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Investigating the Role of Individual Differences in Predicting the Severity of Cybersickness Symptoms in Virtual Reality

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Σημείωμα Συγγραφέα

Ο συγγραφέας βεβαιώνει ότι το περιεχόμενο του παρόντος έργου είναι αποτέλεσμα προσωπικής εργασίας και ότι έχει γίνει η κατάλληλη αναφορά στην εργασία τρίτων, όπου κάτι τέτοιο ήταν απαραίτητο, σύμφωνα με τους κανόνες της ακαδημαϊκής δεοντολογίας.

Abstract

This study investigates the predictors of cybersickness within VR environments, focusing on the impact of individual differences such as age, gender, motion sickness susceptibility, VIMS, and previous digital interaction experiences. A total of 47 participants aged 18-45 completed the MSSQ, VIMSSQ, GSQ, and CSQ-VR, and were immersed in a VR environment featuring a roller coaster ride. Responses to the CSQ-VR were collected both before and after the ride to measure changes in cybersickness levels. The study combined the MSSQ and VIMSSQ metrics to quantify susceptibility, demonstrating their effectiveness in predicting cybersickness outcomes. Demographic variables such as age and gender were not significant predictors of cybersickness intensity. Instead, individual histories of motion sickness and VIMS emerged as substantial predictors. Furthermore, digital interaction experiences, especially gaming and smartphone usage, were also significant predictors. Notably, the combination of the CSQ-VR and GCQ metrics revealed that proficiency in FPS games was strongly associated with reduced cybersickness symptoms, highlighting the protective effects of specific types of gaming experiences. This study advances our understanding of cybersickness by integrating empirical findings with theoretical insights, suggesting that the severity of cybersickness can be mitigated by considering individual susceptibility and digital interaction histories. The knowledge gained will enhance the understanding of the relationship between individual differences and sensitivity to cybersickness, providing valuable information for its prevention and management in VR environments.

Key-words: Cybersickness, Virtual Reality, VR, Individual Differences, Smartphone, Video Game Skills, Motion Sickness

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Introduction

Immersive Virtual Reality (VR) emerges as a groundbreaking technology in the 21st century, marking the advent of a new era in digital immersion into simulated and alternative realities. This cutting-edge technology not only pushes the boundaries of virtual engagement but also promises to transform various sectors ranging from entertainment to healthcare by offering a multitude of promising applications.

In the entertainment industry, early adoption of VR has revolutionized audience experiences, transporting them into realms once only imaginable (Foxman, 2018; Hartmann & Fox, 2021; Williams, 2015). With the declining cost of Head-Mounted Displays (HMDs), VR's accessibility and impact are expanding across various fields, notably in education and training. In higher education, VR enhances student engagement and academic outcomes (Marks & Thomas, 2022; Villena-Taranilla et al., 2022) and provides a rich environment for research (Radianti et al., 2020). In the realm of Serious Games, VR improves learning rates and skill development, leading to increased user satisfaction (Checa & Bustillo, 2020) and has shown its effectiveness in specialized training programs like cultural heritage education (Mortara et al., 2014). It is also effectively used in surgical and anatomical training (Barteit et al., 2021) and remote medical training (De Ponti et al., 2020). Furthermore, VR's realistic simulations significantly impact sectors such as neurosurgery and aviation (Davids et al., 2021; K. M. Stanney et al., 2021), not only enhancing performance in commerce and tourism but also ensuring safer training in high-risk scenarios and fostering cultural and historical empathy (Xie et al., 2021).

Moreover, as VR technology continues to evolve, its impact on healthcare, particularly in pain management and rehabilitation, is expected to grow significantly (Cano Porras et al., 2018; de Araújo et al., 2019; Lei et al., 2019; Pourmand et al., 2018). In neuropsychology, VR offers a wide range of applications, from conducting cognitive assessments to implementing targeted rehabilitation protocols (Chatterjee et al., 2022; de Araújo et al., 2019; Kourtesis et al., 2021; Kourtesis, Kouklari, et al., 2023; Kourtesis & MacPherson, 2021; Shahmoradi & Rezayi, 2022).

VR also supports populations traditionally considered vulnerable or resistant to technological innovations. Older adults, often hesitant about new technology, have adopted VR for cognitive stimulation and depression relief, with tools specifically designed for their needs (Bauer & Andringa, 2020; Piech & Czernicki, 2021; Yen & Chiu, 2021). Individuals diagnosed with Attention-Deficit Hyperactivity Disorder (ADHD) and Autism Spectrum Disorder (ASD) have also benefited from VR solutions aimed at therapeutic and recreational purposes (Corrigan et al., 2023; Glaser & Schmidt, 2022; Kourtesis, Kouklari, et al., 2023; Parsons et al., 2019; Romero-Ayuso et al., 2021; Zhang et al., 2022). Despite VR applications having a profound impact across diverse areas and involve sensitive populations, challenges such as cybersickness remain, potentially hindering the full adoption and maximization of VR technology's potential.

Cybersickness in Virtual Reality

The widespread adoption and utility of VR are significantly hindered by a critical issue – cybersickness, a major health and safety challenge in virtual environments that poses a substantial risk to both usability and performance (Costello & Howarth, 1996). This concern affects a large proportion of users, with estimates suggesting that 20-80% of VR users experience cybersickness (Caserman et al., 2021; H. Kim et al., 2021; Rebenitsch & Owen, 2021). This condition is characterized by a trio of symptoms—nausea, disorientation, and oculomotor disturbances—which substantially impair the enjoyment and effectiveness of VR applications. Unlike similar conditions such as simulator sickness and motion sickness, cybersickness has unique triggers and symptoms, primarily rooted in the immersive VR environment and induced by visual stimuli rather than physical movement (Davis et al., 2014;

K. M. Stanney et al., 1997). Cybersickness not only hinders the adoption and development of VR but also introduces potential biases in its applications. For example, in diagnosing neurodegenerative diseases, cybersickness symptoms could negatively affect spatial cognition, skewing diagnostic measurements (Maneuvrier et al., 2023a).

The etiology of cybersickness remains only partially understood, with no unified theoretical consensus achieved. Current research explores several explanatory frameworks, including the sensory conflict theory, the eye movement hypothesis, the subjective vertical conflict theory, and the postural instability theory (Gallagher & Ferrè, 2018; LaViola, 2000; Lim et al., 2018). Among these, the sensory conflict theory is the most widely accepted, suggesting that cybersickness arises from mismatches among the visual, vestibular, and proprioceptive sensory systems (Davis et al., 2014; LaViola, 2000; Rebenitsch & Owen, 2021). Specifically, VR-induced sensory dissonance arises when there is a mismatch between the visual system's perception of motion and the corresponding vestibular and proprioceptive inputs. This is particularly evident during vection, which is the illusion of motion despite the absence of actual physical movement (Palmisano et al., 2017; K. Stanney, Lawson, et al., 2020). This sensory mismatch is particularly noticeable during VR's simulation of linear and angular accelerations, resulting in a misalignment between perceived and actual spatial orientation (J. Kim et al., 2021; Nesbitt et al., 2017). Addressing cybersickness is crucial for VR's technological advancement and user acceptance, highlighting the need for continued research into its causes and mitigations.

Mitigation of Cybersickness

Efforts to mitigate cybersickness in VR encompass advancements across both hardware and software sectors. Over time, the VR industry and scientific community have significantly enhanced immersive experiences (Kourtesis et al., 2019a). Continuous improvements aim to reduce the sensory mismatch between visual input and physical sensation, a key factor that can destabilize balance and significantly contribute to cybersickness (Kourtesis et al., 2019a, 2019b; Palmisano et al., 2017).

Hardware concerns in VR focus on the specs and performance of HMDs, including display technology, motion tracking, field of view, resolution, and refresh rate. The adoption of OLED screens, for instance, has improved response times and color quality, helping reduce VR-induced symptoms and effects (VRISE) like cybersickness (Kourtesis et al., 2019a). Enhanced computing power in VR HMDs meets the high demands of VR applications, improving user experience. Additionally, the use of external devices and wearables that provide vestibular stimulation and haptic feedback helps synchronize physical sensations with virtual movements, minimizing sensory discrepancies and enhancing immersion and comfort in VR settings (Ang & Quarles, 2023).

On the software front, innovations such as dynamic depth of field, which adjusts the focus based on where the user looks (Ang & Quarles, 2023), and spatial blur techniques like foveated depth-of-field blur, have shown to significantly reduce visual strain and cybersickness, with reductions as high as 66% (Hussain et al., 2021). Implementing Human-Computer Interaction (HCI) principles is crucial, with designs that integrate spatialized sounds and ergonomic navigation methods such as gaze turning, teleportation, and point-to-point movement. Moreover, clear tutorials and user-friendly design significantly decrease discomfort and enhance engagement (Ang & Quarles, 2023; Farmani & Teather, 2020; Kourtesis et al., 2019a, 2019b; Lin et al., 2023; Rebenitsch & Owen, 2016). These enhancements, alongside optimized refresh rates and minimized visual feedback latency, create a smoother and less disorienting VR experience (Ang & Quarles, 2023; Kourtesis et al., 2019a).

The integration of static reference points within the VR environment, such as a virtual nose or cockpit frame, provides users with a sense of orientation relative to fixed objects, significantly alleviating the sensory conflicts that contribute to cybersickness (Ang & Quarles, 2023; Farmani & Teather, 2020; Kemeny et al., 2017). However, the effectiveness of this approach varies depending on the VR application and its context. Additionally, employing music with joyful or calming influences has been found to decrease nausea-related symptoms, although its applicability varies across different VR environments (Kourtesis, Amir, et al., 2023).

To combat cybersickness more actively, strategies such as habituation, which involves frequent exposure to VR to help users build resilience, are employed (Howarth & Hodder, 2008). While this method proves effective, it is both time-intensive and costly, requiring a significant commitment from participants. Techniques such as reducing the field of view or employing "headlock" and "tunneling" methods are also used to mitigate cybersickness, but these can sometimes compromise the immersive quality of the VR experience (Ang & Quarles, 2023; Kemeny et al., 2017, 2020a; Wu & Suma Rosenberg, 2022). Despite these refinements, challenges persist, notably due to the high variability in individual susceptibility to cybersickness. Factors such as age, gender, and prior VR exposure necessitate tailored approaches to VR design (Abeele et al., 2021).

While significant progress has been made, the ongoing challenge of minimizing discomfort while preserving the immersive qualities of VR underscores the industry's commitment to addressing cybersickness through collaborative and innovative efforts. As VR technology continues to evolve, the combined endeavors of developers and researchers are expected to refine and enhance the VR experience, making it more accessible to a broader audience.

Measuring Cybersickness intensity and symptomatology

A common method to assess cybersickness involves administering self-reporting questionnaires before and after VR exposure, allowing researchers to monitor changes in a user's condition and the effects of VRISE (Kourtesis et al., 2019b; Saredakis et al., 2020). Initially, the Simulator Sickness Questionnaire (SSQ), developed by Kennedy et al. (1993) , served as a fundamental tool for documenting and categorizing VR sickness symptoms (Kemeny et al., 2020a). However, its application in VR settings has been critiqued for not adequately covering VR-specific issues, having a complex scoring system, and neglecting key symptoms such as nausea (Bouchard et al., 2021; Golding, 2006; Kourtesis, Linnell, et al., 2023; Sevinc & Berkman, 2020). These limitations prompted the development of the Virtual Reality Sickness Questionnaire (VRSQ), which aims to better target VR-induced symptoms and simplify scoring. Despite improvements, the VRSQ still faces criticism for its complex scoring, over-simplification of assessments, and failure to include important symptoms like nausea, limiting its effectiveness in capturing the full range of cybersickness experiences (H. K. Kim et al., 2018; Kourtesis, Linnell, et al., 2023).

Furthermore, self-reporting methods can interrupt the VR experience and potentially alter physiological responses, leading to biased participant feedback. In response, researchers have shifted towards passive and continuous monitoring of physiological indicators to gain a deeper understanding of cybersickness (Davis et al., 2014; Weech et al., 2019). Techniques like electroencephalography (EEG) (Chang et al., 2023), electrocardiogram (ECG), electrogastrogram (EGG) (Himi et al., 2004), electrooculogram (EOG), and electrodermal activity (EDA) (Yokota et al., 2005) have shown promise in accurately detecting cybersickness (Dennison et al., 2016; Weech et al., 2019). However, these methods come with significant logistical and financial challenges, such as the complexity of using multiple sensors simultaneously and the high costs associated with advanced technologies like EEG.

Key physiological changes linked to cybersickness—such as alterations in stomach activity, breathing patterns (Dennison et al., 2016), photoplethysmography (PPG) via pulse oximeter (Nalivaiko et al., 2015), and skin conductance (Gavgani et al., 2017)—highlight the potential of these monitoring techniques. Yet, their practicality for everyday use is limited by high costs and operational complexity. Alternatively, wearable technologies like haptic gloves that incorporate heart rate monitors, PPG, and EDA sensors offer a more integrated approach to physiological monitoring within VR environments. These innovations, while promising, are often costly and not widely accessible, limiting their use to a narrow segment of consumers (Kourtesis et al., 2022; Pacchierotti et al., 2017).

However, eye-tracking technology is gaining prominence as a tool for measuring and predicting cybersickness intensity. Utilizing metrics like pupil dilation, fixation duration, and gaze deviation, eye-tracking enhances the accuracy of cybersickness predictions and is increasingly recognized for its effectiveness (Chang et al., 2021; Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024; Kourtesis, Linnell, et al., 2023). As this technology becomes more integrated into HMDs, it offers a viable solution to the ergonomic and economic challenges posed by traditional physiological measurements. The growing incorporation of eye-tracking in VR systems underscores its potential in detecting cybersickness efficiently and unobtrusively.

In response to all these challenges and new technologies, the Cybersickness in Virtual Reality Questionnaire (CSQ-VR) has been developed and validated, demonstrating improved internal consistency and psychometric properties (Kourtesis, Linnell, et al., 2023). The CSQ-VR is recognized as a reliable and comprehensive tool for assessing the dynamic nature of cybersickness intensity during VR sessions (Kourtesis, Amir, et al., 2023; Kourtesis, Linnell, et al., 2023; Sokołowska, 2023; K. Stanney, Lawson, et al., 2020). Notably, it also incorporates a 3D-VR format that allows for continuous evaluation without disrupting VR immersion, unlike traditional paper-and-pencil methods. Moreover, the CSQ-VR integrates eye-tracking biometrics, making use of the prevalent eye-tracking technology in modern VR headsets. This makes it a versatile and user-friendly instrument suitable for a broad range of experimental settings in cybersickness detection (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024; Kourtesis, Linnell, et al., 2023).

Age and Cybersickness

The relationship between age and cybersickness intensity in virtual reality is complex and not yet fully understood. Studies suggest that older adults tend to experience more intense cybersickness compared to younger ones, frequently exiting VR simulations prematurely due to discomfort (Kennedy et al., 2010; Keshavarz et al., 2018). This increased susceptibility among older adults has been linked to factors like postural instability, which may worsen with age, increasing their risk of cybersickness (Arcioni et al., 2019; Munafo et al., 2017). However, other studies present contrasting views, suggesting that older adults might experience less cybersickness, potentially due to variations in their physical condition (Boot et al., 2019; Dilanchian et al., 2021). However, our previous studies focusing on a younger demographic have not identified age as a significant predictor of cybersickness severity (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024). This highlights the need for further research across more age-diverse populations to better understand how age influences cybersickness.

Gender and Cybersickness

The relationship between gender and cybersickness remains a nuanced aspect of cybersickness research, with studies offering mixed findings on whether gender significantly influences cybersickness severity (Kourtesis, Amir, et al., 2023; Saredakis et al., 2020). While some studies indicate that women may experience greater sensitivity to cybersickness, potentially pointing to gender disparities (Chattha et al., 2020; Jasper et al., 2020; Munafo et al., 2017), this view is contested by other research that fails to find significant differences between genders (Curry et al., 2020; Melo et al., 2018; Saredakis et al., 2020; K. Stanney, Fidopiastis, et al., 2020). This debate is complicated by factors such as societal influences, with women historically reporting health symptoms more frequently and men to underreport them due to traditional expectations of masculinity (Boerma et al., 2016; Kelly et al., 2023).

Objective physiological measures such as heart rate, EEG, ECG, and GSR collected during VR sessions have consistently demonstrated insignificant gender differences, contrasting with self-reported measures that suggest gender-specific sensitivities (Oh & Son, 2022; Petri et al., 2020). This discrepancy highlights the potential biases in subjective reporting tools like the SSQ, questioning their reliability in accurately reflecting the true nature of cybersickness across genders.

Further complicating the issue, recent studies challenge the notion that biological sex significantly influences VR discomfort. Research adjusting for factors like the proper alignment of the Inter Pupillary Distance (IPD) in VR headsets has shown that when the VR device is correctly adjusted to fit an individual's IPD, gender differences in cybersickness largely disappear (K. Stanney, Fidopiastis, et al., 2020). This suggests that the fit and customization of VR equipment could play a crucial role in the user's experience, rather than inherent gender differences. Additionally, our prior studies suggest that gaming experience may influence the relationship between gender and cybersickness. By controlling for gaming background, differences in cybersickness between genders are reduced (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024), indicating that familiarity with digital environments may affect susceptibility to cybersickness.

Overall, the complex interplay between gender, individual technology experience, and VR system design highlights the need for a nuanced approach to studying cybersickness. Future research should continue to explore these dynamics, using balanced study designs and adapted VR setups to better understand and mitigate the impacts of cybersickness across all users.

Susceptibility to Motion Sickness and Cybersickness

Motion sickness and cybersickness, although triggered by different stimuli—physical movement and visual vection respectively—present clinically similar symptoms, especially in their advanced stages (Mazloumi Gavgani et al., 2018). Individual susceptibility to motion sickness varies widely, influenced by a complex interplay of physiological and psychological factors. Notably, the vestibular and somatosensory systems are crucial in this variability (Golding, 2006; Lackner, 2014). Dysfunctions in the vestibular system can reduce the incidence of motion sickness, while an increased reliance on somatosensory inputs may heighten susceptibility (Golding, 2006; Nachum et al., 2004). This variance extends into VR, where a history of motion sickness in individuals is associated with more severe cybersickness, suggesting underlying similarities in susceptibility between the two conditions (Jasper et al., 2023; Nesbitt et al., 2017; Rebenitsch & Owen, 2014; K. Stanney, Fidopiastis, et al., 2020).

Cybersickness, like motion sickness, shows similar varied susceptibility patterns among individuals, influenced by both physiological and sensory processing factors (Golding et al., 2021; Lukacova et al., 2023). The Motion Sickness Susceptibility Questionnaire (MSSQ) has been validated for assessing motion sickness based on individuals' experiences with physical motion, emphasizing the vestibular system's role (Golding, 2006). However, the rise of cybersickness has led to the development of specialized assessment tools, such as the Visually Induced Motion Sickness Susceptibility Questionnaire (VIMSSQ), which focuses on susceptibility to cybersickness from screen exposure, including smartphones and HMDs (Golding et al., 2021; Keshavarz et al., 2019, 2023).

Despite the limited predictive power of the MSSQ for cybersickness intensity observed in earlier studies (Kourtesis, Amir, et al., 2023; Kourtesis, Linnell, et al., 2023), potentially because it was used to exclude participants with high MSSQ scores, our latest study identifies it as a significant predictor of cybersickness (Kourtesis et al., 2024). In line with suggestions from previous studies (Golding et al., 2021; Keshavarz et al., 2023), our study proposes that combining the MSSQ with the VIMSSQ may offer a more comprehensive understanding of susceptibility to both motion sickness and VIMS. This integrated approach could enhance the prediction of cybersickness intensity and help determine whether general susceptibility to motion sickness or specific sensitivity to vection plays a more significant role in cybersickness symptomatology and intensity.

Technology Experience and Cybersickness

As technology evolves, the landscape continues to shift away from desktop dominance toward mobile devices, which are increasingly becoming the preferred platform for daily digital activities. While desktop computers still hold sway for more complex computing tasks, smartphones have taken over many functions traditionally managed by desktops, such as internet browsing, emailing, document creation, and media editing (Bouchrika, 2024). This transition is driven not just by the portability and user-friendly interfaces of mobile devices but also by their expanding role in our everyday digital interactions.

In our earlier study, computer experience alone was not a reliable predictor of cybersickness (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024). However, literature indicates that visually induced cybersickness can occur from exposure to any type of screen such as smartphones (Kemeny et al., 2020b; Keshavarz et al., 2023; Soewardi & Izzuddin, 2020). Further studies suggests that regular interaction with digital interfaces, particularly through smartphones, may act as a form of gradual acclimatization, reducing cybersickness by fostering sensory adaptation and enhancing the ability to process dynamic visual content (K. Stanney, Lawson, et al., 2020). Our latest study (Kourtesis et al., 2024) corroborates this, providing empirical evidence that extensive smartphone use correlates with diminished cybersickness intensity. This finding supports the notion that as smartphone usage overtakes traditional computing activities, regular interaction with these devices may help mitigate the effects of cybersickness.

Additionally, research suggests that individuals with a significant history of VR usage often report a lower susceptibility to cybersickness, indicating that familiarity with VR environments might mitigate the effects of conflicting visual-vestibular stimuli (Golding, 2006; Johnson, 2005; Knight & Arns, 2006). This reduction in symptoms is likely due to a habituation effect that develops over time. Regular and varied use of VR might therefore enhance resilience to cybersickness, with variations across individuals (Rebenitsch & Owen, 2021). However, the literature presents mixed findings; while some studies observe increased resilience in experienced VR users, others report no significant differences (Tian et al., 2022). Adding to this complexity, recent studies by Jasper et al. (2023) and Kourtesis, Amir, et al. (2023) did not corroborate these findings, potentially due to the skewed distribution of VR users within their sample, underscoring the importance of accounting for VR user experience diversity. In conclusion, the variability in personal experiences with technology appears to significantly influence susceptibility to cybersickness and our understanding of the mechanisms behind resilience.

Gaming Experience and Cybersickness

Research has increasingly shown that gaming is associated with reduced cybersickness intensity, as detailed in studies by Grassini et al. (2021), Keshavarz (2016), Pöhlmann et al. (2021, 2022), and the large study by Weech et al. (2020). Notably, our previous research has identified gaming experience as a significant predictor of decreased cybersickness intensity, highlighting its protective effects by examining both frequency and gaming proficiency (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024; Kourtesis, Linnell, et al., 2023). These findings suggest that extensive gaming may acclimatize users to virtual environments and complex motion cues, thus mitigating cybersickness. However, inconsistencies in the literature findings exist, as some VR gamers continue to experience cybersickness despite their gaming background (Rangelova et al., 2020). These findings indicate a complex relationship between gaming experience and individual susceptibility to cybersickness, implying that nuanced aspects of the gaming experience could significantly influence its impact on cybersickness.

The wide range of gaming genres, including action, first-person shooters (FPS), and role-playing games (RPGs), significantly influences players' physiological and biochemical states and enhances various cognitive abilities (Baniqued et al., 2013; Krarup & Krarup, 2020; Spence & Feng, 2010). The unique demands each genre places on visual processing, spatial navigation, and psychomotor coordination could potentially bolster individual resilience to cybersickness, tailored by specific gaming experiences (Kourtesis et al., 2024).

Visually fast-paced games, particularly in the action and FPS categories, immerse players in environments requiring the management of multiple simultaneous visual stimuli and rapid responses to sudden changes within a dynamic, 360-degree setting (Spence & Feng, 2010). Such gameplay involves extensive camera rotations, where visual rotational oscillations and movements are closely linked with the emergence of cybersickness symptoms (Maneuvrier et al., 2023b). Continuous engagement with these demanding conditions could potentially contribute to long-term cognitive resilience and adaptability to visually induced motion sickness.

Research further indicates that the level of immersion, especially in first-person VR experiences, significantly impacts vection, a key factor in the development of cybersickness (Maneuvrier et al., 2023b). While a first-person perspective intensifies immersion, it may also escalate cybersickness intensity due to increased sensory conflicts (Clarke et al., 2016; Denisova & Cairns, 2015; Martirosov et al., 2022; Monteiro et al., 2018; Shafer et al., 2019).

Consequently, the cognitive benefits of engaging in visually fast-paced games like action and FPS may be unique and lasting, potentially equipping frequent players with a developed resilience to vection and consequently reduced cybersickness intensity.

Current Study Aims

The existing literature highlights that VR is a revolutionary tool with a broad range of applications across education, research, and health industry. Despite the potential of VR technology, the prevalence of cybersickness can significantly hinder its widespread adoption. Ongoing research continues to explore how individual differences—such as technological proficiency, gender, and susceptibility to motion sickness and VIMS—affect the symptomatology and intensity of cybersickness. Furthermore, there is a need to delve deeper into how different gaming genres influence cybersickness aspects, as experiences vary significantly across genres. Given these considerations, the research aims are formulated into the following hypotheses to further investigate these possible effects:

H1: Susceptibility to Motion Sickness and/or VIMS will be significant predictor(s) of the intensity of cybersickness.

H2: The demographics of the participants will not significantly predict cybersickness intensity.

H3: Computer, Smartphone, Gaming, and/or VR experience will predict the intensity of cybersickness symptomatology.

While the literature does not provide definitive evidence on how various game genres specifically impact cybersickness, preliminary observations suggest that fast-paced action games and FPS games may induce a habituation effect, potentially reducing the intensity of cybersickness symptoms. Given this possibility, our research question is formulated as follows:

RQ1: Do action and/or FPS game genres predict a lower intensity of cybersickness symptomatology?

Materials and Methods

Virtual reality Hardware & Software

This study employed the HTC Vive Pro Eye, which features an integrated eye-tracking system capable of capturing binocular gaze data at a frequency of 120Hz refresh rate, with a precision range between 0.5° and 1.1°. It offers a 5-point calibration process and supports a tracking field of view of up to 110°. This equipment not only meets but exceeds the established hardware requirements for reducing or preventing cybersickness, as identified by Kourtesis et al. (2019a). Therefore, its use guarantees that any cybersickness induced within the virtual setting is due to the designed linear and angular accelerations, rather than from hardware limitations. Additionally, the development of the VR software for this study adhered to rigorous guidelines aimed at creating VR applications for research and clinical purposes. These guidelines have been demonstrated to effectively lessen symptoms of cybersickness, according to Kourtesis et al. (2020) and Kourtesis & MacPherson (2021), further minimizing the potential influence of software attributes on the occurrence and severity of cybersickness symptoms.

Virtual Environment Development

The development of the virtual environment employed in the study leveraged the Unity3D game engine, consistent with the methodology used in our preceding research on cybersickness (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024; Kourtesis, Linnell, et al., 2023). Interaction within this environment was enhanced through the use of the SteamVR SDK, which facilitated intuitive engagement mechanisms, specifically through the implementation of virtual hands/gloves. This choice was informed by the recognition that gaming experience can significantly influence task performance (Kourtesis & MacPherson, 2021). Consequently, the environment was configured so that interactions could be initiated and confirmed through simple touch-based actions rather than button presses, enhancing the naturalness of the user experience.

In an effort to eliminate potential biases related to gender or race, the SteamVR virtual gloves were designed to be neutral, following recommendations from prior studies (Schwind et al., 2017). To ensure clarity and ease of task execution, instructions within the VR environment were presented in a multimodal format, combining video, audio, and text. Audio instructions were generated using Amazon Polly, which produced neutral, natural-sounding voice clips. Additionally, audio feedback was spatialized with the SteamAudio plugin to enhance the immersive quality of the environment. The experimental design was managed using the bmlTUX SDK (Bebko & Troje, 2020), which provided tools for exporting data in CSV format, and simplifying the overall management of the experimental protocol.

Roller Coaster Ride: Linear and Angular Accelerations

In this study, the roller coaster simulation, key to our investigation of cybersickness, is designed using the same techniques employed in our previous research (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024; Kourtesis, Linnell, et al., 2023). The ride, lasting approximately 12 minutes, was meticulously crafted to expose participants to a range of linear and angular accelerations, effectively simulating the dynamics of a roller coaster on a moving platform. The ride's trajectory was animated to convey movement on a platform with a primary forward direction, with a notable reverse along the z-axis towards the end. The sequence of accelerations was strategically planned as follows: initially, linear acceleration occurred along the z-axis; this was followed by angular acceleration involving the z- and y-axes; next, there was comprehensive angular acceleration covering the z-, x-, and y-axes; subsequent movements included angular acceleration on the roll axis, intensified linear acceleration on the z-axis, angular acceleration on the yaw axis, and finally, extreme linear acceleration on the y-axis with a subsequent reversal on the z-axis.

Consistent with our previous studies (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024; Kourtesis, Linnell, et al., 2023) the virtual environment was designed with a minimalistic aesthetic, primarily using black and white shades to focus the participants' experience on the accelerations. This choice was deliberate to minimize distractions and potential extraneous variables that could inadvertently influence the onset or intensity of cybersickness symptoms. Additionally, the environment featured a tiled pattern, providing visual cues that assist users in navigating changes in direction and perceiving alterations in altitude. This setup was aimed at ensuring that any symptoms of cybersickness could be attributed to vection, rather than other elements such as color intensity, thereby facilitating a clearer analysis of the ride's effects on cybersickness.

Cybersickness in Virtual Reality Questionnaire (CSQ-VR)

This study used the CSQ-VR, a measure with validated superior psychometric qualities over the SSQ and VRSQ, to assess the intensity and symptomatology of cybersickness (Kourtesis, Linnell, et al., 2023). The CSQ-VR was developed to address previous limitations of the VRISE component of the VR Neuroscience Questionnaire, and it has demonstrated strong structural and construct validity (Kourtesis et al., 2019b). The questionnaire’s format is concise, consisting of just six questions producing clear results (Kourtesis, Linnell, et al., 2023; Somrak et al., 2021). It calculates a total score along with scores from three subcategories: Oculomotor, Vestibular, and Nausea. Each subcategory is assessed with two questions on a 7-point Likert scale that ranges from "1 - absent feeling" to "7 - extreme feeling", with each point clearly labeled both numerically and textually for enhanced clarity. The score for each subcategory is calculated by summing the two corresponding responses, with each subscore relating to a specific type of symptom.

Moreover, CSQ-VR is available in two formats: a traditional paper-and-pencil version and a 3D version designed for use within virtual environments. The paper-and-pencil version is administered before and after VR exposure to measure cybersickness. The 3D version presents questions at the top of the user interface during VR immersion, highlighting selected responses in red. Participants adjust their answers using a slider, selecting a number directly or sliding to the desired value. A video description of the 3D VR version of the CSQ-VR can be viewed at the following link: https://www.youtube.com/watch?v=npW4NKNLXok.

Demographics and Susceptibility of Cybersickness

To collect demographic information, including gender, age, education, and prior computer, smartphone, and VR experience, a customized questionnaire was evaluated. This questionnaire, previously employed in our studies (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024; Kourtesis, Linnell, et al., 2023), determines the score for each variable by adding the responses from two questions per variable, each rated on a 6-point Likert scale. The first question rates the participant's proficiency with computers, smartphones, and VR, with answers like '5: extremely skilled.' The second question assesses how often users interact with these platforms; examples of responses include '4: once a week'. Additionally, the validated Gaming Skills Questionnaire (GSQ) was used to further explore proficiency and frequency in various gaming genres, also using a 6-point Likert scale with ratings and responses similar to those used for technology skills (Zioga et al., 2024).

The study also incorporated the short version of MSSQ (Golding, 2006) and the newly developed short version of VIMSSQ (Golding et al., 2021; Keshavarz et al., 2019) to assess susceptibility to motion sickness and VIMS, respectively. The MSSQ is recognized as a clinically significant tool for assessing an individual's susceptibility to motion sickness. It evaluates experiences by dividing them into two categories: Childhood Experience (prior to age 12), where respondents detail the frequency of sickness or nausea sensations in various transport modes or specific entertainment scenarios, and Adult Experience over the Last 10 Years, where individuals recount instances of sickness or nausea under similar conditions within the past decade. Each component is scored separately, and the total raw MSSQ score is derived by summing the scores from the two components. For enhanced interpretability, this raw score can be converted into a percentile using reference tables or a specific polynomial. As a result, the MSSQ produces three distinct scores: MSA-Child, MSB-Adult, and MSSQ-Total. It is important to note that the term "sickness" in the MSSQ covers a spectrum of symptoms, ranging from mild queasiness to severe nausea or even vomiting. (Golding, 1998, 2006; Golding et al., 2021; Lukacova et al., 2023; Paillard et al., 2013).

The VIMSSQ was specifically developed to assess an individual's susceptibility to VIMS, evaluating symptoms such as nausea, headache, dizziness, fatigue, and eyestrain when using various visual devices. The development and validation of the VIMSSQ, which included both surveys and experimental studies, have underscored its effectiveness in predicting VIMS (Keshavarz et al., 2019). As a complementary tool alongside the MSSQ, the VIMSSQ can be particularly valuable for assessing the susceptibility to cybersickness, enhancing the precision of motion sickness predictions (Golding et al., 2021; Keshavarz et al., 2023).

Participants & Experimental Procedures

Convenience sampling was used to select participants, who were drawn from the National and Kapodistrian University of Athens' internal email lists as well as people the researchers knew. The study was approved by the university's Department of Psychology Ethics Committee. The sample consisted of 47 participants, with nearly equal gender distribution—24 women and 23 men. The participants had a mean age of 27.4 years (SD = 5.28, range = 18–45) and an average education level of 16.8 years (SD = 2.04, range = 12–

23), all possessing normal or corrected-to-normal vision and all were free of evident vestibular disorders. No compensation was offered for their participation.

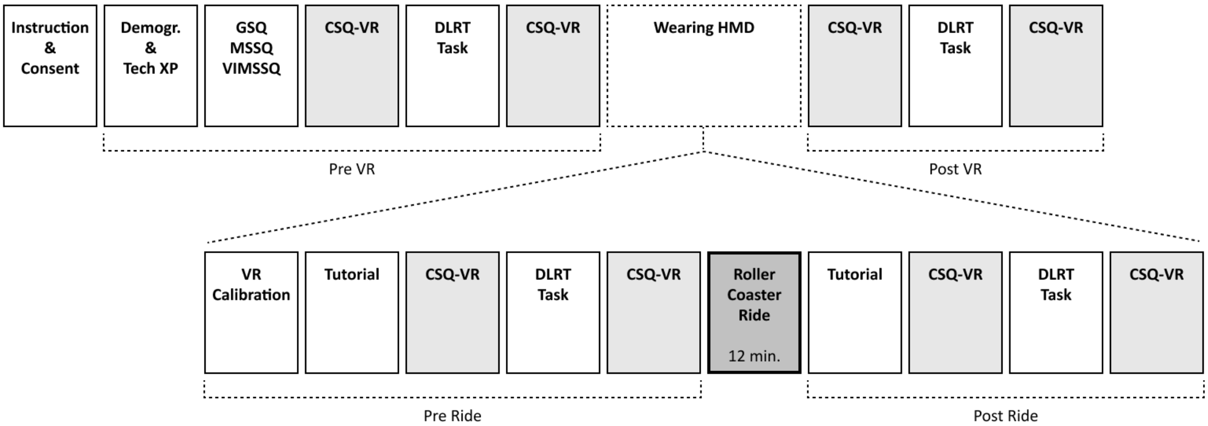
Upon arrival, participants were briefed on the study procedures as outlined in Figure 1 and provided written informed consent. The experimental procedure began with participants filling out demographic data forms along with the MSSQ, VIMSSQ and GSQ. Prior to engaging with the VR, participants completed the CSQ-VR in paper-and-pencil format, followed by the Deary-Liewald Reaction Time Test (DLRT) task, and immediately after, they completed the CSQ-VR in paper-and-pencil format again. An induction session followed, introducing them to VR technology and the HTC Vive Pro Eye headset. Participants then adjusted the VR headset under the experimenter's guidance and completed the eye-tracking calibration using HTC Vive's SteamVR software before positioning themselves at a marked spot labeled 'X'.

The VR session began with detailed tutorials for each task, including video alongside verbal and written instructions. Initially, participants responded to the 3D-VR version of the CSQ-VR questionnaire during their immersion, followed by the VR version of the psychomotor DLRT task. Immediately after completing the DLRT task, participants completed the 3D-VR version of the CSQ-VR questionnaire again. This initial baseline assessment phase lasted approximately 25 minutes. After completing the baseline tasks, participants experienced a 12-minute VR roller coaster ride. Subsequently, they completed the same tutorial and sequence of tasks—3D-VR versions of the CSQ-VR and DLRT tasks once more.

Post-VR immersion, participants filled out the CSQ-VR using a paper-and-pencil format, followed by the DLRT task, and immediately thereafter, they completed the CSQ-VR in paper-and-pencil format again. The entire session, including VR immersion, lasted about 60 minutes per participant. Participants were then provided with electrolyte-rich refreshments and a 10–15-minute rest period before departure. Finally, in order to maintain their safety, they were told not to drive or use heavy machinery for the rest of the day.

Figure 1.

Designed protocol for cybersickness evaluation



Statistical Analyses

Statistical analyses were conducted using Jamovi open-source software version 2.3.21 (The jamovi project, 2024), renowned for its user-friendly interface and robust analytical capabilities. The analysis began with descriptive statistics to provide a comprehensive overview of the sample. This was followed by correlations of every individual difference independent variable in relation to every aspect of cybersickness symptomatology and overall cybersickness intensity. Multiple mixed linear regression analyses were then performed to investigate the predictors of the symptomatology of cybersickness. These analyses incorporated individual differences and all game genres to examine the random effects associated with each stage of measurement timing. Due to the violation of normality conditions, data transformation and centering were necessary; the bestNormalize R package (Peterson & Cavanaugh, 2020) was employed to convert the data into logarithms and z-scores, thereby normalizing the distribution for parametric statistical analysis.

Regression Analyses

To assess residual normality, the Shapiro-Wilk Normality Test was used. Homoscedasticity was verified using the Non-Constant Error Variance Test, ensuring consistent variance across predictions. The Variance Inflation Factor (VIF) was calculated for each predictor to evaluate multicollinearity. Mixed linear regression analyses were conducted to investigate the influence of individual differences on the intensity of cybersickness symptoms. Models were compared using variance analyses, with selection criteria based on the F statistic and its significance, as well as the explained variance (R^2).

In our methodological approach, a broad array of variables were considered potential predictors within the models. Specifically, for the Mixed Model Regression analyses aimed at gauging the intensity of cybersickness across its subcategories, factors such as Sex, Education, Age, Computing Experience, Smartphone Apps Experience, Previous VR Experience, and Gaming Experience with various sub-genres were included. The model development proceeded in a systematic and incremental manner.

Single-Predictor Models: Initially, individual models were crafted with one predictor each. The efficacy of these models was compared to determine which predictor was most impactful.

Dyadic Predictor Models: In the next step, models incorporating two predictors were developed. The best-performing predictor from the initial models was always included. A second predictor was then chosen sequentially from the remaining options. These dual-predictor models underwent thorough evaluation, and the top performer was benchmarked against the best from the initial round.

Iterative Model Development: This phase featured an iterative process where the strongest predictors from earlier rounds were combined with a new predictor from the list. This incremental approach was continued until additional variables ceased to significantly improve the model's performance. If a simpler earlier model demonstrated superior performance over a later, more complex model, it was an indication that the most effective predictor combination had been reached. Ultimately, the final best model chosen through this systematic and structured approach was the most robust, representing the optimal combination of all considered factors.

Results

The descriptive statistics of the dataset are detailed in Table 1. The participants were primarily young adults with an average age of 27.4 years. Education levels are diverse but quite high, with an average of 16.8 years completed, indicating most participants have some form of higher education. In terms of technology usage, participants exhibit strong familiarity with computing and smartphones. However, their experience with VR is considerably lower, indicating that VR is not as familiar compared to other forms of technology. The gaming experience data shows a broad range of proficiency among participants. This diversity is also seen in specific gaming genres, such as FPS, RPG, action games, and puzzles, which could influence how participants perceive and handle VR environments due to differences in cognitive skills developed through gaming. Regarding susceptibility to motion sickness there is a notable shift in scores from childhood to adulthood, suggesting that sensitivity to motion sickness may decrease as one ages. The scores for visually induced motion sickness susceptibility are generally low but show considerable variability among the participants.

The displayed CSQ-VR mean scores capture cybersickness intensity, measured from baseline and immediately after the VR roller-coaster simulation. Initially, participants had a baseline mean total score of 7.62, indicating mild symptoms possibly due to anticipatory anxiety or prior activities. After the roller-coaster ride, there was a notable increase in cybersickness symptoms across all subcategories, with the overall mean score rising to 14.5.

This increase suggests a moderate level of cybersickness intensity. Similarly, scores for nausea, vestibular disturbances, and oculomotor discomfort showed significant increases.

Table 1

Descriptive statistics for demographics, computing experience, smartphone experience, VR experience, gaming experience and genre proficiency, susceptibility to cybersickness, overall cybersickness, and symptom intensity

	Stage	Mean (*SD*)	Range
Age	–	27.4 (5.78)	18-45
Education in Years	–	16.8 (2.04)	12-23
Computing XP	–	10.1 (1.78)	4-12
Smartphone XP	–	10.5 (1.14)	8-12
Virtual Reality XP	–	2.53 (1.02)	2-7
GSQ—Total	–	24.5 (11.5)	12-59
Sport Games Skill	–	3.85 (2.22)	2-10
FPS Games Skill	–	4.55 (3.01)	2-11
RPG Games Skill	–	4.09 (2.93)	2-12
Action Games Skill	–	4.21 (2.69)	1-12
Strategy Games Skill	–	3.32 (2.20)	2-11
Puzzle Games Skill	–	4.49 (2.60)	2-10
MSA—Child	–	6.39 (4.83)	0-18
MSB—Adult	–	4.45 (4.61)	0-18
MSSQ—Total	–	10.8 (8.79)	0-36
VIMSSQ	–	3.47 (4.41)	0-17
CSQ-VR—Total	Baseline	7.62 (1.92)	6-15
	Post-Ride	**14.5 (7.23)**	**6-32**
CSQ-VR—Nausea	Baseline	2.21 (0.508)	2-4
	Post-Ride	**4.53 (2.67)**	**2-12**
CSQ-VR—Vestibular	Baseline	2.15 (0.416)	2-4
	Post-Ride	**4.83 (2.87)**	**2-13**
CSQ-VR—Oculomotor	Baseline	3.26 (1.52)	2-9
	Post-Ride	**5.17 (2.67)**	**2-13**

Note: XP = Experience; GSQ = Game Skills Questionnaire; FPS = First-Person Shooting; RPG = Role-Playing Games; MS = Motion Sickness; MSSQ = Motion Sickness Susceptibility Questionnaire; VIMSSQ = Visually Induced Motion Sickness Susceptibility Questionnaire; CSQ-VR = Cybersickness in Virtual reality Questionnaire.

Correlations

In examining the relationships between the demographics and individual differences—and their correlation with captured intensity to cybersickness—Spearman's rho was selected as the statistical method of choice. This decision reflects the nature of the data under analysis. Since most of our measures do not meet the assumptions required for Pearson's correlation (notably, a normal distribution of data), Spearman's rho is particularly suited for non-parametric data. Furthermore, Spearman's rho is ideal for assessing monotonic relationships, making it well-aligned with the variables in this study, which include ordinal levels of experience and skill ratings.

The correlations presented in Table 2 reveal several insights. Age and higher levels of education appear to have a slight negative correlation with cybersickness across its various measures (Total, Nausea, Vestibular, Oculomotor), suggesting that older participants and those with more education might experience cybersickness less intensely. Experience with computers and smartphones is negatively correlated with cybersickness, with smartphone experience showing the strongest associations. This may suggest that familiarity with digital interfaces and navigating digital content could possibly build resilience against cybersickness. Furthermore, experiences with motion sickness during both childhood and adulthood, as well as VIMS, are all positively correlated with cybersickness. This indicates that individuals with a history of motion sickness, or VIMS, are more likely to experience cybersickness.

Finally, skills in sports and FPS game genres demonstrate significant negative correlations with cybersickness, suggesting that the spatial awareness and quick reflexive controls developed in these types of games may help mitigate the effects of visually induced motion sickness. Interestingly, RPGs, action, and puzzle games show weaker or no significant correlations, possibly due to their unique nature, which may not provide the same level of training in spatial orientation and reaction to rapidly changing visuals.

Table 2

Spearman's rho correlations between demographics, computing, smartphone usage, VR, and gaming experience, and the susceptibility to motion sickness and VIMS, in correlation with CSQ-VR outcome measurements (Total, Nausea, Vestibular, Oculomotor)

	CSQ-VR—Total	CSQ-VR—Nausea	CSQ-VR—Vestibular	CSQ-VR—Oculomotor
Age	-0.150**	-0.076	-0.148**	-0.156**
Sex (Male)	**-0.255*** **	**-0.218*** **	**-0.196*** **	**-0.236*** **
Education	-0.135**	-0.067	-0.120*	-0.142**
Computing XP	-0.141**	-0.137**	-0.266**	-0.037
Smartphone XP	**-0.175*** **	**-0.151** **	**-0.277*** **	-0.087
Virtual Reality XP	-0.098	-0.063	-0.167**	-0.044
GSQ—Total	**-0.215*** **	**-0.152** **	**-0.142** **	**-0.201*** **
Sport Games Skill	**-0.246*** **	**-0.204*** **	**-0.233*** **	**-0.202*** **
FPS Games Skill	**-0.204*** **	**-0.183*** **	**-0.212*** **	**-0.143** **
RPG Games Skill	-0.083	0.022	-0.078	-0.103*
Action Games Skill	-0.099*	-0.047	-0.111*	-0.108*
Strategy Games Skill	**-0.205*** **	**-0.140** **	**-0.236*** **	**-0.142** **
Puzzle Games Skill	-0.055	0.005	-0.023	-0.046
MSA—Child	0.219***	0.207**	0.128*	0.158**
MSB—Adult	**0.356*** **	**0.292*** **	**0.257*** **	**0.309*** **
MSSQ—Total	**0.276*** **	**0.257*** **	**0.194*** **	**0.209*** **
VIMSSQ	**0.269*** **	**0.183*** **	**0.231*** **	**0.286*** **

Note: XP = Experience; GSQ = Game Skills Questionnaire; FPS = First-Person Shooting; RPG = Role-Playing Games; MS = Motion Sickness; MSSQ = Motion Sickness Susceptibility Questionnaire; VIMSSQ = Visually Induced Motion Sickness Susceptibility Questionnaire; CSQ-VR = Cybersickness in Virtual reality Questionnaire; $*p \leq 0.05$, $**p \leq 0.01$, $***p \leq 0.001$.

Best Model Predictors Analysis of Cybersickness Intensity Based on Individual Differences

Mixed linear regression model analyses were conducted to evaluate the significant predictors of cybersickness intensity through individual differences. The results across Tables 3, 4, 5, and 6, which explore predictors for total cybersickness and its sub-categories, consistently affirm H1. Motion sickness susceptibility scores, which include childhood, adulthood, and VIMS, show strong positive correlations with higher cybersickness intensity across all categories. This suggests that a personal history of motion and VIMS is a critical determinant of cybersickness susceptibility, aligning with previous literature.

Contrary to Hypothesis 2, demographic factors such as age and sex emerge as potential predictors of cybersickness. Specifically, being male is associated with lower cybersickness intensity, potentially predicting reduced symptoms. Additionally, age inversely predicts total cybersickness, with older individuals likely experiencing less intense symptoms across various categories.

The analysis, which supports H3, reveals that while computer and VR experiences do not consistently predict cybersickness intensity, other experiences such as smartphone and gaming, particularly FPS games, are significant single predictors. FPS game skills notably predict a lower total intensity of cybersickness across multiple sub-categories, suggesting that certain types of gaming experiences can possibly mitigate aspects of cybersickness.

Regarding RQ1, there is substantial support for FPS games, which consistently predict lower intensity of cybersickness across all symptom categories. This low intensity in symptoms is likely due to the mitigation skills developed in managing fast-paced and immersive environments typical of FPS games, which translate well into coping with similar stimuli in a VR environment. Interestingly, action games do not show a consistent impact on cybersickness, suggesting that not all dynamically intensive games have the same properties, and that specific factors unique to FPS gaming might have a more substantial impact. In contrast, experiences with sports, strategy, puzzles, and RPG games show less consistent effects, occasionally even predicting increased cybersickness symptoms. This inconsistency might stem from the less dynamic nature of these games compared to the immersive environments of VR.

Table 3

Single Predictor Models for Total Cybersickness

Predictor	β	*p*-value	R^2 (Fixed Effects / Overall)
Age	-0.138	0.003**	0.018 / 0.217
Sex (Male)	-0.524	<0.001***	0.065 / 0.265
Education in Years	-0.173	<0.001***	0.028 / 0.228
Computing XP	-0.112	0.018*	0.012 / 0.211
Smartphone XP	-0.166	<0.001***	0.026 / 0.226
Virtual Reality XP	0.006	0.908	0.0 / 0.199
GSQ—Total	-0.166	<0.001***	0.026 / 0.226
Sport Games Skill	-0.173	<0.001***	0.028 / 0.228
FPS Games Skill	-0.195	<0.001***	0.036 / 0.236
RPG Games Skill	-0.036	0.447	0.001 / 0.200
Action Games Skill	-0.033	0.490	0.001 / 0.200
Strategy Games Skill	-0.069	0.147	0.004 / 0.204
Puzzle Games Skill	-0.021	0.662	0.0 / 0.199
MSA—Child	0.224	<0.001***	0.047 / 0.247
MSB—Adult	0.365	<0.001***	0.126 / 0.327

MSSQ—Total	0.308	<0.001***	0.09 / 0.290
VIMSSQ	0.279	<0.001***	0.074 / 0.274

Note: XP = Experience; GSQ = Game Skills Questionnaire; FPS = First-Person Shooting; RPG = Role-Playing Games; MS = Motion Sickness; MSSQ = Motion Sickness Susceptibility Questionnaire; VIMSSQ = Visually Induced Motion Sickness Susceptibility Questionnaire; CSQ-VR = Cybersickness in Virtual reality Questionnaire; *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$.

Table 4

Single Predictor Models for Nausea Symptoms of Cybersickness

Predictor	*β*	*p-value*	R^2 (Fixed Effects / Overall)
Age	-0.056	0.252	0.003 / 0.148
Sex (Male)	-0.431	<0.001***	0.045 / 0.190
Education in Years	-0.049	0.311	0.002 / 0.147
Computing XP	-0.093	0.056	0.008 / 0.154
Smartphone XP	-0.045	0.355	0.002 / 0.147
Virtual Reality XP	-0.029	0.551	0.01 / 0.146
GSQ—Total	-0.116	0.017*	0.013 / 0.158
Sport Games Skill	-0.09	0.065	0.008 / 0.153
FPS Games Skill	-0.179	<0.001***	0.031 / 0.176
RPG Games Skill	-0.042	0.394	0.002 / 0.147
Action Games Skill	-0.034	0.482	0.001 / 0.146
Strategy Games Skill	-0.079	0.103	0.006 / 0.151
Puzzle Games Skill	-0.049	0.312	0.002 / 0.147
MSA—Child	0.233	<0.001***	0.052 / 0.198
MSB—Adult	0.320	<0.001***	0.098 / 0.245
MSSQ—Total	0.294	<0.001***	0.083 / 0.230
VIMSSQ	0.096	0.049*	0.009 / 0.154

Note: XP = Experience; GSQ = Game Skills Questionnaire; FPS = First-Person Shooting; RPG = Role-Playing Games; MS = Motion Sickness; MSSQ = Motion Sickness Susceptibility Questionnaire; VIMSSQ = Visually Induced Motion Sickness Susceptibility

Questionnaire; CSQ-VR = Cybersickness in Virtual reality Questionnaire; *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$.

Table 5

Single Predictor Models for Vestibular Symptoms of Cybersickness

Predictor	β	p-value	R^2 (Fixed Effects / Overall)
Age	-0.104	0.029*	0.010 / 0.191
Sex (Male)	-0.347	<0.001***	0.029 / 0.210
Education in Years	-0.073	0.125	0.005 / 0.186
Computing XP	-0.070	0.146	0.005 / 0.185
Smartphone XP	-0.113	0.018*	0.012 / 0.193
Virtual Reality XP	-0.119	0.013*	0.014 / 0.194
GSQ—Total	-0.052	0.276	0.003 / 0.183
Sport Games Skill	-0.102	0.033*	0.010 / 0.191
FPS Games Skill	-0.165	<0.001***	0.026 / 0.207
RPG Games Skill	-0.032	0.505	0.001 / 0.182
Action Games Skill	-0.055	0.249	0.003 / 0.184
Strategy Games Skill	-0.103	0.032*	0.010 / 0.191
Puzzle Games Skill	-0.038	0.427	0.001 / 0.182
MSA—Child	0.136	0.004**	0.018 / 0.198
MSB—Adult	0.267	<0.001***	0.068 / 0.249
MSSQ—Total	0.219	<0.001***	0.045 / 0.227
VIMSSQ	0.161	<0.001***	0.025 / 0.206

Note: XP = Experience; GSQ = Game Skills Questionnaire; FPS = First-Person Shooting; RPG = Role-Playing Games; MS = Motion Sickness; MSSQ = Motion Sickness Susceptibility Questionnaire; VIMSSQ = Visually Induced Motion Sickness Susceptibility Questionnaire; CSQ-VR = Cybersickness in Virtual reality Questionnaire; *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$.

Table 6

Single Predictor Models for Oculomotor symptoms of Cybersickness

Predictor	*β*	*p*-value	R^2 (Fixed Effects / Overall)
Age	-0.193	<0.001***	0.036 / 0.174
Sex (Male)	-0.423	<0.001***	0.043 / 0.182
Education in Years	-0.161	<0.001***	0.025 / 0.164
Computing XP	-0.042	0.391	0.002 / 0.140
Smartphone XP	-0.088	0.070	0.007 / 0.146
Virtual Reality XP	0.138	0.005**	0.018 / 0.157
GSQ—Total	-0.111	0.023*	0.012 / 0.150
Sport Games Skill	-0.091	0.063	0.008 / 0.146
FPS Games Skill	-0.099	0.042*	0.009 / 0.148
RPG Games Skill	-0.010	0.834	0.0 / 0.138
Action Games Skill	0.008	0.877	0.0 / 0.138
Strategy Games Skill	0.069	0.160	0.005 / 0.143
Puzzle Games Skill	0.034	0.487	0.001 / 0.139
MSA—Child	0.147	0.002**	0.021 / 0.159
MSB—Adult	0.304	<0.001***	0.089 / 0.228
MSSQ—Total	0.221	<0.001***	0.047 / 0.186
VIMSSQ	0.312	<0.001***	0.094 / 0.233

Note: XP = Experience; GSQ = Game Skills Questionnaire; FPS = First-Person Shooting; RPG = Role-Playing Games; MS = Motion Sickness; MSSQ = Motion Sickness Susceptibility Questionnaire; VIMSSQ = Visually Induced Motion Sickness Susceptibility Questionnaire; CSQ-VR = Cybersickness in Virtual reality Questionnaire; $*p \leq 0.05$, $**p \leq 0.01$, $***p \leq 0.001$.

Continuing with the analysis of the best model predictors for overall cybersickness and its subcategories, Table 7 reveals significant findings. H1 is strongly supported, as the table indicates that adult motion sickness history and VIMS are significant predictors of cybersickness across all examined categories. Both predictors exhibit strong positive coefficients and high levels of significance, suggesting that individuals with a history of motion sickness or a high susceptibility to VIMS are likely to experience more severe cybersickness.

Regarding H2, demographic factors such as sex and age were not included in the best model predictors. This absence suggests that when accounting for all variables and the random effects in mixed regression analysis, age and sex do not significantly predict cybersickness intensity compared to the stronger predictors in the model, thereby supporting H2. Furthermore, H3 finds support in the data, specifically showing that smartphone experience significantly predicts cybersickness, with a negative β coefficient in the total and vestibular categories. This indicates that greater familiarity with smartphones may potentially reduce cybersickness symptoms.

Regarding RQ1, although the best models do not specifically include action or FPS gaming experiences as predictors, they do incorporate strategy and puzzle game experiences. Proficiency in strategy games is found to predict a small but significant increase in oculomotor symptoms, suggesting that higher skill levels in these games may predict more intense symptoms. Similarly, expertise in puzzle games is linked to a higher probability of exacerbated vestibular symptoms, indicating that not all gaming experiences are protective; some might even predict a higher level of cybersickness. The absence of action or FPS game experience as predictors in the best models means that a conclusive answer to RQ1 cannot be derived from this analysis alone, highlighting the need for further focused analysis into the effects of different gaming genres on cybersickness.

Table 7

Best models for predicting Overall and per symptom category Cybersickness Intensity

Predicted	Predictor	*β*	*p*-value	R^2 (Fixed Effects / Overall)
CSQ-VR—Total	MSB_Adult	0.315	<0.001***	0.175 / 0.376

	VIMSSQ	0.174	<0.001***	
	Smartphone XP	-0.133	<0.01**	
CSQ-VR— Nausea	MSB_Adult	0.320	<0.001***	0.098 / 0.245
CSQ-VR— Vestibular	MSB_Adult	0.282	<0.001***	0.087 / 0.268
	Smartphone XP	-0.111	0.015*	
	Puzzle Games Skill	0.094	0.042*	
CSQ-VR— Oculomotor	MSB_Adult	0.251	<0.001***	0.156 / 0.296
	VIMSSQ	0.252	<0.001***	
	Strategy Games Skill	0.117	0.009**	

Note: XP = Experience; MS = Motion Sickness; VIMSSQ = Visually Induced Motion Sickness Susceptibility Questionnaire; CSQ-VR = Cybersickness in Virtual reality Questionnaire; *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$.

In summary, the best model regression analysis highlights the significant role of predictors such as susceptibility to motion sickness and VIMS in determining the intensity of cybersickness across various symptom categories. Additionally, these results underscore the mitigating effect of smartphone experience on certain cybersickness symptoms, supporting H1-H3 and aligning with existing literature. However, the outcomes from the best regression models suggest that while certain gaming genres may predict increases in specific symptoms, the overall impact of different gaming genres on all aspects of cybersickness still needs more thorough exploration to comprehensively address RQ1.

Best Model Predictors Analysis of Cybersickness Intensity Across Different Gaming Experiences

To further address RQ1 regarding the impact of different gaming genres on cybersickness, we conducted an additional mixed linear regression best model analysis. This analysis used the same iteration structure for predictor inclusion as applied to all individual differences, but focused exclusively on different gaming genre experiences as potential predictors. The results presented in Table 8 specifically highlight the strong predictive role of FPS gaming experience across various cybersickness symptom categories. Notably, proficiency in FPS games consistently predicts a significant reduction in overall cybersickness intensity, as well as in every symptom subcategory. The strong negative β coefficient suggests that proficiency in FPS games is associated with less severe cybersickness, supporting the idea that FPS gaming could offer protective effects against all symptoms of cybersickness, thus affirming RQ1.

Interestingly, the models do not include the experience in action games as a predictor of cybersickness intensity, suggesting that specific factors unique to FPS gaming might have a more substantial impact on mitigating cybersickness. Additionally, the models include experiences in RPG, puzzle, and strategy games as positive predictors. These findings indicate that proficiency in these game genres might predict an increase in cybersickness symptoms, contrasting with the protective effect of FPS gaming. These types of games typically involve rich narratives, complex decision-making and problem-solving, with less emphasis on rapid visual tracking or dynamic visual input. This could mean that gamers of these genres are less prepared for the immersive environments encountered in VR compared to FPS gamers.

Table 8

Best Predictive Models of Overall and per symptom category Cybersickness Intensity Across Various Gaming Genres

Predicted	Predictor	*β*	*p*-value	R^2 (Fixed Effects / Overall)
CSQ-VR—Total	FPS Games Skill	-0.281	<0.001***	0.047 / 0.247
	RPG Games Skill	0.139	0.019*	
CSQ-VR— Nausea	FPS Games Skill	-0.179	<0.001***	0.031 / 0.176
CSQ-VR— Vestibular	FPS Games Skill	-0.212	<0.001***	0.038 / 0.218
	Puzzle Games Skill	0.121	0.018*	
CSQ-VR— Oculomotor	FPS Games Skill	-0.175	0.002**	0.027 / 0.165
	Strategy Games Skill	0.155	0.005**	

Note: XP = Experience; FPS = First-Person Shooting; RPG = Role-Playing Games; CSQ-VR = Cybersickness in Virtual reality Questionnaire; $*p \leq 0.05$, $**p \leq 0.01$, $***p \leq 0.001$.

Summarizing, FPS gaming experience emerges as a significant protective factor, consistently predicting lower levels of cybersickness across all symptom categories. This suggests that the immersive nature and rapid visual processing required in FPS games may equip players with resilience against the disruptive effects of cybersickness in VR environments. In contrast, experiences in RPG, puzzle, and strategy games, which involve less immersive and dynamic interactions, appear to predict increases in cybersickness symptoms. This emphasizes the unique benefits of FPS gaming in reducing cybersickness and highlights the importance of understanding how different gaming experiences influence cybersickness mitigation.

Discussion

As VR technology becomes more prevalent in educational, research, and clinical applications, understanding the factors that contribute to cybersickness becomes increasingly important. This study focused on how individual differences influence the intensity and occurrence of cybersickness symptoms during VR immersion. We analyzed the predictive value of demographic factors such as sex and age, in addition to variables like susceptibility to motion sickness, VIMS, videogame and computer experience, and experience with VR equipment. By synthesizing the outcomes of our study with existing literature, we offer a comprehensive discussion on the predictors of cybersickness, aiming to enhance strategies for predicting and mitigating its effects across VR environments.

Age and Gender Effects on Cybersickness

In our study, demographic factors such as age and gender could not significantly predict the intensity of cybersickness. While the initial analysis suggested that males and older people may experience less cybersickness, these variables were not included in the final prediction models, indicating that other factors play a more significant role in predicting cybersickness. This observation aligns with the demographic characteristics of our sample; notably, younger females reported higher levels of cybersickness. This group also had less gaming experience and higher susceptibility to motion sickness and VIMS—factors that strongly predicted the intensity and symptomatology of cybersickness.

Our previous studies (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024) have consistently found that age and sex are not significant predictors of cybersickness. In line with our past efforts to minimize gender differences (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024), we utilized the HTC Vive Pro Eye, which enables precise calibration of the IPD. Proper IPD calibration is essential for ensuring equitable VR experiences across genders, a critical factor as emphasized by K. Stanney, Fidopiastis, et al. (2020). Unlike in our prior work (Kourtesis et al., 2024), which featured a balanced sample with comparable gaming experience across sexes—a factor that moderated differences between genders (Kourtesis, Amir, et al., 2023), our current sample did not maintain this balance. This discrepancy might also account for the observed variations in cybersickness intensity between genders in our study.

Ultimately, the unbalanced gaming experience and susceptibility to motion sickness and VIMS in our sample may explain why sex and age had minimal effects on cybersickness, leading to their exclusion from the best predictive models. These findings, consistent with our prior research (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024), challenge traditional views that portray women as more susceptible to cybersickness (Chattha et al., 2020; K. Stanney, Fidopiastis, et al., 2020). This suggests that the actual influence of gender on cybersickness may be more closely tied to the extent and nature of digital interaction and other individual factors rather than inherent biological differences. However, given the limited demographic characteristics of our study, further research is necessary to explore these relationships more thoroughly and to validate our findings across broader populations. Additionally, further efforts should be made to control for the above differences among genders to ensure a more comprehensive understanding of how demographic factors influence cybersickness.

Susceptibility to Motion Sickness and Visually Induced Motion Sickness Effects on Cybersickness

Our research strongly confirms that a personal history of motion sickness, whether general or visually induced, significantly predicts cybersickness. The integration of these metrics, specifically the adult motion sickness susceptibility (MSB-Adult score from the MSSQ) and the VIMSSQ, has proven highly effective in predicting the intensity and symptoms of cybersickness. These findings are consistent with our previous study (Kourtesis et al., 2024), where the MSB-Adult score consistently emerged as a crucial factor as the best regression models for predicting cybersickness across most symptom categories.

The VIMSSQ, a tool designed to assess susceptibility specific to screen exposure (e.g., computers, smartphones and VRHMDs), was also included in the best models for overall cybersickness intensity and oculomotor symptomatology. This aligns with the literature indicating that oculomotor effects are often the initial prominent symptoms in VIMS (Cha et al., 2021; Kennedy et al., 2010; H. K. Kim et al., 2018). Accordingly, the VIMSSQ seems to effectively predict these oculomotor symptoms of cybersickness. This outcome supports the notion, also suggested by recent literature (Golding et al., 2021; Keshavarz et al., 2023; Kourtesis et al., 2024), that combining histories of general and visually induced motion sickness enhances the predictability of cybersickness intensity.

This relationship highlights the shared underlying mechanisms between motion sickness and cybersickness, notably the sensory conflicts that occur when the physical feedback expected from movement is absent in visually dynamic environments. Given that both conditions are provoked by similar motion cues, it's unsurprising that individuals susceptible to one are likely to be susceptible to the other. This is echoed in studies suggesting that patterns of susceptibility to visually induced cybersickness and general motion sickness are comparable (Golding et al., 2021; Lukacova et al., 2023).

Overall, our findings indicate that individuals predisposed to general motion sickness or VIMS are more likely to suffer from severe cybersickness. This underscores the need to consider an individual's motion sickness susceptibility and VIMS history when developing assessment and mitigation strategies for VR users, ensuring a more tailored and effective approach to managing cybersickness.

VR, Computer and Smartphone Experiences as Modulations of Cybersickness

In our study, previous VR experience did not effectively predict cybersickness, likely due to the uneven distribution of VR familiarity among our participants—many of whom had minor prior exposure to VR. This observation underscores the importance of accounting for the diversity of VR user experiences in research, a point also emphasized by the studies of Jasper et al. (2023) and Kourtesis, Amir, et al. (2023). Additionally, computer proficiency did not emerge as a predictor of cybersickness, consistent with findings from our previous studies (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024). In contrast, proficiency with smartphones significantly predicted the overall intensity of cybersickness, reinforcing our earlier findings (Kourtesis et al., 2024) that suggested extensive smartphone use correlates with lower cybersickness intensity.

This relationship is supported by research indicating that visually induced cybersickness can be triggered by exposure to any type of screen, including smartphones (Kemeny et al., 2020b; Keshavarz et al., 2019; Soewardi & Izzuddin, 2020). The pervasive nature of screen-based interactions may lead to a gradual acclimatization process, whereby regular use of smartphones enhances individuals' sensory adaptation, improving their ability to process dynamic visual content (K. Stanney, Lawson, et al., 2020). Therefore, our findings suggest that smartphone usage could serve as a mitigating factor for cybersickness, proposing that habitual interaction with digital screens might enhance an individual’s ability to cope with the sensory conflicts encountered in VR environments, thereby reducing cybersickness symptoms. This alignment with the literature underscores the importance of considering everyday digital habits when assessing susceptibility to cybersickness.

Gaming Experience as Modulation of Cybersickness

Our study indicates the significant role of gaming experience as a predictor of cybersickness intensity, reinforcing findings from our previous studies (Kourtesis, Amir, et al., 2023; Kourtesis et al., 2024; Kourtesis, Linnell, et al., 2023), and aligning with broader research (Grassini et al., 2021; Keshavarz, 2016; Pöhlmann et al., 2021, 2022; Weech et al., 2020). These studies collectively indicate that extensive gaming can acclimatize users to the complex visual and motion cues encountered in virtual environments, effectively reducing cybersickness. This mitigation is likely due to the unique demands gaming places on visual processing, spatial navigation, and psychomotor coordination (Baniqued et al., 2013; Spence & Feng, 2010), which can enhance possible individual resilience to cybersickness. However, different gaming genres may enhance various cognitive abilities, thereby influencing differently the intensity of cybersickness symptomatology.

Our study uniquely integrates the GCQ with the CSQ-VR to assess proficiency and frequency across various gaming genres and their relationship with cybersickness symptomatology. Notably, our findings clearly demonstrate that proficiency in FPS games strongly predicts reduced cybersickness across all symptom categories, including overall intensity, nausea, vestibular, and oculomotor symptoms. FPS games, known for their rapid visuals and demand for managing multiple visual stimuli within dynamic, 360-degree environments, involve extensive camera rotation movements. Such visual rotational oscillations and movements are closely associated with cybersickness symptoms intensity (Maneuvrier et al., 2023b). Moreover, the immersive first-person perspective uniquely found in FPS games significantly influences vection—a major factor of increased cybersickness intensity (Clarke et al., 2016; Denisova & Cairns, 2015; Martirosov et al., 2022; Monteiro et al., 2018; Shafer et al., 2019). Consequently, continuous engagement with such visually intense and immersive conditions may foster long-term cognitive resilience and adaptability to visually induced motion sickness. This suggests that frequent FPS gameplay could possibly equip players with a heightened resilience to cybersickness, underscoring its protective effects on cybersickness.

In contrast, other gaming genres, such as RPGs, puzzle games, and strategy games, do not appear to offer the same protective effects against cybersickness and may be linked to exacerbating symptoms. Sports and action game genres could not significantly predict any cybersickness symptomatology. RPGs, included as predictors for overall cybersickness, typically engage players with rich narratives and character interactions using a top-down camera perspective that demand less from visual dynamics, potentially leaving players less equipped for VR's immersive and motion-intensive demands. Puzzle games, which have the potential to predict increased vestibular symptoms in our models, often focus on static problem-solving and non-immersive two-dimensional graphics, which may not adequately prepare users for VR's three-dimensional environment. Similar to puzzle games, strategy games prioritize strategic thinking over rapid visual tracking, which may leave players unprepared for the intense visual dynamics of VR. This could potentially lead to increased oculomotor strain as players interact with the immersive environments of virtual reality.

This differential impact highlights the importance of considering the specific nature of gaming experiences when assessing their potential to mitigate or exacerbate cybersickness. The protective effect of FPS games may stem from their unique combination of immersive first-person viewpoints and highly dynamic graphics. These games demand rapid visual processing and complex spatial navigation—skills that are crucial for managing the sensory conflicts typical in VR environments. This experience can simulate aspects of VR, potentially fostering habituation to VR's sensory demands that lead to cybersickness. In contrast, the less dynamic and immersive interactions typical of RPGs, puzzle games, and strategy games might not adequately prepare players for VR's intense sensory environment, potentially leading to a higher susceptibility to cybersickness.

Overall, these insights underscore the complexity of how different gaming experiences impact VR interactions and suggest that the attributes of various gaming genres need to be carefully considered in cybersickness research. Further research is required to explore the mechanisms behind these genre-specific effects and determine whether the skills developed in certain gaming environments can significantly reduce the risk of cybersickness.

Limitations and future studies

This study provides valuable insights into cybersickness, but it has certain limitations that must be addressed to enhance the robustness and generalizability of its findings. The primary limitation is the relatively small sample size. Furthermore, the use of convenience sampling limits the findings' generalizability. The demographic homogeneity of the participants, particularly in terms of age, VR experience, and potentially undisclosed factors such as cultural background and physical health, may skew the results. The sample primarily consisted of young adults aged 18-45 with limited VR experience, which may not accurately represent the experiences of older adults or those with varying levels of VR exposure. Future studies should aim for larger and more diverse samples to better understand how cybersickness affects different demographics.

Future research should also investigate the impact of different types of VR content on cybersickness. For example, contrasting educational with entertainment VR experiences or static with dynamic content could pinpoint specific triggers of cybersickness. The insights gleaned could inform the design of VR content that reduces discomfort and enhances user interaction. Additionally, leveraging eye-tracking technology in the CSQ-VR to analyze gaze and pupil size could refine our comprehension of the timing and intensity of cybersickness, potentially serving as an indirect marker of its severity under various conditions. Furthermore, integrating insights from neuroscience and psychology can provide a more comprehensive understanding of cybersickness. Exploring the physiological mechanisms behind cybersickness through neuroscientific methods or applying psychological theories to understand cognitive responses to VR can deepen our knowledge and improve mitigation strategies. Involving multidisciplinary approaches in research is essential for developing effective VR experiences.

The study also underscores the intricate influence of different gaming genres on VR interactions. Further research is needed to unravel how specific genres proficiency, such as FPS, might impact cybersickness intensity and to validate whether skills developed in such gaming contexts could help mitigate the risk of cybersickness. Furthermore, while this study focused primarily on cybersickness triggered by vection—a major cause of cybersickness—additional factors like latency, poor navigation interfaces, and downgraded graphics also contribute to cybersickness and should be meticulously examined. Lastly, it is crucial that future studies delve into the long-term effects of repeated VR exposure through longitudinal research. Such studies could reveal whether users gradually become less susceptible to cybersickness as they acclimate to VR, guiding the development of strategies to mitigate cybersickness among VR users. Understanding these prolonged interactions is essential for reducing the negative impacts of VR and enhancing the user experience.

Conclusions

In this study, we have delved deeply into the possible predictors of cybersickness within VR environments, combining empirical findings with theoretical insights to advance our understanding of how individual differences impact VR experiences. Central to our findings is the significant role of susceptibility to both general motion sickness and VIMS, effectively quantified through the combined use of MSSQ and VIMSSQ. The integration of both of these metrics has proven to be highly effective in predicting the intensity and occurrence of cybersickness, emphasizing the pivotal influence of pre-existing susceptibilities in shaping VR interactions. Our analysis also indicates that demographic factors such as age and gender, initially thought to influence cybersickness, did not retain their predictive power in the refined models. This suggests that experiential factors, particularly those related to digital interaction like gaming and smartphone usage, are more decisive in influencing cybersickness outcomes when considering the random effects in the regression models. This outcome highlights the complex interplay between biological traits, personal experiences, and technological exposure in VR environments.

Notably, immersive gaming experiences, particularly with FPS games, has emerged as an effective mitigator of cybersickness across all symptom categories. This protective effect is likely due to the immersive and dynamic nature of FPS gaming, which closely simulates the sensory demands of VR environments, thus fostering a form of sensory adaptation. This suggests that specific gaming experiences could effectively precondition users for VR environments, and therefore reduce the severity of cybersickness symptoms. Conversely, less dynamic game genres like RPGs, strategy, and puzzle games do not seem to provide the same protective benefits and could potentially predict certain cybersickness symptoms due to their lack of immersive and dynamic interaction. Therefore, the type of gaming experience could significantly influence VR tolerance.

The findings of this study not only enhance our academic understanding, but also offer practical applications for the design and use of VR systems across different sectors. By pinpointing cybersickness predictors, VR experiences can be tailored more effectively to individual needs, reinforcing both the accessibility and utility of VR in education, innovation, and entertainment. Developers can make specific design changes, such as adjustable visual settings, to accommodate users prone to motion sickness, thereby creating more inclusive and comfortable VR environments. These modifications could enable users to adjust visual parameters like field of view and motion sensitivity, reducing the incidence of cybersickness. Additionally, the implications extend to policy and training in VR usage, where guidelines based on these findings could help educational and professional settings tailor VR experiences to individual susceptibilities. For example, institutions could implement pre-use screenings and offer personalized settings or gradual exposure to VR, enhancing safety and accessibility. Further research is necessary to extend these insights across a broader demographic and refine strategies for mitigating cybersickness.

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