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Mitigating Cybersickness in Virtual Reality: Impact of Eye–Hand Coordination Tasks, Immersion, and Gaming Skills

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Abstract: Cybersickness remains a significant challenge for virtual reality (VR) applications, particularly in highly immersive environments. This study examined the effects of immersion, task performance, and individual differences on cybersickness symptoms across multiple stages of VR exposure. Forty-seven participants aged 18–45 completed a within-subjects design that involved the Cybersickness in Virtual Reality Questionnaire (CSQ-VR) and the Deary–Liewald Reaction Time (DLRT) task. Cybersickness symptoms were assessed across four stages: before and after VR immersion, and before and after a 12 min rollercoaster ride designed to induce cybersickness. The results showed significant increases in symptoms following the rollercoaster ride, with partial recovery during the post-ride tasks. Eye–hand coordination tasks, performed after the ride and VR immersion, mitigated nausea, as well as vestibular, and oculomotor symptoms, suggesting that task engagement plays a key role in alleviating cybersickness. The key predictors of symptom severity included a susceptibility to motion sickness and gaming experience, particularly proficiency in first-person shooter (FPS) games, which was associated with a reduced cybersickness intensity. While task engagement reduced symptoms in the later stages, particularly nausea and vestibular discomfort, overall cybersickness levels remained elevated post-immersion. These findings underscore the importance of task timing, individual differences, and immersive experience design in developing strategies to mitigate cybersickness and enhance user experiences in VR environments.

Keywords: virtual reality; cybersickness; VR sickness; motion sickness; reaction time; eye–hand coordination; immersion; mitigation; gaming skills; IT skills

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1. Introduction

Virtual reality's (VR) popularity has gained a lot of momentum in recent years due to its increasing usefulness and applicability in various fields outside of the entertainment industry. This surge in popularity owes itself in big part to the release of more accessible head-mounted displays (HMDs) (e.g., Meta Quest 1 and 2), which made the use of VR more enticing in research. Some of VR's varied uses include the training of health professionals [1], general education and skill learning [2], engineering and product design [3], predicting consumer behavior [4], improving athletic performance [5], improving elderly people's well-being [6], as well as assisting with psychological research and experimentation [7,8] and psychological screening for certain disorders, such as schizophrenia or ADHD [9,10].

However, one prevalent obstacle to the applicability of VR in research that is most often discussed in the literature is cybersickness. Cybersickness, or virtual reality-induced symptoms and effects (VRISEs), refers to a set of symptoms that usually include disorientation, dizziness, nausea, imbalance, and/or oculomotor strain and fatigue. Cybersickness

should not be confused with simulator sickness. While they do share similarities, cybersickness tends to induce more disorientation symptoms in users, such as dizziness, vertigo, or general discomfort, whereas simulation sickness causes more oculomotor symptoms, such as eyestrain or headaches [11,12]. It also differs from motion sickness, where the main contributing factor is vestibular stimulation, whereas, in the case of cybersickness, it is mainly a result of visual stimulation [13].

One of the most cited theories that attempts to explain the negative aftereffects of VR use is the Sensory Conflict Theory [13,14]. This theory suggests there is a discrepancy between the information provided by the vestibular and visual systems. This provides an experience different from people's sensory expectations, which have formed based on their past experiences. Humans experience discomfort as they receive movement information from the visual system while wearing the HMD, but they remain physically stationary, which means that there is no movement information received from the vestibular system, despite an expectation for it. This sensory conflict is what causes VRISEs. Visual information that includes more complex self-motion leads to even more intense conflict and more cybersickness symptoms [15]. Cybersickness poses a threat to VR's applicability since it contributes to the creation of a negative experience for a lot of people, which might even lead to a portion of them rejecting this technology altogether. In this paper, we aim to explore how completed tasks inside VR can have a mitigating effect on cybersickness symptoms. Additionally, we shall explore how individual factors, like gaming habits, and the act of exiting VR, can affect cybersickness experienced, as well as the possible negative aftereffects on reaction times.

1.1. Eye–Hand Coordination Tasks in VR

What might play a significant role in the mitigation process for the VRISEs is the task the participants are asked to perform while inside VR. Adapting to a virtual environment might mean that users will need to readapt to the physical world afterwards to reduce negative symptoms [16]. A recalibration process might occur during which users simply stay idle and wait for the symptoms to subside; a mitigation strategy called natural decay. Alternatively, a different option is for users to complete an activity to help them mitigate their symptoms. Champney et al. [16] reported that a peg-in-hole task, an eye–hand coordination task, can help alleviate VR-induced discomfort after the end of a session. The purpose of the task is to supply the participants with sensory information, reducing tactile and visual conflicts by allowing them to place 25 pegs in holes on a pegboard, thus facilitating corrections to visuospatial distortions and balancing their senses.

Years later, Curtis et al. [17] performed an experiment where the participants would either wait 15 min after a motion sickness-inducing VR task for their symptoms to subside or complete a virtual peg-in-hole task. In the second case, the task required the participants to use a controller to place the pegs into a board with straw-like holes and it would end if either the board was completed or after 15 min had elapsed. Both conditions showed significant improvement in their symptoms without any significant difference between them. Natural decay, eye–hand coordination tasks, virtual natural decay (staying inside an idle virtual environment without movement), and virtual eye–hand coordination tasks have also been tested against each other as possible mitigation methods. In a different study, although the virtual eye–hand coordination task had the slightest influence on a decrease in symptoms, it still had a comparable effect to the other mitigation methods [18].

However, the potential mitigating effects of eye–hand coordination tasks on cybersickness have not been thoroughly explored. For instance, while the Deary–Liewald Reaction Time task [19] used in previous studies involves eye–hand coordination, its potential for reducing cybersickness symptoms has never been systematically examined. The VR version of the DLRT requires synchronization between the visual stimuli and the participant's physical and virtual body movements, which could play a significant role in alleviating symptoms. Despite its relevance, the extent to which eye–hand coordination tasks mitigate cybersickness remains unclear. This gap in the literature presents an opportunity to

investigate whether such tasks interfere with or reduce cybersickness symptoms and to what degree. Addressing this gap is essential for developing more effective strategies to manage cybersickness in VR, particularly for novice users. Understanding these effects could lead to better guidelines for VR use in professional settings and inform the design of VR applications that prioritize user comfort and engagement.

1.2. Exiting VR

A recent study by Kourtesis et al. [20] produced some interesting results regarding the importance of the specific time intervals at which participants are asked to rate their cybersickness symptoms, i.e., before entering the VR, inside the VR, and after exiting the VR. After removing the VR headset, the cybersickness ratings significantly decreased compared to those made inside the VR environment. Specifically, the nausea and vestibular symptoms scores decreased while their oculomotor symptoms remained stable after the immersion. The authors suggest that this finding might be of great importance, as cybersickness ratings in most studies usually occur after the VR headset has been removed and not during an immersion. This means that previous studies might have undermined the effects of cybersickness possibly due to lower ratings being reported after exiting VR.

Moreover, another study tested different levels of immersion based on the type of equipment used by the participants and compared them in terms of their cybersickness scores [21]. The low-immersive group completed the assigned task using a PC with a monoscopic screen, the semi-immersive group used a CAVE system, and the fully immersive group wore a VR headset. The control group did not use any equipment. The fully immersive group produced the highest cybersickness scores out of the three, a finding that further illustrates that being inside a VR environment produces more cybersickness than being in a virtual environment with lower immersion or entirely outside of the virtual environment.

The moment of exiting a VR environment has remained largely understudied. Knibbe et al. [22] assigned 24 participants to four different VR scenarios for 10 min and then interviewed them about what happened when they removed their VR headset. The results from this study describe the act of exiting VR as a brief but intense process where users can experience feelings of disorientation or fast changes to sensory stimuli. This transitional experience also included alterations to how the participants perceived time, space, and control. The readjustment to the physical world can be dynamic, and the sensory adaptation that ensues may explain how specific cybersickness symptoms may be experienced differently or less intensely by participants when exiting a virtual world.

In conclusion, the recent findings suggest that there might be a discrepancy between self-reporting inside a virtual environment and self-reporting in the real world [20]. There is a big gap in the previous literature regarding the time points in the experiment during which researchers decide to measure cybersickness. Most research has only allowed participants to rate their discomfort before and after a VR session, or, like in the case of [23], the researchers had to ask the participants to give a cybersickness rating orally, which can be problematic for maintaining immersion. To our knowledge, only two studies have explained in detail in their methodology a way to allow their participants to rate their discomfort without taking them out of the VR experience [20,24]. It is important to discuss the possibility that the ratings inside a VR environment might be more intense compared to the ratings after the end of a session. To do that, more research is needed that includes even more frequent ratings during immersions.

1.3. Cybersickness and Reaction Times

Reaction times can be defined as the amount of time that passes between the start of a stimulus and the start of the response [25]. Various factors can negatively affect reaction times, such as age [26], sleep deprivation [27], illness [28], and alcohol consumption [29]. Similar reports have been made for cybersickness symptoms, with nausea ratings correlating with a 20–50 ms increase in reaction times [23,30]. Based on these results, it has been suggested that a virtual environment causes spatial disorientation due to sensory conflict,

and more attentional resources are spent to deal with this instead of the reaction time task. In [31], the participants controlled navigation in VR while wearing an HMD with either a gamepad or a bike ergometer. Another group experienced VR on a large TV screen using a bike ergometer for navigation, and a fourth group acted as control and did not participate in any activity (20 participants in each group). The VR activity included riding a bike on an island, and in between the rides on different paths, the participants filled out the SSQ presented on a visual hologram. In total, the VR activity lasted 10 min. While all the VR conditions showed a significant increase in reaction times compared to the control condition, the correlations between cybersickness levels and increases in reaction times were very weak. This led the authors to conclude that there appears to be a general VR aftereffect caused by the visual motor adaptation to a virtual environment, which causes a slight deterioration in reactions, regardless of self-perceived levels of cybersickness. Additionally, in a study with less provocative VR stimuli, the participants were asked to play a simple game of Minecraft VR for 15 min. However, no significant increase in reaction times was reported [32].

Within a different methodological framework, Szpak et al. [33] asked participants to play a VR tennis game and complete the CANTAB five-choice reaction time test and an SSQ before and after a VR session. Compared to the control group, the VR group showed an increase in reaction times, but only on the cognitive component of the test, not the motor component. However, this increase was not related to SSQ scores. On the other hand, Kourtesis et al. [34] decided to measure reaction speeds within a VR environment, consisting of attentional speed (recorded as the time it took the eyes to reach the target) and motor speed (calculated as the remaining time after the eyes reached their target until the participant's hand pressed the correct button). It was shown that cybersickness played a significant role and had a large effect on attentional speed but a small effect on motor speed. The authors suggested that the overall reaction time increase is primarily due to the deterioration of attentional speed.

Understanding how cybersickness influences cognitive functions like reaction times is crucial. However, the previous research findings remain conflicting. Most studies have found that reaction times increase after exposure to a virtual environment, but it is not yet clear if this can be mainly attributed to the cybersickness factor.

1.4. Demographics and Cybersickness

Age appears to influence the intensity of cybersickness, though the evidence is inconsistent. Some research suggests that older adults are more susceptible to intense cybersickness, often leading them to exit VR simulations prematurely due to discomfort. This increased vulnerability in older adults has been linked to factors like postural instability, which may worsen with age and increase the risk of cybersickness [35–38]. However, other studies suggest that older adults may experience less cybersickness, potentially due to differences in physical conditions [39,40]. Interestingly, the studies focusing on younger populations have not found age to be a significant predictor of cybersickness severity [20,34]. These conflicting findings highlight the need for further research across diverse age groups to better understand how age influences cybersickness.

Gender also plays a nuanced role in cybersickness, with studies offering varied conclusions. Some research indicates that women may be more sensitive to cybersickness, pointing to possible gender differences [18,38,41]. However, other studies did not find significant differences between genders, suggesting that societal factors might influence reporting behaviors—women historically report health symptoms more frequently, while men may underreport them due to traditional expectations of masculinity [42–45]. Objective physiological measures like heart rate and EEG generally show negligible gender differences, contrasting with self-reported data that suggest gender-specific sensitivities [46,47].

Further complicating the issue, recent studies question whether biological sex significantly influences VR discomfort. When VR headsets are properly adjusted, particularly with regard to Inter Pupillary Distance (IPD), gender differences in cybersickness largely

disappear, suggesting that the fit and customization of VR equipment are more crucial than inherent gender differences [45]. Additionally, previous research indicates that gaming experience may influence cybersickness, with differences between genders diminishing when accounting for familiarity with digital environments [20,34].

1.5. 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 [48]. 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 [49,50]. Dysfunctions in the vestibular system can reduce the incidence of motion sickness, while an increased reliance on somatosensory inputs may heighten susceptibility [49,51]. 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 [30,45,52,53].

Cybersickness, similar to motion sickness, shows varied susceptibility patterns among individuals, influenced by both physiological and sensory processing factors [54,55]. 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 [49]. 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 [54,56,57].

Despite the limited predictive power of the MSSQ for cybersickness intensity observed in earlier studies [24,34], potentially because it was used to exclude the participants with high MSSQ scores, our latest study identifies it as a significant predictor of cybersickness [20]. In line with the suggestions from previous studies [54,55], our study proposes that combining the MSSQ with the VIMSSQ may offer a more comprehensive understanding of both motion sickness and VIMS susceptibility. This integrated approach could enhance the prediction of cybersickness intensity and help determine whether general susceptibility to motion sickness or a specific sensitivity to vection plays a more significant role in cybersickness symptomatology and intensity.

1.6. Technology Experience and Cybersickness

As technology advances, more people are shifting from desktop computers to mobile devices for their daily digital activities. While desktops are still used for complex tasks, smartphones have become the go-to devices for many functions like internet browsing, emailing, and media editing [58]. This shift is driven by smartphones' portability and ease of use.

In our earlier study, computer experience alone was not a strong predictor of cybersickness [20,34]. However, studies show that visually induced cybersickness can occur from exposure to any screen, including smartphones [57,59,60]. Regular use of smartphones might help reduce cybersickness by gradually acclimating users to dynamic visual content, enhancing their sensory adaptation [61]. Our latest study supports this, showing that frequent smartphone use is linked to a lower cybersickness intensity [20]. This suggests that as smartphones become more prevalent, regular use may help mitigate cybersickness.

Moreover, people with extensive VR experience often report a lower susceptibility to cybersickness, likely due to habituation over time [49,62,63]. Regular and varied use of VR could build resilience to cybersickness, though the results vary across studies. While some research shows an increased resilience in experienced VR users, others find no significant differences [64]. The recent studies by Jasper et al. [52] and Kourtesis et al. [34] did not find strong evidence for this resilience, possibly due to a lack of diversity in VR user experience

in their samples. This highlights the need to consider individual differences in technology experience when studying cybersickness.

1.7. Gaming Experience and Cybersickness

Research has increasingly shown that gaming is associated with reduced cybersickness intensity [65–70]. 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 [20,24,34]. 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 [71]. These findings indicate a complex relationship between gaming experience and individual susceptibility to cybersickness, implying that nuanced aspects of gaming experience could significantly influence its impact on cybersickness.

The wide range of gaming genres, including action, first-person shooters (FPSs), and role-playing games (RPGs), significantly influences players' physiological and biochemical states and enhances various cognitive abilities [72–74]. Each genre's unique demands on visual processing, spatial navigation, and psychomotor coordination could potentially bolster individual resilience to cybersickness, tailored by specific gaming experiences [20].

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 [74]. Such gameplay involves extensive camera rotations, where visual rotational oscillations and movements are closely linked with the emergence of cybersickness symptoms [75]. Regular exposure to these challenging conditions might build 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 [75]. While a first-person perspective intensifies the immersion, it may also escalate cybersickness intensity due to increased sensory conflicts [21,76–79]. 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.

1.8. Research Aims

As it has become clear from this short literature review, there are still a lot of open questions about cybersickness. Factors that can influence cybersickness rates, for example, VR tasks, the act of exiting VR, and cybersickness' possible detrimental effects on reaction times hold scientific significance. Additionally, the ongoing research explores how individual differences—such as technological proficiency, age, gender, and innate 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. Consequently, the research aims of this study are further articulated in the following hypotheses and research question:

H1: *Cybersickness scores will be lower after the task than before the task.*

H2: *Cybersickness scores will be higher in VR compared to Post-VR.*

H3: *Participants' reaction times will deteriorate after the ride and Post-VR.*

H4: *Susceptibility to Motion Sickness and/or VIMS will be the significant predictor(s) of the intensity of cybersickness.*

H5: *The demographics of the participants will not significantly predict cybersickness intensity.*

H6: *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?*

2. Materials and Methods

2.1. Participants

Participants were recruited through two different channels: (1) We contacted as many students as possible through the email address listings of the National and Kapodistrian University of Athens, asking them to participate in a study about cybersickness in VR. We also distributed flyers around the campus. (2) Snowball sampling was used for the participants who did not belong to our institution. This led to half of our sample consisting of psychology students. This study was approved by the Research Ethics Committee of the National and Kapodistrian University of Athens.

In total, 48 people participated in this study. However, one participant had to drop out due to increased levels of discomfort shortly after the ride and did not wish to continue. This left us with a sample of 47 participants, which consisted of 24 females and 23 males. The mean age was 27.4 (from 18 to 45 years; SD = 5.78). The years of education had a mean of 16.8 (SD = 2.04; Min = 12, Max = 23). Basic information about technological literacy was also collected, with 89.3% of the sample reporting that they were at least somewhat skilled with computers and would use one daily. Furthermore, 93.6% reported that they were at least somewhat skilled with smartphones and would use one daily. Most of the sample had never used VR (68.1%) or had only used it once or a few times in their lives (21.3%). Of the participants, 48.9% reported high gaming activity, and 51.1% reported low or no gaming activity.

2.2. Measures

The Deary–Liewald Reaction Time test [19] was used to measure reaction times, and it consisted of two tasks that took place on a web browser page. In the simple reaction time task (SRT), the participants were asked to observe an empty white box and press the space button as fast as possible each time an "X" letter appeared inside it. In the choice reaction time task (CRT), the participants were presented with four empty white boxes placed next to each other. Two fingers from each hand had to be placed on the four keyboard buttons that mirrored the order of the white boxes on the screen. Whenever an "X" letter appeared in one of them, the participants had to press the button corresponding to the correct box as fast as possible. A VR version of DLRTT was also used. Standing upright and using the virtual controllers, the participants inside the simulation had to extend their arms and touch a white box as soon as it turned blue. The same procedure was followed when four white boxes were presented.

Although the Simulator Sickness Questionnaire [80] is widely recognized, we employed the Cybersickness in Virtual Reality Questionnaire (CSQ-VR) due to its superior psychometric properties for measuring cybersickness, as demonstrated by Kourtesis et al. [24]. Unlike the SSQ, developed for simulator sickness, the CSQ-VR specifically targets cybersick-

ness and is better suited to assess virtual reality-induced symptoms and effects (VRISE). The CSQ-VR includes six 7-point Likert scale questions, with two items each assessing nausea, as well as vestibular, and oculomotor symptoms (e.g., "Do you experience disorientation, such as confusion or vertigo?" rated from 1: Not at all to 7: Extremely intense). Notably, the CSQ-VR also has a 3D version designed for use within a virtual environment, allowing participants to complete the questionnaire during immersion. This feature enables the continuous assessment of cybersickness symptoms without breaking immersion, providing a more accurate real-time measure of the experience. The CSQ-VR's superior psychometric properties and ability to capture symptoms during VR immersion make it an ideal tool for this study.

To collect demographic information, including gender, age, education, and prior computer, smartphone, and VR experience, a customized questionnaire was used. This questionnaire, previously employed in our studies [20,24,34], 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 [81,82].

This study incorporated the short versions of the MSSQ [49] and VIMSSQ [54,56] to assess motion sickness and VIMS susceptibility. The MSSQ evaluates childhood (before age 12) and adult experiences (over the last 10 years) with motion sickness across different modes of transport or entertainment, yielding three scores: MSA-Child, MSB-Adult, and MSSQ-Total. The VIMSSQ focuses on symptoms like nausea, headaches, and eye-strain caused by visual devices, providing a complementary assessment to the MSSQ for predicting cybersickness [54,57].

2.3. Procedure

Upon arrival, the participants were briefed on the study procedures outlined in Figure 1 and agreed to a formal consent form. The form included explicit information about the study's aims, the different questionnaires used, and the VR tasks. It highlighted that the data collected are entirely anonymous, that participation is completely voluntary, and that they can leave the laboratory whenever they wish. They were also instructed that if their symptoms were too severe and they could not continue inside the virtual environment, they should immediately inform the researcher to terminate the process.

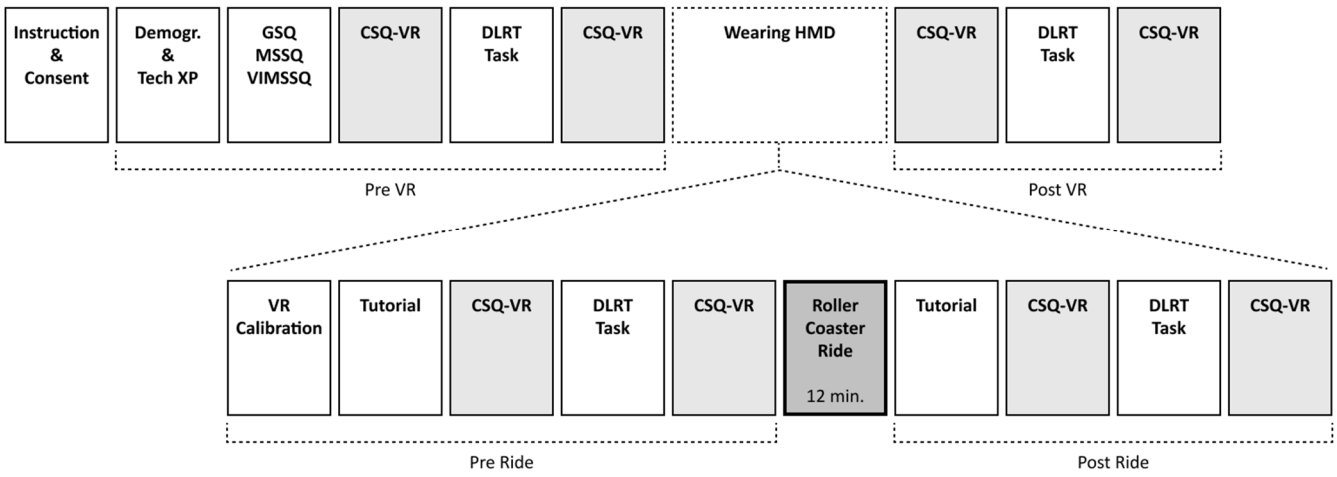


Figure 1. Designed protocol for cybersickness evaluation.

The questionnaires were created and completed using Google Forms. The participants first filled out the demographic questionnaire and the MSSQ, VIMSSQ, and GSQ. Afterwards, the order of test completion was as follows: CSQ-VR, DLRT, CSQ-VR. After the pre-immersion stage was over, the participants were asked to stand up and were given instructions on how to wear the HMD. Calibration ensued inside the Steam Lab application to ensure that the HMD and the interpupillary distance fit everyone well. Then, the participants received the controllers, and the task began. An HTC Vive Pro Headset was used with a 3.5″ AMOLED display, 2880 × 1600 pixels resolution per eye, 90 Hz refresh rate, 110° field of view, and 3D spatial sound. This hardware exceeds the requirements for preventing cybersickness [83], ensuring any cybersickness was due to designed accelerations, not hardware limitations. The VR software followed the guidelines proven to minimize cybersickness [84,85].

Specifically, the virtual environment was developed using the Unity3D game engine, incorporating several advanced features to enhance realism and maintain performance. We used the SteamVR SDK for interaction design, which facilitated intuitive hand animations and provided haptic feedback to increase immersion. Lighting within the environment was configured using the Lightweight Render Pipeline (LWRP), employing baked lights to optimize rendering efficiency. Textures and meshes were also baked and optimized extensively using the MeshBaker package, which significantly reduced draw calls and maintained a consistent 120 Hz refresh rate, crucial for minimizing cybersickness. Furthermore, spatial audio feedback was integrated using Steam Audio, ensuring realistic and immersive soundscapes that dynamically responded to the user's position and actions within the virtual space. This comprehensive setup was designed to create a stable and engaging VR experience, minimizing performance-related discomfort and enhancing the overall user experience.

Oral instructions were delivered via Amazon Polly to provide a clear, natural voice without disrupting the participants' immersion. In addition to spoken instructions, video and written guidelines were provided, covering how to complete both the VR version of the CSQ-VR and the VR version of the DLRT task. The virtual environment was developed using the Unity3D game engine, following the methods used in previous cybersickness studies [20,24,34]. Interaction within the environment was enhanced by the SteamVR SDK, using virtual hands/gloves for intuitive engagement, allowing touch-based actions instead of button presses to create a more natural user experience. 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.

To eliminate potential biases related to gender or race, the virtual gloves were designed to be neutral, as recommended by prior studies [86]. The experimental design was managed using the bmlTUX SDK [87], which allowed easy data export in CSV format and streamlined the experimental protocol.

The process in VR was as follows: the participants received the instructions on how to complete the questionnaire, filled out the CSQ-VR, received instructions on how to complete the DLRT task, and after they completed it, filled out the CSQ-VR again. This initial baseline assessment phase lasted approximately 25 min. A 12 min roller coaster ride ensued. During the ride, the participant stands on a platform that moves forward inside a minimalistic black-and-white design to reduce distractions and avoid the extraneous variables affecting cybersickness onset. In line with the previous studies [20,34], the ride was designed to simulate a roller coaster, exposing the participants to various linear and angular accelerations. The animated trajectory moved primarily forward, with a reverse on the z-axis toward the end. The acceleration sequence was carefully planned: starting with linear acceleration on the z-axis, followed by angular accelerations on the z- and y-axes, and then comprehensive angular acceleration on the z-, x-, and y-axes. This was followed by roll-axis angular acceleration, intensified z-axis linear acceleration, yaw-axis angular acceleration, and extreme y-axis linear acceleration, ending with a z-axis reversal. After the

ride ended, the participants completed the same tutorial and sequence of tasks—CSQ-VR, DLRT, and CSQ-VR again in that order. Then, the immersion ended.

After the participants carefully removed the VR headset, they were asked to sit in front of the computer immediately and complete the CSQ-VR, DLRTT, and CSQ-VR once again, in this order. The CSQ-VR was completed eight times in total during the experiment. This was to ensure that we recorded all the possible fluctuations in cybersickness rates' intensity. The CSQ-VR was also filled out immediately after an exit from the immersion, which made it easier to monitor any changes that might be due to the change in immersion stage. After the experiment was over (approximately 1 h later), the participants received beverages rich in electrolytes to reduce any lingering symptoms and were asked to stay in the laboratory for a few more minutes if the cybersickness adverse effects were very intense and leave only when they felt better.

2.4. Statistical Analyses

All statistical analyses were conducted using the R programming language [88] within the RStudio environment [89]. The following R packages were used: psych for *t*-tests and correlational analyses [90], ggplot2 for data visualization [91], lme4 for repeated measures ANOVA and mixed-effects regression models [92], emmeans for post-hoc comparisons [93], and bestNormalize for data normalization [94].

2.4.1. Descriptive Statistics and Normality Checks

Descriptive statistics were computed to provide an overall summary of the sample characteristics. Normality was assessed using the Shapiro–Wilk test, which revealed violations of normality in several variables ($p < 0.001$). To address this, data were transformed using the bestNormalize package, which applied optimal transformations, and all numeric variables were subsequently converted to z-scores, allowing for the use of parametric tests.

2.4.2. Repeated Measures ANOVA (H1 & H2)

To evaluate the changes in the cybersickness scores before and after the task (H1), as well as before and after the VR session, repeated measures ANOVAs were performed. The dependent variable was the CSQ-VR score, and the independent variables were the Task Stage (pre-task vs. post-task) and Immersion Stage (pre-VR, pre-ride, post-ride, post-VR). Linear mixed-effects models were used, with participant ID included as a random effect to account for repeated measures. Post-hoc pairwise comparisons were conducted using the emmeans package with Bonferroni correction to adjust for multiple comparisons.

2.4.3. Paired-Samples *t*-Tests (H3)

Paired-samples *t*-tests were employed to evaluate H3, comparing the performance on the PC version of the DLRT tasks before and after the VR session, as well as the performance on the VR version of the DLRT tasks before and after the VR ride. These tests examined whether cybersickness induced changes in reaction times, both before and after their exposure to the VR tasks and ride.

2.4.4. Mixed-Effects Regression Models (H4–H6 and RQ1)

Mixed-effects regression models were used to investigate H4, H5, H6, and RQ1, assessing the effects of various predictors—such as motion sickness susceptibility, VIMS Susceptibility, demographics, and technology experience—on the intensity of cybersickness symptoms. Participant ID was included as a random effect to account for repeated measures within individuals.

The model comparisons were based on the adjusted R^2 and the F-statistic. The models with higher R^2 values and significant F-statistics were selected as the best-fit models. Specifically, the following:

- For H4, we examined whether susceptibility to motion sickness and VIMS predicted overall cybersickness intensity.

- For H5, demographic factors such as age and sex were tested as predictors of cybersickness intensity.
- For H6, the effect of prior experience with computers, smartphones, gaming, and VR on cybersickness symptoms was evaluated.
- For RQ1, we tested whether action or FPS game genres predicted lower levels of cybersickness symptomatology.

Our methodological approach considered a wide range of variables as potential predictors within the models. Specifically, for the mixed-effects regression analyses aimed at gauging the intensity of cybersickness across its subcategories, factors such as sex, education, age, computing experience, smartphone app experience, prior VR experience, and gaming experience (with various sub-genres) were included. The model development followed a systematic and incremental process:

Single-Predictor Models: Initially, individual models were built with only one predictor at a time. These models were compared based on their adjusted R^2 and F-statistics to determine which predictor had the most substantial effect on cybersickness intensity.

Dyadic Predictor Models: In the next phase, models with two predictors were constructed. The best-performing predictor from the single-predictor models was retained, and a second predictor was added from the remaining variables. Each dual-predictor model was thoroughly evaluated, and the best-performing model was compared to the top single-predictor model to assess improvements in fit.

Iterative Model Development: This step involved an iterative process where the strongest predictors from the previous rounds were combined with a new predictor. This approach was continued until adding more variables no longer resulted in a significant improvement in the model's performance, as indicated by the adjusted R^2 and F-statistic. If a simpler model from an earlier iteration demonstrated superior performance over a more complex one, the simpler model was retained. Ultimately, the final best model, selected through this systematic approach, represented the optimal combination of all the considered predictors and provided the most robust explanation of cybersickness intensity.

3. Results

3.1. Descriptive Statistics

The descriptive statistics of the dataset are detailed in Tables 1 and 2. Regarding technology usage, the participants exhibit strong familiarity with computing and smartphones. However, their experience with VR is considerably lower, indicating that VR is less familiar than other forms of technology. The gaming experience data show a broad range of proficiency among the participants. This diversity is also seen in specific gaming genres, such as first-person shooters, role-playing games, action games, and puzzles, which could influence how the participants perceive and handle VR environments due to differences in the cognitive skills developed through gaming. Regarding susceptibility to motion sickness, there is a notable shift in the scores from childhood to adulthood, suggesting that sensitivity to motion sickness may decrease as one ages. The visually induced motion sickness susceptibility scores are generally low but show considerable variability among the participants.

Tables 2 and 3 present the descriptive statistics of the CSQ and DLRT scores. All eight time points at which CSQ data were captured can be seen on the left of the table, with four points occurring while the participants were inside of VR and four points while they were outside, before or after each task. After taking a first look, we can see there was a sharp increase in cybersickness scores after the ride was over. Next, the participants' average scores in seconds are reported for the results of the DLRT test. An increase in the SRT was observed after the end of the VR session, as well as a reduction in the CRT.

Table 1. Descriptive statistics for demographics, computing experience, smartphone experience, VR experience, gaming experience, and genre proficiency.

	M	SD	Minimum	Maximum
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

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.

Table 2. Descriptive statistics for CSQ and DLRT scores for every time point.

CSQ-VR	M	SD	Minimum	Maximum
Pre-VR–Pre-Task	7.62	1.92	6	15
Pre-VR–Post-Task	7.96	2.25	6	15
Pre-Ride–Pre-Task	8.85	3.26	6	18
Pre-Ride–Post-Task	9.36	4.26	6	24
Post-Ride–Pre-Task	14.5	7.23	6	32
Post-Ride–Post-Task	12.9	6.42	6	33
Post-VR–Pre-Task	12.2	6.02	6	29
Post-VR–Post-Task	10.8	4.63	6	23

Note: CSQ-VR = Cybersickness in Virtual Reality Questionnaire.

Table 3. Descriptive statistics for Deary–Liewald Reaction Time scores (Simple Reaction Task—Choice Reaction Task) for every time point.

DLRT (SRT—CRT)	M	SD	Minimum	Maximum
SRT–Pre-VR	0.270	0.0311	0.224	0.375
CRT–Pre-VR	0.439	0.0672	0.346	0.682
SRT–Post-VR	0.284	0.0392	0.218	0.399
CRT–Post-VR	0.421	0.0520	0.311	0.566
CRT–Pre-Ride	0.585	0.0948	0.437	0.867
SRT–Pre-Ride	0.511	0.0753	0.370	0.759
CRT–Post-Ride	0.578	0.0935	0.426	0.893
SRT–Post-Ride	0.500	0.0786	0.296	0.678

Note: SRT = Simple Reaction Time Task; CRT = Choice Reaction Time Task.

3.2. ANOVA Analyses: Cybersickness Symptomatology Intensity

3.2.1. Overall Cybersickness

The ANOVA analysis revealed several statistically significant effects related to the impact of immersion and task time on overall cybersickness (i.e., CSQ Total Score). There was a significant main effect of immersion, $F(3, 322) = 62.19$, $p < 0.001$, with a moderate effect size of $\omega^2 = 0.17$, indicating that the stages of immersion (pre-VR, pre-ride, post-ride, post-VR) significantly impacted the cybersickness levels. However, the main effect of task time was not significant, $F(1, 322) = 2.20$, $p = 0.139$, suggesting that the duration of the task

performance did not independently influence the cybersickness scores. However, there was a significant interaction between immersion and task time, $F(3, 322) = 2.79$, $p = 0.041$, with a small-to-moderate effect size of $\omega^2 = 0.01$. This interaction indicates that the effect of immersion on cybersickness varies depending on when the task was performed, suggesting that task timing plays a role in the severity of symptoms experienced across the different immersion stages.

The post-hoc comparisons across the different stages of immersion (pre-VR, pre-ride, post-ride, and post-VR) revealed significant changes in symptoms over time (see Figure 2). A moderate increase in cybersickness was observed between the pre-VR and pre-ride stages, with a significant effect size (Hedges' $g = 0.52$, $p = 0.0016$). This suggests that participants began to experience mild cybersickness symptoms even before the rollercoaster ride, likely due to the initial exposure to the VR environment and tasks. The largest increase in cybersickness occurred after the rollercoaster ride, as indicated by a significant difference between pre-ride and post-ride scores (Hedges' $g = 1.37$, $p < 0.001$). The participants' cybersickness symptoms intensified considerably following the 12 min ride, confirming the ride's potent effect on inducing severe cybersickness.

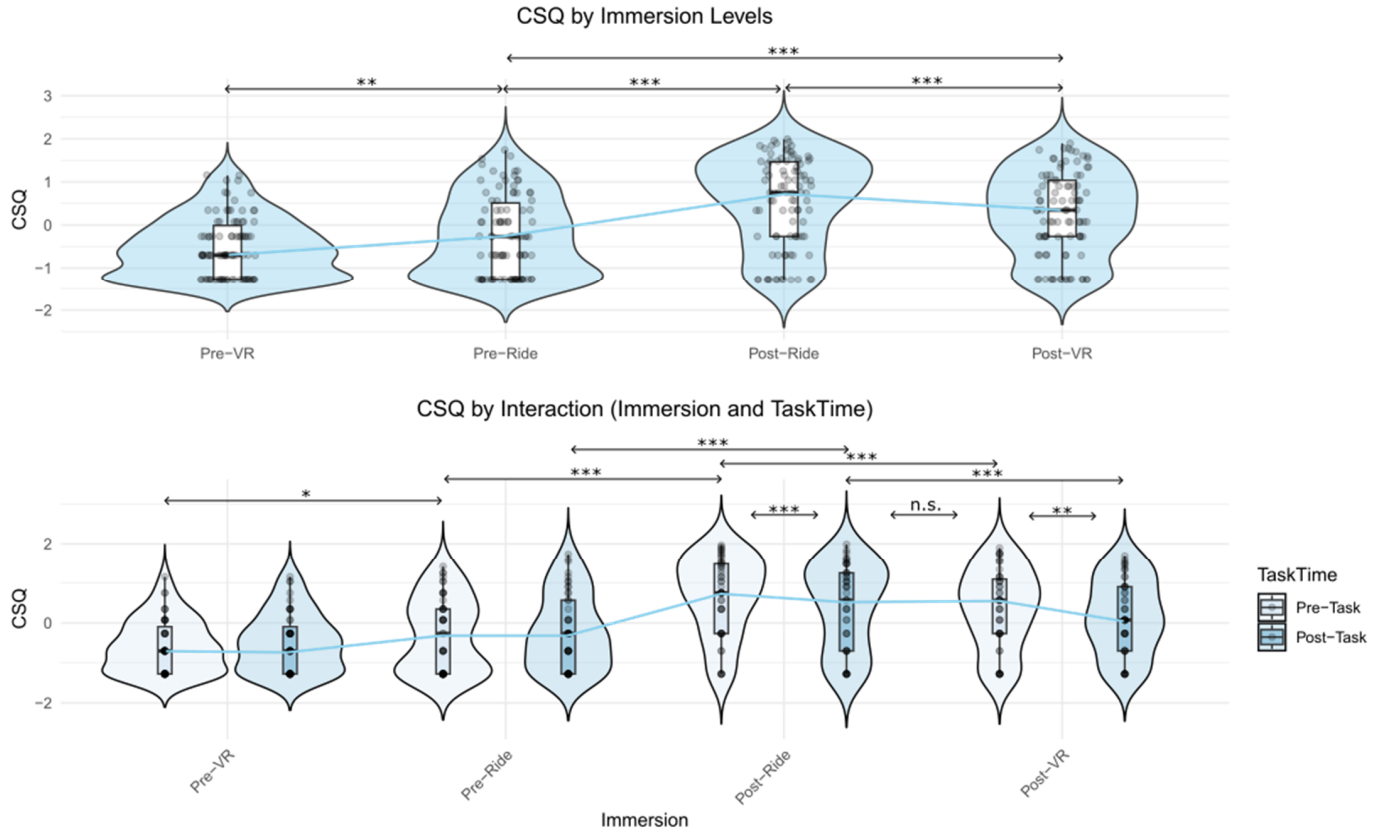


Figure 2. Significant comparisons of cybersickness across the immersion and task time stages. Only the meaningful comparisons are displayed. The CSQ scores are displayed as z scores. n.s. = non-significant, $p < 0.05$ *, $p < 0.01$ **, $p < 0.001$ ***.

Comparing pre-VR to post-ride, a large effect size was observed (Hedges' $g = 1.16$, $p < 0.001$), further emphasizing the substantial impact of the ride on cybersickness compared to the baseline levels before immersion. Notably, even after completing the post-VR tasks, the participants' cybersickness scores remained significantly elevated compared to their baseline, as shown by the comparison between the pre-VR and post-VR scores (Hedges' $g = 1.08$, $p < 0.001$). However, a moderate reduction in cybersickness symptoms was observed between post-ride and post-VR (Hedges' $g = 0.88$, $p < 0.001$), indicating some recovery, though the symptoms did not return to the baseline levels. These results demonstrate that the rollercoaster ride had the greatest effect on inducing cybersickness, with

partial recovery occurring during the subsequent VR tasks, but the symptoms remained above baseline levels even after completing the VR experience.

The post-hoc comparisons for the interactions between immersion stages (pre-VR, pre-ride, post-ride, and post-VR) and task times (pre-Task vs. post-task) revealed significant differences in the cybersickness (CSQ) scores across the conditions (see Figure 2). In the pre-VR stage, no significant difference was observed between the pre-task and post-task cybersickness scores (Hedges' $g = -0.20$, $p = 0.16$), indicating stable symptoms before and after task performance. Similarly, during the pre-ride stage, task performance did not significantly affect cybersickness levels (Hedges' $g = -0.14$, $p = 0.34$). In contrast, after the more immersive stages, task performance had a different effect. In the post-ride phase, cybersickness significantly decreased from pre-task to post-task (Hedges' $g = 0.55$, $p < 0.001$), suggesting that engaging in the tasks post-ride helped alleviate some cybersickness symptoms. A similar trend was observed in the post-VR phase, where a significant reduction in symptoms was noted after task performance (Hedges' $g = 0.43$, $p < 0.005$).

Comparing across the immersion stages, the pre-task comparison revealed a significant increase in cybersickness from pre-VR to post-ride (Hedges' $g = 1.22$, $p < 0.001$) and from pre-VR to post-VR (Hedges' $g = 0.79$, $p < 0.001$), indicating that the rollercoaster ride and VR immersion substantially worsened cybersickness before task performance. Similarly, in the post-task condition, cybersickness remained significantly higher in both the post-ride and post-VR stages compared to the pre-VR stage. The increase in symptoms from pre-ride to post-ride (Hedges' $g = 0.59$, $p = 0.002$) and from pre-ride to post-VR (Hedges' $g = 0.40$, $p = 0.02$) also reflects the intensifying effect of the immersive experiences.

Overall, while immersion significantly increased cybersickness, the results indicate that task performance after the ride and post-VR immersion phases contributed to a reduction in symptoms. Despite this reduction, the cybersickness levels remained higher in the post-ride and post-VR stages compared to the earlier immersion phases, particularly following the rollercoaster ride. This suggests that task engagement may have a mitigating effect on cybersickness in the later stages of immersion, but it is not enough to fully eliminate the symptoms induced by the immersive experience.

3.2.2. Nausea Symptoms

The ANOVA analysis revealed the statistically significant effects of immersion and the task time on the nausea scores, as well as a significant interaction between the two factors. There was a significant main effect of immersion, $F(3, 322) = 43.56$, $p < 0.001$, with a moderate effect size of $\omega^2 = 0.15$, indicating that the nausea scores varied significantly across the different stages of immersion (pre-VR, pre-ride, post-ride, and post-VR). The main effect of the task time approached significance, $F(1, 322) = 3.65$, $p = 0.057$, suggesting a potential influence of task timing on nausea, although this effect did not reach the conventional significance threshold. There was also a significant interaction between immersion and task time, $F(3, 322) = 2.87$, $p = 0.037$, with a small effect size of $\omega^2 = 0.01$, indicating that the impact of immersion on nausea varied depending on when the tasks were performed (pre-task or post-task).

Post-hoc comparisons revealed significant changes in nausea symptoms across the stages of immersion (see Figure 3). A moderate decrease in nausea was observed between the pre-VR and pre-ride stages (Hedges' $g = 0.28$, $p = 0.005$), indicating that the participants experienced a mild reduction in nausea after the initial VR exposure. However, the largest increase in nausea occurred between pre-ride and post-ride, with a large effect size (Hedges' $g = 1.42$, $p < 0.001$), suggesting that the rollercoaster ride induced severe nausea in the participants. The comparison between pre-VR and post-ride also showed a significant increase in nausea (Hedges' $g = 1.52$, $p < 0.001$). Interestingly, nausea symptoms showed a significant reduction between the post-ride and post-VR stages (Hedges' $g = 0.53$, $p = 0.0012$), indicating partial recovery after completing the VR tasks. However, the nausea scores remained elevated compared to the baseline (pre-VR vs. post-VR: Hedges' $g = 0.49$, $p = 0.0012$).

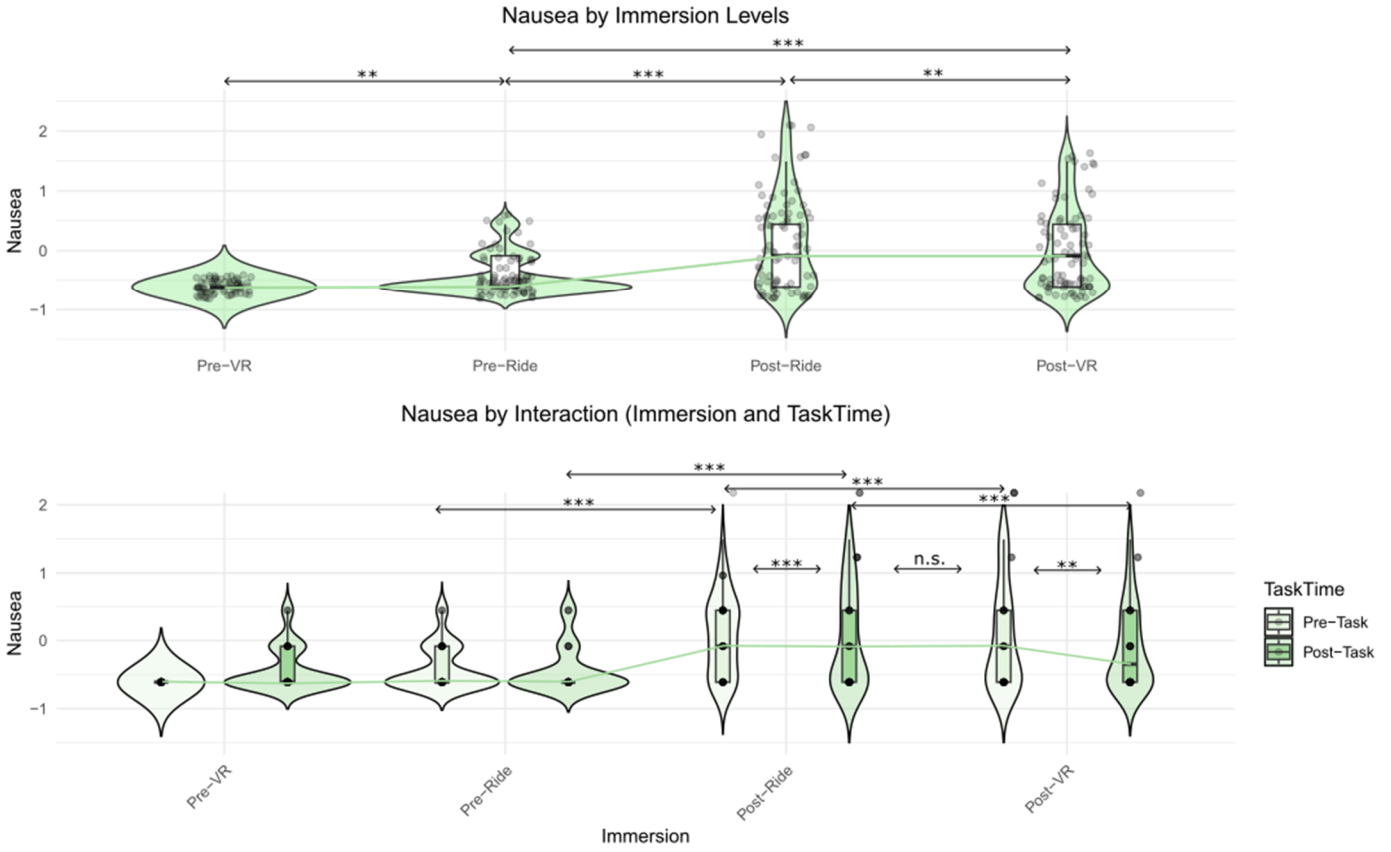


Figure 3. Significant comparisons of nausea intensity across the immersion and task time stages. Only the meaningful comparisons are displayed. The nausea scores are displayed as z scores. n.s. = non-significant, $p < 0.01$ **, $p < 0.001$ ***.

The post-hoc analysis of the interactions between the immersion stages and task time (pre-task vs. post-task) revealed distinct patterns in nausea across the stages (see Figure 3). In the pre-VR stage, no significant difference was found between the pre-task and post-task nausea scores (Hedges' $g = -0.25$, $p = 0.08$), suggesting stable symptoms before and after tasks. The same trend was observed during the pre-ride stage (Hedges' $g = -0.14$, $p = 0.32$). However, task performance had a different effect in the more immersive stages. In the post-ride stage, nausea decreased significantly after task performance (Hedges' $g = 0.53$, $p < 0.001$), indicating that engaging in tasks helped alleviate some nausea symptoms. A similar trend was found in the post-VR stage, where nausea symptoms decreased after task performance (Hedges' $g = 0.47$, $p < 0.002$). Comparing across the immersion stages, the pre-task analysis revealed a significant increase in nausea from pre-VR to post-ride (Hedges' $g = 1.22$, $p < 0.001$), as well as from pre-VR to post-VR (Hedges' $g = 0.72$, $p < 0.001$). The post-task comparisons showed a similar pattern, with nausea increasing from pre-VR to both post-ride (Hedges' $g = 0.72$, $p < 0.001$) and post-VR (Hedges' $g = 0.35$, $p = 0.003$).

The results in conjunction suggest that nausea symptoms were most severe immediately after the rollercoaster ride, with significant recovery observed after task performance, particularly in the post-ride and post-VR stages. While task engagement appeared to mitigate nausea symptoms, the participants still experienced elevated nausea compared to their baseline, especially after the rollercoaster ride. These findings highlight the importance of task timing in modulating the severity of nausea symptoms during and after immersive VR experiences.

3.2.3. Vestibular Symptoms

The ANOVA analysis revealed the significant effects of immersion and task time on vestibular symptoms, and a significant interaction between the two factors. A significant

main effect of immersion was found, $F(3, 322) = 33.91$, $p < 0.001$, with a moderate effect size of $\omega^2 = 0.14$, indicating that vestibular symptoms varied significantly across the different stages of immersion (pre-VR, pre-ride, post-ride, and post-VR). There was also a significant main effect of task time, $F(1, 322) = 6.15$, $p = 0.014$, suggesting that task timing influenced vestibular symptoms. Additionally, a significant interaction between immersion and task time was observed, $F(3, 322) = 3.88$, $p = 0.009$, with a small effect size of $\omega^2 = 0.02$, indicating that the effect of immersion on vestibular symptoms differed depending on task timing (pre-task or post-task).

The post-hoc comparisons revealed the significant changes in vestibular symptoms across the stages of immersion (see Figure 4). A moderate decrease in vestibular symptoms was observed between the pre-VR and pre-ride stages (Hedges' $g = 0.13$, $p = 0.005$), suggesting a mild reduction in vestibular discomfort before the rollercoaster ride. The most pronounced increase in vestibular symptoms occurred between the pre-ride and post-ride stages, with a large effect size (Hedges' $g = 1.75$, $p < 0.001$), indicating that the rollercoaster ride induced severe vestibular symptoms. A significant increase in vestibular symptoms was also found between the pre-VR and post-ride stages (Hedges' $g = 1.41$, $p < 0.001$). A moderate reduction in vestibular symptoms was observed between the post-ride and post-VR stages (Hedges' $g = 0.60$, $p = 0.001$), indicating partial recovery during the VR tasks, although the symptoms did not return to baseline. Comparing pre-VR to post-VR, vestibular symptoms remained higher but with a smaller effect size (Hedges' $g = 0.39$, $p = 0.001$), with the participants showing residual symptoms even after completing the VR tasks.

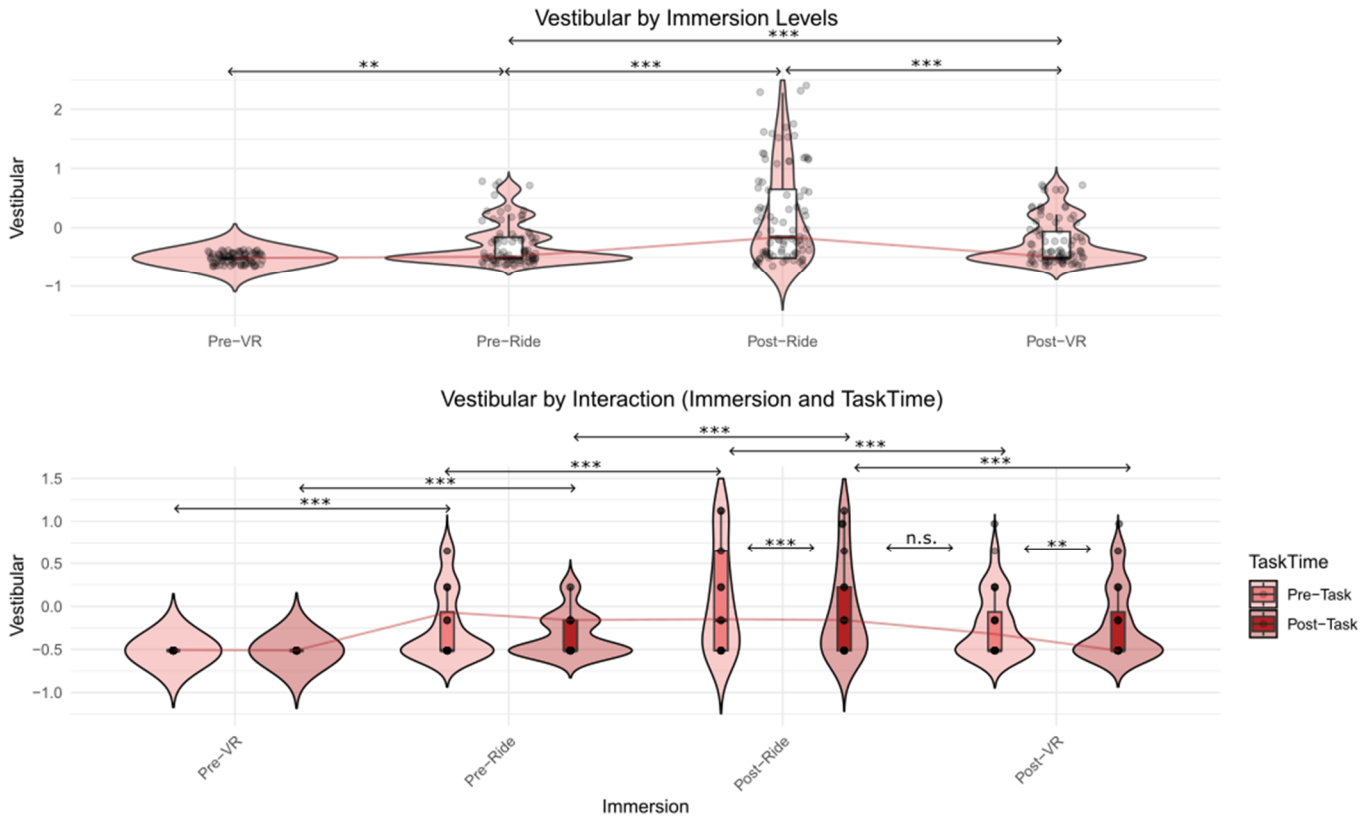


Figure 4. Significant comparisons of vestibular symptom's intensity across the immersion and task time stages. Only the meaningful comparisons are displayed. The vestibular scores are displayed as z scores. n.s. = non-significant, $p < 0.01$ **, $p < 0.001$ ***.

The post-hoc analysis of the interaction between the immersion stages and task time revealed specific patterns of vestibular symptoms depending on when the tasks were performed (see Figure 4). In the pre-VR and pre-ride stages, there were no significant dif-

ferences between pre-task and post-task vestibular symptoms (Hedges' $g = -0.13$, $p = 0.38$ for pre-VR; Hedges' $g = -0.11$, $p = 0.45$ for pre-ride), indicating stable symptoms before and after task performance. However, a significant reduction in vestibular symptoms was observed post-task in the post-ride stage (Hedges' $g = 0.52$, $p < 0.001$), indicating that task performance after the ride helped reduce vestibular symptoms. A similar trend was observed in the post-VR stage, where vestibular symptoms also significantly decreased post-task (Hedges' $g = 0.40$, $p = 0.008$), suggesting that engaging in tasks after the VR immersion contributed to symptom alleviation. Across the immersion stages, the pre-task comparison showed a significant increase in vestibular symptoms from pre-VR to post-ride (Hedges' $g = 1.41$, $p < 0.001$) and from pre-VR to post-VR (Hedges' $g = 0.89$, $p < 0.001$). The post-task comparisons reflected similar patterns, with significant increases in vestibular symptoms from pre-VR to post-ride (Hedges' $g = 0.89$, $p = 0.001$) and pre-VR to post-VR (Hedges' $g = 0.31$, $p = 0.002$).

To summarize, the results indicate that vestibular symptoms peaked after the rollercoaster ride, with partial recovery observed during the subsequent VR tasks. While task performance appeared to alleviate some symptoms in the post-ride and post-VR stages, vestibular discomfort remained higher than baseline, particularly following the rollercoaster ride. This suggests that task engagement may play a role in reducing vestibular symptoms after high-immersion experiences, but it does not completely eliminate the residual effects of such immersion.

3.2.4. Oculomotor Symptoms

The ANOVA analysis revealed a significant main effect of immersion on oculomotor symptoms but no significant effects of task time or the interaction between immersion and task time. Specifically, the main effect of immersion was significant, $F(3, 322) = 45.93$, $p < 0.001$, with a moderate effect size of $\omega^2 = 0.11$, indicating that oculomotor symptoms varied significantly across the stages of immersion (pre-VR, pre-ride, post-ride, and post-VR). However, the main effect of task time was not significant, $F(1, 322) = 0.04$, $p = 0.84$, suggesting that task timing did not influence oculomotor symptoms. Additionally, the interaction between immersion and task time was non-significant, $F(3, 322) = 1.63$, $p = 0.18$.

The post-hoc comparisons revealed significant changes in oculomotor symptoms across the immersion stages (see Figure 5). A moderate decrease in oculomotor symptoms was observed between the pre-VR and pre-ride stages (Hedges' $g = 0.29$, $p = 0.005$), indicating that symptoms slightly improved before the rollercoaster ride. However, a large increase in oculomotor symptoms was observed between the pre-ride and post-ride stages (Hedges' $g = 1.67$, $p < 0.001$), suggesting that the rollercoaster ride significantly worsened oculomotor symptoms. The comparison between pre-VR and post-ride also indicated a substantial increase in symptoms (Hedges' $g = 1.20$, $p < 0.001$).

Interestingly, oculomotor symptoms improved after completing the post-VR tasks, as evidenced by a significant reduction between the post-ride and post-VR stages (Hedges' $g = 0.43$, $p = 0.0098$). However, symptoms remained higher in the post-VR stage than the baseline levels (Hedges' $g = 0.66$, $p < 0.001$), indicating that oculomotor symptoms did not fully return to baseline even after completing the VR tasks. Given the non-significant interaction between immersion and task time, no substantial differences were observed between the pre-task and post-task conditions across the stages of immersion. Oculomotor symptoms remained relatively stable between the pre-task and post-task conditions in all the stages, including pre-VR (Hedges' $g = -0.13$, $p = 0.84$), pre-ride (Hedges' $g = -0.11$, $p = 0.45$), post-ride (Hedges' $g = 0.52$, $p = 0.18$), and post-VR (Hedges' $g = 0.40$, $p = 0.18$). The lack of a significant interaction suggests that task performance did not significantly impact the severity of oculomotor symptoms in any immersion stage.

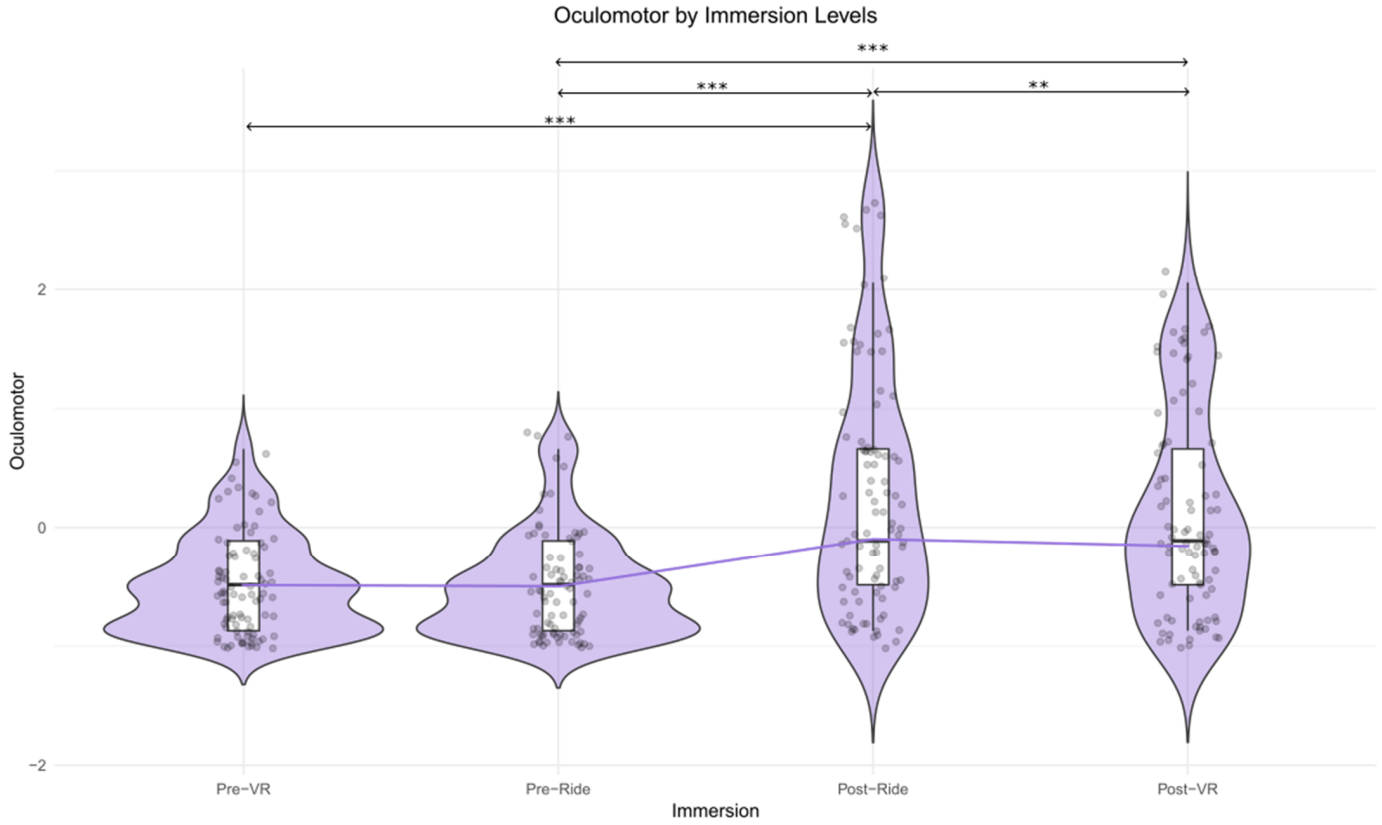


Figure 5. Significant comparisons of oculomotor symptoms intensity across the immersion stages. Only the meaningful comparisons are displayed. The oculomotor scores are displayed as z scores. $p < 0.01$ **, $p < 0.001$ ***.

The results indicate that oculomotor symptoms worsened significantly after the rollercoaster ride and remained elevated after the VR immersion, though some recovery was observed after task performance. Despite the improvements in symptoms after the tasks in the post-VR stage, oculomotor discomfort did not return to the baseline levels, particularly after the rollercoaster ride. Task timing, however, had no significant impact on the severity of oculomotor symptoms across any of the immersion stages, as indicated by the non-significant interaction effect. This suggests that oculomotor symptoms were primarily influenced by the level of immersion and the specific stage of the experience, with the rollercoaster ride having the most pronounced effect.

3.3. Performance Comparisons: Eye–Hand Coordination Reaction Time

The Deary–Liewald Reaction Time task results revealed notable differences between the VR and PC versions and their respective impacts on reaction time performance pre- and post-immersion (see Figure 6). In the PC version, the simple reaction time task showed a significant increase in reaction times after VR immersion (Hedges' $g = -0.38$, $p = 0.01$), indicating slower responses post-immersion. Conversely, the choice reaction time task demonstrated a significant performance improvement (Hedges' $g = 0.35$, $p = 0.02$), with the participants responding faster after VR exposure. These contrasting results suggest that the negative effects of cybersickness impacted the simple task more, while the practice effect in the more complex choice task may have mitigated this impact. The findings align with H3, which hypothesized that reaction times deteriorate post-VR. This pattern suggests that task complexity and practice effects play key roles in offsetting cybersickness in post-immersion performance.

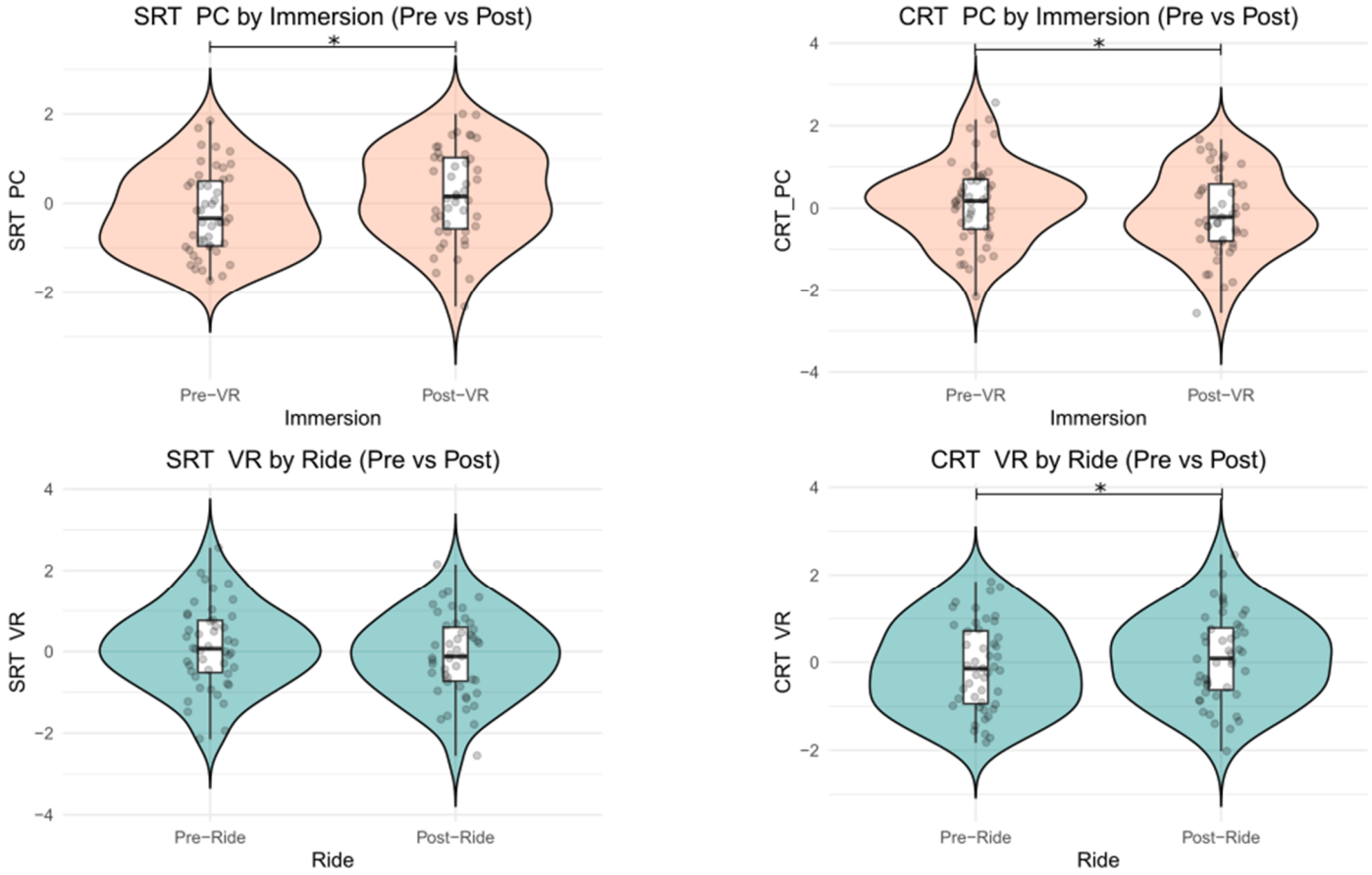


Figure 6. Comparisons of the performances in the Single Reaction Task (SRT) and Choice Reaction Task (CRT) in the PC and VR versions before and after the immersion and the ride, respectively. The reaction time values are z scores. $p < 0.05$ *.

A different pattern emerged in the VR version, where the participants performed the tasks immediately after a cybersickness-inducing rollercoaster ride. For the simple reaction time task, there was no significant difference between the pre- and post-ride performances (Hedges' $g = 0.24$, $p = 0.11$), implying that the full-body interaction in VR may have helped mitigate the effects of cybersickness. However, for the choice reaction time task, there was a significant increase in reaction times post-ride (Hedges' $g = -0.38$, $p = 0.01$), indicating that the more cognitively demanding task was negatively affected by the immediate aftereffects of the ride. These results support H3, reinforcing the notion that the participants who experience greater cybersickness also show a higher increase in reaction times, particularly in the tasks with higher cognitive demands. The differential effects between the simple and choice tasks point to the importance of task complexity and sensory engagement in moderating the impact of cybersickness.

3.4. Mixed Model Regressions: Individual Differences as Predictors of Cybersickness

Continuing with the analysis of the best model predictors for overall cybersickness and its subcategories, Table 4 reveals the significant findings. H4 is strongly supported, as the table indicates that adult motion sickness history and VIMS are significant predictors of cybersickness across all the 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.

Table 4. Best models for predicting overall cybersickness intensity and cybersickness intensity per symptom category.

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; * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

Regarding H5, demographic factors such as sex and age were not included in the best model predictors. This absence suggests that when accounting for all the variables and the random effects in a mixed regression analysis, age and sex do not significantly predict cybersickness intensity compared to the stronger predictors in the model, thereby supporting H5. Furthermore, H6 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 a 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 incorporate strategy and puzzle game experiences. Proficiency in strategy games was 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 analyses into the effects of different gaming genres on cybersickness.

In summary, the best model 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 specific cybersickness symptoms, supporting H4–H6 and aligning with the existing literature. 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 address RQ1 comprehensively.

Gaming Skills Across Diverse Genres

A mixed linear regression best model analysis was conducted to further address RQ1 regarding the impact of different gaming genres on cybersickness. This analysis used the same iteration structure for predictor inclusion as applied to all the individual differences but focused exclusively on different gaming genre experiences as potential predictors. The results presented in Table 5 specifically highlight the strong predictive role of FPS gaming experience across the various cybersickness symptom categories. Notably, proficiency in FPS games consistently predicts a significant reduction in overall cybersickness intensity and 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.

Table 5. Best predictive models of overall cybersickness intensity and cybersickness intensity per symptom category across various gaming genres.

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

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

Interestingly, the models do not include 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 with RPGs, puzzles, and strategy games as predictors. These findings indicate that a proficiency in these game genres might predict an increase in cybersickness symptoms, contrasting with the protective effect of FPS gaming. These 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.

In summary, the FPS gaming experience emerges as a significant protective factor, consistently predicting lower levels of cybersickness across all the symptom categories. This suggests that the immersive nature and rapid visual processing required in FPS games equip players with resilience against the disruptive effects of cybersickness in VR environments. In contrast, experiences in RPGs, puzzles, 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.

4. Discussion

Cybersickness can negatively influence a person's decision on whether to continue using VR. Consequently, it is imperative to have as thorough an understanding of it as possible [95]. The findings of this study provide a comprehensive understanding of how different stages of immersion, task performance, and individual differences influence cybersickness symptomatology in virtual reality (VR) environments. The data reveal clear distinctions between overall cybersickness, nausea, vestibular symptoms, and oculomotor symptoms, with immersion playing a predominant role in increasing symptom intensity, particularly after the rollercoaster ride. Task engagement appeared to mitigate symptoms to some extent, but the residual effects of immersion remained. These findings have important implications for understanding the factors contributing to cybersickness and for designing VR systems that minimize discomfort.

4.1. The Effects of Immersion on Cybersickness

The results consistently demonstrated that the stage of immersion was the primary factor driving the severity of cybersickness symptoms across all the categories. Specifically, the participants experienced the highest levels of overall cybersickness, nausea, vestibular

discomfort, and oculomotor discomfort after the rollercoaster ride. This confirms that highly immersive, intense experiences, such as those with rapid motion and sensory input, are the strongest contributors to cybersickness. The large effect sizes found in the post-hoc comparisons between the pre-VR and post-ride stages across all the symptom categories underscore the powerful impact of immersive, high-motion experiences on inducing severe symptoms.

These findings support the existing literature on the effects of sensory overstimulation and intense motion in VR, which can overwhelm the vestibular and oculomotor systems, leading to the characteristic symptoms of cybersickness [44,78,79]. Notably, even after the VR tasks were completed, the cybersickness symptoms remained above baseline levels, particularly in the vestibular and oculomotor categories, indicating that the residual effects of high-immersion experiences can linger even after the immersive activity ends. This highlights the need for cybersickness assessments to happen during immersion, immediately after the intense virtual activity is over, as symptoms tend to greatly increase during that time. This can provide researchers with an accurate representation of the intensity of symptoms, which cannot be acquired if the assessment happens outside of immersion when symptoms gradually decrease. Task characteristics, such as cognitive load and the duration of a session can alter the persistence of symptoms. Within the framework of Sensory Conflict Theory, highly immersive VR activities that also include fast and intense motions, as in the roller coaster ride, can lead to increased and prolonged symptoms of cybersickness [14,15,96]. This may also explain why cybersickness levels remained above baseline after the session was over.

Lastly, even though symptoms became milder as the participants removed the HMD, the decrease was not immediate. Although there was an overall reduction in symptoms post-VR, this reduction may have been influenced by other factors, such as the eye–hand coordination task performed earlier. In the study by Kourtesis et al. [18], the participants spent more time in VR completing multiple tasks, and the final cybersickness assessment occurred before task completion. The decrease in symptoms observed in that study may have started during task completion and gradually intensified. In our study, cybersickness began to decrease after the task but remained stable after HMD removal, suggesting that more time may have been needed for a steady reduction in symptoms. Both studies align when considering the similar points of assessment—before and after the main tasks. What we observed was that symptoms could peak and start decreasing even during immersion after the most provocative stimuli, without a significant change upon exiting VR alone. Future research should further explore the cybersickness scores both during and after immersion without task interventions to better understand the effects of exiting VR.

4.2. Mitigating Effects of Task Engagement

While immersion was a significant factor in increasing cybersickness symptoms, task engagement after the rollercoaster ride appeared to have a mitigating effect on symptoms. In both the post-ride and post-VR stages, the participants exhibited a significant reduction in symptoms after performing tasks, particularly in the nausea and vestibular categories. In line with previous findings, an eye–hand coordination task seems to facilitate a band-aid effect [16–18], possibly by diverting attention away from the symptoms or engaging sensory–motor coordination that helps alleviate discomfort. This is an interesting finding because it suggests that eye–hand coordination tasks, regardless of the time they take place, during or after the session, can initiate the attenuation of cybersickness symptoms. Such insights could inform the design of VR content that minimizes discomfort and enhances user interaction. A practical implication is that VR application developers could include eye–hand coordination tasks within virtual environments to induce mitigation effects and promote a smooth user experience. This approach could be helpful for professional training or therapeutic settings where maintaining low user discomfort and high user engagement and task performance are important.

However, while the reduction in symptoms post-task was significant, it is important to note that the symptoms did not return to baseline levels. For example, even after task performance, the oculomotor symptoms remained higher than the pre-immersion levels, indicating that task engagement, while beneficial, is not a complete remedy for cybersickness. These findings suggest that while task performance can alleviate some discomfort, more effective strategies are needed to mitigate the aftereffects of intense VR experiences fully.

Another takeaway from this should be that researchers must be very considerate of how tasks can affect cybersickness differently and should carefully choose the appropriate time intervals to measure the symptoms. Even if no tasks are completed, the simple act of staying idle inside the virtual environment without watching any fast motions can cause virtual natural decay, which means that the symptoms will start decreasing on their own [18]. The opposite could also happen when the tasks provide a greater challenge for the participants and thus raise discomfort levels. The attentional resources needed and task workload can alter the amount of cybersickness experienced [52,97]. A memory task that requires attentional resources can cause more severe symptoms and higher dropout rates than a condition with a simpler task or a condition without a task [97].

Additional studies are needed to understand how each task (i.e., attention, reaction times, memory, spatial ability, etc.) can positively or negatively affect cybersickness rates. Idling while receiving auditory cues could also be considered a part of natural decay and should be given more attention in future studies as a potential cause of symptom moderation. Moreover, despite their possible benefits [98–100], widely used applications and their included tasks have not received much attention regarding their cybersickness aftereffects. We suggest that future experimental designs employ tasks that closely simulate those found in widely adopted applications to establish their potential mitigation effects better. For instance, contrasting educational with entertainment VR tasks or static with dynamic content could help pinpoint specific mitigation triggers.

4.3. Reaction Times

The results of the reaction time tasks performed both in VR and on the PC platform highlight how the immersive virtual reality environment, specifically the rollercoaster ride designed to induce cybersickness, differentially impacts cognitive and motor performance.

In the PC version, a clear divergence between the simple and choice reaction time tasks was observed post-immersion. The simple reaction time task exhibited a significant decline in performance, with participants taking longer to respond after VR immersion, which aligns with the previous studies [23,30,31]. This suggests that the residual effects of cybersickness—likely exacerbated by the relatively simple motor demands of pressing a key—were dominant, with no opportunity for the practice effects to counteract the decline in reaction speed. The task's simplicity leaves little room for skill development, and as a result, the negative effects of cybersickness may have prevailed.

In contrast, the choice reaction time task showed significant improvement after immersion, suggesting that the more cognitively demanding nature of the task allowed for a practice effect. This effect may have counteracted any lingering symptoms of cybersickness, leading to the faster reaction times post-immersion. The increased complexity of choosing between four targets, compared to the simple motor response of pressing a single key, likely allowed the participants to refine their decision-making and visual search processes, resulting in an improved performance despite any cybersickness experienced during VR immersion.

The results from the VR version present a different picture, where the participants performed the tasks immediately after the rollercoaster ride without exiting VR. For the simple reaction time task, no significant difference was found between the pre- and post-ride performances, suggesting that the physical, full-body interaction involved in the VR task, which included both extensive whole-body movements (using the hand controllers to touch targets) and vestibular activation through head movements, may have mitigated the effects

of cybersickness. The embodied nature of the task, where the participants engaged with the environment physically, likely helped recalibrate their sensory systems, offsetting any negative effects of the ride. In this case, the full-body interaction may have served as a natural buffer against the effects of sensory conflict, allowing the participants to maintain their performance levels. This is supported by research showing that VR hardware that allows for more ergonomic interactions (hand and body movement within the VR environment) can lead to a more pleasant experience and reduced levels of cybersickness [83].

However, in the choice reaction time task in VR, the participants showed significantly slower reaction times after the rollercoaster ride. This task demands more cognitive resources—visual search, attention, and decision-making—and these demands, combined with the sensory disruption caused by the ride, likely overwhelmed the participants' ability to maintain the pre-ride performance levels. The immediate exposure to a cognitively challenging task post-ride, without the recovery time that was available in the PC version, may have amplified the impact of cybersickness on performance.

Overall, these findings suggest that full-body interaction in VR tasks may help moderate the effects of cybersickness, particularly in simple motor tasks. However, for more complex cognitive tasks like choice reaction time, the immersive environment and immediate task engagement post-ride appear to hinder performance, particularly when no recovery period is allowed. The differences between the PC and VR results also highlight the impact of the time interval between immersion and task performance. In the PC condition, this delay may have facilitated a natural recovery from cybersickness, further underscoring the importance of both the timing and nature of task performance in VR environments.

The increase in reaction times remains concerning and should be of note to people not used to the virtual environment and who must perform tasks after exposure that require precision and fast reflexes, i.e., driving. Professionals who employ VR applications for training, education, or rehabilitation purposes should be aware of the possible intense feelings of discomfort and deterioration of reaction times, which might contribute to a negative user experience. In real-life scenarios, people may have to spend more time inside the virtual environment and experience higher levels of cybersickness [101]. It is not yet clear how much time cybersickness symptoms can persist after immersion, with previous results varying from 10 min to 4 h in the case of longer sessions and are dependent on the VR content [96]. Furthermore, research has shown that repeated exposures throughout different days can cause habituation and decrease the amount of cybersickness experienced [102,103]. As it is not clear from this or previous research how long the deterioration of reaction times may persist along with cybersickness symptoms, an important recommendation for future studies would be to create longitudinal designs that would test participants' reaction times after repeated exposures of varying durations within several days or weeks.

4.4. Individual Differences in Predicting Cybersickness

The mixed model regression analysis revealed that individual differences, particularly susceptibility to motion sickness and visually induced motion sickness (VIMS), were strong predictors of cybersickness across all the symptom categories. The participants with a history of motion sickness or high VIMS scores were significantly more likely to experience severe symptoms, supporting H4. This outcome aligns with our findings that integrating these metrics—specifically the adult motion sickness susceptibility score (MSB-Adult from the MSSQ) and the VIMSSQ—has proven highly effective in predicting the intensity and symptoms of cybersickness [20]. These results are consistent with the prior research suggesting that individuals predisposed to motion sickness are more vulnerable to cybersickness, as both involve similar vestibular and visual disruptions [54,55]. Both conditions share underlying sensory conflicts caused by the absence of expected physical feedback in visually dynamic environments, making those susceptible to one more likely to experience the other.

Additionally, smartphone experience emerged as a significant predictor of lower cybersickness intensity, particularly for vestibular symptoms, where a greater familiarity with

smartphones was associated with reduced discomfort. This aligns with H6, which posits that regular use of modern technology—especially devices requiring frequent head and eye movements—could provide some protection against cybersickness by improving users' ability to handle visual motion in VR. Our findings, consistent with previous research [20], suggest that habitual interaction with digital screens may enhance an individual's ability to cope with the sensory conflicts in VR environments, ultimately mitigating cybersickness symptoms. However, our findings do not suggest that prior VR experience reduces cybersickness intensity or contributes to a faster adaptation process. Future research should further investigate the possibility of VR familiarity playing a role in faster adaptation and response times.

Finally, our findings indicate that gaming experience plays a key role in cybersickness mitigation. Interestingly, while first-person shooter (FPS) gaming experience predicted a reduction in cybersickness symptoms, strategy and puzzle gaming experience were linked to increased symptom severity, particularly in the vestibular and oculomotor categories. This supports RQ1, indicating that not all gaming experiences are protective against cybersickness. These results align with the recent research, suggesting that habitual gamers, especially those who play FPS games, are better equipped to reduce cybersickness in VR environments [69]. FPS games, which require rapid visual tracking and spatial awareness, may better prepare individuals for the immersive, dynamic nature of VR, whereas slower-paced games with static visuals may not offer the same benefits.

4.5. Limitations and Future Studies

While this study offers valuable insights into cybersickness symptomatology and the mitigating effects of task engagement in VR, several limitations should be considered. The sample composition is a fundamental limitation, as it primarily included young adults aged 18–45 with limited VR experience, potentially limiting the generalizability of the findings. Younger participants, who are generally more technologically adept, may exhibit a lower susceptibility to cybersickness compared to a more diverse population. Older populations, often more susceptible to motion sickness, or individuals with extensive VR experience, may experience cybersickness differently. Additionally, the homogeneity of the sample, with many participants being psychology students, may have introduced biases. Including participants from diverse educational and cultural backgrounds would enhance the applicability of the results. Future studies should aim to include a more diverse range of participants, particularly older adults and experienced VR users, to better understand how cybersickness varies across different demographic and experience groups.

Another limitation relates to the within-subjects design. While it was effective for tracking changes in symptoms over time, future research could benefit from the inclusion of a control group. A control group exposed to non-immersive or less intense VR environments would help isolate the specific effects of immersion and task engagement on cybersickness. Additionally, exploring different types of immersive experiences, such as varying levels of visual complexity or motion intensity, would provide further insights into how different VR applications influence cybersickness. This study also highlights the importance of task timing and the nature of tasks in mitigating symptoms. Future research should explore whether certain tasks, particularly those with varying cognitive or sensory demands, are more effective in reducing specific symptom categories, such as vestibular or oculomotor discomfort.

Finally, task engagement appeared to alleviate some symptoms, but this study did not account for continuous engagement throughout the VR experience, as there were brief idle periods for instructions. Future studies should control for these idle periods to better understand the continuous impact of task performance on cybersickness. Moreover, this study focused on a single VR session, and future research should investigate how symptoms evolve over longer exposure times or across multiple sessions. This could reveal important insights into long-term tolerance or habituation to VR environments. Despite these limitations, this study provides a foundational understanding of cybersickness and

highlights the need for more comprehensive research involving diverse populations, varied tasks, and extended immersion periods.

4.6. Practical Implications and Future Directions

The findings of this study have important implications for both VR designers and users. First, the significant impact of high-immersion experiences, particularly those involving intense motion, highlights the need to consider how such content is delivered carefully. Reducing the duration of high-motion experiences or integrating more gradual transitions between the stages of immersion could help mitigate the onset of severe cybersickness symptoms.

Second, the potential mitigating effect of task engagement suggests that incorporating interactive elements after intense experiences may help reduce symptoms. Designers should consider including tasks that require moderate cognitive engagement, as these may help alleviate some discomfort without overwhelming the user. However, as symptoms did not fully return to baseline after the tasks, more research is needed to identify effective strategies for eliminating cybersickness.

Lastly, individual differences such as motion sickness susceptibility and gaming experience should be considered when designing VR experiences. Offering customizable settings based on user profiles, such as options for adjusting the level of motion or visual complexity, could help reduce cybersickness for more vulnerable users.

5. Conclusions

This study provides critical insights into the dynamics of cybersickness in immersive VR environments, particularly highlighting how symptom severity evolves across different stages of immersion. The findings demonstrate that immersive experiences, especially those involving highly dynamic elements such as a rollercoaster ride, significantly exacerbate cybersickness symptoms, with the most pronounced effects observed in nausea and vestibular discomfort. However, task engagement—especially tasks involving eye–hand coordination—appeared to mitigate some of these symptoms, though not entirely eliminate them, particularly after the most intense stages of immersion.

The results suggest that the relationship between task complexity, sensory demands, and cybersickness is multifaceted. Simple tasks, such as an SRT, may be more susceptible to the negative effects of immersion, while more cognitively demanding tasks, like a CRT, could benefit from practice effects that counterbalance some post-immersion symptoms. However, despite these mitigating effects, cybersickness remains an enduring challenge in VR, particularly in tasks involving intense motion, suggesting the need for continued exploration into task design as a tool for symptom management.

Future research should focus on diversifying participant demographics and VR experiences to understand these findings' broader applications better. Additionally, longer-term studies exploring the effects of extended exposure to VR and the use of more complex and varied tasks will be crucial in developing comprehensive strategies for mitigating cybersickness across different populations and use cases. This study provides an important foundation for such future work, offering valuable perspectives on the interaction between task performance, immersion, and cybersickness in VR environments.

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