic blur processing, the picture will appear stiff, thereby aggravating the motion sickness symptoms.

4. Measurement and evaluation of VR motion sickness

4.1. Subjective scale

Research on VR motion sickness most widely relies on subjective assessment methods. Among these, the most widely recognized is the Simulator Sickness Questionnaire (SSQ), developed by Kennedy et al. [13]. This Questionnaire consists of 16 items, covering three dimensions: nausea, eye fatigue and disorientation, and is scored either by computer or manually. It can comprehensively reflect the user's discomfort conditions. It has the advantages of simple operation and suitability for large-scale experiments, its limitations include a reliance on subjective feedback and potential susceptibility to psychological influences.

In contrast, the Fast Motion Sickness Scale (FMS) provides a method for recording the dynamic changes of motion sickness symptoms [14]. It employs a single-item scoring method, ranging from 0 to 20 points, which allows for real-time tracking of changes in user discomfort during the experiment. However, the precision is insufficient. It is difficult to distinguish different types of symptoms. Furthermore, some studies have also proposed the MSAQ (Motion Sickness Assessment Questionnaire) and VRSQ (Virtual Reality Sickness Questionnaire) as methods to conduct supplementary studies for specific scenarios, which are usually combined with the SSQ to enhance the comprehensiveness of the assessment [15-16].

4.2. Objective indicators

In addition, the objective assessment method, as an important supplement to the subjective assessment, mainly quantifies discomfort through physiological indicators (such as heart rate variability and eye movement) or behavioral indicators (such as head movement stability), which has the advantage of strong objectivity. However, it usually relies on professional equipment, has a relatively high cost, and its application scenarios are relatively limited.

5. Methods of alleviation and intervention

5.1. Technology optimize

To alleviate the discomfort caused by motion sickness and reduce users' resistance to VR experiences, some studies have proposed intervention strategies, which can be classified into three types: optimizing technology, improving design, and enhancing adaptability.

On the technical front, studies have shown that users are likely to feel uncomfortable when the motion-to-photon latency exceeds a certain large [17]. Therefore, by optimizing hardware and algorithms, improving system performance, and reducing latency, the probability of motion sickness can be effectively decreased. Additionally, increasing the refresh rate can significantly alleviate motion sickness symptoms by avoiding the extra load on the visual system caused by frame stuttering and trailing. At the same time, enhancing resolution and picture stability also helps to relieve discomfort caused by image distortion.

5.2. Content design improves

In terms of content design, developers have gradually recognized the importance of employing reasonable interaction methods and visual presentation to reduce motion sickness. Users are more prone to motion sickness when experiencing highly stimulating VR content, while content with minimal movement is less likely to cause it [3]. Therefore, adopting segmented displacement methods or reducing intense acceleration and rapid rotation actions can significantly lower the discomfort caused by sensory conflicts. Moreover, introducing a stable visual reference frame at the edge of the screen (such as the helmet boundary) provides users with a reference point, thereby reducing confusion and dizziness.

5.3. User adaptability enhance

Regarding user adaptability, encouraging users to gradually get accustomed to and trained with VR through short, low-intensity experiences can enhance the nervous system's tolerance. Additionally, some physical methods have been proven to alleviate symptoms, such as incorporating vibration feedback or other tactile or olfactory stimuli during use to provide consistent sensory input in conjunction with the visual experience.

6. Conclusion

This review mainly discusses the potential hazards of motion sickness in VR visual generation. Factors such as binocular stereoscopic imaging, head tracking delay, insufficient refresh rate, and optical distortion can all cause sensory conflicts, thereby leading to a range of physiological and psychological discomfort reactions. This review also integrates previous studies, discusses the current mainstream causes of motion sickness, introduces and compares assessment methods such as SSQ and FMS, and summarizes previous relief measures into three types. However, the current prevention and control methods still lack unified standards and personalized adaptation mechanisms, making it challenging to meet the diverse needs of various application scenarios. This merits further research and discussion. However, this article only analyzes and organizes some research results and does not yet contain specific experimental content. Further experimental research or application design will be conducted in the future.

References

- [1] Hettinger, L. J., Berbaum, K. S., Kennedy, R. S., Dunlap, W. P., & Nolan, M. D. (1990). Vection and simulator sickness. *Military psychology*, 2(3), 171-181.
- [2] Riccio, G. E., & Stoffregen, T. A. (1991). An ecological theory of motion sickness and postural instability. *Ecological psychology*, 3(3), 195-240.
- [3] Howard, M. C., & Van Zandt, E. C. (2021). A meta-analysis of the virtual reality problem: Unequal effects of virtual reality sickness across individual differences. *Virtual Reality*, 25(4), 1221-1246.
- [4] Gonçalves, G., Melo, M., & Bessa, M. (2018, November). Virtual reality games: A study about the level of interaction vs. narrative and the gender in presence and cybersickness. In *2018 international conference on graphics and interaction (ICGI)*(pp. 1-8). IEEE.
- [5] Paillard, A. C., Quarck, G., Paolino, F., Denise, P., Paolino, M., Golding, J. F., & Ghulyan-Bedikian, V. (2013). Motion sickness susceptibility in healthy subjects and vestibular patients: effects of gender, age and trait-anxiety. *Journal of Vestibular Research*, 23(4-5), 203-209.
- [6] A. Robertson, R. Khan, D. Fick, W. B. Robertson, D. R. Gunaratne, S. Yapa, V. Bowden, H. Hoffman, and R. Rajan, "The effect of virtual reality in reducing preoperative anxiety in patients prior to arthroscopic knee surgery: A randomised controlled trial," in *Proc. IEEE 5th Int. Conf. Serious Games Appl. Health (SeGAH)*, Apr. 2017, pp. 1–7.
- [7] Bo Y., , Xia Z., , Zhang B., Peng Z., , & Zhang Y., . (2024). Research on the Impact of Distortion in Stereoscopic Image Acquisition on Visual Induced Motion Sickness. *Laser & Optoelectronics Progress*, 61(4), 0409001.
- [8] Fernandes, A. S., and Feiner, S. K. (2016). "Combating VR sickness through subtle dynamic field-of-view modification," in *2016 IEEE Symposium on 3D User Interfaces (3DUI)* (Greenville, SC).
- [9] Lin, J. W., Duh, H. B. L., Parker, D. E., Abi-Rached, H., & Furness, T. A. (2002, March). Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment. In *Proceedings ieee virtual reality 2002* (pp. 164-171). IEEE.
- [10] Ryu, Y., & Ryu, E. S. (2021). Overview of Motion-to-Photon Latency Reduction for Mitigating VR Sickness. *KSII Transactions on Internet & Information Systems*, 15(7)
- [11] Wu, T. L. Y., Gomes, A., Fernandes, K., & Wang, D. (2018). The Effect of Head Tracking on the Degree of Presence in Virtual Reality. *International Journal of Human-Computer Interaction*, 35(17), 1569–1577.
- [12] Ortiz, S., Siedlecki, D., Grulkowski, I., Remon, L., Pascual, D., Wojtkowski, M., & Marcos, S. (2010). Optical distortion correction in optical coherence tomography for quantitative ocular anterior segment by three-dimensional imaging. *Optics express*, 18(3), 2782-2796.
- [13] Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology*, 3(3), 203-220.
- [14] Keshavarz, B., & Hecht, H. (2011). Validating an efficient method to quantify motion sickness. *Human factors*, 53(4), 415-426.
- [15] Gianaros, P. J., Muth, E. R., Mordkoff, J. T., Levine, M. E., & Stern, R. M. (2001). A questionnaire for the assessment of the multiple dimensions of motion sickness. *Aviation, space, and environmental medicine*, 72(2), 115-119.
- [16] Kim, H. K., Park, J., Choi, Y., & Choe, M. (2018). Virtual reality sickness questionnaire (VRSQ): Motion sickness measurement index in a virtual reality environment. *Applied ergonomics*, 69, 66-73.
- [17] Choi, S. W., Lee, S., Seo, M. W., & Kang, S. J. (2018). Time sequential motion-to-photon latency measurement system for virtual reality head-mounted displays. *Electronics*, 7(9), 171.