DOI
https://doi.org/10.18690/um.fov.2.2025.10

ISBN
978-961-286-963-2

Side Effects of Using Virtual Reality Tools and Their Measurement

Samantha Cossio,[1] Gaia Magro,[1] Sara Dentice,[1] Stefania Chiappinotto,[1] Alessandro Galazzi[2]

[1] University of Udine, Department of Medicine, Udine, Italy
cossio.samantha@spes.uniud.it, magro.gaia@spes.uniud.it, dentice.sara@spes.uniud.it, stefania.chiappinotto@uniud.it
[2] LUM University, Department of Medicine and Surgery, Bari, Italy
alessandro.galazzi@uniud.it

Virtual reality (VR) is becoming increasingly important in education, offering immersive learning experiences. However, head-mounted displays (HMDs) often cause side effects such as cybersickness and discomfort, which can affect learning outcomes. The study of side effects using validated tools is becoming increasingly important as it can influence the perceived quality of education. An overview of virtual reality and tools for measuring side effects can be a starting point for future research and suggests that the prevalence of VR sickness is still problematic and little is known about side effects, also making these issues a primary aim of future studies and considering not only students but also professionals involved in Virtual Reality Education.

Keywords:
full immersive virtual reality;
head-mounted displays;
cybersickness;
discomfort;
education

University of Maribor Press

1 Introduction

In recent years, Virtual Reality (VR) has played an increasingly important role in education, providing opportunities for learning through simulations that safely and effectively replicate real-world environments and situations. VR allows students and professionals to practice in highly immersive virtual environments; however, the use of immersive VR devices, such as head-mounted displays (HMDs), during or after VR immersion can cause certain side effects known as cybersickness (e.g., nausea, headache, dizziness, disorientation) or discomfort (e.g., thermal discomfort, weight discomfort), which can negatively affect the user experience. This review will provide a starting point for future research into virtual reality and adverse effects.

2 Virtual Reality in Education

VR is an advanced technology that allows users to immerse themselves in digitally simulated environments and interact in a multi-sensory way through devices such as headsets, hand controllers and sensors to simulate realistic experiences (Elmqaddem, 2019). In fully immersive VR, users are completely immersed in a virtual environment, creating a highly realistic and interactive experience. This technology relies on VR headsets, glasses, hand controllers and various sensor devices to closely simulate real-life situations. Immersive VR, as described by Freina and Ott (2015), aligns with the concept of HMD and motion tracking to achieve a sense of complete 'presence' in an artificial environment. This technology allows the user to engage and practice with realistic scenes and objects, creating a multi-sensory dynamic experience that evokes the feeling of being in a real environment, all within a virtual environment (Simón-Vicente et al., 2024).

VR for the consumer market is currently mostly used for gaming and entertainment (viewing 360 videos and live events), but the scope is very broad and suitable for use in industrial and business environments (Somrak et al., 2019). In the following years, numerous competitors entered the market and launched their own HMDs, making this innovative technology accessible to a wider audience, including for research and educational purposes (Jensen and Konradsen, 2018).

Their immersive nature is not always an advantage, and in some cases the immersive experience can even hinder learning, as it can distract from the task at hand (Jensen and Konradsen, 2018).

In educational contexts, the effectiveness of VR use has been extensively investigated, with several reviews supporting its use. However, these reviews have tended to focus either on the causes of cybersickness in different contexts (Chang, Kim, & Yoo, 2020; Saredakis et al., 2020; Caserman et al., 2021) or on the acceptability and feasibility of VR (Bazavan et al., 2021; Renganayagalu et al., 2021; Tang et al., 2022; Bicalho et al., 2023; Simón-Vicente et al., 2024). Although numerous studies reported cases of cybersickness and discomfort (Renganayagalu et al., 2021), these issues were often addressed as secondary outcomes. While HMDs have shown promise in many settings, they have been documented to produce worse cybersickness outcomes than traditional desktop displays (Yildirim, 2019). These symptoms can occur during or after HMD use and can impair user performance and force sensitive users to terminate VR use prematurely, even in controlled experimental settings (Mittelstaedt et al., 2018).

3 Side Effects Of Virtual Reality

Side effects of using virtual environments have been referred to by many terms, including simulator sickness (Kennedy et al., 1993), motion sickness (Kennedy et al., 2010), cybersickness (LaViola, 2000), and VR sickness (Kim et al., 2018).

The term simulator sickness originated from the early use of flight simulators in the military (Kennedy et al., 1993) and is still used in research using modern HMD technology (Tyrrell et al., 2018).

The term motion sickness refers to a range of symptoms experienced in moving environments, such as air, land or sea travel, and is not specific to HMDs. Symptoms can vary significantly depending on the context; for example, nausea tends to be more intense in seasickness than in simulator use (Kennedy et al., 2010). In addition, the symptomatology associated with sickness differs between technologies. Research has shown that HMDs often produce severe symptoms related to nausea, dizziness and blurred vision (Kennedy et al., 2003).

The term cybersickness was coined to describe adverse effects resulting from the use of virtual environments (McCauley and Sharkey, 1992); it encompasses a range of symptoms similar to motion sickness, particularly associated with the use of VR technology, such as nausea, dizziness, disorientation and eye strain (LaViola, 2000). Currently, cybersickness is not formally recognised as a health condition (Keshavarz et al., 2019). This problem is compounded by a lack of understanding of the underlying causes of cybersickness and the existence of competing theories to explain its occurrence (Chang, Kim and Yoo, 2020). It is likely to be caused by a mismatch between the physical properties of the screen ('accommodation') and the focal point of the virtual environment that the user is observing ('vergence'). This mismatch between the optical information received through the HMD and other sensory inputs, such as spatial perception, can lead to symptoms such as nausea, headaches and general discomfort (Davis et al., 2014; Rupp, 2024). Several potential solutions to the 'vergence-accommodation conflict' are being explored, which may have implications for the wider use of VR in medical education (Kramida, 2016; Vovk et al., 2018). In the meantime, technical advances such as improved HMD resolution and reduced latency are being implemented to mitigate these symptoms.

Discomfort refers to a range of physical and psychological symptoms that users may experience when using VR headsets (Chen, Wang and Xu, 2021). Ergonomic problems such as excessive weight, uneven distribution of gravity, localised pressure, restricted head mobility and inadequate thermal regulation can result from the weight, fit and prolonged wear of HMDs, especially if the device is poorly adjusted. The weight of the device can influence the duration and impact of user discomfort. In particular, when experiencing VR with an HMD, wearing a heavy object on the head for long periods of time may cause discomfort to the user, regardless of the VR content (Chang, Kim and Yoo, 2020). Comfort therefore relates to the personal experience of wearing the headset (Rupp, 2024). These ergonomic challenges not only negatively impact the physical and mental well-being of users, but also limit the potential applications of VR technology in various fields (Chen, Wang and Xu, 2021). Advances in graphics, sensors and battery technology can increase the weight and thermal profile of the headset, so VR headset designers must balance immersion and comfort to optimise the user experience (Rupp, 2024).

3.1 Tools for the evaluation of cybersickness and discomfort

Measuring VR sickness is a fundamental part of determining prevalence and symptomatology in virtual environments. There are objective and subjective methods of assessing the severity of simulator sickness. The Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) is the most commonly used validated sickness scale (Rebenitsch and Owen, 2016), but dedicated Likert scales asking study participants to rate individual symptoms are also used (Keshavarz and Hecht, 2011). Very few studies report the use of objective physiological measures (e.g. heart rate, skin conductance, electroencephalograms, eye blink rate, and electrogastrogram) that do not rely on individual self-report data (Kim et al., 2005).

3.1.1 Simulator Sickness Questionnaire (SSQ)

The SSQ was developed by Kennedy, Lane, Berbaum and Lilienthal in 1993. The scale contains 16 items grouped into three non-exclusive categories that assess disorientation (difficulty concentrating, nausea, head fullness, blurred vision, dizziness with eyes open, dizziness with eyes closed, dizziness), nausea (general discomfort, sweating, nausea, vomiting), and oculomotor disturbance (difficulty concentrating, fatigue, abdominal awareness, burping), nausea, difficulty concentrating, abdominal awareness, burping) and oculomotor disturbance (general discomfort, fatigue, headache, eye pain, difficulty focusing, difficulty concentrating, blurred vision) on a 4-point Likert scale (0 none, 1 mild, 2 moderate, 3 severe). The score for each category is defined as the sum of its symptom scores. These subscales are weighted differently, multiplied by a constant scaling factor and summed to give the SSQ total score. The SSQ total score ranges from 0 to 235.62 (Simón-Vicente et al., 2024); total scores are obtained using a conversion formula in which the highest scores indicate the most severe disorders and, for each domain, a score between 5 and 10 is considered as minimal symptoms, between 10 and 15 significant symptoms, between 15 and 20 significant symptoms and more than 20 severe symptoms. A total score above 20 was considered 'poor' (Stanney et al., 1997). The questionnaire has good internal consistency (Cronbach's alpha of 0.87). The scale was originally developed to assess simulator sickness in flight simulators (Kennedy et al., 1993); however, it has also been used in VR, although there is ongoing debate about the relationship between cybersickness and simulator sickness (Stanney et al., 1997; Bos, Diels, and Souman, 2022).

3.1.2 Simulator Sickness Questionnaire - French (SSQ-F)

The French adaptation of the SSQ was validated by Bouchard et al (2007), who criticised the SSQ for its complicated factor structure and for having been developed on a dataset of military personnel; the factors were revised on the basis of a population of adults from the general public and different HMDs were evaluated. The SSQ-F contains 16 items grouped into two categories: nausea (general discomfort, increased salivation, sweating, nausea, headache, dizziness with eyes open, dizziness with eyes closed, vertigo, abdominal awareness, burping) and oculomotor (fatigue, headache, eye strain, difficulty focusing, difficulty concentrating, head fullness, blurred vision), rated on a 4-point Likert scale from 0 (not at all) to 3 (very much). Bouchard et al (2007) reported their results as means for the nausea (from 0 to 27) and oculomotor (from 0 to 21) factors and the total score as the sum of these means (from 0 to 48).

3.1.3 Virtual Reality Sickness Questionnaire (VRSQ)

The VRSQ is an extended iteration of the SSQ. Kim et al. (2018) used nine symptoms from the original SSQ to represent oculomotor and disorientation constructs. Its items were derived from the SSQ and tailored to assess symptoms experienced in a virtual reality environment (Josupeit, 2023). The scale consists of nine items divided into two categories: disorientation (including headache, feeling full, blurred vision, dizziness with eyes closed and vertigo) and oculomotor (including general discomfort, fatigue, headache, eye strain and difficulty focusing). Responses are measured on a 4-point Likert scale (0 none, 1 mild, 2 moderate, 3 very severe). The total VRSQ score is calculated by averaging the scores from the oculomotor and disorientation categories, but the scale does not provide a specific total score.

Sevinc & Ilker (2020) found in their study that the VRSQ is more specifically designed to measure cybersickness and has better psychometric properties for assessing HMD VR applications when compared to the SSQ and SSQ-F, which are instruments designed to measure simulator sickness. They provided evidence for the validity of the VRSQ as a measure of cybersickness, whereas the SSQ and SSQ-F could not be psychometrically validated. Their results provided evidence for the reliability of all measures. The VRSQ was highly sensitive to differences between the application aspects of the VEs evaluated, although they investigated fewer symptoms than the simulator sickness scales.

3.1.4 Motion Sickness Assessment Questionnaire (MSAQ)

The MSAQ is a validated instrument for the assessment of motion sickness; it was developed by Gianaros at al. (2001) and is used to assess motion sickness as a multidimensional construct. It was developed to measure motion sickness in general, without a specific focus on VR and simulators. These distinct dimensions may respond differently to different types of real or apparent motion. Furthermore, individuals may experience different degrees of activation along each of these dimensions in the same type of motion environment. The MSAQ scale contains 16 items grouped into four categories: gastrointestinal (nausea, vomiting), central (lightheadedness, dizziness, vertigo), peripheral (sweating, feeling warm) and somatosensory (irritability, drowsiness, fatigue) on a 9-point Likert scale from 0 (none) to 8 (severe).

3.1.5 Fast Motion Sickness Scale (FMS)

The FMS (Keshavarz and Hecht, 2011) is considered to be a brief assessment method to assess motion sickness as a unidimensional construct. FMS uses a rating scale from 0 (no sickness at all) to 20 (overt sickness) focusing on nausea, general discomfort, and stomach problems, which can be used to quickly capture sickness scores during exposure. Results show that scores obtained using this measure are highly correlated with SSQ dimensions and total severity scores (Keshavarz and Hecht, 2011, 2014). Several studies have also used similar single-item assessment methods to measure simulator sickness (e.g., McCauley et al., 1990), but these methods have not been psychometrically evaluated.

4 Implications for future research

Despite the improvements in HMD technology, Rebenitsch and Owen (2016) suggested that the prevalence of VR sickness is still problematic, and little is known about the side effects. The varying quality and lack of robustness in the existing research underscore the need for further, more rigorous investigations to explore the most promising applications of HMDs in educational environments. In practice, the use of full-immersive virtual reality holds great potential across all educational contexts. However, research underscores the need for further investigation into cybersickness and discomfort, treating these issues as primary objectives for future studies and considering not only students but also professionals. It is crucial to account for the technological advancements of head-mounted displays (HMDs) and the specific purposes for which they are employed. Furthermore, a thorough evaluation of adverse effects using tools tailored to educational settings could yield more accurate and comparable results. The increased use of virtual reality and HMDs may stimulate research to investigate more common side effects and to explore the correlation between side effects and time of use the HMDs and the characteristics of participants to find the most suitable way to implement the virtual reality in educational context and training contexts. Also, bio signals response (e.g. galvanic skin) will be investigated to predict and detect side effects in real-time. In this field locomotion techniques will be analyse to explore the relation between movement and side effects.

References

Bazavan, L. C., Roibu, H., Petcu, F. B., Cismaru, S. I., & George, B. N. (2021). Virtual reality and augmented reality in education. In *Proceedings of the 30th Annual Conference of the European Association for Education in Electrical and Information Engineering (EAEEIE)*, Prague, Czech Republic (pp. 1-4). IEEE. https://doi.org/10.1109/EAEEIE50507.2021.9531005

Bicalho, D., Piedade, J., & Matos, J. (2023). The use of immersive virtual reality in educational practices in higher education: A systematic review. *Proceedings of the SIIE 2023 Conference.* IEEE. https://doi.org/10.1109/SIIE59826.2023.10423711

Bouchard, S., Robillard, G., & Renaud, P. (2007). Revising the factor structure of the simulator sickness questionnaire. *Annual Review of CyberTherapy and Telemedicine*, 5, 128-137.

Bos, J. E., Diels, C., & Souman, J. L. (2022). Beyond seasickness: a motivated call for a new motion sickness standard across motion environments. *Vibration* 5, 755–769. https://doi:10.3390/vibration5040044

Caserman, P., Garcia-Agundez, A., Gámez Zerban, A., & Göbel, S. (2021). Cybersickness in current-generation virtual reality head-mounted displays: Systematic review and outlook. *Virtual Reality, 25*(4), 1153–1170. https://doi.org/10.1007/s10055-021-00513-6

Chang, E., Kim, H. T., & Yoo, B. (2020). Virtual reality sickness: A review of causes and measurements. *International Journal of Human–Computer Interaction*, 36(17), 1658–1682. https://doi.org/10.1080/10447318.2020.1778351

Chen, Y., Wang, X., & Xu, H. (2021). Human factors/ergonomics evaluation for virtual reality headsets: A review. *CCF Transactions on Pervasive Computing and Interaction*, 3, 99–111. https://doi.org/10.1007/s42486-021-00062-6

Davis, S., Nesbitt, K., & Nalivaiko, E. (2014). A systematic review of cybersickness. *IE2014: Proceedings of the 2014 Conference on Interactive Entertainment*, 1–9. https://doi.org/10.1145/2677758.267778

Elmqaddem, N. (2019). Augmented reality and virtual reality in education: Myth or reality? *International Journal of Educational Technology*, 14(3), 123-130. https://doi.org/10.3991/ijet.v14i03.9289

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. *11th International Conference Elearning and Software for Education*. https://doi.org/10.12753/2066-026x-15-020

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.

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. Educational Information Technology, 23, 1515–1529. https://doi.org/10.1007/s10639-017-9676-0

Josupeit, J. (2023). Cybersickness as the virtual reality sickness questionnaire (VRSQ) measures it!? – an environment-specific revision of the VRSQ. Frontiers in Virtual Reality, 4, 1291078. https://doi:10.3389/frvir.2023.1291078

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. https://doi.org/10.1207/s15327108ijap0303_3

Keshavarz, B. (2016). Exploring behavioral methods to reduce visually induced motion sickness in virtual environments. In International Conference on Virtual, Augmented and Mixed Reality. Springer, Cham, pp. 147–155.

Keshavarz, B., & Hecht, H. (2011). Validating an efficient method to quantify motion sickness. Human Factors, 53(4), 415–426. https://doi.org/10.1177/0018720811403736

Keshavarz, B., & Hecht, H. (2014). Pleasant music as a countermeasure against visually induced motion sickness. Applied Ergonomics, 45(3), 521–527. https://doi.org/10.1016/j.apergo.2013.07.009

Keshavarz, B., Philipp-Muller, A. E., Hemmerich, W., Riecke, B. E., & Campos, J. L. (2019). The effect of visual motion stimulus characteristics on vection and visually induced motion sickness. Displays, 58, 71-81. https://doi.org/10.1016/j.displa.2018.07.005

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. https://doi.org/10.1016/j.apergo.2017.12.016

Kramida, G. (2016). Resolving the vergence-accommodation conflict in head-mounted displays. *IEEE Transactions on Visualization and Computer Graphics, 22*(7), 1912–1931.

LaViola, J. J. (2000). A discussion of cybersickness in virtual environments. *ACM SIGCHI Bulletin, 32*(1), 47–56. https://doi.org/10.1145/333329.333344

McCauley, M. E., & Sharkey, T. J. (1992). Cybersickness: perception of self-motion in virtual environments. Presence 1, 311–318. doi: 10.1162/pres.1992.1.3.311

McCauley, M.E., Hettinger, L.J. & Sinacori, J.B. (1990). The effect of visual-motion synchrony on simulator induced sickness. *Proceedings of the AIAA Flight Simulation Technologies Conference.* (Paper Number AIAA-90-3172). Washington, D.C. American Institute ofAeronautics and Astronautics.

Mittelstaedt, J. M. (2020). Individual predictors of the susceptibility for motion-related sickness: A systematic review. *Journal of Vestibular Research, 30*, 165–193. https://doi.org/10.3233/VES-200702

Rebenitsch, L., Owen, C. Review on cybersickness in applications and visual displays.
Virtual Reality 20, 101–125 (2016). https://doi.org/10.1007/s10055-016-0285-9

Renganayagalu, S., Mallam, S. C., & Nazir, S. (2021). Effectiveness of VR head-mounted displays in professional training: A systematic review. *Technology, Knowledge and Learning, 26*, 999–1041. https://doi.org/10.1007/s10758-020-09489-9

Rupp, M. A. (2024). Is it getting hot in here? The effects of VR headset microclimate temperature on perceived thermal discomfort, VR sickness, and skin temperature. *Applied Ergonomics, 114*, Article 104128. https://doi.org/10.1016/j.apergo.2023.104128

Sevinc, V., & Berkman, M. I. (2020). Psychometric evaluation of Simulator Sickness Questionnaire and its variants as a measure of cybersickness in consumer virtual environments. *Applied Ergonomics, 82*, Article 102958. https://doi.org/10.1016/j.apergo.2019.102958

Stanney, K. M., Kennedy, R. S., & Drexler, J. M. (1997). Cybersickness is not simulator sickness. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 41*(2), 1138–1142. https://doi.org/10.1177/107118139704100292

Simón-Vicente, L., Rodríguez-Cano, S., Delgado-Benito, V., Ausín-Villaverde, V., & Cubo Delgado, E. (2024). Cybersickness: A systematic literature review of adverse effects related to virtual reality. *Neurología, 37*(10), 701-709. https://doi.org/10.1016/j.nrl.2022.04.009

Somrak, A., Humar, I., Hossain, M. S., Alhamid, M. F., Hossain, M. A., & Guna, J. (2019). Estimating VR sickness and user experience using different HMD technologies: An evaluation study. *Future Generation Computer Systems, 94*, 302-316. https://doi.org/10.1016/j.future.2018.11.041

Tang, Y. M., Chau, K. Y., Kwok, A. P. K., Zhu, T., & Ma, X. (2022). A systematic review of immersive technology applications for medical practice and education-Trends, application areas, recipients, teaching contents, evaluation methods, and performance. Educational Research Review, 35, 100429. https://doi.org/10.1016/j.edurev.2021.100429

Tyrrell, R., Sarig-Bahat, H., Williams, K., Williams, G., & Treleaven, J. (2018). Simulator sickness in patients with neck pain and vestibular pathology during virtual reality tasks. Virtual Real. 22, 211–219. https://doi: 10.1007/s10055-017-0324-1

Vovk, A., Wild, F., Guest, W., & Kuula, T. (2018). Simulator sickness in augmented reality training using the Microsoft HoloLens. *Proceedings of the 2018 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, 1–8. https://doi.org/10.1109/ISMAR.2018.00012

Yildirim, C. (2020). Don't make me sick: Investigating the incidence of cybersickness in commercial virtual reality headsets. *Virtual Reality, 24*, 231–239. https://doi.org/10.1007/s10055-019-00401-0