Is Video Gaming a Cure for Cybersickness? Gamers Experience Less Cybersickness Than Non-Gamers in a VR Self-Motion Task

Katharina M. T. Pöhlmann, Gang Li, Graham Wilson, Mark McGill, Frank Pollick, and Stephen Brewster

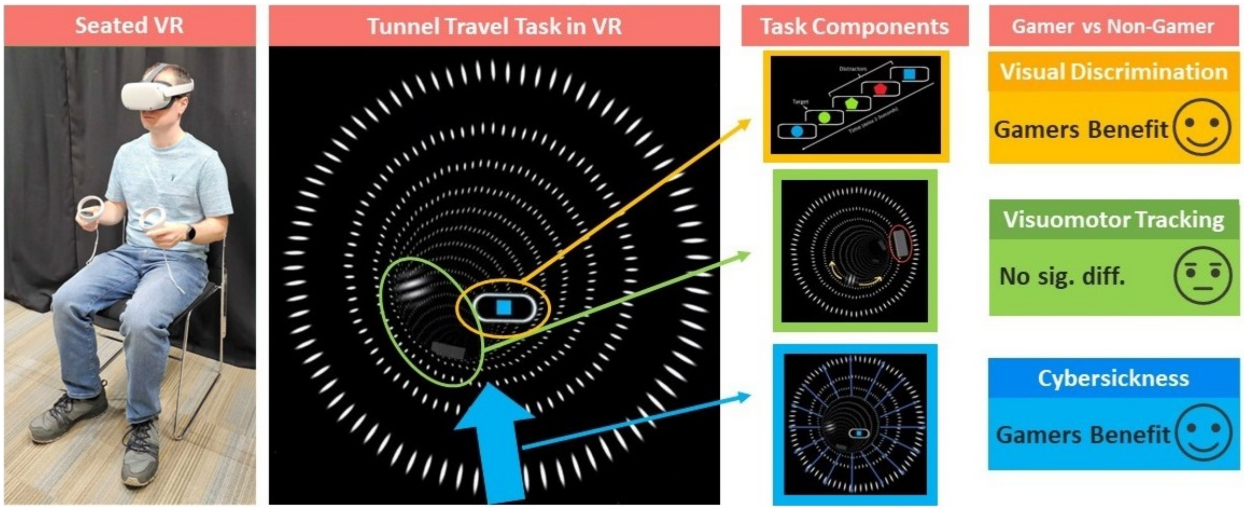

Fig. 1: (Left) Study set up in the lab with participant wearing a Meta Quest 2, (Middle) Presentation of Tunnel Travel Task and its components and (Right) Findings of the study.

Abstract—
Cybersickness remains a major drawback of Virtual Reality (VR) headsets, as a breadth of stationary experiences with visual self-motion can result in visually-induced motion sickness. However, not everybody experiences the same intensity or type of adverse symptoms. Here we propose that prior experience with virtual environments can predict ones degree of cybersickness. Video gaming can enhance visuospatial abilities, which in-turn relate negatively to cybersickness - meaning that consistently engaging in virtual environments can result in protective habituation effects. In a controlled stationary VR experiment, we found that 'VR-naive' *video gamers* experienced significantly less cybersickness in a virtual tunnel-travel task and outperformed 'VR-naive' *non-video gamers* on a visual attention task. These findings strongly motivate the use of non-VR games for training VR cybersickness resilience, with future research needed to further understand the mechanism(s) by which gamers become cybersickness resilient - potentially expanding access to VR for even the most susceptible participants.

Index Terms—Virtual Reality, Video Gamers, Cybersickness, Habituation

1 Introduction

One major obstacle that limits the widespread adoption of VR is *cybersickness*, with a significant proportion (40% to 70%) of the population being unable to engage in stationary VR experiences (e.g. seated or standing) that include visual self-motion, such as adventure or shooting games, racing games or flight simulators [56]. Cybersickness, similar to motion sickness, comprises symptoms such as nausea, headache, dizziness, and eye strain, with these adverse symptoms often believed to be caused by a conflict between the visual and vestibular systems [75] and/or due to postural instability caused by the novel environment [84]. When a VR user is sitting or standing and viewing content that includes visual and auditory self-motion (hereafter just "self-motion"), such as being on a roller coaster or seeing their character moving through a virtual scene, there is perceivable visual motion but no matching vestibular stimulation. Modifying the visual content presented in the display can reduce cybersickness symptoms by reducing this sensory mismatch, for example reducing the field of view (FOV) [3, 4, 24, 86, 91], reducing the speed of motion [22] or introducing blur [14, 43, 61]. However, all these techniques limit the experience of the user, e.g. harming the sense of presence [60] and/or applying restrictions on the content that VR developers can create.

There are also strong individual differences when it comes to the experience of cybersickness [41, 47, 54] making such content-focused mitigation techniques suitable for some individuals but potentially less suitable and insufficient for others [64]. One potential characteristic that has been associated with reduced visually-induced motion sickness is habitual video gaming [46, 51, 72, 88]. This relationship, however, is not yet well explored with some studies finding limited or no support for these beneficial effects in video gamers [30, 31]. The existing supporting research mainly lacks in-depth investigations into the relationship of video gaming and cybersickness. The focus of these works is generally on a different aspect of an individual's experience of sickness; they rarely focuses on the types of video games played by participants or the amount of time spent playing them. Similarly only two studies [46, 72] have reported a relationship between gaming and cybersickness experienced in VR HMDS. Given such limited and

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Manuscript received xx xxx. 201x; accepted xx xxx. 201x. Date of Publication xx xxx. 201x; date of current version xx xxx. 201x. For information on obtaining reprints of this article, please send e-mail to: reprints@ieee.org. Digital Object Identifier: xx.xxxx/TVCG.201x.xxxxxxx

somewhat conflicting results, further investigation into the relationship of video gaming and cybersickness resilience is necessary.

We propose two potential contributing factors to this resistance. Firstly, gamers build up habituation to self-motion stimuli in virtual environments through their consistent engagement with them [74, 87]. Secondly, certain types of video games (action video games) have been associated with enhancements in various cognitive and perceptual abilities [33, 33, 34, 55, 82] and, in turn, enhanced visuospatial skills have been related to a resistance to motion sickness [81]. Therefore, playing such games can, on one hand, build up resistance (habituation) to the sensory conflict induced by virtual self-motion in the stationary player and, on the other, train visuospatial abilities which are known to indirectly help reduce cybersickness.

These proposed relationships are of great potential significance to both efforts towards more widespread adoption of VR for training or leisure, as well as how VR research studies are designed and analysed. Firstly, they suggest that users could be trained, or train themselves, to adapt to visual-motion experiences, and so reduce the likelihood or severity of experienced cybersickness symptoms. Users could partake of game experiences with increasing range and magnitude of visual motion over time to strengthen such training. This would allow a much wider range of users to benefit from VR experiences, such as being better able to engage in professional VR applications (such as training simulators or 3D design), or to make more use of a personal VR headset for social, leisure or productivity experiences. The latter benefit could become increasingly important as companies such as Apple and Meta position their immersive devices for all-day, everyday use [6, 65, 66]. Secondly, the above relationships mean that any VR study that investigates cybersickness, involves experiences with a lot of visual self-motion, or uses visuospatial tasks will need to take participants' gaming experience into account, as it is likely to be a confounding variable.

As-yet, whilst research has hinted at the relationship between gaming and VR cybersickness resilience, no study has definitively demonstrated this relationship. Therefore, we present the first investigation into two key topics: 1) the potential resilience of those who regularly experience first-person action games and 2) whether such games improve visuospatial abilities. For topic 1, we examine whether gamers who play first-person perspective non-VR action games - i.e. individuals that regularly experience locomotion through a virtual environment on flatscreen 2D displays - experience resilience to cybersickness induced in VR environments via Head Mounted Display (HMD). For topic 2 we examine whether visuomotor tracking and visual discrimination task performance is also impacted by first-person action gameplay, which would indicate improved visuospatial abilities in gamers. We performed a lab-based VR study that included first-person perspective video gamers as well as non-video gamers. All participants had no or very little prior experience with VR HMDs (i.e. were *VR-naive*) and gender was equally distributed in both gamer groups to ensure that their prior experience with these devices and their gender did not affect their robustness to cybersickness and so the outcomes of this study. The key findings of this work are:

1. Habitual (non-VR) first-person perspective gamers experience significantly lower cybersickness symptoms when exposed to a 3D virtual environment presented in an HMD compared to non-gamers;

2. Gamers also show enhanced visuospatial discrimination and similar visuomotor tracking abilities compared to non-gamers.

Through these findings, we further our understanding regarding the positive effects of video gaming on cognitive skills as well as the potential of transferable habituation effects for cybersickness that can be built up using 2D devices that are more comfortable, readily available and less sickness-inducing. This opens up promising new research directions for the design of training applications to reduce or even eliminate cybersickness and allow individuals that are extremely susceptible to cybersickness to benefit from VR HMDs.

2 Related Work

2.1 Cybersickness Mitigation

Cybersickness is believed to arise, at least partly, due to a user's intolerance to the conflict between the visually simulated self-motion displayed on a screen (e.g. in a VR HMD) and the actual physical movement of the user [75]. An alternative explanation is the postural instability theory which states that such novel environments can cause postural instability, in the user which in turn causes adverse symptoms in them - and to overcome such symptoms the user must adopt a new posture compatible with this novel environment [84]. Traditional mitigation techniques against cybersickness include FOV restrictors, blur, reduction in visual speed, as well as using less natural locomotion techniques such as teleportation [3, 4, 14, 43, 86, 91]. These, however, can have drawbacks in terms of complexity of implementation, reduction in the sense of presence and increases in disorientation [8, 13, 14] and they can be perceived as distracting or annoying [60].

2.1.1 Habituation

Motion sickness in the real world, as well as cybersickness in virtual environments, decreases with repeated exposure, for example in sea travel [59], for flight and driving simulators [20, 39, 50] and for VR HMDs [40, 42, 51, 77]. Habituation, however, is believed to be very stimulus-specific [74, 87], meaning that a reduction in cybersickness with repeated exposure would only be found for the exact same type of virtual environment. For example, when practising on a driving simulator habituation effects would only be found when exposed to the same driving simulator again and does not transfer to, for example, a VR HMD. Using habituation as a method of cybersickness training has some disadvantages. It can be time-consuming, and thus requires motivation and dedication in the user, with extremely susceptible users potentially being unable to engage long enough for habituation to work. Additionally, if it is stimulus-specific, the training would only be useful for a specific VR application. If, however, there is a process similar to habituation that results in long-lasting and transferable effects it could allow us to make VR accessible to even those who are more susceptible to cybersickness. A recent study found that cybersickness-susceptible individuals can be trained with abstract visual environments in VR headsets and build up habituation effects to self-motion in richer naturalistic environments [2]. Their participants were exposed to an abstract visual stimulus on three consecutive days slowly increasing visual motion speed. This training resulted in a weaker sensation of cybersickness when immersed into a naturalistic and visually richer virtual environment [2]. If playing video games on 2D displays can result in a similar transferable stimulus unspecific habituation effect, it would allow for training using different types of displays while using a more engaging content compared to such abstract stimuli which in turn could increase motivation and willingness to engage with the content.

2.1.2 Visuospatial Abilities

Another user-centred technique that could reduce cybersickness is training the visuospatial abilities of an individual. Males often outperform females on visuospatial tasks, such as rod-and-frame, mental rotation or card rotation tasks [62, 80]; this dominance is often attributed to differences in sex hormones. Similarly females have often been found to experience more motion sickness compared to their male counterparts [25, 69], with some studies suggesting that this sex difference in motion sickness could be due to difference in visuospatial abilities, with males with poorer spatial abilities also being more prone to experiencing motion sickness [57]. A recent study found that training individuals on a simple mental rotation task not only enhances their visuospatial abilities but also reduces motion sickness experienced in a simulator as well as a "real world scenario" when travelling in a vehicle [81]. This suggests that visuospatial abilities are a dynamic skill that can be improved through training and therefore indirectly help reduce motion sickness symptoms.

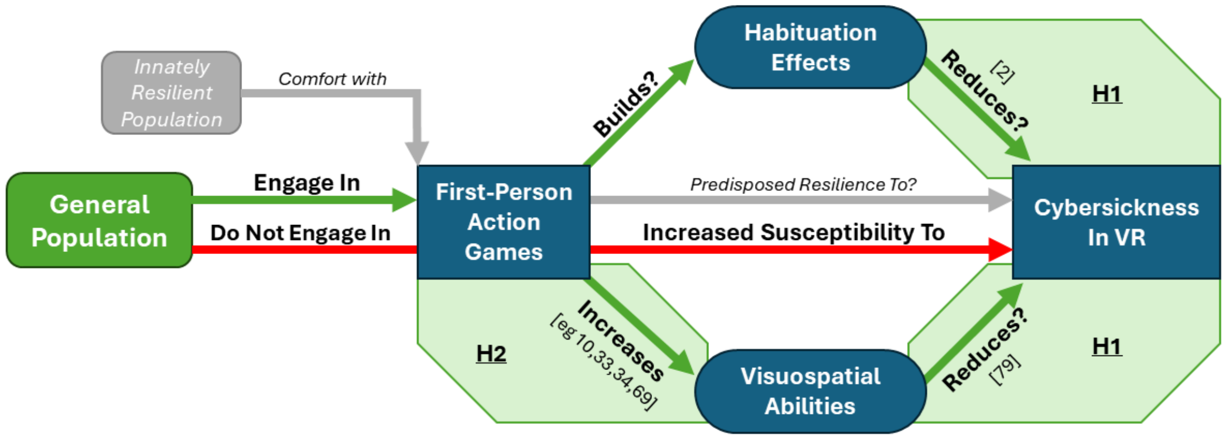


Fig. 2: Diagram depicting the potential explanations for the reduced experience of cybersickness in individuals engaging in First Person-Perspective video games. Includes our two hypotheses and the relationships being probed in this study (green boxes).

2.2 Playing Video Games as Sickness Mitigation

2.2.1 Enhanced Cognitive and Visuospatial Skills in Gamers

Video gaming has been related to enhanced perceptual, visual and cognitive skills [33, 55]. Most research in the area has focused on a subset of video games termed *action video games*. Typical action video games are First- or Third-Person Shooters, such as Call of Duty [1] or Counter-Strike [89], as well as Action-RPG and Adventure Games, such as Skyrim [11], Grand Theft Auto [45] and Tomb Raider [38]. These types of games require players to attend to rapidly changing and visually dense virtual environments while having to make accurate decisions about how to respond to incoming stimuli in three dimensions under time pressure [55].

Action Video Game Players (AVGP) have been shown to have various enhanced aspects of cognitive and attentional control related to visual processing, such as the number of objects that can be attended simultaneously, the ability to divide attention and the spatial and temporal distribution of visual selective attention [5,9,10,16,17,23,26,27,33–35]. Playing such games has also been found to improve visual information processing abilities, such as motion perception [18, 44, 78], with gamers outperforming non-gamers - in both precision and speed - when choosing perceived motion direction [36, 71] as well as on object tracking tasks [34]. This improvement in motion tracking is potentially due to enhanced attentional control functions, with gaming improving one's ability to filter out irrelevant information while focusing on task-relevant information [10]. These positive implications are found both for habitual video game players as well as after video game training [33, 34]. This suggests that video game players are not necessarily predisposed to have such enhanced visual attention abilities which would contribute to them becoming habitual players, but rather that the game play itself causes these improvements in visual skills. The enhanced visuospatial abilities in video gamers in turn could also contribute to their reduced motion sickness susceptibility [81]. In contrast, some research has found that gaming experience is negatively related to cognitive control and particularly the ability to ignore distractors or competing response alternatives [7], this research would suggest that the increase in visual perception could result in problems in cognitive control functions. For example, gamers might be faster at shooting an enemy but also potentially make more mistakes in a shoot/don't shoot task, where they first have to determine whether the entity is a target or not.

2.2.2 Experience with Virtual Environments

Video gaming - spending several hours per week playing video games - shows some beneficial effects on cybersickness when exposed to virtual environments [2, 51, 53, 72, 88]. For example, gamers have been found to experience less motion sickness symptoms compared to non-gamers when viewing videos or performing simulated driving tasks on large projector screens [51, 88].

These non stimulus-specific (i.e. stimulus-agnostic) habituation effects displayed by gamers have also been found for cybersickness experienced when using VR HMDs [72]. A recent study focused on action video game players specifically [72], these games generally include many instances of virtual self-motion from a first-person perspective, which in VR HMDs is often related to cybersickness [48, 75]. In Pöhlmann *et al.* [72] individuals that spent a minimum of 5-10 hours a week on average playing action video games experienced significantly less cybersickness when immersed in a simple virtual environment using a VR headset compared to their non-video gamer player counterparts. The visual stimulus presented here was an abstract motion illusion that elicited a weak sensation of self-motion in participants, however no real simulated visual motion was presented in this study. Similarly, in an experiment investigating the effect of music on cybersickness, greater gaming experience was found to be related to a weaker sensation of cybersickness [53]. Participants in this study were exposed to sickness-inducing virtual linear and angular accelerations mimicking self-motion while wearing the VR headsets. Further research also found that individuals that indicated that they engaged in video game play experienced less cybersickness in a VR maze task [46] or a VR navigation tasks [68, 76]. However, none of these prior studies investigating the relationship of video gaming experience and cybersickness have consistently controlled for prior VR experience, gender, and the type of video game played in their studies. Both prior VR experience and gender has been found to affect cybersickness in VR (e.g. [28, 69]). While the types of video games played dictate the gamers prior experience with virtual environments inducing a sensation of self-motion and therefore a potential conflict between sensory systems, for example first-person perspective games, such as *Call of Duty* consist mainly of sequences including self-motion through a virtual environment, while real time strategy games, such as *Age of Empire* or multiplayer online battle arena games, such as *Dota 2* do not include any or almost no virtual self-motion. Only games including instances of virtual self-motion are expected to contribute to the build up of habituation effects towards cybersickness. Similarly, not all types of video games are expected to contribute to enhancements in visuospatial abilities, with mostly action video games having been related to these enhancements (e.g. [10, 34]). Many of these experiments also fail to report how many of their participants qualified as gamers and non-gamers and how gender was distributed in these groups and how many participants of each group performed the different experimental conditions. Given the uncontrolled and somewhat limited nature of prior research this study sets out to systematically investigate the relationship of VR-naive first-perspective gamers as well as VR-naive non-gamers and cybersickness experienced in VR.

We therefore hypothesise that there is a process that occurs with regular first-person perspective video game play that contains aspects

Participant	Most Played First-Person Perspective Games		Time Spend Playing in Hours	
	This Year	Prior	This Year	Prior
2	Counter Strike	Counter Strike	5-10	1-3
5	Rainbow Six Siege, Call of Duty, Modern Warfare	Rainbow Six Siege	10+	10+
6	Counter Strike: Global Offensive, Chivalry, Satisfactory	Counter Strike: Global Offensive, Satisfactory	10+	10+
7	Call of Duty	Call of Duty	10+	10+
8	Borderlands, Overwatch 2	Borderlands	5-10	5-10
14	Halo, Call of Duty, Metro, Fallout 4, Crysis	Halo, Doom	10+	10+
19	Call of Duty	Call of Duty	5-10	3-5
21	Fallout New Vegas, Call of Duty: Black Ops 2	Fallout New Vegas, Call of Duty: Black Ops 2, Modern Warfare	5-10	3-5
22	Call of Duty	Call of Duty	3-5	5-10
25	Cyberpunk 2077, Half-Life, Metro	Doom, Quake	10+	3-5
26	Counter Strike: Global Offensive	Counter Strike: Global Offensive	10+	10+
27	PUBG	PUBG	5-10	5-10
29	APEX	APEX	5-10	5-10
31	Team Fortress 2, Borderlands 2, Left 4 Dead 2, Unreal Tornament 1999	Team Fortress 2, Borderlands 2, Left 4 Dead 2	3-5	5-10
32	Counter Strike: Global Offensive, Escape from Tarkov	Call of Duty	5-10	5-10

Table 1: Most played first-person perspective games for each participant in the gamer, both in the last year and year prior, including the time spent playing these games.

of habituation, with effects that are long lived as well as transferable to novel and potentially more sickness-inducing virtual environment. Simultaneously, regular gaming also has the potential to enhance visuospatial abilities in the individual, which in turn builds up resilience to sickness-inducing environments.

3 Study Methodology

Cybersickness resilience found in video game players could be due to habituation to virtual environments as well as improved visuospatial skills obtained through habitual gameplay. This study is the first to examine the relationship between cybersickness and task performance for gamers and non-gamers. We do so using a virtual tunnel-travel task presented in a VR HMD that is known to induce cybersickness [58] to VR-naive individuals classed as first-person perspective "Video Gamers" or "Non-Gamers".

3.1 Study Design

The study used a between-subjects design with *Cybersickness* and *Task Performance* as dependent variables and *Gamer Type* (Gamer, Non-Gamer) as independent variable. The experiment was approved by the University of Glasgow's ethics committee.

The study consisted of one experimental session in which participants were immersed in a virtual tunnel-travel task [5] displayed using a Meta Quest 2 headset, see Figure 1. The design was chosen for this study as it has previously been shown to be a reliable method to induce cybersickness in participants. The task elicited a sensation of self-forward motion (vection). Throughout the main task, participants travelled through an abstract tunnel that involved the perception of motion in depth. The route within the tunnel enacts visual locomotion often found in VR games (e.g., a roller coaster, driving game, or first-person shooter), including forward motion, curves, uphill and downhill paths, but without upside down and off-axis paths. The task includes passive motion rather than active self-motion controlled by the participant to firstly, ensure that all participants experienced the same motion profiles and to secondly, ensure that video gaming experience and therefore experience with controls would not affect cybersickness ratings. This tunnel travel task was adapted from Anguera *et al.* [5], a well-established gamified paradigm for the assessment of multitasking cognitive control abilities. During the tunnel travel participants performed a visuomotor tracking task (moving a game object to hit oncoming targets), see Figure 3 (b), as well as a visual discrimination task (responding to the appearance of a specific coloured shape), see Figure 3 (a) [5,58].

3.2 Measures

Gamer Type *Gamers* were individuals that spent at least **5** hours on average per week playing first-person video games in the last year, or have an extensive past experience, playing at least 5-10 hours per week on average before the last year and spend at least 3-5 hours per week playing within the last year. The most-played first-person perspective games in the last and prior years by the gamer group, as well as the time spent playing those games, can be found in Table 1. *Non-Gamers* have no experience with first-person perspective games and spend no more than 3 hours a week engaging in any type of video game (e.g. phone games) [33].

Cybersickness Participants filled in the Simulator Sickness Questionnaire (SSQ) [49] before and after the experiment and they rated their experience of cybersickness every 4 minutes on the Fast Motion Sickness Scale (FMS; from 0 to 20) [52]. This resulted in five FMS ratings per participant. The experiment was terminated if participants reached a score of 11 or higher to prevent them from becoming too unwell.

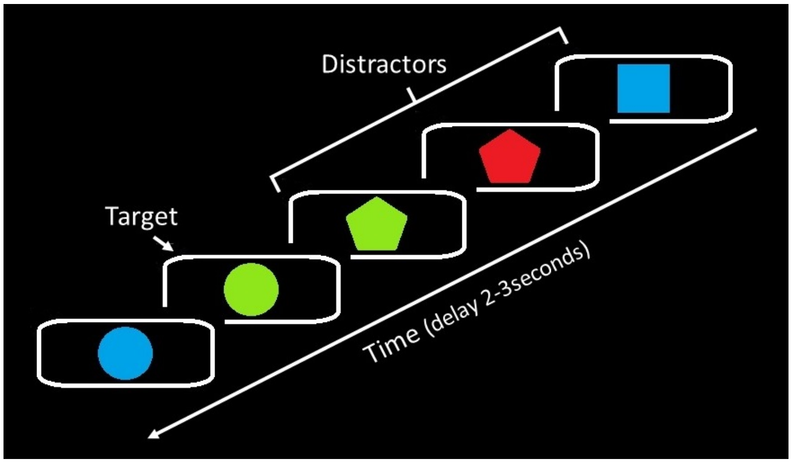
Cognitive Task Performance The **visuomotor tracking task** was integrated into the tunnel environment (see Figure 3 (b)): participants had to track and control a white and black game object to move it round the inside of the tunnel and hit the centre of approaching cubes, by using the right thumbstick on the VR controller. The **visual discrimination task** was presented in the centre of the participant's field of view, see Figure 3 (a). A stream of different coloured (red, green, blue) shapes (circle, pentagon, square) was presented. Participants had to respond only to a target (green circle), which appeared every 2-3 seconds, while ignoring all other shapes and colours (distractors). They had to respond to the target as quickly as possible by pressing the trigger button on the left VR controller. Participants received correct/incorrect sound feedback on this discrimination task.

3.3 Participants

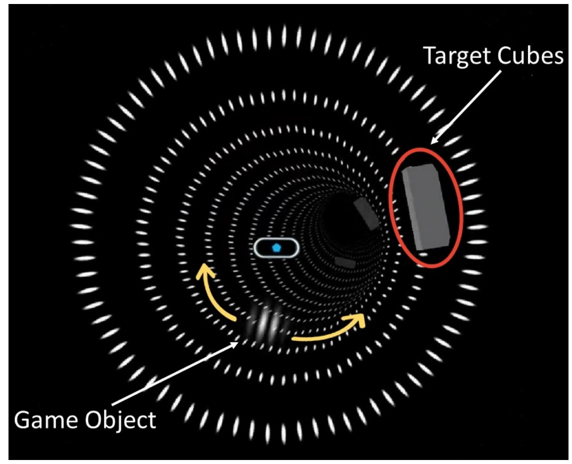
Thirty-two participants took part, recruited through University forums and mailing lists as well as various social media channels. All participants had normal or corrected-to-normal vision, and were self-reported as free from neurological/psychiatric disorders. Participants ranged in age from 18 to 34 years (M = 25.09, SD = 3.76), with 17 identifying as male, 13 as female and 2 as gender non-binary. Fifteen had never used VR before and the remaining 17 had used it between 1-10 times (Mdn = 3 times, $\pm$ 0.72). Fifteen participants were classified as *Gamers*, based on the above criteria (male: 9, female: 5, gender non-binary: 1; VR experience: 9, No VR experience: 6 ; aged 22 to 30 years (M = 25.00, SD = 2.90)) and 17 were classified as *Non-Gamers* (male: 8, female: 8, gender non-binary: 1; VR experience: 9, No VR experience: 8 ; aged 18 to 34 years (M = 25.18, SD = 4.48)). Participants received £10 for completing the study.

3.4 Hypotheses

We want to validate the prior effect around improved cognitive task performance in Gamers on a visual discrimination and visual motor tracking task and examine whether this typical set of gamers, with the expected cognitive enhancement on visual tasks, exhibit resilience to cybersickness. Based on this and the study design we formulated the following hypotheses, (see Figure 2):



(a) Visual Discrimination Task



(b) Visuomotor Task

Fig. 3: (a) Schematic representation of the visual discrimination task and (b) Representation of the visuomotor task. See video figure for footage of task being performed.

H1 Gamers will experience less cybersickness in the virtual tunnel-travel task compared to Non-Gamers;

H2 Gamers will perform better on the cognitive tasks compared to Non-Gamers, confirming previous work [10, 26, 33].

3.5 Procedure

Participants were pre-screened based on their gamer type, motion sickness susceptibility (MSSQ [32]), VR experience and medication. Participants were invited if they qualified as either a *Gamer* or *Non-Gamer*, had no or very limited VR experience, took no medication that could affect nausea and other adverse symptoms related to motion sickness and were neither resistant to motion sickness nor extremely susceptible (MSSQ scores between: 10-36).

In the lab, participants gave informed consent and the researcher explained the task. Following this, participants were seated on a chair wearing the Meta Quest 2 headset and held the controllers. Once in VR they filled in the pre-session SSQ, after which they went through a training phase. This lasted 4 minutes and allowed participants to familiarise themselves with the controls and task. The training was followed by the main tunnel-travel task which lasted 20 minutes in total, comprised of 5 sessions lasting 4 minutes each. After each session, participants rated their experience of cybersickness on the FMS followed by a 3 minute break before the next session started. The original version of the task used a fixed movement speed [15], however, we chose to linearly increase the movement speed with each session to increase task difficulty and the potential sickness-inducing properties of the environment [19, 83]. After completing the VR task, participants were debriefed and received their compensation.

4 Results

4.1 Cybersickness

Three of the 32 participants that took part in the experiment dropped out before completing all trials as they reached an FMS score of 11 or higher. Their last recorded sickness score was reported for the reminder of the trials [21]. All of the participants that dropped out prematurely were part of the Non-Gamer group. Due to data not being normally distributed, we used Kruskal-Wallis one way analyses of variance for comparisons between Gamer groups.

4.1.1 FMS Ratings

A significant main effect of Gamer Type on maximum FMS ratings was found (χ^2(1, N = 32) = 5.61, p = .018, η^2 = .15), with Gamers experiencing less cybersickness (Mdn = 1 ($\pm$2)) compared to Non-Gamers (Mdn = 3 ($\pm$3)) (see Figure 4).

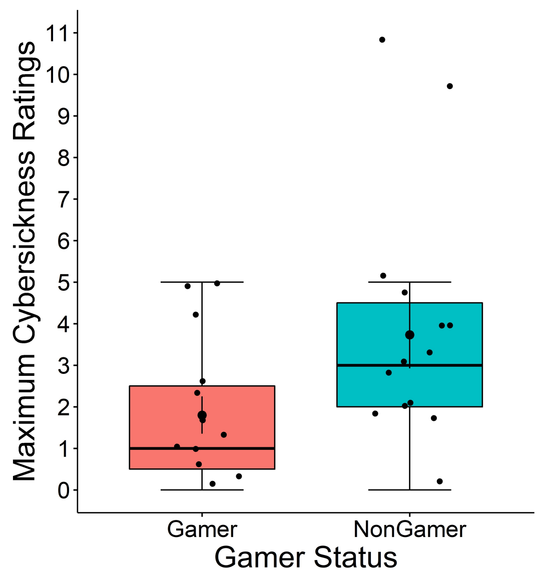


Fig. 4: Maximum FMS ratings during tunnel travel task. Black lines represent the median and the colour of the boxes represents the two gamer groups

4.1.2 Simulator Sickness Questionnaire

Analyses of the total scores, the Oculomotor and the Disorientation sub-scales showed similar results, with no difference found between Gamers and Non-Gamers, while a significant difference between gamer groups was found for Nausea scores. For brevity, we only report the results of the total scores and the Nausea sub-scale.

Total SSQ Scores No significant effect of Gamer Type on total SSQ scores was found (χ^2(1, N = 32)= 2.43, p = .119, η^2 = .05), with Gamers rating their discomfort similarly (Mdn = 22.44 ($\pm$37.40)) to Non-Gamers (Mdn = 33.66 ($\pm$26.18))

Nausea Subscale A significant effect of Gamer Type on SSQ Nausea scores was found (χ^2(1, N = 32)= 4.00, p = .045, η^2 = .10), with Gamers scoring lower on the Nausea subscale (Mdn = 9.54 ($\pm$28.62)) compared to Non-Gamers (Mdn = 28.62 ($\pm$28.62)).

4.2 Task Performance

4.2.1 Visual Discrimination Task

A Repeated-Measures ANOVA was performed to calculate the effect of Gamer Type on Reaction times and Task Performance (d'). D Prime scores were compared for the groups. D' represents an index of accuracy that takes hits, misses, correct rejects and false positives into account when calculating task performance, with higher scores representing increased performance (max value: 4.65 based on Hit rate = .99, False alarm rate = .01) [37].

Reaction Time A significant effect of Gamer Type on Reaction Time was found, $F(1,147) = 31.10$, p<.001, $\eta_p^2 = .18$. Gamers reacted faster to targets (M = 622ms, SD = 65ms) compared to Non-Gamers (M = 684s, SD = 71ms).Figure 5).

Task Performance Gamers (M = 3.63, SD = 1.51) outperformed Non-Gamers (M = 3.04, SD = 1.25) on the visual discrimination task, $F(1,148) = 6.94$, p = .009, $\eta_p^2 = .05$.

4.2.2 Visuomotor Tracking Task

A Kruskal Wallis one way analysis of variance found no significant effect of Gamer Type on performance (χ^2(1, N = 30) = 2.31, p = .129, η^2 = 0.01), with Gamers hitting on average 60.5% (Mdn = 58.1% (25.4%)) of targets and Non-Gamers hitting 55.4% (Mdn = 55.0% (22.3%)).

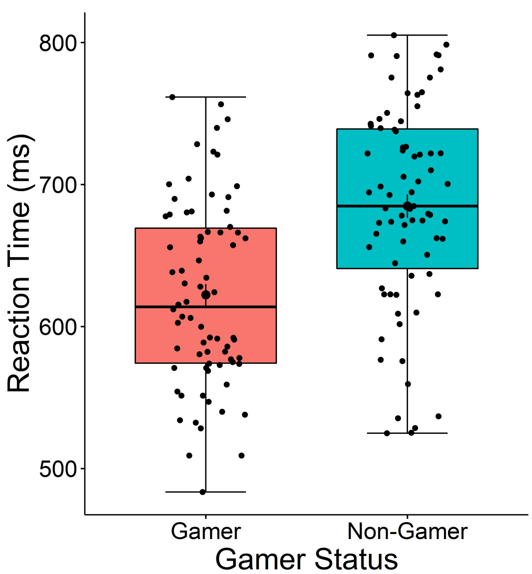


Fig. 5: Reaction time during discrimination task. Black lines represent the median and the colour of the boxes represents the two gamer groups

5 Discussion

5.1 Summary of Findings

This study for the first time experimentally validates that VR-naive first-person perspective Gamers experience significantly less cybersickness when immersed in an engaging and vection-inducing virtual environment compared to similarly VR-naive Non-Gamers. None of the Gamers dropped out of the experience due to cybersickness, and they scored significantly lower on the FMS and SSQ Nausea subscale, supporting **H1** (2). Gamers outperformed Non-Gamers on the visual discrimination task, being more precise and reacting faster to targets, showing increased cognitive control and performed similarly to Non-Gamers on the visuomotor tracking task, partially supporting **H2** (2).

5.2 First-Person Perspective Gamers Experience Less Cybersickness

Gamers experienced less adverse symptoms compared to Non-Gamers when immersed in our tunnel-travel task, with none of them terminating the experiment early. Individuals that had consistent experience with first-person perspective video games played on the computer or different types of gaming consoles (2D displays) showed more resilience to cybersickness in a vection-inducing task compared to their Non-Gamer counterparts. While previous work has commented on lower cybersickness in gamers, we proposed and experimentally validated two potential contributing factors to this greater resilience to cybersickness in gamers. One relating to the enhanced visuospatial abilities that have been attributed to playing action games and one relating to their extensive prior experience with virtual environments. These two are not mutually exclusive but are more likely to work together, see Figure (2). Playing first-person perspective video games could result in a phenomenon similar to habituation that is both long-lived and transferable from one type of virtual environment to another. Training an individual's visuospatial skills is known to reduce susceptibility to motion sickness and consequently could also be contributing here [81]. Such training tasks could be directly integrated into a video game making the training more engaging and thereby potentially more successful.

We propose that the beneficial effects of video game play on the experience of cybersickness are based both on participants previous experience with vection-inducing virtual environments as well as due to their superior perceptual skills developed during the game play [18].

> ***Implication 1:*** **First-person action video games can potentially habituate VR-naive users to cybersickness.** This provides a means for the large population who experience cybersickness in VR to be able to engage in immersive experiences for work and leisure, by engaging in first-person perspective games as a form of training, potentially with increasing levels of visual motion. This habituation is likely to become more important with the widespread adoption of everyday eXtended Reality (XR) headsets across domains and industries continues.

> ***Guideline 1:*** **VR research that includes any emphasis on cybersickness should take gaming experience into account.** Gaming experience introduces a potentially confounding variable, particularly given the discrepancy in the occurrence of gamers in the general population vs student population, which often makes up study participants. Researchers should therefore either aim to control for the participants gaming experience during the recruitment phase or take it into account during the analysis and formulation of their results.

5.3 Gamers Experience Better Cognitive Performance

Our results show that Gamers displayed significantly better cognitive performance, in terms of both reaction times and visual discrimination measured by their performance on the visual discrimination task. However, no difference in performance between Gamers and Non-Gamers was found on the visuomotor tracking task. VR headsets are no longer just a device used for entertainment purposes but are being readily used in the educational sector [29] as well as for training [90] and productivity [6, 63]. Gaming outside VR could potentially improve performance on some of these tasks. Faster reaction times and more precise performance when discriminating between targets and non-targets, can be extremely important and even life-saving for military personnel or first responders [12, 73].

> ***Implication 2:*** **Gaming has the potential to improve performance in cognitive VR tasks.** Reaction times and visual discrimination may be significantly better when users have gaming experience, suggesting that the cognitive benefits obtained from gaming are retained in immersive 3D environments.

***Guideline 2:* VR research that uses visuospatial tasks should take gaming experience into account.** Much like Guideline 1 above, VR research that involves visuospatial tasks (e.g. multiple object tracking [67] or attentional blink task [79]) - particularly those that require fast reactions or visual discrimination - should consider gaming experience during recruitment and/or analysis.

5.4 Is Video Gaming a Cure for Cybersickness?

Based on the study design we cannot exclude the possibility that our gamer sample was made up of cybersickness resistant individuals that were predisposed to this resistance and, due to that resistance, spend their time engaged in video games, see Figure 2. If this was the case, it would suggest that rather than video gaming contributing to this resilience due to habituation and improved visuospatial abilities facilitated by the game play, these individuals were "born" with such a resilience to cybersickness.

Although there remains more uncertainty about whether this resilience comes from habituation to vection, visuospatial training, or both, based on our findings and findings of related research we strongly suggest that habitual video gaming is the main cause for this resilience and not a predisposition in these individuals. Firstly, our Gamer and Non-gamer groups did not differ in their susceptibility to traditional motion sickness (MSSQ), suggesting that the two groups were similar in their overall susceptibility to conflicting visual and vestibular motion. Secondly, Gamers also outperformed the Non-Gamers on a visual discrimination task, suggesting enhanced visual perceptual skills, which in turn are linked to reduced sickness symptoms. Such improved visuospatial and attentional skills have previously been found both in habitual video gamers as well as in naive gamers that were trained up [33, 34], which supports the notion that video gamers are not predisposed to these enhanced skills but that these skills were acquired throughout game play. This is important as it suggests that everyone can be trained in such skills, which in turn reduces their susceptibility to cybersickness.

Nonetheless, further research is needed to confirm that our finding is a result of habituation due to gaming as we suggest, rather than innate resilience; Non-gamers should be trained using video games, their visuospatial skills should be measured throughout the training and the effect of such training on cybersickness in a HMD should be assessed. If such training is successful, it will open up the world of XR to even the most susceptible individuals.

5.5 Limitations

5.5.1 Game Genres

In this study, we focused on individuals that play first-person perspective video games, such as first-person shooters and adventure games. This genre was chosen due to the locomotion performed in the games being similar to the one perceived when navigating through a virtual environment using an HMD. Having extensive experience with such games would therefore suggest a form of habituation to vection-inducing locomotion. We would expect that, if any type of video game fosters resilience to cybersickness, it would be first-person perspective ones. This notion was confirmed by our results with gamers experiencing less cybersickness. As a next step, the effects of various other game genres on cybersickness should be investigated to identify which are most suitable and comfortable for training. Additionally, the exact type of first-person perspective game could be investigated in more detail to identify what aspects of these types of games result in these beneficial effects on cybersickness. There is a wide array in the type of first-person perspective games and the visual stimuli perceived by the player, with a significant difference in quickness of movements, cognitive load and overall game play between for example an online multi-person first-person shooter and an offline single player first-person survival game.

5.5.2 Virtual Environment

The choice of our tunnel travel task was based on previous research highlighting its usability as a measure for cognitive performance in multitasking scenarios as well as for cybersickness research. This task however might not be representative of all VR experiences as it contains passive self-motion only and does not allow for users to control their own self-motion through the virtual environment. This was done to ensure that all participants experienced the same self-motion and to ensure that prior experience with controls did not affect cybersickness - but could potentially limit the generalisability of findings to other VR content. Additionally to ensure that all participants had a similar experience we controlled for prior VR experience to ensure that familiarity with the technology would not affect our results. Some participants could potentially have had more experience with similar virtual experience (e.g. specific types of video games, such as flight simulators) that we were not able to control for in this study. Further investigation should include VR experiences allowing for both active and passive self-motion as well as a potentially more detailed recording of participants prior experience with all types of virtual environments.

5.5.3 Device Type

We did not control for the device type and therefore display size that gamers used to play first-person perspective games. Gamers that use smaller hand-held devices such as a Nintendo Switch [70] or their phone will experience a weaker sensation of vection compared to someone playing the same game using a large TV screen or monitor [85]. The effects that display size and type during game play have on cybersickness need to be further investigated to identify potential trade offs between ease of use and effectiveness for training.

5.6 Next Steps: Towards Serious Games for VR Cybersickness Resilience

5.6.1 Validating that Gaming (as opposed to Gamers) Improves VR Cybersickness Resilience

Our findings take us one step closer to understanding the benefits of video gaming for cybersickness resilience in VR users and towards the potential of therapeutic training to increase this resilience. This study highlights the difference between gamers and non-gamers in cybersickness susceptibility with a further need to understand whether habitual gaming leads to cybersickness resilience or whether such resilience is innate with a self-selection bias in gamers. If there is a predisposition in individuals that become gamers, we need to investigate where this comes from and how this knowledge can be used to help reduce cybersickness for everyone.

5.6.2 Understanding Why Gaming Increases Cybersickness Resilience

If, as we suspect, it is the case that video gaming builds up resilience to cybersickness, we need to understand *how* such first-person perspective games can build up this resilience and whether there are other types of video games that are equally or potentially better suited to this. We need to identify what role the types of visual motion perceived in these games plays in the development of cybersickness resilience and how enhancements in cognitive and visual perception abilities obtained through these games can contribute to this resilience. In-line with this, the effective FOV during game play is likely to play an important role. The display size of the devices used to engage in games varies greatly, with some monitors and TVs covering up to 60° of the player's field of view. Self-motion cues presented on such large screens can cause a stronger sensation of vection [85], which in turn should benefit the build up of habituation. Gaming on larger screens could therefore be more effective in building resilience.

A further step would be to design serious games for cybersickness resilience habituation training. Based on our data and these future avenues, we can move towards designing more effective and potentially shorter and easier-to-adapt games or tasks that, through their environment and in-built cognitive demands, can build long lasting resilience to cybersickness.

6 Conclusion

In this paper we investigated the differences between habitual video gamers and non-gamers in terms of cybersickness and in the performance on visual discrimination and motor tasks during a tunnel travel experience presented using a VR HMD. Our findings indicate that first-person perspective gamers have more resilience to cybersickness and improved visual discrimination abilities. Demonstrating this resilience to cybersickness in video gamers brings us one step closer to understanding how we can train individuals to be resilient. This work builds a foundation for research developing such training, by firstly pointing away from innate resistance as the reason behind gamers' cybersickness resilience and by secondly understanding how gaming contributes to resistance and thirdly by operationalising it in serious games for cybersickness. This will allow even the most susceptible individuals to engage with and benefit from VR.

Acknowledgments

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