Workload's significant impact on cybersickness: A new frontier

by

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

I dedicate this thesis to my parents, Mary and Dan. Without their endless love and support, I wouldn’t be the person I am today.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

This study explored the impact of task workload on virtual reality (VR) cybersickness. Participants (*N* = 151) completed one of three variations of the same VR environment that differed solely in task workload. Cybersickness is a negative side effect of using VR content to which a majority of users are susceptible. The VR environment, the Cybersickness Corn Maze, contained cybersickness-inducing visual effects. Attention of the users was modified with three different task conditions to evaluate the relationship between workload and cybersickness. The No-Task group experienced it passively with no controllers. The 0-Back group used a controller to point in a visual attention task. The 2-Back group performed the 2-Back memory task and used a controller to point in a more difficult visual attention task. Presence, workload, cybersickness and task accuracy were compared across conditions. Previous research touches only superficially on the impact on task workload on cybersickness. Thus, it was uncertain whether increased task workload would decrease or increase cybersickness.

Workload was found to statistically significantly increase from No-Task to 0-Back to 2-Back, validating the task manipulation. Cybersickness in the 2-Back condition was statistically significantly higher than No-Task (140% higher) and 0-Back (54% higher) conditions as measured by simulator sickness questionnaire (SSQ) Δ (Post SSQ-Pre SSQ). Cybersickness dropout rates between conditions showed that the addition of the task reduced discomfort from No-Task (19% dropped) to 0-Back (10% dropped), but 2-Back's increased task load increased dropouts (33% dropped). These results indicate that 1) task workload affects cybersickness and 2) its effect could be non-linear. Presence was shown to increase with the addition of a task but plateaued between the 0-Back and 2-Back groups, suggesting that presence can be affected by task workload but only to a certain extent. Task accuracy was shown to negatively correlate with

cybersickness within the task conditions. This work highlights the need for task workload and attention to be studied as components of the mechanisms underlying cybersickness, which could offer a new frontier of research. Put simply: the task required in virtual experiences changes cybersickness symptoms.

CHAPTER 1. INTRODUCTION

Cybersickness, a physical discomfort that can arise from virtual reality (VR) experiences, presents a barrier to the wide acceptance of the technology (K. Stanney, Lawson, et al., 2020). The use cases of VR are vast and span a variety of industries including training, medicine, architecture, astronomy, data handling, teleoperation and entertainment (Kolasinski, 1995; K. Stanney, Lawson, et al., 2020). The recent development of affordable VR head-mounted display (HMD) systems has led to rise in popularity of the devices. Stanney et al.'s (2020) work shows a resurgence of the term "virtual reality" in 2015 with Google Trend data. This result aligns with Facebook's (now Meta) purchase of Oculus in 2014 which accelerated the growth of VR into the mainstream. Google Cardboard and Samsung Gear VR's release in 2015 allowed phone users to experience VR at any time with their handheld devices. Then HTC released the Vive in 2016, furthering the growth of VR in consumer markets to where it is today. Current VR technology relies on the use of consumer priced head-mounted displays (HMDs) such as the Oculus Quest 2, HTC VIVE Pro 2, or Valve Index.

Literature about cybersickness has sought to understand its causes, provide measurements, and identify possible mitigations. However, existing research on the causes and potential mitigations of cybersickness on the effect of the user's task or the effect of the user's sense of task-based presence on the sickness experienced is lacking. VR experiences do not happen without context and normally have a purpose, whether it be for entertainment, education, engineering, driving or flight simulation. VR users' ability to immerse themselves into an environment and imagine themself as "being there" is identified as a sense of presence (Slater, 2003). The tasks being carried out in these experiences may have a greater impact on the side effects experienced by the user than originally thought in previous research. The impact of a task can be measured with mental demand, defined by Hart & Staveland, (1988), as the amount of mental or perceptual activity that was required by a task, including activities like thinking, deciding, calculating, remembering, etc. Overall workload is the total workload associated with a task, taking into account all potential sources and components (Hart & Staveland, 1988). Mental effort and overall workload within VR tasks, and especially their impact on cybersickness, have not been thoroughly explored in reviews (Barrett, 2004; Chang et al., 2020; Davis et al., 2014; Rebenitsch & Owen, 2016; Saredakis et al., 2020; Tian et al., 2022). Loading participants with a difficult task may make them more likely to drop out of an uncomfortable experience or it may increase their presence in the virtual environment and keep them engaged for longer. This research aims to address two primary questions:

RQ1) What is the relationship between VR task workload, presence, and cybersickness?

RQ2) How do groups with different VR task workloads differ in presence, task performance, and cybersickness?

RQ1 aims to identify if workload, presence, and cybersickness have relationships that are tied to each other. RQ2 focuses on if predictions can be made about presence, performance, and cybersickness if a participant's workload is known.

This research was conducted within one virtual environment, the Cybersickness Corn Maze (https://github.com/isuvrac/CyberSickness-Cornmaze), at the Virtual Reality Application Center (VRAC) of Iowa State University. This virtual environment built on previous work (Curtis et al., 2015; Jasper et al., 2020; Meusel, 2014). Useful background information related to this research includes brief overviews of motions sickness vs. cybersickness, workload and mental demand, and presence vs. immersion.

Motion Sickness vs. Cybersickness

Cybersickness is similar to, but not the same as motion sickness. A negative physiological response to stimulus related to movement from cars, planes, trains, or boat travel is deemed motion sickness (Reason & Brand, 1975). Symptoms include stomach discomfort (e.g., nausea, stomach awareness, salivation, appetite issues), oculomotor issues (e.g., headache, drowsiness, dizziness), and general discomfort (e.g., odor sensitivity, increased body temperature) (Lackner, 2014). Persons who experience these symptoms may experience any combination of these sorts of discomfort. Motion sickness, by definition, occurs when the body experiences physical acceleration or movement that can disrupt proper functioning of the vestibular system (Golding, 2006).

Cybersickness Overview

In some situations, similar symptoms can appear without physical motion (K. Stanney & Kennedy, 1997). In circumstances where individuals experience motion sickness symptoms without the presence of motion, individuals experience visually induced motion sickness (VIMS) (Keshavarz et al., 2014). Categories of VIMS can include simulator sickness, first noted by Havron & Butler in 1957, and cybersickness (McCauley & Sharkey, 1992). The largest differentiation between the two is that simulator sickness arises from simulators (such as flight or driving simulations in which the person is not moving but is sitting in a realistic mixed-reality cockpit or driver's seat), while cybersickness occurs during exposure to virtual environments with virtual or augmented reality devices (usually HMDs).

Simulators can induce sickness, though the profile is different than that of cybersickness. Cybersickness involves higher rates of oculomotor and disorientation problems, with less nausea (Stanney et al., 1997). The symptoms of cybersickness and simulator sickness are similar, and current research on the causes point to sensory conflict theory, ecology theory, or evolutionary theories for explanations. Each theory is explained in greater detail in CHAPTER 2.

Overall Workload and Mental Demand

An area of research that has not been investigated as thoroughly is the relationship between mental workload and cybersickness. Previous literature has denoted the potential importance of tasks in VR and their relationship to cybersickness (Barrett, 2004; Chang et al., 2020). Workload is a hypothetical construct that represents costs incurred by humans to achieve a specific level performance and is not an objective experience (Hart & Staveland, 1988). A component of workload is mental demand, the necessary mental/perceptual activity that is required to accomplish a task. Task activities have varied with previous research, but no consistent relationships between task workload and cybersickness has been established (Barrett, 2004; Davis et al., 2014; Dilanchian et al., 2021; Meusel, 2014; Rebenitsch & Owen, 2016; Weech et al., 2019). The components of this activity may include thinking, deciding, calculating, remembering, looking, or searching. These measures aim to capture how much effort and mental workload humans experience during various tasks. Current literature has identified the importance of tasks on cybersickness but only with respect to task duration and controllability (Chang et al., 2020; Davis et al., 2014). Workload and mental demand are factors related to the tasks that are carried out in VR that should be considered, and this research aims to provide insights into these factors.

Presence vs. Immersion

There has been significant confusion between the ideas of presence and immersion within discussions about virtual environments. Slater (2003) discusses the two terms and identifies immersion as what the technology delivers from an objective point of view. This description relates to the rendering software and hardware that is being used to visualize the virtual environment, e.g., number of pixels, framerate, or field of view. Immersion contains components that are objective and measurable, allowing for someone to distinguish one system as having a higher level of immersion than another (Bowman & McMahan, 2007). Slater (2003) then defines presence as the human reaction to immersion. Thus, given the same system, it is possible that different people experience different levels of presence, but the system would have the same level of immersion. The two are separable and are analogous to the difference between the wavelength of light (objective like immersion) and color perception (subjective like presence), since light wavelengths can be objectively measured scientifically, but the human perception of the color cannot.

Sra (2018) discusses at length the overall goal of virtual reality to create worlds that look, sound, act, and feel real. The connection between all of the senses allows individuals to perceive themselves as “being there” when experiencing a VE, also known as presence. Gilbert (2016) discusses the definition of presence as the engagement of being elsewhere and it is affected by immersion and authenticity. Authenticity being the amount that the virtual experience meets humans’ expectations. Skarbez et al. (2018) furthered work in this area with the idea of coherence being included as a factor for presence. Place illusion and plausibility illusion were differentiated with the place illusion being about the feeling of being in a place and plausibility illusion being the feeling of depicted events actually happening. Plausibility illusions may cause users of VR to experience more cybersickness because of the acceptance of events happening (e.g., movement) may lead them to experience more severe sensory conflict. The effect of cognition required by a task on presence and cybersickness is unknown. The VACP scale, created by Aldrich et al. (1989), breaks down task workload into four categories: visual, auditory, cognitive, and psychomotor. The proposed work plans to further extend the literature by connecting mental workload to presence and cybersickness measures via a task that involves all four of these components (and is therefore closer to a real-world task than many traditional lab-based research tasks).

Hypotheses

The following are the expected hypotheses of this work:

H1: Increased task workload will lead to higher perceived presence (part of RQ1).

H2: Increased presence will be correlated with reduced cybersickness (part of RQ1).

H3: Participants assigned to task groups will show higher levels of workload, presence, and lower levels of cybersickness than participants without a task (part of RQ2).

H4: Better performance in a real-world VR task will be correlated with reduced cybersickness (part of RQ2).

For more detailed evaluations of these hypothesis, see CHAPTER 5.

Thesis Overview

Chapter 1 outlines the research questions and hypotheses and covers the concepts to be explored with cybersickness, workload/mental demand, and presence and immersion. Chapter 2 reviews previous work done within the area of cybersickness theories, measuring cybersickness, workload within tasks, and presence in VR and addresses the gaps in the literature related to the relevance of tasks in VR. Chapter 3 covers the methods and procedures followed to conduct a study within a virtual environment to address the research questions. Chapter 4 presents all relevant data and results collected from the study. Chapter 5 discusses the data collected, answers the posed questions and addresses limitations of the approach. The final chapter also summarizes the research and identifies future work to be done related to new research questions stemming from this work.

CHAPTER 2. BACKGROUND

Since this research focuses on cybersickness and how task workload and presence may affect it, it is useful to review existing research on current theories on the mechanism of cybersickness, known triggers of cybersickness, and cybersickness measurement techniques. Because the task in this study is designed to be a game-like task (justification described below), it is also useful to review previous research on tasks and workload in VR, video game tasks vs. lab tasks, presence in VR, and System 1 vs System 2 thinking during gaming tasks.

Almost all susceptible individuals with continued exposure to a provocative virtual environment (VE) can experience cybersickness symptoms. A VE, as defined by Sherman & Craig (2003), is an instance of a virtual world presented in an interactive medium. The VEs in this research are 3D experiences experienced through an HMD in which users experience virtual representation of movement while seated and not moving. Cybersickness has been noted to occur in augmented reality (AR) experiences as well (Hughes et al., 2020), but this work focused on cybersickness in VR alone. Also, cybersickness can occur when the user wearing an HMD is physically moving, e.g., locomoting through the VE by walking physically around a room that is the approximate size of the VE (e.g., da Silva Marinho et al., 2022; Melo et al., 2021), but this research focused on seated users.

Simulator sickness, a close relative to cybersickness, has been shown to have relationships with the following mental factors: previous experience with a real-world version of the task being simulated, mental rotation ability, degree of control, duration, among many other non-mental factors (Kolasinski, 1995). Cybersickness' relationship to simulator sickness indicates the importance of mental factors when considering the causes of cybersickness. The precise mechanism of cybersickness is still not identified, but the leading theories in the field are:

Sensory Conflict Theory, Ecological / Postural Instability Theory, and Evolutionary Theory. Each of these is worth exploring, particular the role of the task within each.

Theories of the Mechanisms of Cybersickness

Cybersickness has yet to have a proven explanation of its mechanism, but there are three leading theories. McCauley & Sharkey (1992) discussed the effect of human perceptual systems' ability to provide orientation and movement information while traveling through an environment. These systems sometimes struggle with new experiences in VEs related to illusory self-motion, which could result in cybersickness.

Sensory Conflict Theory

Sensory or cue conflict theory proposes that motion sickness is the result of conflict between sensory inputs, such as the eyes and the ears (Reason, 1978). These senses normally align to help humans build an accurate mental model of the environment and their current experience. Motion sickness research provides this theory as the main cause of sickness. For example, with sea sickness, the boat's constant rocking provides constant stimulus to the vestibular system, but visual signs of movement may not be present. In the case of cybersickness, the sensory mismatch between the visual optic flow, which normally occurs during movement and the vestibular system, which indicates no motion, is one of the leading explanations of sickness. The visual system in VR headsets is fully immersed in whatever VE is being portrayed through the stereoscopic viewports within the HMD. This complete visual display blocks the user from interpreting any visual input besides that of the virtual environment. The eyes may perceive movement, also known as illusory self-motion or vection, while the vestibular system does not. This mismatch between the two internal systems can result in sickness.

The vestibular system relies on fluids within the inner ear to detect the movement and orientation of the head. As the head moves, the fluid in the ears moves around and allows the human to perceive orientation and movement. When experiencing VR, the eyes can perceive movement through the movement of the camera in the virtual space that the vestibular system does not perceive. Akiduki et al. (2003) noted that visual-vestibular inputs are processed in different neural pathways, which results in subjective autonomic and postural responses by the body. Previous work has shown that using an HMD as a personal viewing system, where head tracking is turned off (the vestibular system detects movement but the visual system does not), results in more frequently reported cybersickness symptoms (Howarth & Costello, 1997). Cybersickness caused by purposeful visual-vestibular conflict suggests the conflict can cause cybersickness and postural instability (Nishiike et al., 2013). That same work also found that adaptations to these sort of conflicts decreased the weighting of visual inputs for postural control, which provided potential for rehabilitation of dizzy patients by subjecting them to a VR experience to cause a reweighting of sensory inputs. Motion sickness research proposes that the sickness experienced is due to conflicting neural signals originating in subservient brain regions to spatial orientation causing discomfort (Oman, 1990). The current research into tasks and cognitive load are based in this theory. While humans process incoming information and stimuli, the key resource is attention (C. D. Wickens et al., 2021). Attention impacts the perception of the external environment and offers an opportunity to manipulate human perception of a virtual environment. It is possible that including a task may distract individuals from the sensory mismatch that causes cybersickness.

Ecological / Postural Instability Theory

An alternate hypothesis to cue conflict is known as the ecological, or postural instability theory. The foundation of the theory is that when humans are in situations in which they cannot balance themself, they become sick. Riccio & Stoffregen (1991) identify and discuss the postural instability theory as a replacement of the aforementioned sensory conflict theory. In their article defining the ecological theory, they identify that the sensory conflict theory relies on the assumption that animals make inductive inferences about the world as they interact with it. In 1979, Gibson's (2014) questioned the assumptions about the role of inference in perception. The sensory conflict theory relies on the assumption that humans have expectations about how experiences are going to be perceived with all senses and that when mismatches occur, sickness is the result. Riccio & Stoffregen (1991) claim that motion sickness symptoms arise from prolonged instability in postural control. They also argue that sensory conflict may not exist. The conflict theory would say that unfamiliar situations coincide with sickness because they do not align with previous expectations, while the postural instability theory says this is due to the inability of the animal to properly manage its posture.

Arcioni et al. (2019) showed in a recent study that postural stability predicted the likelihood of cybersickness in VR. In that work, researchers identified that individuals who had postural instability when standing quietly had a higher likelihood of experiencing cybersickness. Navigating stairs, a movement likely to induce postural instability, was mediated by using a ramp instead and showed a reduction in sickness within an HMD using a gamepad for a controller (Dorado & Figueroa, 2014).

Constant speed experiences, which are commonly recommended to reduce sickness by reducing postural sway, were not shown to reduce sickness experienced in previous work (Widdowson et al., 2019). Da Silva Marinho et al. (2022) showed no significant difference in postural stability between games and non-gamers in VR. The study in this work targeted tasks in which individuals in the no task group may have been less motivated to look around at their environment, possibly resulting in less postural instability. Increased workload presented by a task may lead individuals to feel overwhelmed and more likely to destabilize their posture. Or, tasks may keep them engaged and more likely to maintain a more stable posture.

Postural instability is the closest thing to an alternative to the sensory conflict theory to explain cybersickness. There is not clear evidence to support either claim definitively, which leaves another claim, the evolutionary hypothesis, the opportunity to fill in some gaps.

Evolutionary Theory

The evolutionary hypothesis builds upon the sensory conflict theory and identifies that an ancestral reaction to sensory conflicts is nausea (Money, 1990). This theory proposes that the body in natural circumstances does not get exposed to situations where sensory conflict would occur, so the immune system perceives that there has been some sort of poison ingested. This interpretation by the central nervous system results in vomiting to remove the poison. This theory is also known as the poison hypothesis. Disturbances in sensory input can be produced by ingested toxins, a similar reaction to sensory conflict experienced in VR. This response is an accidental byproduct of this defense system against neurotoxins (Treisman, 1977).

The current research explores the effect of task workload on cybersickness, which, if impactful, would suggest another component to add to the blueprint of the bodily mechanism leading to cybersickness.

Known Triggers of Cybersickness

This study aimed to provide the same experience to all participants in terms of hardware, movement, and application quality, keeping those constant to view the differing effects of mental workload and immersion on cybersickness. Known triggers of cybersickness were purposefully included in the study environment to ensure sickness could be measured. The following is a description of previously known triggers of cybersickness.

Hardware

Hardware (graphics cards, display devices, connections) play a key factor in determining the quality of a VR experience. Hardware aspects related to display type, field of view (FOV), latency, and flicker have all been shown to impact cybersickness, as described in more detail below. As hardware has increased in quality, a near complete removal of cybersickness has been expected in research communities. This has not been the case, as it persists in the modern hardware (Stanney et al., 2020; Yildirim, 2020). Increased quality of rendering devices has made for more realistic and visually pleasing virtual experiences, but still cybersickness persists.

Display types such as 2D display screens, Cave Automated Virtual Environment (CAVE) displays, and HMDs have all been investigated to understand user's experiences. Monitors, TVs, or phone screens (2D screens) are the most common implementation of virtual experiences. These screens portray images monoscopically compared to the more immersive displays such as an HMD or CAVE. CAVE systems are virtual reality spaces in which the floor, ceiling, and walls can all act as projection surfaces (Cruz-Neira et al., 1992). CAVE displays, especially when the user wears 3D stereoscopic glasses, can allow for increased mental immersion than other systems, though they also create new interaction challenges (Muhanna, 2015). HMDs create a stereoscopic percept by displaying different images to each eye. HMDs and CAVEs allow for stereoscopic content in VR, which allows for increased depth perception and a higher fidelity VR experience. These benefits may also lead to more severe cybersickness (Chang et al., 2020; Dennison et al., 2016; Kim et al., 2014; Naqvi et al., 2015). Kim et al. (2014), for example, compared the three display types and showed that the highest sense of presence was with the CAVE system and the highest sickness incidence rate was with the HMD. More recently, Mittelstaedt et al. (2018) showed a similar result as other studies with HMDs inducing more cybersickness than a large 2D display. Yildirim, (2020) showed a significant difference in sickness experienced between desktop displays and HMDs, with HMDs having higher reported sickness. The current research used an HMD.

FOV, field of view, is the range of vision available to a user, usually communicated in degrees, of the virtual environment. This can encapsulate either horizontal or vertical FOV but, horizontal FOV is the more commonly reported of the two in this area of research. FOV is a hardware specification which comes from the maximum visual angle of the display but it can also be modified by the software or application being used. The approximate human FOV with both eyes (binocular) is around 200 degrees (Dagnelie, 2011), and this is often greater than what is available in most HMDs. FOV limitations can occur in both hardware and software. Hardware FOV, also referred to as external FOV, is determined by screen size and the distance from the user's eyes. It is related to the FOV permitted by the device itself, e.g., when there are limitations of the technology's view frame near the periphery of the eyes that reduce how much a user could see. Additionally, content FOV manipulations, also referred to as internal FOV, change the presentation of virtual content with modifications of how wide the view is rendered within the device.

Some uses of FOV limitation include game scenarios in which developers want to limit field of view to increase viewing difficulty or enhance the drama of a scene by focusing a player's view on a focal point Ang & Quarles (2020). Previous work has looked at the effects of FOV on cybersickness (Draper et al., 2001; Harvey & Howarth, 2007; Y. Y. Kim et al., 2008; Shigemasu et al., 2006; Toet et al., 2008; van Emmerik et al., 2011). Among these works, the only major consensus is that reducing the user's FOV has been shown to reduce cybersickness, especially during acceleration and rotational locomotion. Otherwise, there have been mixed results on the effect of hardware FOV matching the content FOV. GingerVR, a tool created by

Ang & Quarles (2020), aimed at providing solutions to cybersickness with an open-source repository of reduction techniques such as reduction of field of view or dynamically blurring a user's vision. In the current research, the Cybersickness Corn Maze does not use FOV to trigger cybersickness, and it remains constant across all conditions.

Latency and flicker are both known causes of discomfort in a VR experience. Latency occurs when head movement by a user results in calculation of a new image in the display corresponding to the motion. Latency is the lag or time difference between what the display showed and what the user perceived with their movement. A higher latency has been shown to be closely related to cybersickness (Rebenitsch & Owen, 2016). The act of when a human rotates their head results in the use of the vestibulo-ocular reflex, which is the cooperation of the vestibular and visual systems to stabilize visual images in the eye (Chang et al., 2020). This results in a lot of potential sensory conflict (discussed above) with higher latency. Increased delays (higher latency) were shown to have higher sickness (DiZio & Lackner, 1997). An opposing result from Draper et al. (2001) showed that if the user could adapt to a consistent lag in the display, as if it were constant, there would be no difference in the degree of subjective discomfort.

A display's flickering can be caused by a display's refresh rate and brightness of the screen (Renkewitz & Alexander, 2007). Flickering presents an issue specifically for commercial VR systems currently, as they are designed to be high performing but can have sudden drops in frame rates or higher latency, which can induce sickness. Flicker and framerate were held constant for all conditions in the Cybersickness Corn Maze by utilizing the same hardware and software throughout the entire study.

Fidelity

Graphic realism has also been analyzed to view its impact on cybersickness. Efforts to make virtual experiences more realistic have not shown results of a better VR user experience (Pouke et al., 2018; Tiiro, 2018). The more realistic virtual environments may encourage users to expect better vestibular stimuli and thus result in more sensory conflict (Chang et al., 2020).

Optic flow in a VR scene enables a user to feel vection, also known as illusory self-motion. This optic flow leads to users experiencing the feeling of movement, which can cause sensory conflict. The rotation among different axis has been evaluated and has shown that rotational movements are more uncomfortable for users than translational ones (Bonato et al., 2009; Keshavarz & Hecht, 2011b; Lo & So, 2001; So & Lo, 1998). Navigation speed has also been shown to change the level of cybersickness experienced (Richard H. Y. So et al., 2001), with nausea and vection showing significant increase when moving from 3m/s to 10m/s. Stability in sickness was experienced in speeds beyond 10m/s in the Soo et al. study. The experience in the current study was designed to vary the speed from stopped (0 m/s) to fast (13 m/s) to try to induce sickness. The VR experience in this study contained many turns of 90 degrees, vertical walls to descend and climb, and slides. The rotational motion included in the experience was meant to induce sickness based on this previous research.

In addition to navigation speed, motion sickness (not cybersickness) was shown to have a key correlation to acceleration. Acceleration within a virtual environment relates to movement of the camera in the virtual space, which could be due to the active or passive movement within a virtual experience. Previous work has indicated that passive movement, or movement that is not controlled by the human, causes higher incidence of cybersickness. (Stanney & Kennedy, 1997) Humans struggle with average acceleration and had increased sickness as a monotonic function of the acceleration level (O'Hanlon & McCauley, 1974). The maze in this study was designed to include varying levels of acceleration to ensure acceleration varied enough to potentially induce sickness. Widdowson et al. (2019) showed no convincing evidence for constant speed being more comfortable for VR scenarios. Acceleration was included to create a less monotonous experience. The Cybersickness Corn Maze in this experience built on previous work from (Curtis et al., 2015; Meusel, 2014).

In the literature, two other distinct variables identified related to tasks are duration and control. How long a participant is exposed to a VR experience can cause them to experience more or less sickness, with some users experiencing sickness symptoms with exposures of less than ten minutes (Dennison et al., 2016). Control of movement in virtual environments has also been shown to be a key factor in cybersickness symptoms. Reviews of cybersickness from the last 25 years have all indicated the importance of control of movement in causing sickness symptoms (Chang et al., 2020; Keshavarz et al., 2014; K. Stanney, Lawson, et al., 2020; K. Stanney & Kennedy, 1997). With this knowledge, the Cybersickness CornMaze was designed with no control of movement for any of the study conditions. The experience designed for this current research was designed to last around 15 minutes for all of the conditions.

Individual Differences

Despite all of these known triggers of cybersickness, there are still some individuals who experience little to no negative side effects while in VR. Individual differences in susceptibility account for some of the difficulty of doing cybersickness research. Lackner (2014) noted how individuals differ in cybersickness susceptibility, adaptation, and recovery by factors of more than 100. Individual difference analysis is beyond the scope of the current research, but the large sample size was collected to possibly account for individual difference variation. Also, it is worth briefly reviewing previous research on cybersickness individual differences to appreciate the factors that may influence cybersickness levels beyond the task workload.

Cybersickness triggers associated with age, gender, prior VR experience, and motion sickness susceptibility have been identified in literature reviews (Chang et al., 2020; Rebenitsch & Owen, 2016; Stanney et al., 2020; Tian et al., 2022). Older individuals have been shown to experience higher levels of sickness in previous studies (Hakkinen et al., 2002; Park et al., 2006). Arns & Cerney (2005) discuss the relationship between age and cybersickness experienced in immersive CAVE experience and countered previous results that suggested that older individuals were more susceptible to cybersickness. A meta-analysis from Saredakis et al. (2020) noted different results with older individuals (>35 years) with significantly lower SSQ scores.

Gender differences have been touted as a reason for increased sickness; a highly cited paper from Stanney, Fidopiastis, et al. (2020) claims that VR is sexist. Sources such as FOV, hormone levels, and motion sickness history were identified as possible reasons for the gender difference (Chang et al., 2020). Fulvio et al., 2021) showed that with proper interpupillary distance calibration, nearly all sex differences in VR cybersickness disappeared. A broad meta-analysis deemed sex differences to be inconclusive as a definitive cause of cybersickness (Saredakis et al., 2020). Also, some of the gender differences noted with cybersickness reporting may be due to personality, in that women may be more likely to report sickness than men (Jasper et al., 2021).

Measuring Cybersickness

There have been many attempts to measure the severity of cybersickness, including subjective, objective, and additional sensory measures.

Subjective measures attempt to capture data regarding sickness through self-reported questionnaires. Chang et al. (2020) reviewed 77 experimental studies and showed that the most widely used subjective measurement was the simulator sickness questionnaire (SSQ). The SSQ was developed based on the motion sickness questionnaire (MSQ) and verified with a series of factor analyses. Kennedy et al.'s (1993) SSQ has 16 items across three subscales (nausea, oculomotor, and disorientation) with answers from 0 to 3 related to participant sickness symptoms. A higher SSQ score in VR studies indicates the participant experienced more severe cybersickness. Table 1 shows symptom clusters as investigated by Stanney et al. (1997).

Table 1. Cybersickness symptom clusters sorted by SSQ scale (Stanney et al., 1997)

Nausea	Oculomotor	Disorientation
Stomach Awareness Increased Saliva Burping	Eyestrain Difficulty Focusing Blurred Vision Headache	Dizziness Vertigo

Additional subjective measures for sickness have been developed such as the Fast Motion sickness Scale (FMS), the misery scale (MISC), a forced-choice question, the Virtual Environment Performance Assessment Battery (VEPAB), and the motion sickness assessment questionnaire (MSAQ). Each of the tools aim to capture how sick a participant is based on their responses. The FMS has participants report sickness every minute on a scale of 0-20 (Keshavarz & Hecht, 2011a). The MISC has participants report sickness on a scale from 1-10 based on current sickness severity (Wertheim et al., 2001). A forced-choice question is a simple yes or no inquiry about if the participant is feeling sick in VR (Chen et al., 2011). The MSAQ has fewer questions than the SSQ with a broader rating scale (Gianaros et al., 2001). The VEPAB is a tool to measure performance in VR with vision, locomotion, object manipulation and reaction time tasks (Lampton et al., 1994).

Questionnaires like the SSQ and others have limitations. The SSQ contains 16 questions and can be difficult to administer during an experience without disturbing the presence of the participant. Additionally, there are individual differences in how participants self-report discomfort (Jasper et al., 2021). Where one individual may report sickness, another person may not. Also, most questionnaire data are collected after finishing a VR experience, which fails to collect data in real-time.

Attempts to create objective sensory measures have not led to a widely accepted solution. Predictive models based on demographics, software, and hardware factors have been documented (Rebenitsch & Owen, 2021). Neural network models have attempted to quantify and estimate sickness experienced in real time (Jin et al., 2018; J. Kim et al., 2019; Roberts & Gallimore, 2005). Body measures such as EEG, e.g., Islam et al. (2020); Dennison et al. (2016), or electrodermal activity (EDA) (K. Kim et al., 2014; Meusel, 2014) are captured in real time and fed into models to identify sickness as it happens to help modulate it. The most common objective measurements captured in previous research per Chang et al. (2020) are: postural sway, electrocardiogram, electrogastrogram, eye measures, electrodermal activity, electroencephalogram, photoplethysmogram, respiration pneumogram, skin temperature, and blood pressure. No objective measures have been widely regarded as a direct measure of cybersickness. Due to the lack of consensus of objective measures, the current research study used SSQ.

Tasks and Workload in VR

Tasks within VR provide context and purpose to a virtual experience. Previous literature has denoted the potential importance of tasks in VR and their relationship to cybersickness (Barrett, 2004; Chang et al., 2020). While there has been acceptance of the importance of tasks within cybersickness research, the number of studies in this area is not extensive. Chang et al.'s (2020) review of cybersickness research identified five areas of interest (optic flow, task, field of view, graphic realism, and reference frame) related to content within previous work, with task being one of them. That work identified that only two major characteristics of tasks have been investigated: duration and controllability. An older review identified several factors related to the task including: duration, global visual flow, rate of acceleration, and type of maneuvers (Barrett, 2004). A more recent review identified task-related features as navigating, translational or rotational velocity and acceleration (Tian et al., 2022). Across all of these reviews, the relevance of task workload and perceived difficulty of tasks has not been identified as an area of importance for cybersickness.

Duration in tasks is related to the amount of time users spend in the virtual environment, with longer exposures producing more symptoms (Kennedy et al., 2000). Even short experiences (< 10 minutes) have been shown to induce sickness (Dennison et al., 2016), but longer experiences have been shown to induce greater degrees of sickness (Kennedy et al., 2000; Lo & So, 2001; Richard H. Y. So et al., 2001). Barrett (2004) came to a similar conclusion that duration is one of the most important factors that influence the likelihood of cybersickness, in their review.

The duration of the experience in this study across all conditions was maximized at 15 minutes for all conditions. Understanding that duration is a problem does not help developers who want to immerse users for longer periods of time and leads to questions about factors within tasks. The other task-related factor that has been investigated previously is controllability.

Controllability is discussed as an area of importance, specifically with identifying the differences between active or passive experiences (Chen et al., 2011; Farmani & Teather, 2020; Mittelstaedt et al., 2018; K. Stanney & Hash, 1998). Active navigation includes experiences where the user is in control of their movements such as exploring a room by walking around. Passive navigation restricts the user’s ability to control movement, such as in a roller coaster where the user is along for the ride. Passive navigation has repeatedly been shown to be a cause of more severe cybersickness (Chen et al., 2011; Dong & Stoffregen, 2010; Stanney et al., 2020; Stanney & Hash, 1998). This study subjected participants to passive navigation purposefully to create an environment to cause sickness and investigate the effect of different tasks and workload on that sickness. In Chang et al.'s (2020) review of cybersickness literature, the task was rarely mentioned as a factor that impacts cybersickness.

The impact of the task carried out in VR seems to be a research area of significant importance. What users are doing within a virtual environment likely affects the types of side effects they experience from exposure. Attention and cognitive workload may be the missing pieces to understanding the triggers of cybersickness. It may be that sickness-inducing VR experiences pose visual attentional demands to maintain health. If this is true, then modifying the workload of a task should impact the sickness experienced.

Game Task vs. Lab Task

Beilock et al. (2002) noted that athletes' focused attention in athletic tasks was sometimes counterproductive, leading to over-analysis and preventing the person from using well-practiced behaviors. The athletes performed better by not focusing conscious attention to their tasks. Similarly, with cybersickness, it may be possible that attention to a task in VR could reduce cybersickness by reducing the conscious attention focused on the sickness-inducing visual cues.

A proposed model of this interaction is shown in Figure 2. Palmisano & Constable (2022) identified that cybersickness experienced can be game-specific. That study provides further motivation for cybersickness research to consider the context in which cybersickness is being studied. Variance in gameplay types and tasks within the gameplay may lead to variance in cybersickness. Previous research has shown that a past history of video game play can predict cybersickness (Rebenitsch & Owen, 2014). Additionally, work from Weech et al. (2020) showed that the effect of a narrative on cybersickness is impacted by previous gaming experience. Older studies have shown conflicting results, where gamers experienced more sickness (Jaeger & Mourant, 2001; Knight & Arns, 2006). In the current study, the researchers intended to create a game-like experience to study cybersickness in the same context as its most popular industry of use. The most common current commercial use for VR is in gaming, and research in this area specifically can help with wider adoption of the technology (Gilbert, 2021).

Research in cybersickness sometimes uses heavily constrained lab-based tasks that are easier to study but which do not replicate game-like tasks or naturalistic VR experiences, and the non-naturalistic aspects of these VR lab tasks may affect participants' cybersickness. In this context, the terms "naturalistic" and "game-like" tasks refer to VR contexts that are highly similar to typical experiences that users would have from commercial off the shelf VR gaming paradigms. Two characteristics of these naturalistic game-like tasks are important. First, game-like tasks occur in the context of experiences designed to entertain the participant. This entertainment context, or more generally, the framing of the activity's purpose, likely affects users' motivations and engagement, and may impact their experience of cybersickness. If it can be shown that the purpose framing of a VR activity affects cybersickness, an additional component will need to be added to the theories of the cybersickness mechanism.

Second, naturalistic experiences should employ more commonplace or standards-based user interfaces and affordances that are familiar to a VR user, e.g., the system should include head tracking to control movement and the use of VR controllers with the hands rather than require using a computer mouse. The researchers suggest that research in VR should ideally provide naturalistic VR interactions rather than more constrained lab-based tasks. The purpose of this study was to use a game-like VE with known cybersickness triggers to identify the differences between task conditions within a naturalistic VR environment.

Research studies have used commercial-off-the-shelf (COTS) games to investigate cybersickness. These experiences can help the community understand how VR is used in naturalistic settings and is an approach that could be adopted more frequently. Weech et al. (2018) compared sickness between commercially available games looking for differences between “Intense” and “Comfortable” games as rated on the Oculus Store (intense games tend to make users more cybersick). Task workload may be a factor that goes into these store ratings. Another recent study looked at sickness within video game environments to study results with natural VR interactions (Yildirim, 2020). Researchers performing studies in these types of environments may get results that generalize better to real-world VR use cases (e.g., entertainment). Farmani & Teather (2020) investigated viewpoint control to reduce cybersickness with a zombie shooting game but failed to enable standard VR controls and used a mouse to control look direction. This sort of research is insightful but not natural to VR experiences that use head tracking. Davis et al. (2015) evaluated the onset of cybersickness between two virtual roller coasters, and while this study is closer to the style of VR gameplay that can entice gamers to adopt VR, it does not seem like the type of experience that will keep players coming back. The research community should aim to create naturalistic testbeds, such as the Cybersickness Corn Maze, to study cybersickness in contexts more similar to those in which the everyday VR user would find themselves. This scoping of research can help lead to quicker adoption of VR.

A review of literature shows that studies infrequently consider the type of task as a possible confound or mediator of cybersickness. Studies such as Arns & Cerney (2005), discuss cybersickness, but fail to identify the experience they subjected participants to. Lo & So (2001) investigated scene rotational movements with cybersickness in a custom VR environment that contained no game-like tasks. Emmerik et al., (2011) used the Source engine (from Valve's Half-Life 2) to create a passive virtual tour with no game task elements. Kemeny et al. (2017) discussed new potential VR navigation techniques with promising preliminary results. Within that study they did not have a task besides walking, but the context of those navigation changes matters, and different types of tasks may have had different results. Krokos & Varshney (2022) tracked sickness with EEG during a roller coaster-like experience with no task and were given the controller as a method to track their current sickness level. Fransson et al. (2019) tracked adaptation to sickness with repeated roller coaster experiences. Dennison & D'Zmura (2017) subjected participants to a spinning VE to study postural sway but provided no task or game-like experience. The studies highlighted above have failed to consider that the task they are subjecting participants to may be affecting the results of their work.

Overall, previous research is inconsistent with its testing methods and whether tasks are included in the experiences. This work aimed to develop a testbed of a naturalistic VR experience that induces cybersickness to test the differences between task groups with a game-like task.

Mental Workload of Tasks

Workload of tasks is a hypothetical construct that captures the cost incurred by a human to achieve a particular level of performance. There are several approaches to measure mental workload, such as the Bedford workload scale (Roscoe & Ellis, 1990), the Instantaneous Self-Assessment (ISA) (Tattersall & Foord, 1996), and the NASA-TLX (Hart & Staveland, 1988). Each individual experiences different levels of difficulty when conducting tasks, and thus the NASA-TLX (the measurement tool used in this study) is human-centered. The NASA-TLX will be used in this study because it is widely accepted, is simple to administer, and the subscales feature different areas of interest in this research such as mental demand, frustration, performance, and temporal demand. Workload is related to the interaction between task requirements, circumstances under which tasks are performed (e.g., time-pressure), and the skills, behaviors, and perceptions of the operator (Hart & Staveland, 1988).

The relevance of mental workload in cybersickness has not been extensively investigated. It may be reasonable to assume that there exists some relationship between cybersickness and mental workload due to the attention of the user being diverted from potential sensory mismatches or postural instability and onto the task. Wickens et al.'s (2021) human information processing model, as seen in Figure 1, notes that attention impacts perception, which supports that idea that it may also affect cybersickness, if cybersickness is influenced by perception (which it must be, since cybersickness is triggered noticeably by visual stimuli). Per Wickens (2021), attention can be understood as conceptually in two ways, as a filter and as a resource. These two concepts are key to predicting how attentional demands might influence cybersickness (see Figure 2) and understanding the role of attention and workload in the cybersickness mechanism. First, attention can be understood as a filter of selective attention that chooses what information from the environment is being processed. In this context, attention has two possible effects on cybersickness. 1) Placing attentional demands on an individual may reduce cybersickness, because the individual is filtering the perceived inputs and focusing on the task requirements rather on the visual inputs that may lead to cybersickness. Or, 2) task attentional demands may increase cybersickness, if a person is actively using attention to filter out sickness-triggering visual inputs to maintain health, and the additional task requirements prevent that filtering from occurring. The researchers in the current study predict the first case, as shown in Figure 2, in which additional attentional demands can effectively distract users from cybersickness-inducing cues.

Similarly, when attention is understood as a resource, it enables information processing, but it forms a constraint on tasks and limits multitasking. Again, there are two possible outcomes for the impact of attentional workload on cybersickness. 1) If maintaining one's health in the face of cybersickness-triggering visual stimuli is a task in itself that requires attention as a resource, then adding an additional task may reduce performance in the health-maintenance task, thus increasing cybersickness. Or, 2) if attending to the virtual environment is a task that has less attention allocated to it because of the additional task workload, then cybersickness may decrease. As noted above, the researchers predict the second case to be true, in that additional workload will result in less attention allocated to the VE, which in turn will decrease cybersickness. To evaluate these predictions in the current study, three different forms of tasks were included to modify the attention resources of individuals experiencing a sickness-inducing VR experience.

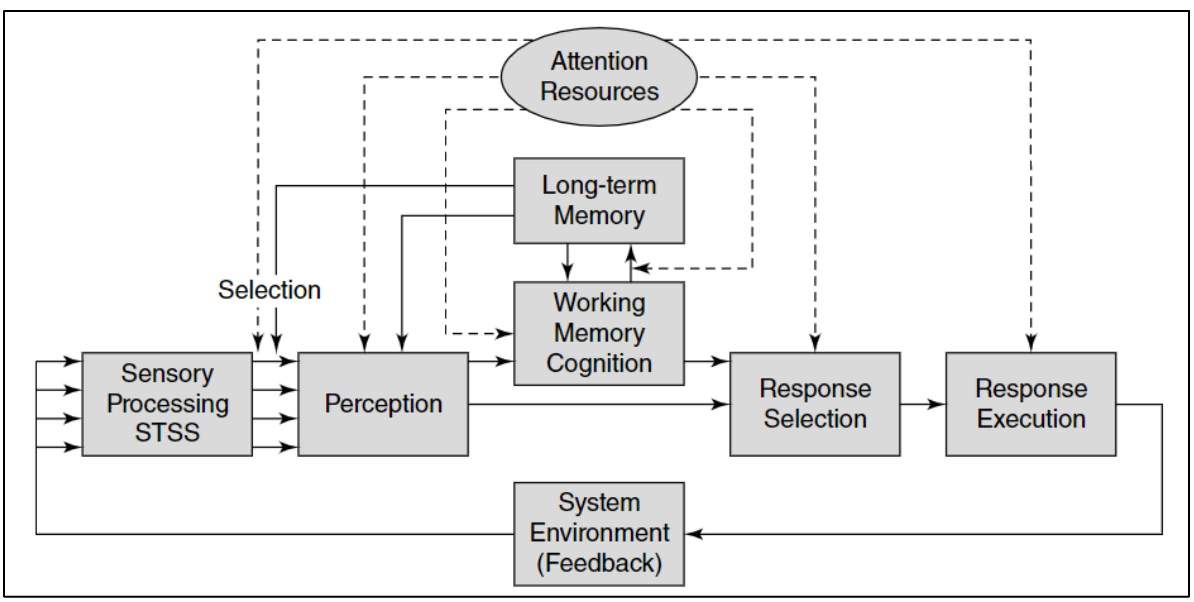


Figure 1 Human information processing model (Wickens et al., 2021)

Mental Workload and Cybersickness

Previous literature regarding mental workload and cybersickness is lacking. Meusel (2014) identified a positive relationship between mental workload and cybersickness (higher mental workload led to higher cybersickness). Comparisons across three video games showed variance in cybersickness and workload, but no significant results were reported (Vlahovic et al., 2021). Lin et al. (2020) investigated presence and peripheral blur's relation to cybersickness and mentioned utilizing a task with lower cognitive load but did not elaborate further. Another study specifically investigating mental demand had no reported problems concerning cybersickness (Reinhardt et al., 2020). Bruck & Watters (2011) discussed mental demand and its impact on different potential measures of cybersickness (e.g., heartrate) but did not draw any connections between mental demand and cybersickness. There seems to be potential for workload to impact cybersickness based on initial results, and it could be a measurement that all cybersickness studies moving forward should include, per the model of forces, or mechanisms, affecting cybersickness proposed in Gilbert et al. (2021).

N-Back Task

To change the amount of workload imposed on participants during the current research a modified version of the N-Back task was used. The N-Back task, originally introduced by Kirchner (1958), presents participants with stimulus sequences and they are required to identify if the current stimulus matches the stimulus from "N" items ago. In this research participants were asked to conduct a "2-Back" task in which they were presented with animals in the Cybersickness Corn Maze and asked to click on them with a laser pointer if they matched. Additionally, a "0-Back" condition was included in which participants were asked to click on any animal of a specific type. This condition was included to determine the difference between a simple visual task (0-Back) and a cognitively demanding task (2-Back).

An example from the Cybersickness Corn Maze of a 2-Back sequence would be the following order of animals appearing: Cow, Skunk, Cow. The participant would point the laser pointer and click on the cow currently visible as long as the animal 2-Back was also a cow. This task, which requires participants to remember the recent history of the sequence of animals, has been shown to take significant mental resources (Jaeggi et al., 2010; Miller et al., 2009; Rac-Lubashevsky & Kessler, 2016) and impacts working memory as well as attention, both of which are included in Wickens et al.'s (2021) human information processing model.

Presence in VR and Cybersickness

Presence, as discussed above, is the feeling of "being there" while experiencing a virtual experience. This sort of feeling may help a user fully engage themself within a VR environment. Weech et al.'s (2019) review on presence showed a consistently negative relationship between presence and cybersickness. As users perceived a higher sense of presence in virtual environments, they experienced less sickness. Studies have shown this relationship to exist in different VR contexts such as nursing (Servotte et al., 2020) or older adult research (Dilanchian et al., 2021). Melo et al. (2021) evaluated the effect of different types of roles within a VR experience and showed that the group with the most control and ability to explore within a game-like tasks experienced the highest levels of both presence and cybersickness. Thus, the higher levels of presence might not always show reductions in cybersickness as mentioned above.

The mechanism for this relationship has not been identified specifically, but one can speculate that in situations in which individuals are more engaged in the environment, they pay less attention to inconsistencies (cue conflicts) that induce sickness. This relationship may relate to the concept of "willing suspension of disbelief" (Coleridge, 1950) in which people know that something is not real (such as in fiction novels or movies) but suspend that disbelief in order to become more immersed in an experience or fictional narrative (Schaper, 1978). Gilbert (2016) highlights the need for authenticity within VR environments, i.e., that VR experiences should match previous human experiences of how the world is supposed to work, which corresponds with enabling users to more easily suspend disbelief.

Willing suspension of disbelief allows for readers, or in our case VR users, to interpret experiences as closer to reality than they are. This idea may give insight into why previous VR experiences or game experience have been shown to negatively correlate with reported cybersickness. Freitag et al. (2016) noted that first time VR users experience more sickness symptoms. Given this result, it could be that users who have less experience with VR have less of an ability to suspend disbelief. Gamers practice this tactic nearly every time they pick up a game controller. When they play a game, they typically immerse themselves into the worlds of their virtual characters, adopting their background stories as their own and fully engaging with the virtual world to get the most out of the experience (Jennett, Cox, & Cairns, 2008). Gamers may also be able to modulate sickness symptoms due to adaptation. For the purposes of this study, the question arises as to the cognitive mechanism underlying willing suspension of disbelief. Previous research is unclear on this topic, but tends to focus more on beliefs, e.g., (Schaper, 1978), rather than attention or perception. If willing suspension of disbelief is a higher-level cognitive process, and not an attentional task that demands workload, then a person with a greater capability to suspend disbelief and greater sense of presence could be in some sense shielded from cybersickness-inducing cues, and additional task workload would not affect sickness.

In the current study, users' sense of presence was measured with the Immersion Questionnaire from Jennett et al. (2008). While other presence measuring instruments exist, e.g., the ITQ and presence questionnaire (Witmer & Singer, 1998), this instrument is designed to capture immersion more in terms of games and how the players interpreted their gameplay, which is a better fit for this study because of its gaming focus (Jennett, Cox, Cairns, et al., 2008). Gamers' ability to do this may explain the difference between gamers experiencing less sickness than non-gamers.

System 1 vs. System 2 and Video Games

While psychologists have described two ways of thinking for over 100 years, Kahneman (2017) popularized the labels for these ways of thinking: System 1 and System 2. System 1, the subconscious mind, operates automatically, making rapid judgments, e.g., "That person is angry." System 2 allocates attention to mental activities that require more effort, e.g., multiplying two three-digit numbers. System 2 has beliefs, is in charge of making choices, decides what to think about and what to do (Kahneman, 2017). System 1 is the automatic system that helps with tasks such as detecting the distance of objects in view, detecting where a sound is coming from, making a face when smelling a foul odor, etc. System 2 is the more complex system that helps with tasks such as: hearing the person you are talking to in a crowded room, searching memory to identify a surprising sound, telling someone your phone number, answering a math problem, or filling out a tax form (Kahneman, 2017).

The relevance of these "Systems" when it comes to cybersickness has not been explored extensively. As stated above, when gamers immerse themselves in a video game environment, they may be able to reorient their System 1 to focus on a completely fictional and virtual world. Through this reorientation, they can perform at high levels and increase enjoyment of that experience with less draw on attentional resources. Speculation from previous research (Norman, 2013) has indicated that using more System 1 processing reduces mental workload. Additionally, that work suggested that when subjected to distractions that occupy working memory, individuals benefit from being able to rely more on System 1 if they can (e.g., practiced expertise). This attunement and reliance on System 1 during high workload may be why gamers, who may be able to reorient their System 1, experience less cybersickness. Attention resources identified by Wickens (2021) are associated with System 2 (Kahneman, 2017). Just as with the discussion of willing suspension of disbelief above, if users are highly present, and their System 1 is handling the VE (and even the possible cybersickness-inducing cues), they will have more attentional resources available to process the task (System 2) and could handle higher workload. With this knowledge, participants in the current study were subjected to different attentional demands in hope of investigating the effect of those demands on sickness, presence, and perceived task difficulty. The incorporation of a task may shift individuals from a System 1 focus (e.g., riding a roller coaster and taking in the surroundings) to a System 2 focus (keeping the previous order of animals in working memory via the 2-Back task). The addition of a methodical task (2-Back) should shift participants from System 1 to System 2 by increasing the mental demand. This shift from the subconscious mind (System 1), that is potentially more susceptible to sensory mismatches and coherence about the inconsistencies that exist with VR, to System 2, where deeper thought and focus is occurring, might reduce cybersickness. Again, this study may shed light on these possible mechanisms underlying cybersickness by exploring the relationships between cybersickness, workload, task performance, and presence. The researchers' hypothesized relationships are show in Figure 2.

This model consolidates ideas from the literature review above to show presumed relationships between variables of interest. As workload increases on the X-axis, cybersickness is expected to decrease (as participants are distracted from sickness-inducing stimuli), presence is expected to increase (as participants become more engaged in the task), and performance is expected to rise to a peak then decrease once workload becomes too much (similar to the Yerkes-

Dodson Law). Attention on task is expected to mitigate cybersickness through the increase in presence and the distraction from cybersickness inducing stimulus.

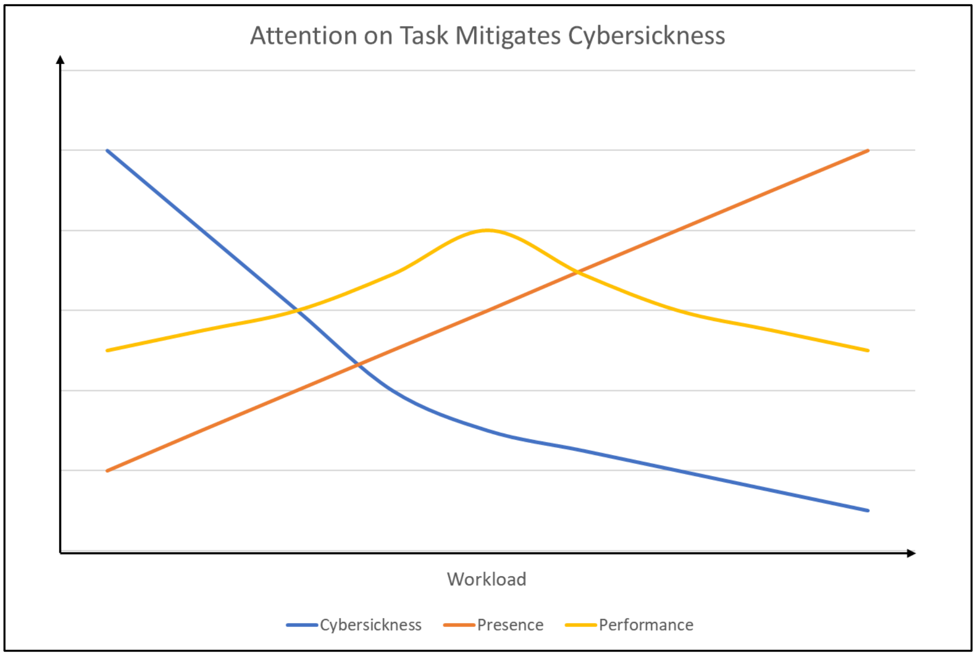


Figure 2. Proposed model of relationships between cybersickness, workload, task performance, and presence.

With the use of a VR environment that includes triggers known to cause sickness, the introduction of tasks with varying attentional demands creates an opportunity to see if a transfer from System 1 to System 2 has any effect. This study aims to capture the presence of the scenario across three task conditions, while subjecting all participants to an equally sickness-inducing experience.

CHAPTER 3. METHODS AND PROCEDURES

This chapter describes the details of how the current study was designed and carried out, including a description of the participants, the procedure, study design, and relevant independent and dependent variables. The chapter ends with predictions for the outcomes of the research questions. This study was designed in collaboration with Angelica Jasper, who had separate research questions for this study. Some of the data collected served her research purposes related to individual differences in cybersickness (Jasper et al., 2021).

Methods

Participants

By the end of the study, 153 (54 females, 94 males, 3 other, 2 undisclosed) people completed a single session after responding to recruiting emails, flyers, and social media posts. Participants included people who were at least 18 years old (M = 25.0, SD = 9.5), fluent in English, and had normal or corrected to normal vision. Participants were allowed to participate if they had no history of photosensitive seizure disorders. Participants with a wide variety of video game experiences were accepted. All participants signed informed consent paperwork during the sign-up process of the study per the Iowa State University IRB approved protocol 21-345. The session lasted approximately one hour with approximately 15 minutes wearing a VR headset, and participants were paid $10 in the form of an e-gift card for their time upon completion of the study.

Apparatus

The study was conducted with one VR HMD device, an Oculus Quest 1. The Oculus Quest was manufactured by Facebook and was selected due to the stability provided by the head mounts. The newest hardware, the Oculus Quest 2, uses a lightweight cloth strap design to fix the HMD to the head of the user, while the Oculus Quest 1 has a rigid molded plastic design with a snugger fit that is more easily adjustable than its successor. The Quest 1 has a 1600x1440 Dual OLED display with a refresh rate of 72Hz. The default SDK Color Space is Rec.2020 gamut, 2.2 gamma, D65 white point. The Quest was linked to a PC running Windows 10 with a NVIDIA GeForce RTX 2060 SUPER graphics card. The PC was used to run a custom-built VR experience in the Quest headset via Oculus Link in junction with SteamVR. The virtual environment used in this study was created with Unity 3D and sometimes required use of one Quest controller (depending on condition).

Procedures

Overview

The primary focus of this study was to determine the effect of a visual attention task on immersion and cybersickness. Participants were transported through the Cybersickness Corn Maze, a maze designed to induce cybersickness (https://github.com/isuvrac/CyberSickness-Cornmaze). The maze was a re-creation of a previous maze that was used to study the effects of a hand-eye coordination task on mitigating visually induced motion sickness (Curtis et al., 2015; Meusel, 2014). The sections of the maze were created based on tasks from the Virtual Environment Performance Assessment Battery (VEPAB; (Lampton et al., 1994). The main structure of the maze was based on the "Turns" task, which consisted of many left and right 90˚ turns. This task was used by Meusel (2014) and (Curtis et al., (2015) to induce sickness in participants, and was extended upon in this work by never allowing participants to control their movement. Passive observers without control of movements have a higher rate of cybersickness (Stanney & Kennedy, 1997). Additional components were included in the maze to further induce sickness such as trampolines, optokinetic drums, nondescript ramps, and a spiral slide. The maze was recreated with 3D corn plants, which differs from the original that had images of corn mapped onto walls. The trampolines and optokinetic drums were included to provide rotational and translational scene oscillations (O'Hanlon & McCauley, 1974; Richard H. Y. So et al., 2001). The participants were transported through the maze by progressing through turns and movements automatically to reduce the participants' feeling of control. Also, between turns, the participant sped up along the length of the straightaways. A participant started out slowly and traveled faster by the time they reached the next turn, then came to a sudden stop and restarted movement as the visual scene was rotated to face the next straightaway. Throughout the maze, different farm animals appeared at three-second intervals. These animals were used for the attention task and the conditions are explained below. The maze took approximately seven minutes to complete one lap, and participants were subjected to two laps during the study, ending with about 14-15 minutes of exposure (or fewer if they chose to exit the maze earlier). A top-down view of the maze, which had two levels in order to include a downhill slide, can be seen in Figure 3.

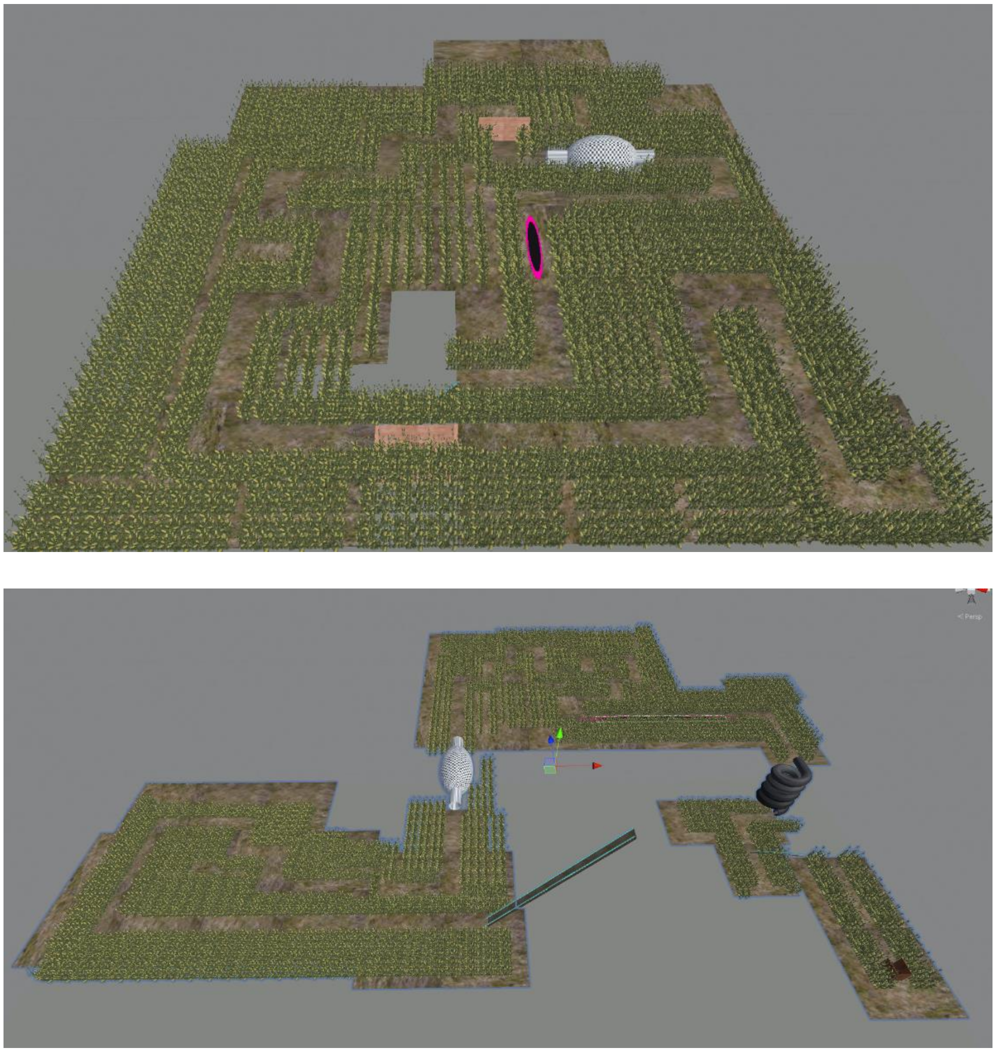


Figure 3. Top portion of the Cybersickness Corn Maze (Top) and bottom portion of the maze (Bottom). Participants begin in the bottom right of the top portion (Top) and progress through the maze until reaching the middle (Top), where they begin to descend to the lower portion via the diagonal ramp (Bottom). Participants ride through the bottom portion of the maze until they experience a dark grey spiral slide, shown on the right (Bottom), before coming up a ramp to the finish.

Independent Variable (IV)

The sole IV was the task load condition, which had three levels that could be experienced by a participant. All participants were subjected to the same overall experience regardless of condition. The only thing that changed across levels was the task. In all three conditions, animals appeared at 119 possible locations throughout the maze. There were three types of animals:

skunks, cows, and pigs. The first condition was the “No Task” group, and participants in this group just watched the maze experience with no controller. Animals were still present so as to not change the experience and visual stimulus of the maze, but participants did not have to engage with them. The next condition was the “0-Back” group, in which participants were tasked with collecting skunks by pointing and clicking with a controller on every skunk. The final condition was “2-Back,” in which participants were required to remember the order of animals that they saw and only collect (click) an animal if it was identical to the one presented two animals back.

The sequence of animals was random with each potential location having equal odds (1/3 chance) of being any of the three animals (skunk, cow, pig). The order was randomly generated in real time before each potential location to minimize bias of the order and so each lap through the maze was different for each participant. Each condition had roughly the same number of 2-back and 0-back targets due low number of possible animals (3) and the high number of animal placements (238 across two maze laps).

Dependent Variables (DVs)

The primary metrics collected in this study were cybersickness, mental workload, presence, and task performance (Table 2). For cybersickness, SSQ scores were measured pre- and post-exposure to the VR environment. The SSQ survey was administered via 16 Likert scaled questions on a computer to determine how sick a participant was feeling (K. Stanney, Lawson, et al., 2020). The NASA-TLX (Hart & Staveland, 1988) was conducted after the post-SSQ to have a measure of the perceived workload introduced by the condition. Additionally, an immersion questionnaire (Jennett, Cox, Cairns, et al., 2008) was collected to have a quantitative measure of participants’ presence in the VE. Task performance was calculated for the conditions that included a collection task, where errors included incorrect animals clicked (Type I error) and failing to click animals that were supposed to be clicked (Type II error). Immediate feedback was provided to participants via a negative sound on errors and a positive sound on correct animal clicks. Overall accuracy in the task was calculated by the number of correct responses out of possible responses. Misclicks were also tallied if a participant clicked but not on an animal.

Table 2. Dependent Variables

Construct	Metric	Data Acquisition	Variable Type (Range)
Cybersickness	SSQ – 3 Sub-Scales	Pre- and Post-Exposure Questionnaires (Post – Pre)	Continuous (0-25) per subscale
Immersion	Total Immersion Score	Post-Exposure Questionnaire	Continuous (31-155)
Mental workload	NASA-TLX	Post-Exposure Questionnaire	Continuous (0-21) overall; integer per subscale
Task Performance	Accuracy	Cybersickness Corn Maze software log	Percentage (0-100%), Maximum of 238 Trials
Task Performance	Errors (Type I & Type II)	Cybersickness Corn Maze software log	Percentage (0-100%), Maximum of 238 Trials
Task Performance	Misclicks	Cybersickness Corn Maze software log	Integer (0-Infinite)

Study Design

The study had a between-subjects design to prevent potential carryover effects of cybersickness symptoms across conditions. The participants in the two task conditions, 0-Back and 2-Back, were given a controller for their dominant hand to point and collect animals by using the back trigger (pulled with trigger finger). No-Task participants were not given a controller and just sat through the maze experience. Experimenters watched the participants from a nearby desktop to ensure participants were attending to the maze.

The study had four main phases: pre-exposure, training, maze exposure, post-exposure, as shown in Figure 4. The SSQ scores were taken prior to VE exposure during pre-surveys, which also included other demographic and personality questions, as well as during post-exposure to calculate differences in scores. The NASA-TLX workload and immersion questions were answered by the participant post-exposure using a nearby computer. The VR software automatically calculated the performance of the participant and outputted data to a .csv file that was used for later analysis. This study served two research purposes, investigating individual differences within cybersickness (Angelica Jasper's work) and investigating the effect of task load on cybersickness (the current analysis).

Study Process

The entire study process can be seen in the diagram in Figure 4. This section describes the four phases in more detail.

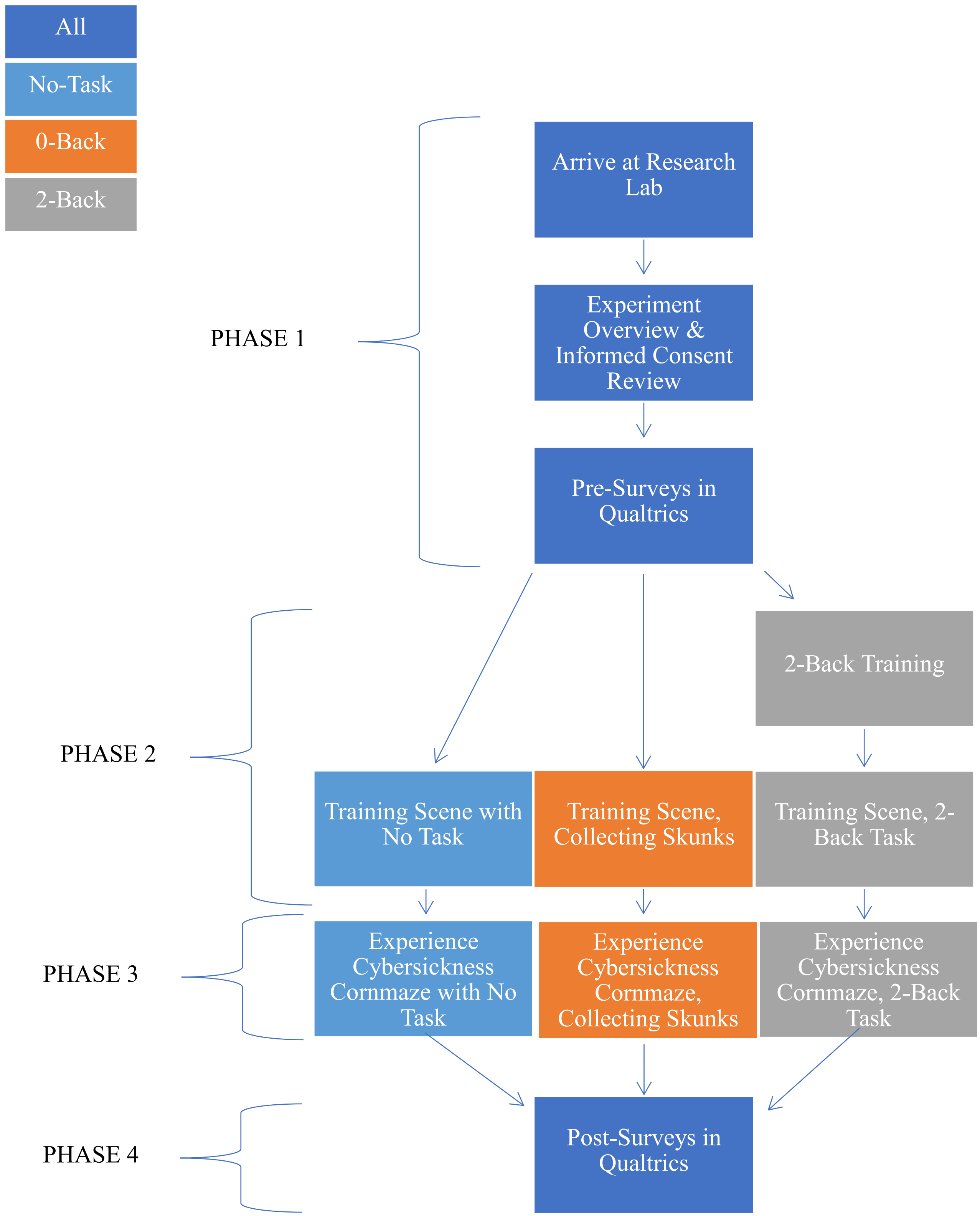


Figure 4. Study Process Diagram

Pre-Exposure

Participants filled out an online consent form during the digital sign up for the study. Upon arrival to the study lab, participants were informed about the overall purpose of the study. Experimenters confirmed that the participants were 18 years or older, had no history of photosensitive seizure disorders, and asked if they had any questions about the consent form they signed previously.

The participants were then asked to complete a pre-exposure SSQ, a video game history survey, a VR experience survey, and an additional set of pre-surveys (used by Angelica Jasper but not in this study) including: a Stroop task, demographic survey, a motion sickness history survey, and a personality assessment. All assessments were completed on a survey computer in the study lab.

If the participant was in the 2-Back condition, after the surveys, they experienced a short training (3-5 minutes) on the general 2-Back task on the computer here: https://www.psytoolkit.org/experiment-library/experiment_touch_nback2.html.

The participants were then set up in the VR HMD. The experimenter measured the participant's IPD with a ruler or the EyeMeasure phone app (https://apps.apple.com/us/app/eyemeasure/id1417435049). After getting the participant's measurements, the experimenter calibrated the headset IPD setting to match the participant's IPD. The headset was then given to the participant for them to put on while seated. The experimenter helped fit the HMD to the participant's head properly to ensure no wobbling or undesired HMD movement during the study.

Training

The participants were then shown instructions within the VR headset and were read instructions aloud to ensure they understood the task. After verifying the participant understood the instructions, the VR training started. This training required no locomotion through the environment, though the player did turn their head. While the player remained in one place within the VE, animals appeared at 20 different locations in front of the player and allowed the player to target them with a laser pointer coming out of the controller and collect them by pulling the trigger on the controller (Figure 5), if in the 0-Back or 2-Back conditions. The No Task participants also experienced the appearance of animals but just observed. The training took less than two minutes. The application played a positive feedback sound upon a correct click. A negative sound was played upon an error, as noted above. Participants were then asked if they had any questions before advancing to the maze.

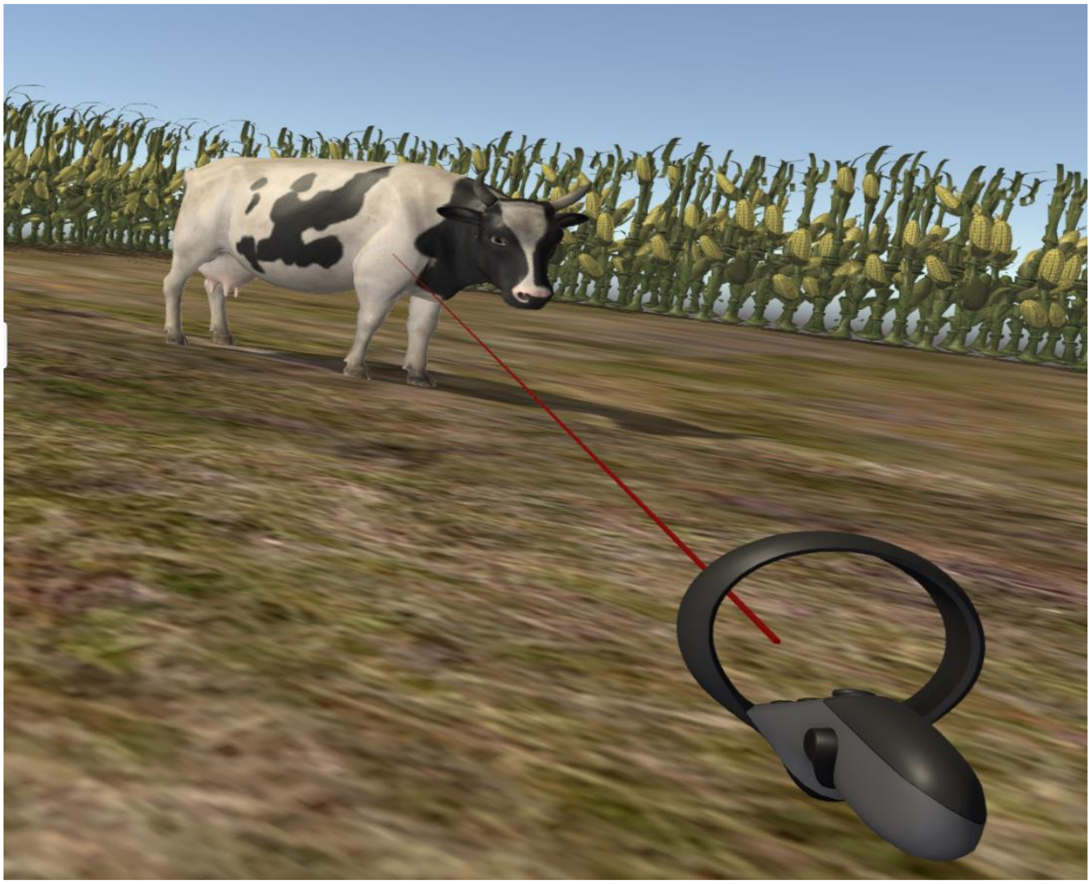


Figure 5. Screenshot of training scene with laser pointer and controller.

Maze Exposure

After completion of the training, the maze was then started for the participant. The participants were moved through the maze experience with animals appearing at a new location in front of them every three seconds. The animal that appeared in the location was randomly distributed between the three animal types: pig, cow, and skunk. Depending on the condition, the participants had to point and collect animals throughout the maze, with the exception of the “No Task” group. The participants went through an uncontrolled roller coaster-like experience for up to 15 minutes but were reminded prior to the experience that they could stop any time they pleased by removing the HMD. Once the participant removed the HMD, they could not return to the maze. An image of the maze during the exposure phase is shown in Figure 6.

Figure 6. Screenshot of Cybersickness Corn Maze showing a pig that might need to be clicked and an upcoming pit into which the player will descend before re-emerging up into the maze.

Post-Exposure

After the participant removed themselves or completed the entire maze, they were then asked if they needed any water or time to recover with an option to lie down on a nearby couch. If time was needed to recover, it was given. Otherwise, participants returned to the same survey computer they used during Pre-Exposure. The participants filled out post-surveys including: a post-SSQ, an immersion questionnaire, the NASA-TLX, and a personal performance self-assessment (used by Angelica Jasper but not in this study). Upon completion of the surveys, the participants were cleared to leave if they were feeling comfortable. Their $10 e-gift card was then emailed to them.

Measures

Simulator Sickness Questionnaire (SSQ)

Kennedy's Simulator Sickness Questionnaire (SSQ; Kennedy et al., 1993) was used as the survey tool to assess cybersickness induced by the maze. (Stanney et al. (2020) wrote that cybersickness symptoms are most often measured through surveys like the SSQ. It has been noted (Arcioni et al., 2019; Davis et al., 2015; Jasper et al., 2020; Meusel, 2014; So et al., 2001; Risi & Palmisano, 2019; Stanney et al., 2020) that these methods are well validated, but they are difficult to use during situations where operators cannot stop their task while immersed in the simulator to answer the questions. Automated physiological solutions could provide a better alternative to quantifying sickness in the future, but currently the SSQ remains the most reliable and validated solution to measure sickness (K. Stanney, Lawson, et al., 2020).

The SSQ was administered pre-exposure during pre-surveys and was administered early on in the survey to prevent its questions from being the most recent ones in the participant's mind as they entered the VR experience, a form of recency bias (Tversky & Kahneman, 1973). Young et al. (2006) showed the use of a pre-SSQ indicated that reports of sickness after immersion were greater than when only a posttest questionnaire is used. The SSQ was then administered again post-exposure to allow the capture of the difference the VR experience had on the participant's current state. In the SSQ, the participants answered 16 Likert scaled questions ranging from 0 (No symptoms) - 3 (Severe). The items were then scored to output an overall sickness score, referred to as total severity. The SSQ can also be broken down into its sub-scales: oculomotor, nausea, and disorientation. The metric shown in the results is the Post-SSQ – Pre-SSQ. The scoring for the scales, the total severity, and the full questionnaire can be found in Appendix A (Kennedy et al., 1993).

Immersion Questionnaire

Upon leaving the maze, participants were asked to answer 31 questions regarding their immersion in the VR experience. The questions, taken from previous work (Jennett, Cox, Cairns, et al., 2008), aimed at capturing the participants involvement in virtual experience. The questions were answered on a Likert scale with zero being answers such as “Not applicable, Not at all, Very little, Definitely not” and with four being answers such as “Very much so, Very aware, Very difficult, Definitely yes.” The total immersion was calculated as a summation of all Likert values from the 31 questions. Questions 6, 8, 10 and 18 were reverse-coded by the researchers to decrease straight-lining and promote more thoughtful responses within the survey. The original research offered no guidance on this issue (Jennett, Cox, Cairns, et al., 2008). The questions used can be found in Appendix B.

NASA-Task Load Index (TLX)

The NASA-TLX was administered to participants upon completion of the maze and is a six-question subjective evaluation of task difficulty (Hart & Staveland, 1988). The six questions consider mental demand, physical demand, temporal demand, effort, performance, and frustration. This research is focused on all the sub-scales in relation to cybersickness. The questions assess workload on a 21-point scale varying from very low (1) to very high (21) or perfect (1) to failure (21) for performance. No weighting procedure was used to aggregate TLX scores as outlined in Moroney et al. (1992), as it did not add enough significant value. Rather the Raw-TLX score, as noted by (Hart, 2006), was calculated by adding the score from each of the scales to estimate overall workload. This questionnaire can be seen in Appendix C.

Task Performance

The participant’s task performance was logged by the Cybersickness Corn Maze software. Software was written to output data at each location, which was a location where an animal would appear within the maze. The following data points were included in the file for each trial location: Participant ID, Run Number (What lap the participant was in), Condition, Trial Number, Object (what animal was present at the trial location), ShouldClick (binary TRUE if the participant was to click the object), Clicked (TRUE if the participant clicked the object), Response Time (seconds), Correct (TRUE if ShouldClick = Clicked), Misclicks (if the participant clicked but missed the object), Exposure Time (time in minutes and seconds from the time the participant started training). Most of these data fields aided in measuring task performance.

Predictions

Per RQ1, the SSQ total severity of sickness measure, the difference between post experience total severity and pre-experience total severity, is expected to decrease as workload increases as stated in H1. Second, previous work (Servotte et al., 2020; Weech et al., 2019) showed that increases in presence can reduce cybersickness experienced. An inverse relationship between presence and cybersickness is expected as stated in H2. Predictions of cybersickness, presence and task performance can be seen in a predicted model shown in Figure 2.

Per RQ2, the No-Task group is expected to have the lowest perceived mental demand, temporal demand, effort and frustration, with the 0-Back group having more, and the 2-Back group having the most as stated in H3. The condition that is predicted to have the most sickness is the No-Task group, with the other task groups showing less sickness, which contradicts previous work(Meusel, 2014). Meusel (2014) indicated that overloading the participant can overwhelm them and lead to potentially increased cybersickness. Previous work has mixed results on the effect of mental workload on cybersickness, but in this study the complexity of the task is expected to distract participants from cybersickness-inducing virtual effects. The complexity of the 2-Back task may cause participants to turn to System 2 and away from System

1, where most of the perceptual problems related to cybersickness may occur. The leading theories in cybersickness are related to sensory conflict and postural sway, which are both subconscious systems. Per H4, performance among participants is expected to be negatively correlated with sickness, such that higher performing individuals in the task group are expected to have a lesser experience of sickness symptoms. This expectation is due to the potential increased difficulty of the task if a participant is experiencing sickness symptoms. It is also expected that participants who are performing more highly are more immersed into the environment and the task, which has previously been shown to reduce cybersickness (Servotte et al., 2020).

Data Analysis

The two types of analysis performed to answer the research questions were Pearson's correlations and one-way ANOVAs. The Pearson correlation was used to evaluate the relationships between dependent variables (e.g., is an increase in workload correlated with an increase in cybersickness?). However, significant correlations between dependent variables do not identify causal relationships, since correlation is not causation. One-way ANOVAs were used to compare the impact of the task condition on the dependent variables (e.g., does the 2-Back group have significantly higher SSQ TS scores than those in the 0-Back or No-Task groups).

CHAPTER 4.   RESULTS

The results of the study are described below, first by presenting descriptive statistics and charts for all of the dependent variables, and then with inferential statistics discussing the impact of the independent variable (task condition) on the dependent variables.

Cybersickness: Descriptive Statistics

This study evaluated the change in total severity(TS) of cybersickness (SSQ TS Δ = Post SSQ Total Severity – Pre-SSQ Total Severity) with data from 150 participants (three participants failed to complete all the SSQ questions and were excluded). SSQ TS Δ could feasibly range from 0 to 235.62, assuming Post is always greater than Pre. A histogram of this data can be found in Figure 7. Four participants did report feeling better after the maze than before (negative values). Recovery time was rarely needed (only 11 participants had over 2 minutes). One participant had the longest recovery time at 10 minutes, with two participants with the second highest at 5 minutes. While a lengthy recovery time could lead to lower post-SSQ ratings, since the post-SSQ survey was given after recovery, because recovery times were so short, they were not factored into the analysis.

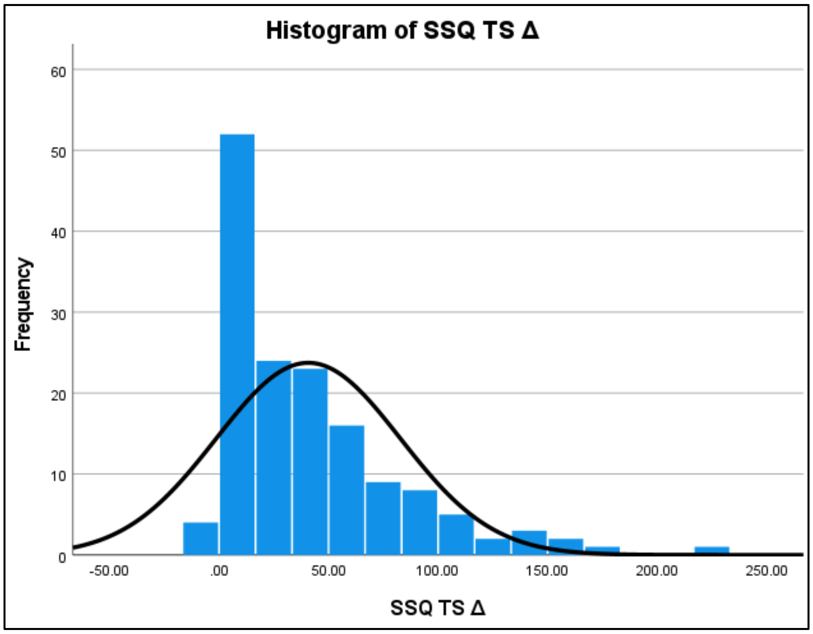


Figure 7. SSQ TS Δ, All Data (*M* = 40.77, *SD* = 41.994, *n* = 150).

The goal during the data collection was to obtain an equal distribution of participants among the three conditions: No-Task (*n*=49), 0-Back (*n*=51), 2-Back (*n*=51). The SSQ score could not be calculated for one participant in the 2-Back group due to failure to answer all the questions in the survey and was removed from SSQ TS Δ analysis. The distribution of sickness total severity for each of the respective conditions is shown in Figure 8. Distributions were found to not be normal for the SSQ TS Δ, but further analysis continued as planned due to Pearson's correlation and one-way ANOVA being robust to deviations from normality, especially when sample sizes are approximately equal between conditions, as they were in this study (Laerd Statistics, 2017). Boxplots showing the data from each condition are shown in Figure 15.

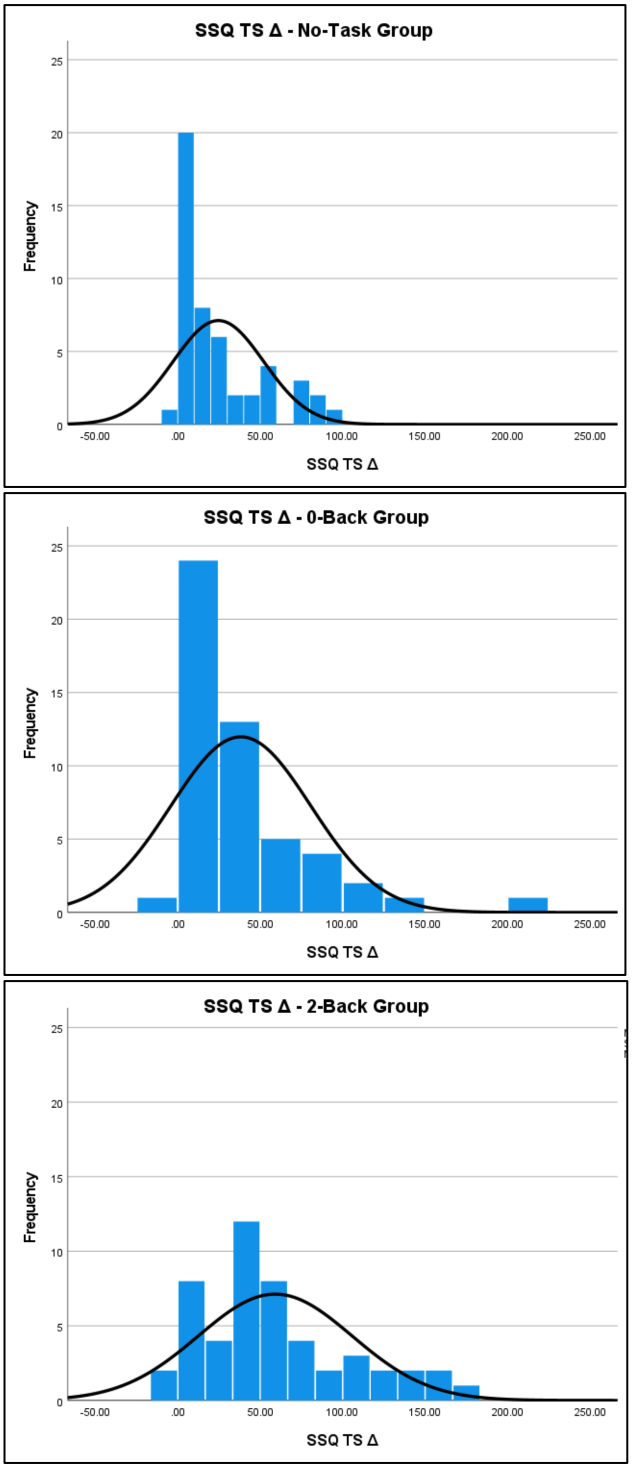


Figure 8. Histograms for SSQ TS Δ, (Top) No-Task Group (*M* = 24.65, *SD* = 27.451, *n* = 49), (Middle) 0-Back Group (*M* = 38.28, *SD* = 42.462, *n* = 51), (Bottom) 2-Back Group (*M* = 59.09, *SD* = 46.645, *n* = 50).

Dropouts Based on Cybersickness

During the study, participants were informed that if they felt too sick or uncomfortable to continue, they could stop at any time. The percentage of dropouts (# of early stoppages / # of participants) are reported in Figure 9 for No-Task (*n*=47), 0-Back (*n* = 49), 2-Back (*n*=51).

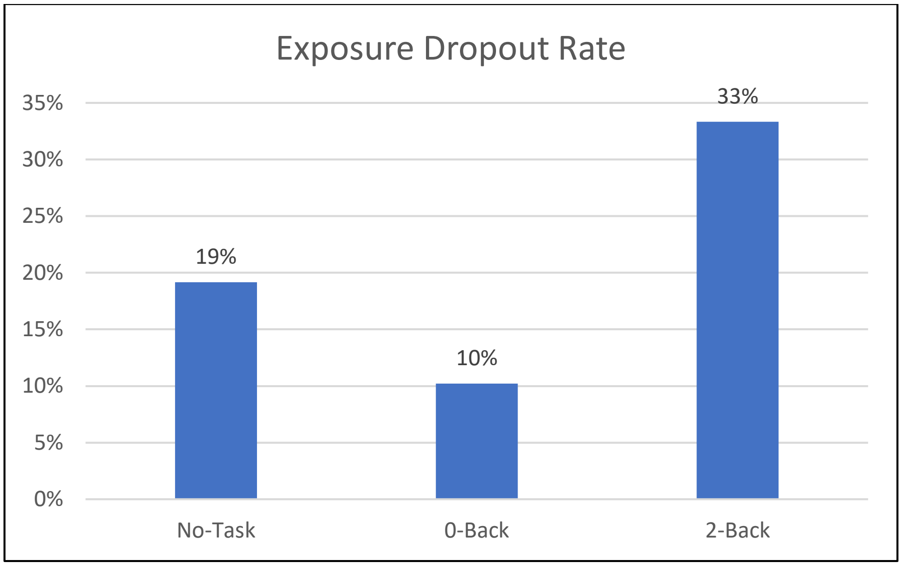


Figure 9. Stoppage Rate by Condition.

Presence: Descriptive Statistics

Presence was measured upon completion of the VR experience. All of the presence scores (sum of IMQ items, which can feasibly range from 0 to 124) are shown in Figure 10. The presence score distributions for each condition are shown in Figure 11. Boxplots comparing presence scores by condition are shown in Figure 17. Presence scores could not be calculated for two participant who did not answer all the presence questions.

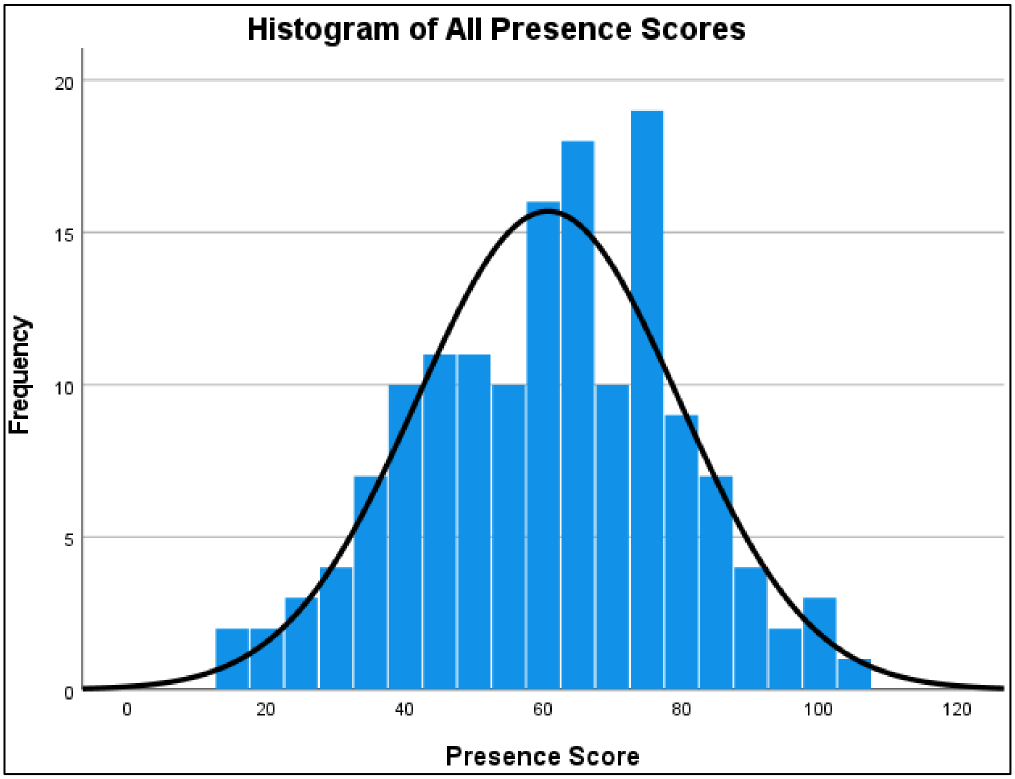


Figure 10. Presence Scores, All Data (*M* = 60.67, *SD* = 18.937, *n* = 149).

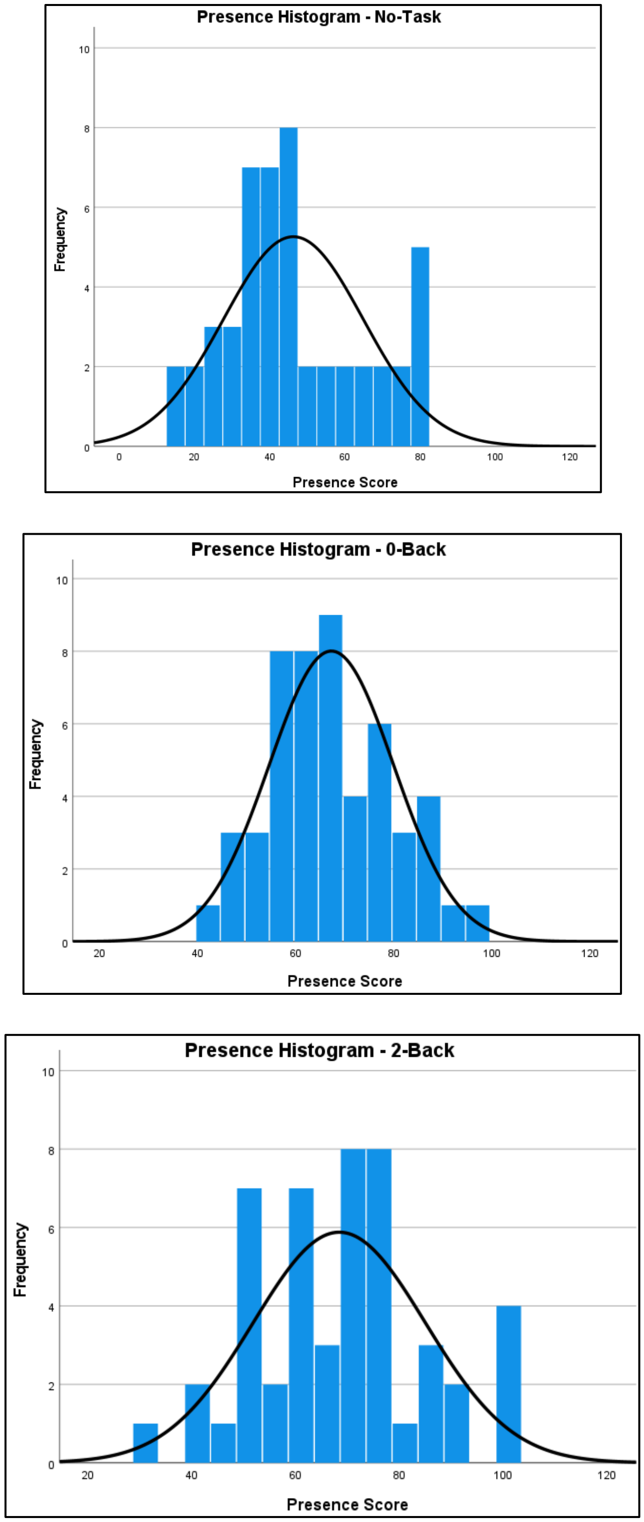


Figure 11. Presence Scores, (Top) No-Task Group (*M* = 46.27, *SD* = 18.57, *n* = 49), (Middle) 0-Back Group (*M* = 67.16, *SD* = 12.71, *n* = 51), (Bottom) 2-Back Group (*M* = 68.33, *SD* = 16.62, *n* = 49).

Workload: Descriptive Statistics

Workload was measured post-VR using the Raw-TLX score (average of all TLX scales) as justified above. Feasible workload values ranged from 1 to 21. The workload score distribution of all the data is shown in Figure 12. The distribution for each condition is shown in Figure 13. Boxplots of Workload by condition are shown in Figure 16. Data for 12 participants could not be calculated due to lack of responses.

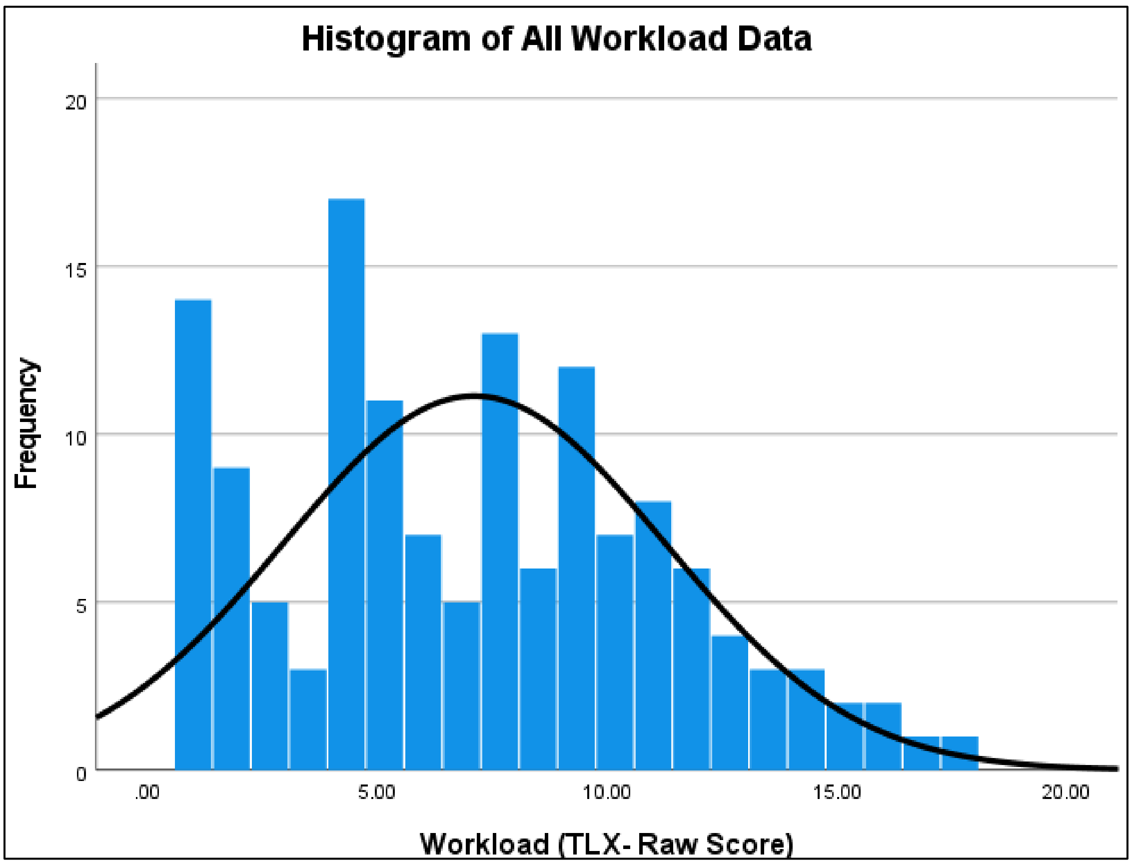


Figure 12. Workload Scores, All Data (*M* = 7.11, *SD* = 4.15, *n* = 139).

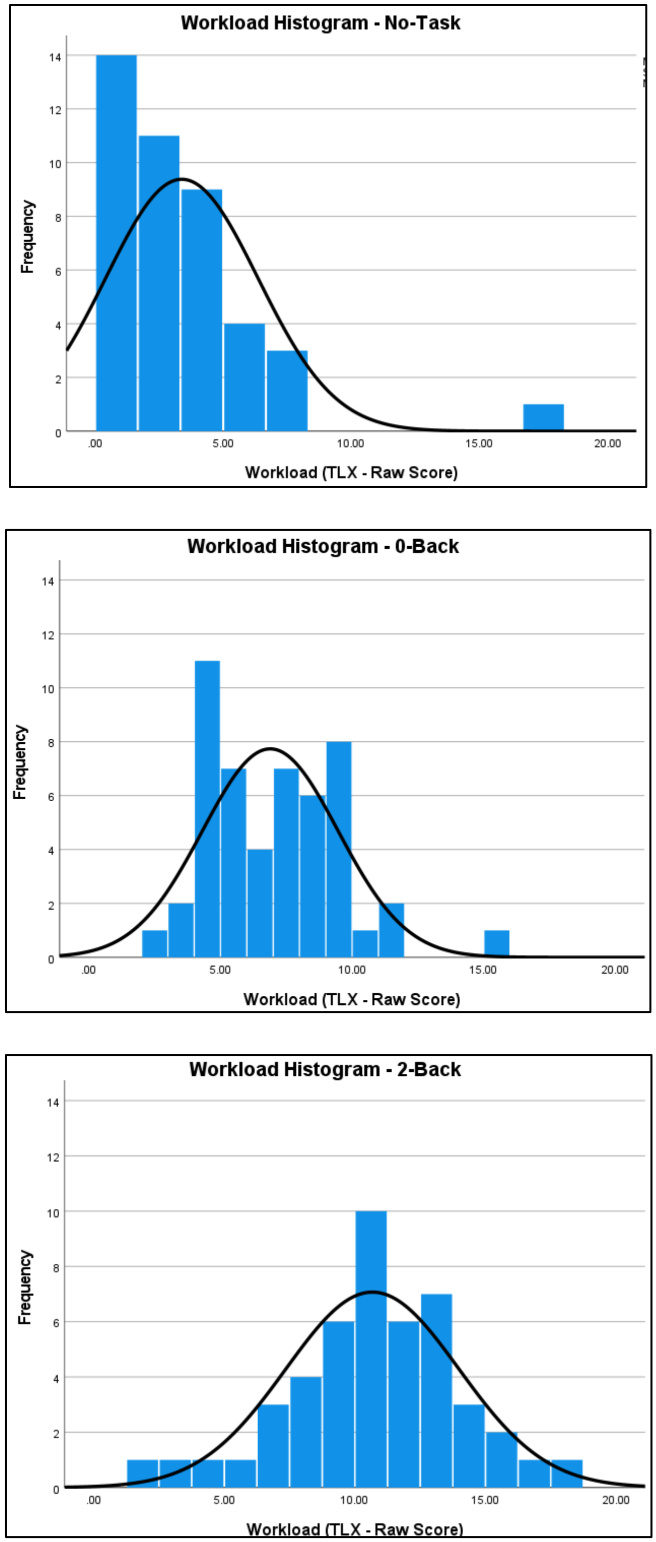
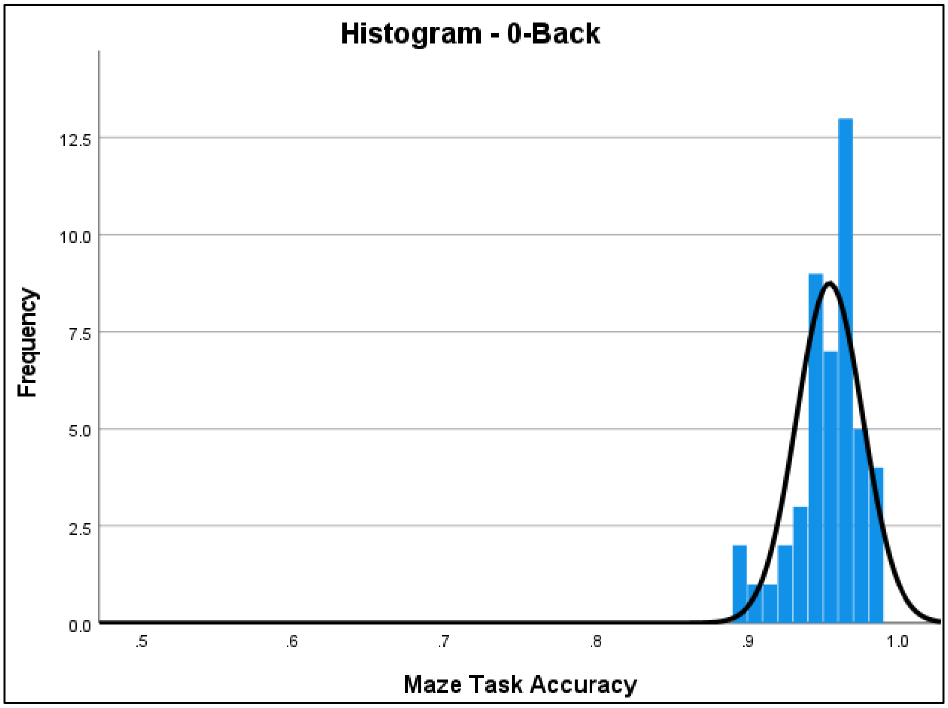


Figure 13. Workload (TLX – Raw Score), (Top) No-Task Group (M = 3.38, SD = 2.97, n = 42), (Middle) 0-Back Group (M = 6.89, SD = 2.57, n = 50), (Bottom) 2-Back Group (M = 10.67, SD = 3.31, n = 47).

Task Performance: Descriptive Statistics

Task performance was captured within the Cybersickness Corn Maze software. The maze task accuracy ((total trials - total errors) / total trials) could range for 0.0 (worst possible performance) to 1.0 (perfect performance) and is shown for both task conditions in Figure 14. “Trial” means the appearance of an animal (there are 238 possible trials, or fewer if participants dropped out). An error is counted based on either a click on an incorrect animal or a missed click on a correct animal. For participants who dropped out, their performance was calculated using a denominator of the trials they experienced, so their performance was not penalized for stopping early.



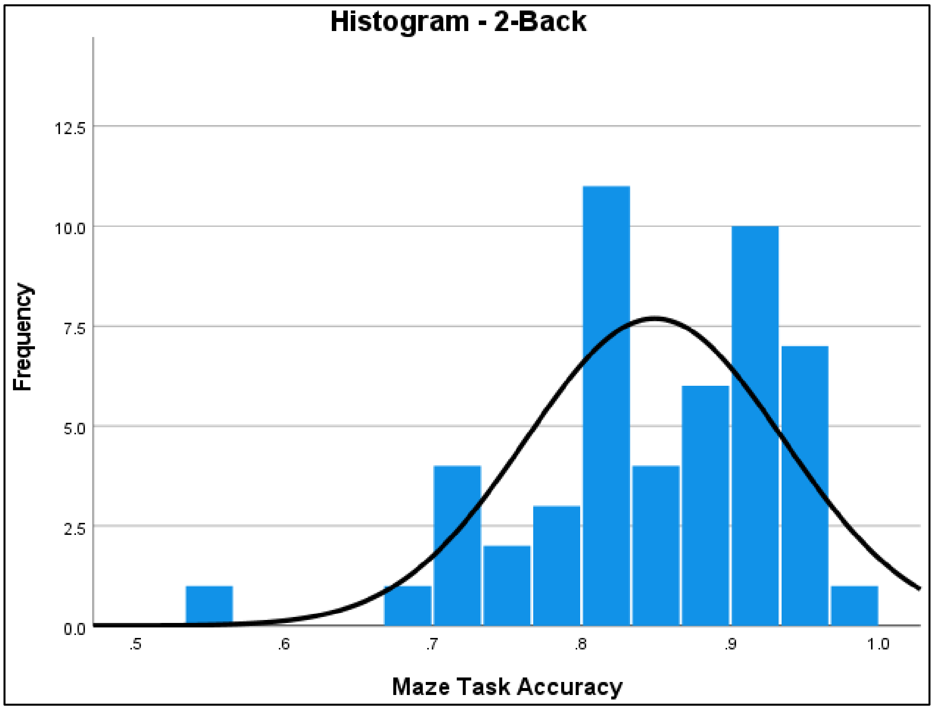


Figure 14. Maze Task Accuracy, (Top) 0-Back Group (*M* = .9544, *SD* = .0219, *n* = 48), (Bottom) 2-Back Group (*M* = .8492, *SD* = .0864, *n* = 50)

Correlations of Workload, Presence, and Cybersickness

A Pearson's product-moment correlation was used to assess the relationship between workload (as measured by the NASA-TLX raw score), presence (measured with the immersion questionnaire from Jennett, Cox, Cairns, et al., 2008), and cybersickness (as measured by the Post-SSQ Total Severity Score – Pre-SSQ total severity scores). These calculations were performed for participants from each of the three conditions: No-Task (n=49), 0-Back (n=51), and 2-Back (n=50). The correlation analysis can be found in Table 3.

Table 3. Pearson's product-moment correlations between cybersickness, workload, and presence.

No-Task	Cybersickness	Workload
Workload	0.459*	
Presence	0.012	0.286
0-Back	Cybersickness	Workload
Workload	0.473*	
Presence	0.087	0.255
2-Back	Cybersickness	Workload
Workload	0.491*	
Presence	−0.364*	−0.130

* = statistically significant at p < .05 level.

For the No-Task group, Pearson's correlation analysis was performed to assess the relationship between cybersickness, presence and workload. There was a statistically significant, moderate positive correlation between cybersickness and workload, $r(42) = .459$, $p < .002$, with workload explaining 21% of the variation in cybersickness. The relationship between cybersickness and presence was also evaluated. There was a non-statistically significant correlation between cybersickness and presence, $r(49) = 0.012$, $p = .936$, with presence explaining less than 1% of the variation in cybersickness. Similarly, there was a non-statistically significant correlation between workload and presence, $r(50) = 0.286$, $p = .066$, with presence explaining 8% of the variation in workload.

For the 0-Back group, Pearson's correlation analysis was performed to assess the relationship between cybersickness and workload. There was a statistically significant, moderate positive correlation between cybersickness and workload, $r(50) = .473$, $p < .001$, with workload explaining 22% of the variation in cybersickness. The relationship between cybersickness and presence was also evaluated. There was a non-statistically significant correlation between cybersickness and presence, $r(51) = 0.087$, $p = .542$, with presence explaining less than 1% of the variation in cybersickness. Additionally, there was a non-statistically significant correlation between workload and presence, $r(42) = 0.255$, $p = .073$, with presence explaining 7% of the variation in workload.

For the 2-Back group, Pearson's correlation analysis was performed to assess the relationship between cybersickness, presence and workload. There was a statistically significant, moderate positive correlation between cybersickness and workload, $r(47) = .491$, $p < .001$, with workload explaining 24% of the variation in cybersickness. Additionally, there was a statistically significant, moderate negative correlation between cybersickness and presence, $r(49) = -0.364$, $p < .01$, with presence explaining 13% of the variation in cybersickness. There was a non-statistically significant correlation between workload and presence, $r(47) = -0.130$, $p = .384$, with presence explaining 2% of the variation in workload.

The Effect of Task Condition on Cybersickness, Workload, Presence, and Performance

A one-way ANOVA exploring the effect of task condition was performed on the measures for cybersickness, workload, and presence measures to explore the effect of task workload on each of these measures. All assumptions required by an ANOVA, besides homogeneity of variance and normality, were met (continuous variables, categorical groups, independence of observations, and outliers). Homogeneity of variance (for the presence score and the SSQ TS Δ) and normality (for the SSQ TS Δ) were not met, but these violations were not a concern as long as the sample size in each group is similar, as they were in this study (Laerd Statistics, 2017). Effect size for each comparison was measured using η^2, for which 0.02 is consider a small effect, 0.13 is a medium effect, and 0.26 is a large effect (J. Cohen, 1988).

The Effect of Task Condition on Cybersickness

The SSQ TS Δ (cybersickness measurement) was found to be significantly different between the three conditions $F(2,147) = 9.412$, $p < .001$, $\eta^2 = .114$. The presence measure was also statistically significantly different for the different conditions evaluated in this study, $F(2,146) = 29.247$, $p < .001$, $\eta^2 = .286$. Finally, workload was also statistically different for the conditions $F(2,136) = 67.249$, $p < .001$, $\eta^2 = .497$. Post hoc analyses using the Scheffé post hoc criterion for significance was used to determine the significance between task groups. See Figure 15 for boxplots and Table 4 for condition comparisons.

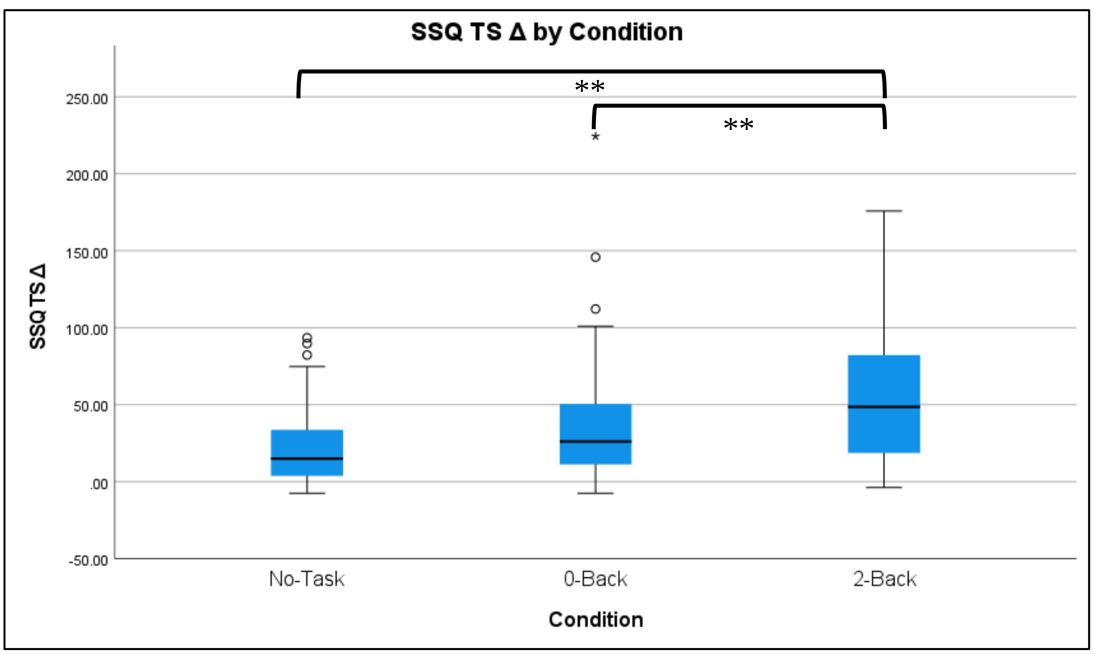


Figure 15. SSQ TS Δ by Condition boxplots. ˚ = potential outlier data point, * = extreme outlier data point, ** = significant difference at a $p < .05$ level.

There was an increase in cybersickness from the No-Task group (*M* = 24.65, *SD* = 27.451) to the 0-Back group (*M* = 38.28, *SD* = 42.462), a mean increase of 13.627, 95% CI [−6.065, 33.318], which was not statistically significant (*p* = .235). There was an increase in cybersickness from the No-Task group (*M* = 24.65, *SD* = 27.451) to the 2-Back group (*M* = 59.09, *SD* = 46.645), a mean increase of 34.439, 95% CI [14.651, 54.226], which was statistically significant (*p* = .001). There was an increase in cybersickness from the 0-Back group (*M* = 38.28, *SD* = 42.462) to the 2-Back group (*M* = 59.09, *SD* = 46.645), a mean increase of 20.812, 95% CI [1.221, 40.403] which was statistically significant (*p* = .034). These differences are illustrated in the boxplots shown in Figure 15. Potential outliers and extreme outliers within boxplots are defined within SPSS based on the data point's relationship to the interquartile range (IQR) of the rest of the data (Geert van den Berg, 2022).

Table 4. ANOVA Scheffé post hoc analysis Condition Comparisons.

Condition Comparisons

Dependent Variable	Condition (I)	Comparison Condition (J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
SSQ TS Δ	Control	0-Back	−13.627	7.963	.235	−33.318	6.065
		2-Back	−34.439 *	8.002	.000	−54.226	−14.651
	0-Back	Control	13.627	7.963	.235	−6.065	33.318
		2-Back	−20.812 *	7.922	.034	−40.403	−1.221
	2-Back	Control	34.439 *	8.002	.000	14.651	54.226
		0-Back	20.812 *	7.922	.034	1.221	40.403
Workload (TLX - Raw)	Control	0-Back	−3.505 *	0.620	.000	−5.040	−1.970
		2-Back	−7.285 *	0.629	.000	−8.843	−5.728
	0-Back	Control	3.505 *	0.620	.000	1.970	5.040
		2-Back	−3.780 *	0.602	.000	−5.270	−2.290
	2-Back	Control	7.285 *	0.629	.000	5.728	8.843
		0-Back	3.780 *	0.602	.000	2.290	5.270
Presence Score	Control	0-Back	−20.892 *	3.223	.000	−28.861	−12.922
		2-Back	−22.061 *	3.255	.000	−30.110	−14.012
	0-Back	Control	20.892 *	3.223	.000	12.922	28.861
		2-Back	−1.170	3.223	.936	−9.139	6.800
	2-Back	Control	22.061 *	3.255	.000	14.012	30.110
		0-Back	1.170	3.223	.936	−6.800	9.139

*. The mean difference is significant at the 0.05 level.

The Effect of Task Condition on Workload

There was an increase in workload from the No-Task group (M = 3.39, SD = 2.98) to the 0-Back group (M = 6.89, SD = 2.58), a mean increase of 3.51, 95% CI [1.97, 5.04], which was statistically significant (p = .001). There was an increase in workload from the No-Task group (M = 3.39, SD = 2.98) to the 2-Back group (M = 10.67, SD = 3.31), a mean increase of 7.29, 95% CI [5.73, 8.84], which was statistically significant (p = .001). There was an increase in workload from the 0-Back group (M = 6.89, SD = 2.58) to the 2-Back group (M = 10.67, SD = 3.31), a mean increase of 3.78, 95% CI [2.29, 5.27] which was statistically significant (*p* = .001). Figure 16 shows these differences.

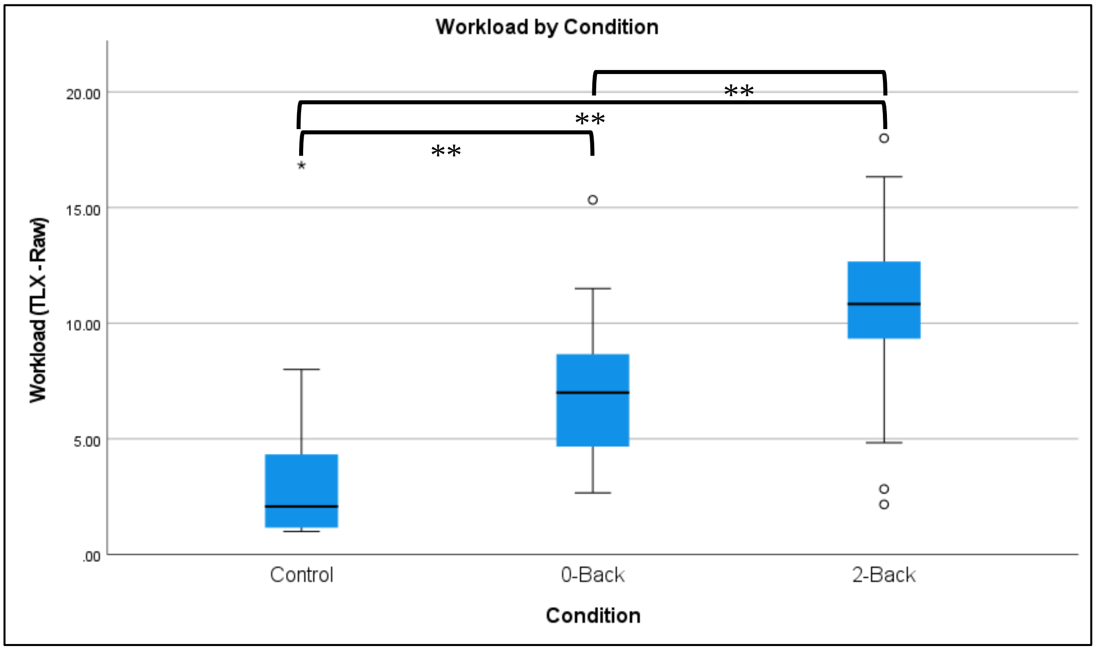


Figure 16. Workload by Condition boxplot. ˚ = potential outlier data point, * = extreme outlier data point, ** = significant difference at a *p* < .05 level.

The Effect of Task Condition on Presence

There was an increase in presence from the No-Task group (*M* = 46.27, *SD* = 18.57) to the 0-Back group (*M* = 67.16, *SD* = 12.70), a mean increase of 20.892, 95% CI [12.92, 28.86], which was statistically significant (*p* = .001). There was an increase in presence from the No-Task group (*M* = 46.27, *SD* = 18.57) to the 2-Back group (*M* = 68.33, *SD* = 16.62), a mean increase of 22.06, 95% CI [14.01, 30.11], which was statistically significant (*p* = .001). There was an increase in presence from the 0-Back group (*M* = 67.16, *SD* = 12.70) to the 2-Back group (*M* = 68.33, *SD* = 16.62), a mean increase of 1.170, 95% CI [−6.80, 9.14] which was not statistically significant (*p* = .936).

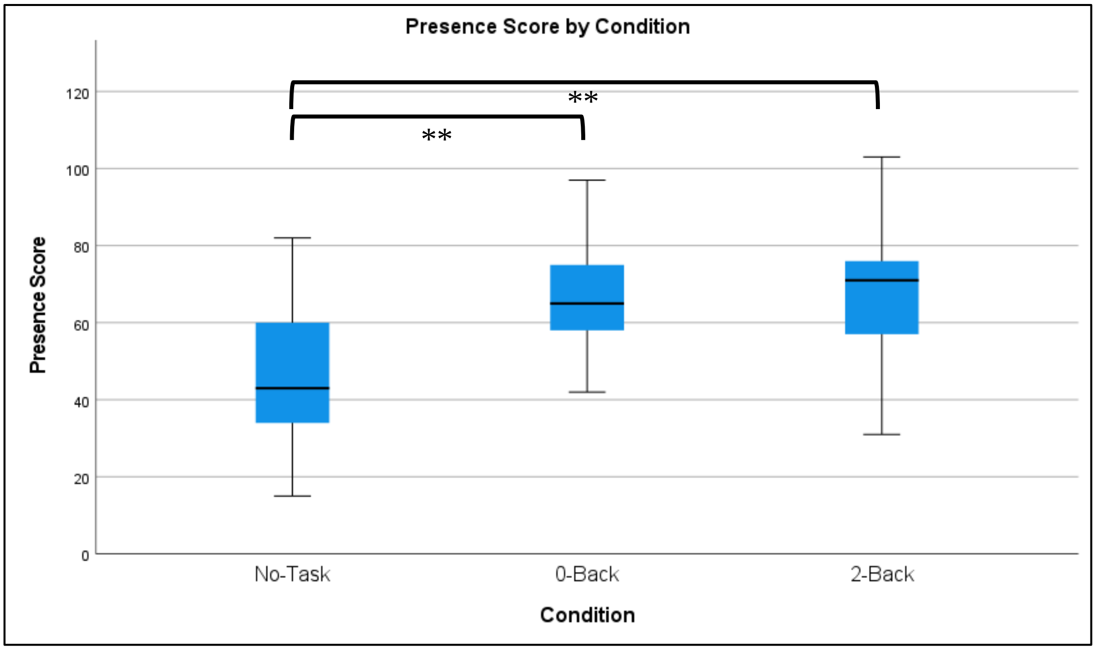


Figure 17. Boxplots of presence scores by condition; ** = significant difference at a $p < .05$ level.

The Effect of Task Condition on Task Performance

A review of the task performance consisted of three different elements: task accuracy, misclicks, and average response time. An ANOVA was performed to evaluate look for differences between the 0-Back and 2-Back groups. All assumptions for an ANOVA were met for these criteria. There was a decrease in task accuracy from the 0-Back group (M = .954, SD = .022) to the 2-Back group (M = .849, SD = .086) that was shown to be significantly different, $F(1,97) = 66.932$, $p < .001$, $\eta^2 = .411$. There was a decrease in misclicks from the 0-Back group (M = 46.31, SD = 29.40) to the 2-Back group (M = 16.70, SD = 15.93), that was shown to be significant, $F(1,97) = 38.86$, $p < .001$, $\eta^2 = .288$. No significant difference was found between response times by condition.

Pearson's correlations, shown in Table 5, were calculated to identify any relationships between the metrics of accuracy, misclicks, response time, presence, cybersickness, and workload. Analysis was completed on 3 subsets of the data: 0-Back group, 2-Back group, and both task groups (0-Back and 2-Back). This was done to look for trends in both groups individually as well as a whole.

Table 5. Pearson's correlations for task groups individually and combined for task metrics.

0-Back	Cybersickness	Workload	Presence	Accuracy	Misclicks
Workload	0.473*				
Presence	0.087	0.255			
Accuracy	−0.219	−0.259	−0.217		
Misclicks	−0.296*	−0.253	0.077	.091	
Response Time	−0.023	0.045	−0.198	−.273	−.050
2-Back	Cybersickness	Workload	Presence	Accuracy	Misclicks
Workload	0.491*				
Presence	−0.036*	−0.130			
Accuracy	−0.228	−0.293*	0.302*		
Misclicks	−0.343*	−0.072	0.279	−0.026	
Response Time	−0.014	−0.051	−0.003	−0.339*	.067
Both	Cybersickness	Workload	Presence	Accuracy	Misclicks
Workload	0.519*				
Presence	−0.159	0.041			
Accuracy	−0.317*	−0.526*	0.126		
Misclicks	−0.381	−0.402*	0.111	0.348*	
Response Time	0.025	0.074	−0.089	−0.301*	−0.094

* = statistically significant at p < .05 level.

Within the 0-Back group, there was a statistically significant negative correlation between cybersickness and misclicks, $r(48) = -.296$, $p = .041$, with misclicks explaining 9% of the variation in cybersickness. No correlation between accuracy or response time was found to be significant for other variables of interest for 0-Back.

For the 2-Back group, there was a statistically significant negative correlation between cybersickness and misclicks, $r(49) = -.343$, $p = .016$, with misclicks explaining 12% of the variation in cybersickness. There was a statistically significant correlation between accuracy and presence, $r(48) = .302$, $p = .037$, with presence explaining 9% of the variation in accuracy. A statistically significant negative correlation between workload and accuracy, $r(46) = -.293$, $p =$

.048, with workload explaining 9% of the variation in accuracy was found. Another statistically significant, negative correlation between accuracy and average response time, $r(49) = -.339$, $p = .017$, with response time explaining 16% of the variation in accuracy was found. No additional statistically significant relationships were found for 2-Back participants.

For the combined dataset (0-Back and 2-Back), there were significant relationships. First, there was a negative correlation between sickness and accuracy, $r(97) = -.317$, $p = .002$, with accuracy explaining 10% of the variation in cybersickness. Cybersickness also negatively correlated with misclicks, $r(97) = -.381$, $p < .001$, with misclicks explaining 15% of the variation in cybersickness. Accuracy, $r(93) = -.526$, $p < .001$) and misclicks, $r(93) = -.402$, $p < .001$, also showed a significantly negative correlation with workload with accuracy accounting for 28% and misclicks accounting for 16% of the variance in workload. There was a statistically significant, correlation between accuracy and misclicks, $r(98) = .348$, $p < .001$ with misclicks explaining 12% of the variation in accuracy. There was a statistically significant, negative correlation between average response time and accuracy, $r(97) = -.301$, $p = .003$, with response time explaining 9% of the variation in accuracy. No additional significant correlations were found for this group.

To explore further whether performance in a real-world VR task was correlated with reduced sickness, scatter plots were created to visualize the data in case there were visible patterns not visible in the statistics. A scatter plot of SSQ TS Δ by maze accuracy is shown in Figure 18. A cluster of high performers with low sickness reported can be seen in the lower right-hand corner of the plot. Figure 19 and Figure 20 show similar scatter plots for participants in the 0-Back and 2-Back conditions, respectively.

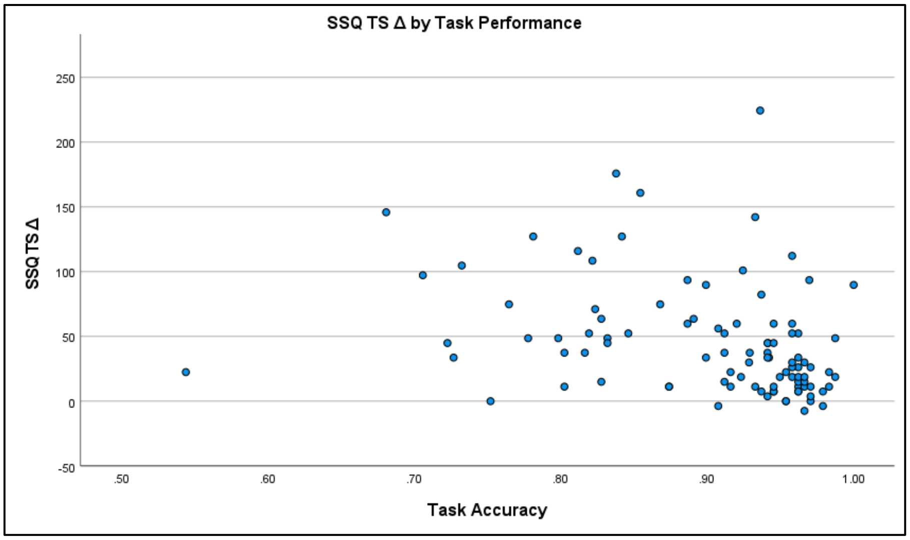


Figure 18. Scatter plot of cybersickness by task performance.

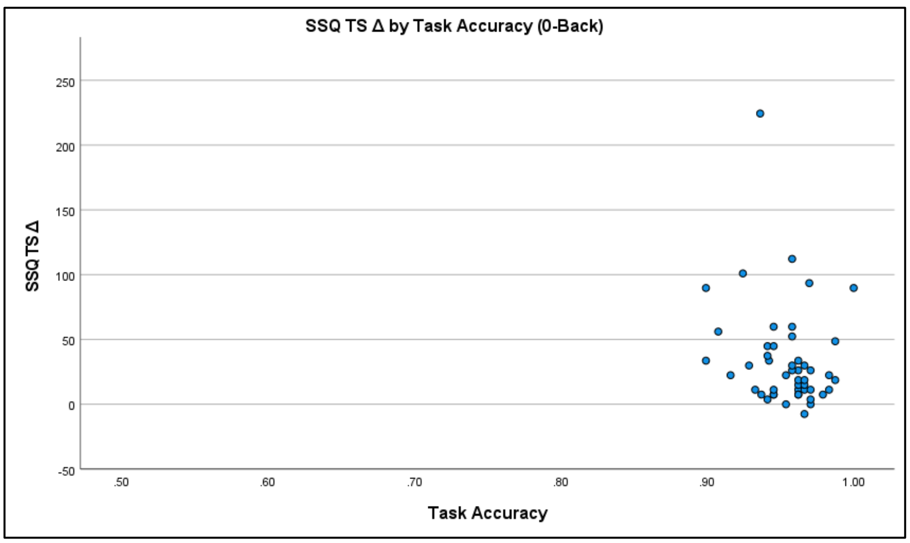


Figure 19. Scatter plot of SSQ TS Δ by task accuracy for 0-Back group.

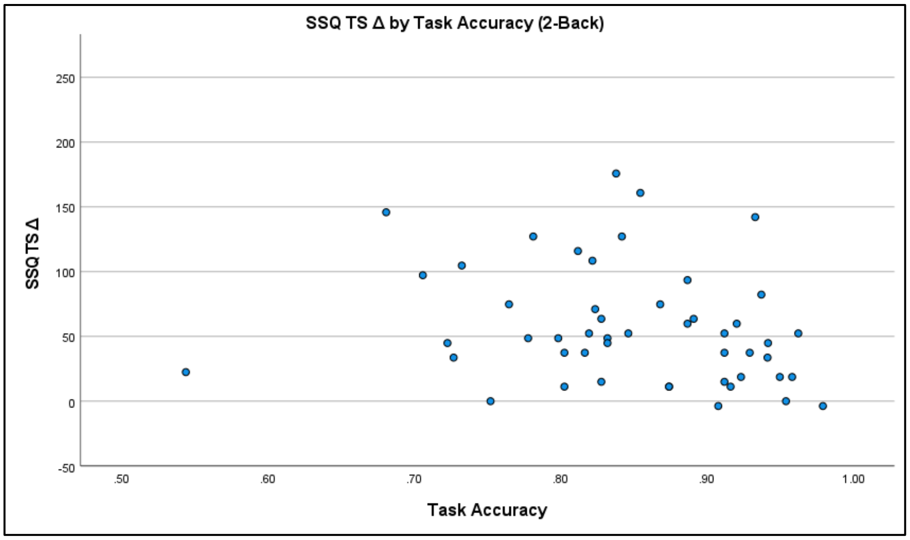


Figure 20. Scatter plot of SSQ TS Δ by task accuracy for 2-Back group.

Additional Results

Effect of Video Game Experience

Analysis on video game history data was complicated by confusion with the question asked during the pre-surveys. The question read: "On a typical weekday in the last calendar year (Monday through Friday), estimate how many hours you play video games?" Some participants seemed to have interpreted the question as asking how many hours per week rather than per day, leading to some results of over 10 hours per day for participants (one participant answered 24 hours, with multiple participants answering over 15). The researchers are confident that these numbers stem from confusion (rather than extreme enthusiasm for gaming) given that the Entertainment Software Association's 2021 report (2022) notes note that average players (even in 2021, with partial COVID isolation), spend an average of only 7.5 hours week on games. This misinterpretation of the question led to difficulty analyzing the data. As an attempted workaround, results were grouped into 3 groups based on 33rd and 66th percentiles (less than 1.1 hrs/day, in between 1.2 and 3 hrs/day, and greater than 3 hrs/day). Due to the weak validity of this analysis, there is no reportable relationships between video game history and other factors of interest. A small potential difference in perceived workload was experienced by the group with the most hours played, but this result should be taken lightly due to the issues with the data set. A similar difficulty arose with the other video game experience question, “On a typical weekend day in the last calendar year (Saturday and Sunday), estimate how many hours you play video games?” The data for this question was similarly invalid and analysis was not performed.

Effect of VR Experience

Whether previous VR experience related to cybersickness was also an area of interest. There was not obvious relationship between increased VR use and reported cybersickness values reported. Analysis comparing these categories was not completed because the three categories of most frequent use as shown in Figure 21 at right had sample sizes of 7, 2, and 2 respectively.

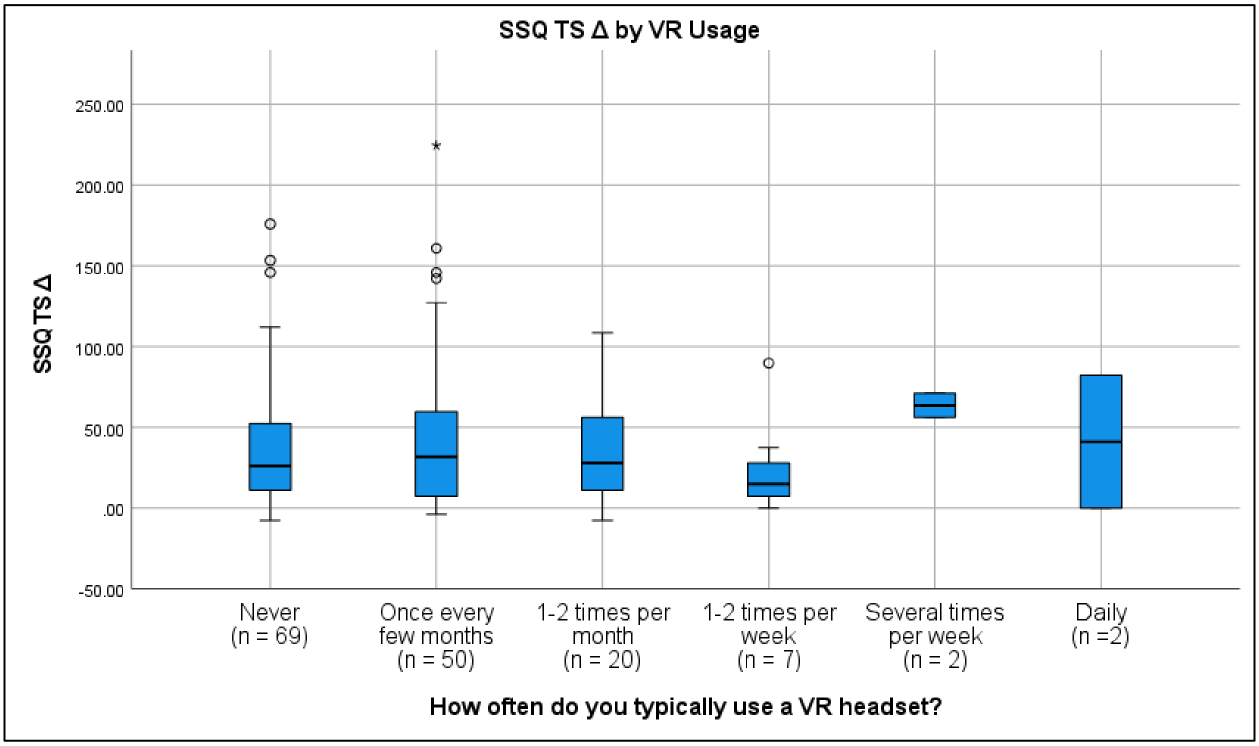


Figure 21. SSQ TS Δ by VR Usage with minimal sample sizes for right three categories, ° = potential outlier, * = extreme outlier.

Because of the small sample sizes in the higher usage categories, data was collapsed into first time VR users (never) vs. previous VR users (other categories). A boxplot comparing sickness scores between first time VR users (M = 38.647, SD = 39.302, n = 69) and previous VR users (M = 42.571, SD = 44.322, n = 81) is shown in Figure 22. A one-way ANOVA was performed to compare these two groups. All assumptions required by an ANOVA were met (continuous variable, categorical groups, independence of observations, normality, and outliers). Analysis found no significant difference between the groups $F(1,148) = .324$, $p = .570$, $\eta^2 = .002$. A similar analysis was performed to see if previous VR experience affected SSQ by task condition. A clustered set of boxplots of cybersickness by condition and previous VR experience can be seen in Figure 23. No significant differences were found.

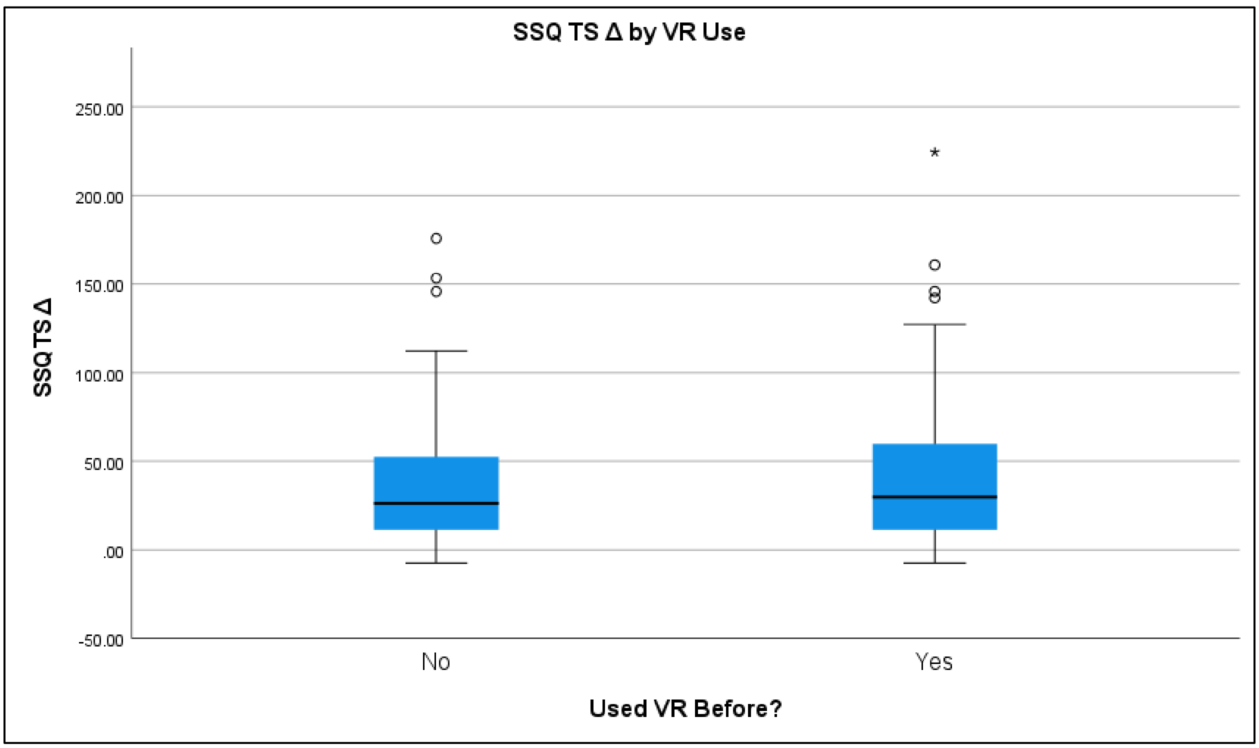


Figure 22. SSQ TS Δ by previous VR user for all data, no obvious trend to be found, ˚ = potential outlier, * = extreme outlier.

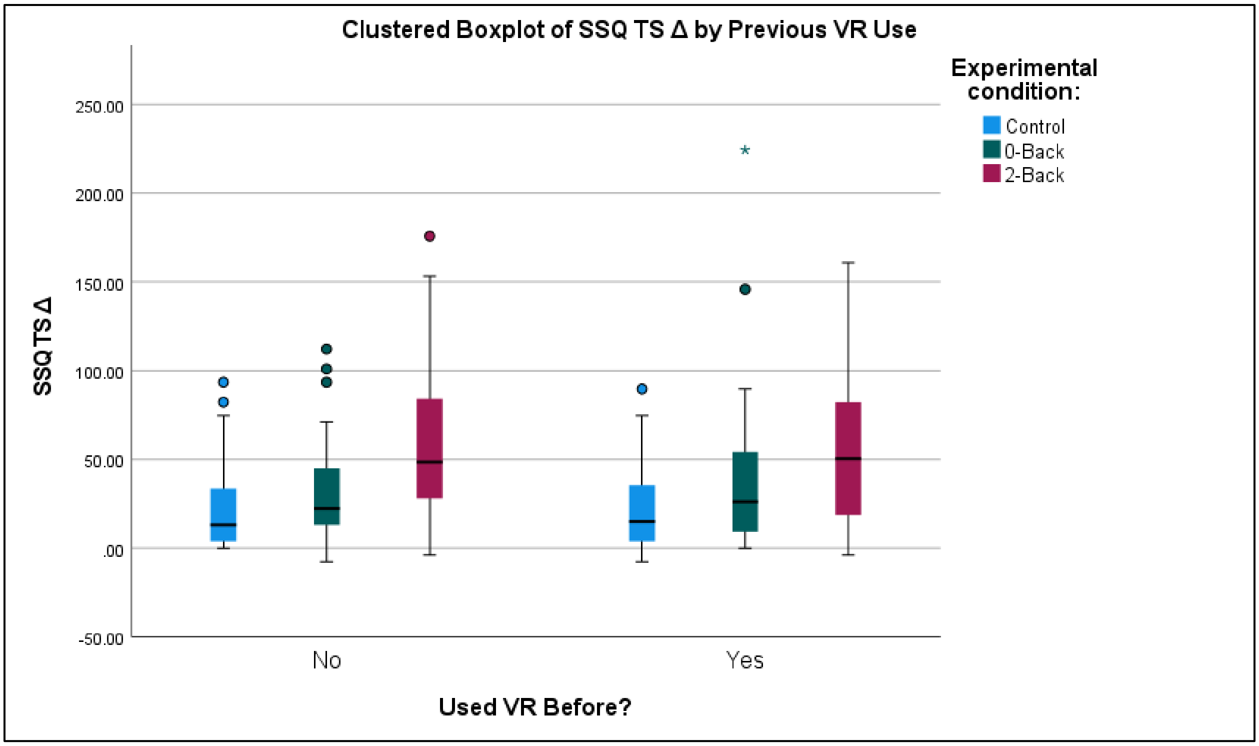
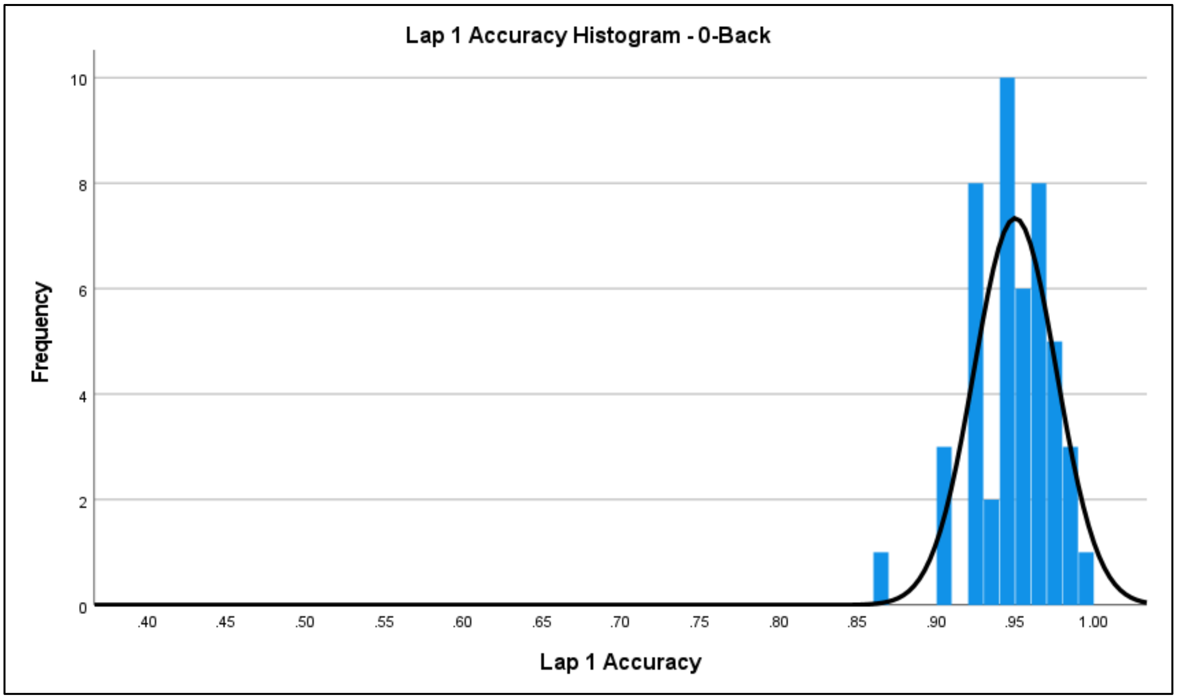


Figure 23. Cybersickness by Previous VR use and Condition. No significant differences were found. ˚ = potential outlier, * = extreme outlier.

Analysis was also performed to see if there was any relationship between cybersickness and participants' answer to the question: "How many minutes do you typically use a VR headset in one sitting?" No relationship was found.

Effect of Practice from Lap 1 to Lap 2

Analysis of task accuracy between the two maze laps was evaluated to explore whether there was a practice effect. Histograms for the accuracy spread for each lap for 0-Back, and 2-Back are shown in Figure 24 and Figure 25 respectively. Maze accuracy was calculated as the ratio of errors to the number of trials experienced; this method did not penalize participants who dropped out early.



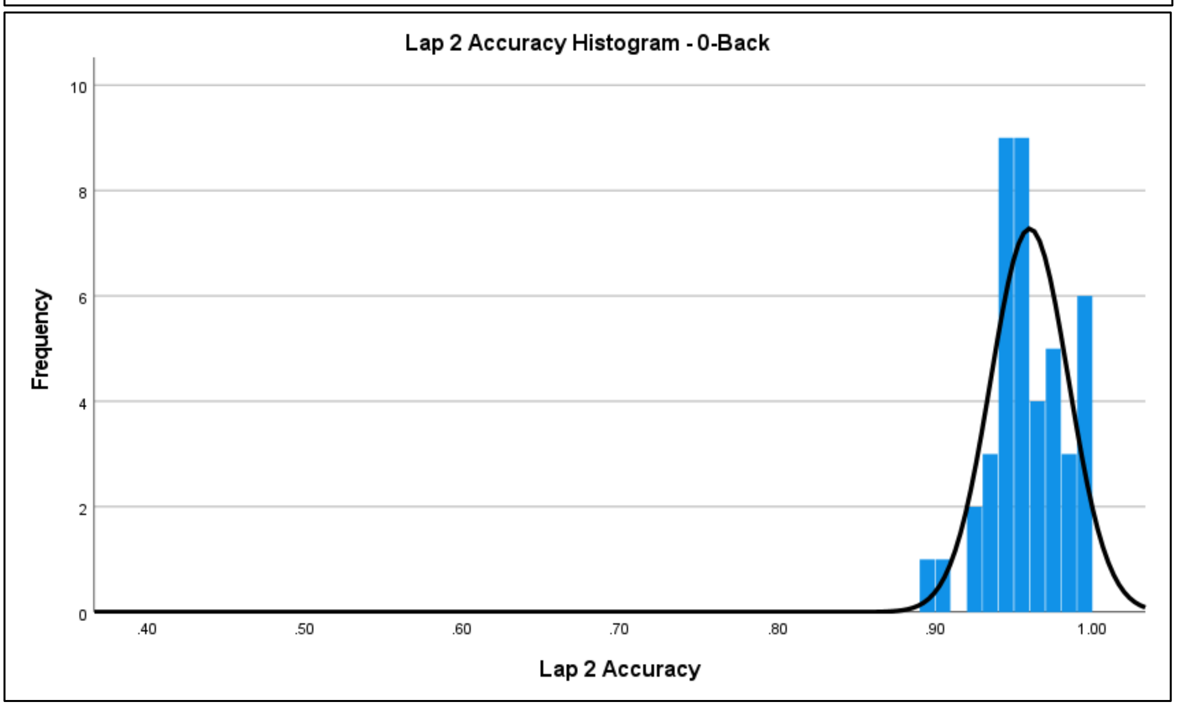
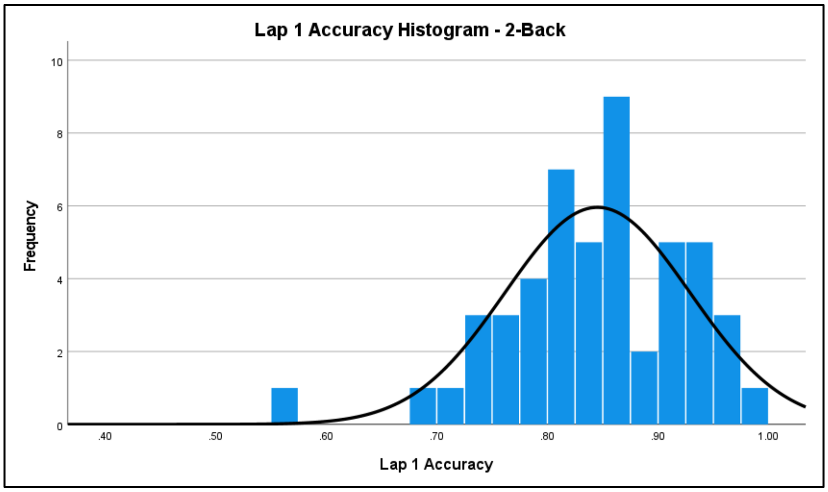


Figure 24. Maze Task Accuracy for 0-Back group, (Top) Lap 1 (M = .950, SD = .026, n = 48), (Bottom) Lap 2 (M = .960, SD = .025, n = 45).



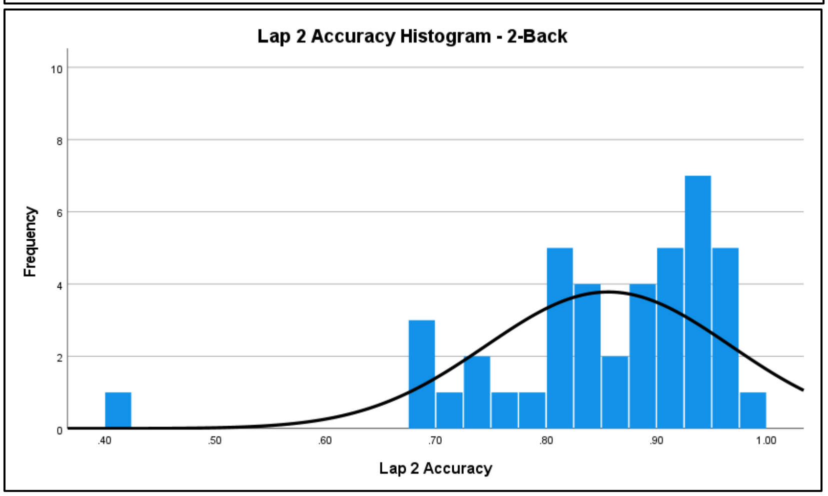


Figure 25. Maze Task Accuracy for 2-Back group, (Top) Lap 1 (M = .845, SD = .084, n = 48), (Bottom) Lap 2 (M = .856, SD = .111, n = 50).

A boxplot showing the differences from Lap 2 to Lap 1 between conditions is shown in Figure 26. Lap Accuracy Δ (Lap 2 Accuracy – Lap 1 Accuracy) was calculated to determine differences between laps. This could only be calculated for participants that persisted into two laps for 0-Back (n = 45) and 2-Back (n = 42). An ANOVA was performed to determine if there were differences between the 0-Back group (M = .0110, SD = .0281) and the 2-Back group (M = .0072, SD = .0608), for the Lap Accuracy Δ. No significant difference was found F(1,86) = .139 , p = .410, η^2 = .002. A scatter plot of Lap Accuracy Δ and SSQ TS Δ is shown in Figure 27. Using Pearson's product-moment correlation to assess the relationship between Lap Accuracy Δ and cybersickness, a significant positive correlation was found, $r(96) = .253$, $p < .019$, with Lap Accuracy Δ explaining 21% of the variation in cybersickness. This finding means that sicker participants tended to perform better on the second lap, and vice versa. This finding seems counterintuitive. One explanation may be that some participants used cybersickness mitigation strategies (such as holding the head still rather than visually following the turns) that reduced their sickness but also their task performance, since they no longer saw animals sitting just around the corner of a turn until later. Another explanation could be that some participants were highly committed to performing well on the task, despite the sickness, and simply endured it, growing sicker while scoring well.

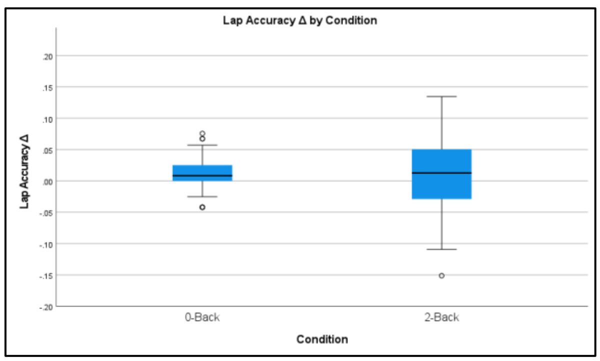


Figure 26. Lap Accuracy Δ boxplots by condition. There is no significant difference between the conditions, despite the larger variation in the 2-Back condition.

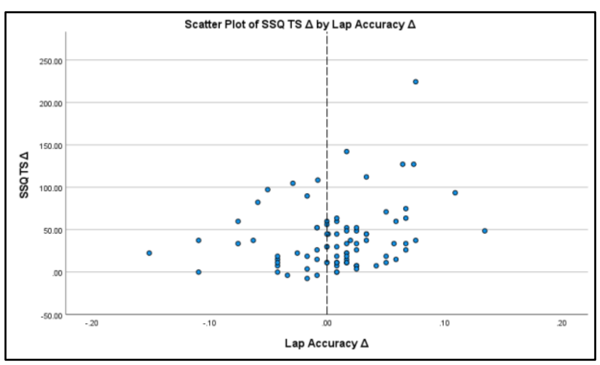


Figure 27. SSQ TS Δ by Lap Accuracy Δ. Participants who scored better on Lap 2 are at right. Participants at left scored worse on Lap 2.

CHAPTER 5. SUMMARY AND DISCUSSION

Findings from Chapter 4 will be interpreted in this section. Connections to previous research as well as future research in this area will also be included. Findings will be discussed in the order they were presented in the results.

The two primary research questions that were addressed by this research were:

RQ1) What is the relationship between VR task workload, presence, and cybersickness?

RQ2) How do groups with different VR task workloads differ in presence, task performance, and cybersickness?

To summarize the results by hypothesis:

H1, that increased task workload would lead to higher perceived presence, was not supported. No significant correlation between workload and presence was found in any of the conditions.

H2, whether increased presence would be correlated with reduced cybersickness, was partially supported. For the 2-Back group, a significant negative correlation between cybersickness and presence was found.

H3, the prediction that groups with a task would show higher presence and workload and lower sickness, was partially supported. Workload significantly increased between each condition, with the No-Task group being the lowest and the 2-Back group being the highest. However, presence was shown to be significantly more for than the No-Task group for both 0-Back and 2-Back. There was no significant difference in presence between the 0-Back and 2-Back groups. Cybersickness showed the opposite of the expected result, with cybersickness increasing between each condition, with the No-Task group being the lowest and the 2-Back group being the highest.

H4, predicting that better performance in a real-world VR task will be correlated with reduced sickness, was supported by the results. For each task group individually, no direct relationship between sickness and task accuracy was found, but for both groups as a whole, there was a negative correlation found. Misclicks were also shown to negatively correlate with sickness for each group. Misclicks were also shown to positively correlate with task accuracy for task-groups combined.

Research Question 1: What is the relationship between workload, presence, and cybersickness?

Workload's impact on cybersickness is an area lacking research. Previous research has investigated presence's relationship between cybersickness and shown a negative relationship between them (Dilanchian et al., 2021; Melo et al., 2021; Servotte et al., 2020; Weech et al., 2019, 2020). Factors related to the task completed while within VR have not been researched extensively, with the only key factors identified being control and duration (Barrett, 2004; Chang et al., 2020; Davis et al., 2014; Saredakis et al., 2020; Tian et al., 2022).

Increased workload was suggested as a factor increasing cybersickness due to overwhelming the user by Meusel (2014). The current study showed a significant positive correlation between reported cybersickness and workload. Participants who perceived themself as under a higher workload also perceived themself as experiencing more sickness, regardless of the condition they were exposed to. This relationship definitively places task workload as a factor that should be considered within cybersickness research. Attention as a limited resource factors into the amount of sickness experienced by an individual. The attentional demand that varied between the three task conditions was associated with the amount of cybersickness experienced while keeping all other visual stimuli constant. This suggests that researchers and developers need to consider the workload to which they are subjecting users if sickness-inducing stimuli are present.

Presence, measured post-experience in this study, showed that for users with a higher task workload (the 2-Back group), a significant negative correlation between presence and cybersickness exists. The only significant relationship between presence and cybersickness was found in the 2-Back condition. This finding suggests that for experiences where high workload and high potential sickness are present, increasing the presence of the user may be important for keeping sickness low. It may also suggest that in contexts with a risk of cybersickness, it is difficult to design a high workload task while maintaining presence. The lacking significant correlation between presence and cybersickness for the lesser task groups (No-Task, 0-Back), shows that these participants did not benefit from an increased level of presence compared to those in the 2-Back group. Presence was not found to have any significant correlation with perceived workload within conditions.

H1: Increased task workload will lead to higher perceived presence.

Initially, it was speculated that as users increased involvement in a task by increasing mental workload, their sense of presence would also increase. This relationship was not found in this study when looking at data within participant groups. This result may be due to presence measures not accurately capturing the amount of engagement in a task or simply that the relationship does not exist. An insignificant positive correlation between workload and presence was found for No-Task and 0-Back groups, but an insignificant negative relationship was found for 2-Back. This small switch in correlations direction, even though they correlations are non-significant, may suggest that in future research, it may be worth exploring whether the relationship between presence and workload is affected by the difficulty of the task. Increasing the task workload with the conditions in the study did show significant differences in presence, with both task groups (0-Back, 2-Back) experiencing higher presence than the No-Task group. However, no significant increase in presence was found between 0-Back and 2-Back, suggesting that adding a task increases presence (moving from No-Task to 0-Back), but that this effect plateaus rather than continuously increasing as the difficulty of the task increases.

H2: Increased presence will be correlated with reduced cybersickness.

Based on previous work (Dilanchian et al., 2021; Melo et al., 2021; Servotte et al., 2020; Weech et al., 2019, 2020), a negative correlation between presence and cybersickness was expected. Agreeing with previous findings, this relationship was identified with a negative correlation only for the 2-Back group. Presence was not found to be significantly higher in 2-Back than 0-Back, but the strong negative relationship between presence and cybersickness sickness symptoms in the 2-Back group suggests that presence has a greater benefit as task complexity increases. This finding suggests that presence's impact on cybersickness depends on the task being conducted in VR. This finding also suggests that presence alone is not enough to mediate sickness symptoms.

Research Question 2: How do groups with different VR task workloads differ in presence, cybersickness, and task performance?

This work aimed to answer questions related to workload that have not been addressed by previous research. The three different conditions in this work were No-Task, 0-Back, and 2-Back.

The presence experienced within the No-Task group was significantly lower than the presence in the other two groups. As noted above, this finding suggests that adding a task to a VR experience significantly increases the presence experienced within VR. A participant who is exposed to the same amount of sickness-inducing stimulus has more presence simply by providing them with a controller and a simple task (collect all the skunks). The more interesting finding related to presence is that there was no significant increase in presence between 0-Back and 2-Back. This lack of significant change suggests that by increasing the complexity of the task (collect an animal only if the animal you saw two animals ago was the same as that animal), did not increase the presence induced by that task. This result suggests that, depending on the VR experience, presence can be modified by a task, but only to a certain extent. More specifically, increasing workload does not necessarily increase presence.

The No-Task group experienced the least amount of cybersickness, the 2-Back group experienced the most cybersickness, and the 0-Back group was in the middle. There was a significant increase in sickness from the No-Task group to 2-Back group but not between No-Task group and the 0-Back group. This significant change in sickness implies that the 2-Back group had something different about their experience that made them sicker. One might suppose that this difference was related to the increased need for head movement, but the same head movement was required by the 0-Back task. The measure originally assumed to reduce sickness from H1, workload, was shown to be a key differentiator for the 2-Back task from the 0-Back task. From these results, one may infer that increasing workload beyond a certain point definitively increases cybersickness experienced.

H3: Participants assigned to task groups will show higher levels of workload, presence, and lower levels of cybersickness than participants without a task.

This hypothesis was partially supported, in terms of workload and presence, but not cybersickness. The hypothesis that the assignment of participants to task groups increases workload was found to be true, as it significantly increased from No-Task to 0-Back to 2-Back. This workload measure also coincided with the significant difference in task accuracy between 0-Back and 2-Back.

Before this study, increased presence was hypothesized to reduce sickness. It was thought that increases in workload would further immerse participants. The hypothesis was not supported for presence, as presence was shown to significantly increase from the No-Task group to 0-Back/2-Back but not from 0-Back to 2-Back. Cybersickness was shown to be significantly higher for 2-Back than both other conditions, but No-Task and 0-Back did not have significant differences. These results, found between cybersickness and presence, suggest that adding a task alone did not increase sickness, but adding a cognitively demanding task (2-Back) had adverse effects. Adding a task (moving from No-Task to 0-Back) did not significantly change sickness experienced per SSQ, but the statistics regarding dropout rates demonstrated that a different component of the participants' experience related to discomfort changed between the conditions. The dropout rates showed that the No-Task group (19%, 9/47) had 9% more dropouts than the 0-Back group (10%, 5/49). For the participants in the 0-Back group, the researchers suggest that the task captured their attention and helped decrease the dropouts. Previous research compared an "Intense" rated experience (as rated on the Oculus Store) in which participants "freely explored a simulated space station" to a "Comfortable" rated experience in which "participants were encouraged to perform simple actions such as picking up and throwing objects" (Weech et al., 2018). Participants in the comfortable group, who had a simple task beyond exploring, experienced less sickness. These findings align with the current study and show potential that the addition of the task may be contributing to the reduction of sickness. In the current study, the 2-Back group (33%,17/51) made participants very uncomfortable and had the most dropouts. Notable 2-Back participant quotes when asked about how they felt post-exposure included: "awful," "miserable," and "uncomfortable."

Participants levels of cybersickness also showed a significant negative correlation with misclicks for the 0-Back and 2-Back groups. This measure captured how many times participants clicked but not on a target animal. As a result, this metric may give some insight into how curious or invested they were in the game. As players explored controls or tried hard to click animals, it may have resulted in a lot of extra clicking to ensure they hit the target, especially since there was no penalty for extra clicks. This sort of investment may be used as a proxy measure of presence and thus coincide with the negative correlation between cybersickness and presence found for the 2-Back participants. Being more invested or involved in the gameplay helped players reduce sickness experienced. A significant correlation between misclicks and presence scores was found to back up this idea. This result also suggests that a future study might explore whether willing suspension of disbelief, the ability of a person to be able to accept a fictional reality, may have allowed users of VR to suspend their attention to sickness-causing cues and reduce sickness.

This finding, in unison with the result that showed a significant negative correlation between presence and cybersickness for the 2-Back group, indicates greater importance for cognitively demanding VR experiences to engage the user and increase the sense of “being there” or presence.

H4: Better performance in a real-world VR task will be correlated with reduced cybersickness.

Performance in a real-world VR task correlating with reduced cybersickness was supported. For each group separately, there was no significant correlation found, but when the data from both task groups was pooled, there was a significant negative correlation between accuracy and cybersickness. This correlation does not imply a causal relationship, however, as it is not obvious if performing well at the task made participants less sick, or if being less sick made participants perform better.

From the findings detailed above, an updated version of the model proposed in Figure 2 was updated in Figure 28. This model, with workload increasing on the x-axis, shows a high amount of cybersickness with low workload, a dip down where workload is just right, and an increase once workload becomes overwhelming. The Cybersickness-Workload relationship may mirror the Yerkes-Dodson law (Cohen, 2011), which indicates that there is an optimal level of arousal for performance, or in the case of cybersickness, an optimal level of workload to minimize sickness. This finding corresponds with the finding in this work of a reduced dropout rate for participants in the 0-Back group. Presence was shown to not continuously increase with workload and plateaued after the inclusion of a task. Accuracy was shown to negatively correlate with increases in workload.

The invalidity in the predicted model with respect to cybersickness and presence may have been due to a flawed understanding of the impact of workload on cybersickness. The original model failed to incorporate the negative side effects of increases in workload. These negative side effects became prevalent for the 2-Back group, who experienced the highest levels of cybersickness and dropouts. The shift in attention that was predicted to reduce sickness symptoms was shown between the No-Task and 0-Back groups (with lower dropouts in 0-Back), but once workload became overwhelming (2-Back group), it made the experience more uncomfortable rather than helping. This finding implies that there is an interesting relationship between attention and cybersickness that is worth exploring further. It may be that a portion of attentional capacity or workload capacity becomes allocated to managing cybersickness after a certain threshold. These results suggest that a mechanism exists in which adding a task reduces discomfort in VR experiences, and although it cannot be identified from the current work, these results may help constrain the possible solution space for the mechanism.

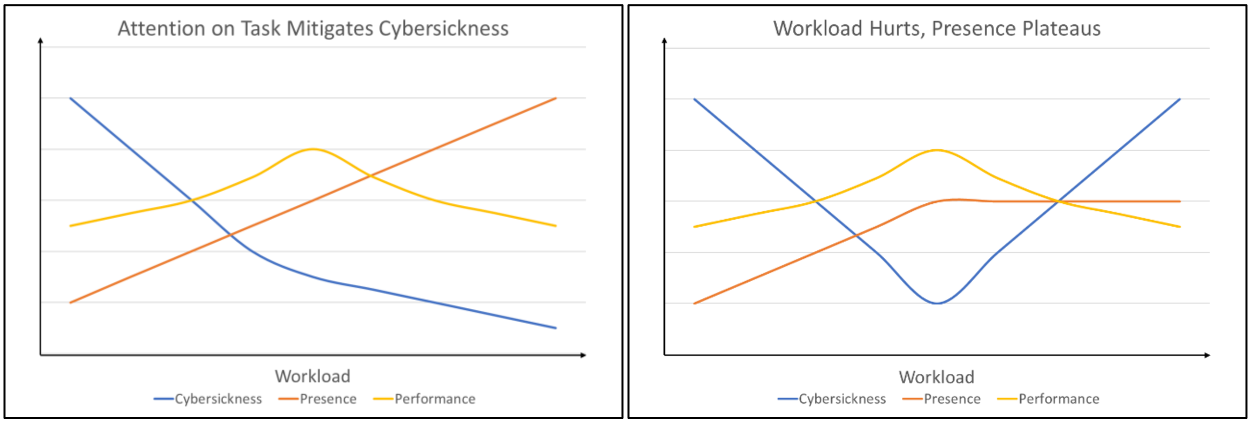


Figure 28. Predicted model (Left) compared to the updated cybersickness model (Right), based on results from this work, detailing the relationship between cybersickness, presence, workload, and performance.

Limitations

Key limitations of the research include subjective measures, lack of head tracking data, and lab-based study limitations. One of the largest limitations of this research is the use of subjective measures to track the three main constructs of interest. The SSQ (Robert S. Kennedy et al., 1993), used to measure cybersickness, was originally designed to measure simulator sickness. There has been significant effort in this research area to replace this measurement with an objective physiological one, but results have been inconsistent. The NASA-TLX (Hart & Staveland, 1988) as a measure of workload is widely accepted and captures the key components of workload, but as with any subjective questionnaire, it is difficult to know if all participants are answering questions consistently. The IMQ (Jennett, Cox, Cairns, et al., 2008), was used to measure presence experienced because of its game-like focus. There are other presence measures, such as the PQ (Witmer & Singer, 1998), but these lack the gaming perspective that may be necessary to capture engagement with environments in the modern era.

In addition to subjective measures, this study did not utilize any HMD head tracking logging to identify different trends in postural sway. This was excluded from data collection, as the participants were seated in a chair and minimal movement was expected. However, researchers observing participants noted that some attempted sickness-reducing strategies such as keeping the head extra still or bracing for automated turning, which suggested that head tracking may have been a good additional source of data in this study.

This work was a lab-based study that brought participants into a foreign space to immerse themselves into a completely virtual environment. For most VR users, this sort of experience usually happens in a more intimate space such as one's home. Results in this work may be skewed due to discomfort for participants who would feel more comfortable at home or in their own headset, thus leading to the potential for results to not completely generalize to at-home VR experiences.

Another possible limitation of the data was the failure of the questionnaire questions to accurately capture previous gaming experience. The questions asked users to report how many hours on the average weekday or weekend day they play video games, but responses included times over 10 hours (and some of 24 hours), which led to problems properly analyzing the data.

Priming the participants to be aware of cybersickness symptoms is a problem unique to studies in this area. Due to IRB obligations, the consent form included language indicating potentially negative symptoms being experienced in during the study. The name of the study during recruitment also used language including the word cybersickness, furthering potential priming effects with users subjectively reporting sickness. The use of a pre-SSQ also potentially primed users to experience or be more aware of cybersickness symptoms, as discussed by previous researchers (Young et al., 2006). However, in this study, Pre-SSQ scores were consistently low, so while this was not a substantial concern for this study, the priming effect still may have been present.

Conclusions

This work aimed to answer two research questions "What is the relationship between workload, presence, and cybersickness?" and "How do groups with different VR task workloads differ in presence, cybersickness, and task performance?"

This VR study compared three conditions of varying task load for a real-world (similar to commercial off the shelf) task, where the only independent variable was the task completed (and thus workload subjected to). This variable allowed for the study of users being exposed to the same cybersickness-inducing visually uncomfortable stimulus (via the Cyber Sickness Corn Maze) but with varied attentional demands via the task. The No-Task group sat through the experience with no controllers. The 0-Back group used the controller to point a laser pointer in a visual attention task. The 2-Back group performed the 2-Back memory task (Kirchner, 1958) and used a controller to point a laser in a more complex visual attention task. The increase of attentional workload with a task had a significant effect on cybersickness moving from 0-Back to 2-Back.

For the first question, the previous literature on mitigations and triggers of cybersickness has not investigated the role of workload as a potential cause or moderator. Workload was shown to impact the reported amount of participants' cybersickness when comparing three conditions of workload (No-Task, 0-Back, 2-Back). Workload's negative relationship with cybersickness needs to be considered in cybersickness research. Presence was shown to have a negative correlation (2-Back Condition) with cybersickness. As users became more engaged and involved with the experience, it may have helped them mitigate or cope with cybersickness symptoms they were experiencing. The more invested that participants were in the task they were completing in VR, the more it helped them mediate the incoming sickness-inducing stimuli. This investment and engagement coincided with tracking of misclicks, which correlated negatively with cybersickness. Presence was also positively correlated with task performance.

For the second question, the differing task workloads significantly affected cybersickness, presence, and task performance in the task groups evaluated. Cybersickness was shown to significantly increase for the 2-Back group when compared to the 0-Back and No-Task groups. No difference in sickness was found between the No-Task and 0-Back groups. This result implies that adding a task alone did not change cybersickness, but the addition of a cognitively demanding task (in the 2-Back group) increased discomfort significantly. This has implications for all future research in cybersickness, as the workload and the type of task completed impacts cybersickness.

Rates of dropouts (participants who stopped early due to discomfort) indicated a different pattern than cybersickness rates between the No-Task and 0-Back conditions, with 19% of participants stopping for the No-Task group and only 10% dropping out for 0-Back. This result points to evidence that participants in the 0-Back group were more interested in the experience, which was shown by a significant difference in presence between the groups. Presence did not significantly differ from 0-Back to 2-Back, which may indicate that only a certain level of presence can be modified with the inclusion of a task.

The 2-Back group performed significantly worse at their task than the 0-Back group while performing a similar but more cognitively demanding task (as measured by the NASA-TLX). Meanwhile, cybersickness was shown to decrease with improvements in task performance. The relationship between cybersickness and task performance was further investigated and showed that individuals who improved performance in the second half of a task felt worse than those who got worse. This is a further indication that cybersickness and task performance are related, but a causal relationship cannot be identified.

The overall conclusion from this research is that changes in task workload impact cybersickness and presence experienced in VR environments. This work enabled researchers to modify the task completed within a cybersickness-inducing virtual environment to see the impact of that task. Results showed that the addition of a simple task changed the presence experienced in VR significantly, and a more complex task made individuals sicker at consistently higher rates. Performance of the task was also negatively related to cybersickness, increasing the importance of reducing cybersickness if high task performance is required. These results should be considered moving forward in cybersickness research. Put simply: the task required in virtual experiences matters.

Future Work

With the awareness of cybersickness having a definite relationship with workload, studies that compare differing experiences could measure workload to ensure it is not the cause of changes of cybersickness between conditions. Evaluations of workload across different VR experiences, such as games or other immersive applications, should be completed to further validate the results shown in this work. The findings in this work highlighted the connection between attention on a task and a reduction in sickness. The exact mechanism that caused this change was not detected, but further research in this area is needed to understand it completely.

Head tracking data from participants' HMDs was missing from this analysis. Head tracking data within tasks could provide interesting results between task conditions and show how differing tasks result in different amounts of postural sway. This sort of head tracking and postural sway data could give further insights into the causes of varying sickness between tasks.

Future work should aim to strategically capture previous gaming experience as a factor related to cybersickness. Gamers can mitigate cybersickness through learned strategies, one of which may be the ability to suspend disbelief. This ability may be something that can be taught and should be something researched further.

The newfound relationship between attention, workload, presence, and cybersickness discussed in this work identifies an opportunity for new research. An interesting relationship between workload and cybersickness that is worth exploring further has been discovered. This study gives justification to investigate the modification of attention to impact cybersickness. The results in this work indicate that a mechanism exists that makes adding a task reduce discomfort in VR experiences. Future work should further explore this mechanism to identify if people can be trained or experiences can be designed to take advantage of this reduction. From the results in this work, it may be that a portion of attentional or workload capacity is used by the body to manage cybersickness symptoms. This potential new understanding of cybersickness provides a new frontier of questions and answers to better understand cybersickness.

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APPENDIX A. SIMULATOR SICKNESS QUESTIONNAIRE

(Kennedy et al., 1993)

	None	Slight	Moderate	Severe
General discomfort	0	1	2	3
Fatigue	0	1	2	3
Headache	0	1	2	3
Eyestrain	0	1	2	3
Difficulty focusing	0	1	2	3
Increased salivation	0	1	2	3
Sweating	0	1	2	3
Nausea	0	1	2	3
Difficulty concentrating	0	1	2	3
Fullness of head	0	1	2	3
Blurred vision	0	1	2	3
Dizziness (eyes open)	0	1	2	3
Dizziness (eyes closed)	0	1	2	3
Vertigo	0	1	2	3
Stomach awareness	0	1	2	3
Burping	0	1	2	3

Computation of SSQ Scores

SSQ Symptom[a]	Weight *N*	Weight *O*	Weight *D*
General discomfort	1	1	
Fatigue		1	
Headache		1	
Eyestrain		1	
Difficulty focusing		1	1
Increased salivation	1		
Sweating	1		
Nausea	1		1
Difficulty concentrating	1	1	
Fullness of head			1
Blurred vision		1	1
Dizzy (eyes open)			1
Dizzy (eyes closed)			1
Vertigo			1
Stomach awareness	1		
Burping	1		
Total[b]	[1]	[2]	[3]

Score

$N = [1] \times 9.54$

$O = [2] \times 7.58$

$D = [3] \times 13.92$

$TS^{c} = [1] + [2] + [3] \times 3.74$

[a]Scored 0, 1, 2, 3. [b]Sum obtained by adding symptom scores. Omitted scores are zero. [c]Total Score.

APPENDIX B. IMMERSION QUESTIONNAIRE

Jennett, Cox, Cairns, et al.'s (2008) questionnaire was modified to include specific language about the Cybersickness Corn Maze used in this study.

Reverse Coded Questions - 6, 8, 10 and 18

Immersion Questionnaire
Instructions: Please answer the following questions about how you felt at the end of the Corn Maze game. (Responses for items are either: Not at all/Not applicable, 2, 3, 4, A lot; Not at all /Not applicable, 2, 3, 4, Very much so; Very little /Not applicable, 2, 3, 4, A lot; Not at all /Not applicable, 2, 3, 4, Very aware; Not at all /Not applicable, 2, 3, 4, Very difficult; Definitely not /Not applicable, 2, 3, 4, Definitely yes).

1. To what extent did the Corn Maze game hold your attention?
2. To what extent did you feel you were focused on the Corn Maze game?
3. How much effort did you put into playing the Corn Maze game?
4. Did you feel that you were trying your best?
5. To what extent did you lose track of time?
6. To what extent did you feel consciously aware of being in the real world whilst playing?
7. To what extent did you forget about every day concerns?
8. To what extent were you aware of yourself in your surroundings?
9. To what extent did you notice events taking place around you?
10. Did you feel the urge at any point to stop playing and see what was happening around you?
11. To what extent did you feel that you were interacting with the Corn Maze game environment?
12. To what extent did you feel as though you were separated from your real-world environment?
13. To what extent did you feel that the Corn Maze game was something you were experiencing, rather than something you were just doing?
14. To what extent was your sense of being in the Corn Maze game environment stronger than your sense of being in the real world?
15. At any point did you find yourself become so involved that you were unaware you were even using controls?
16. To what extent did you feel as though you were moving through the Corn Maze game according to your own will?
17. To what extent did you find the Corn Maze game challenging?
18. Were there any times during the Corn Maze game in which you just wanted to give up?
19. To what extent did you feel motivated while playing?
20. To what extent did you find the game easy?
21. To what extent did you feel like you were making progress towards the end of the Corn Maze game?
22. How well do you think you performed in the Corn Maze game?

23. To what extent did you feel emotionally attached to the Corn Maze game?
24. To what extent were you interested in seeing how the Corn Maze game's events would progress?
25. How much did you want to "win" the Corn Maze game?
26. Were you in suspense about whether or not you would win or lose the Corn Maze game?
27. At any point did you find yourself become so involved that you wanted to speak to the game directly?
28. To what extent did you enjoy the graphics and the imagery?
29. How much would say you enjoyed playing the Corn Maze game?
30. When interrupted, were you disappointed that the Corn Maze game was over?
31. Would you like to play the Corn Maze game again?

APPENDIX C. NASA-TLX

(Hart & Staveland, 1988)

Please rate your Corn maze task experience.

1 8 14 21

How mentally demanding was the task?
(1: very low, 21: very high)

How physically demanding was the task?
(1: very low, 21: very high)

How hurried or rushed was the pace of the task?
(1: very low, 21: very high)

How successful were you in accomplishing what you were asked to do?
(1: perfect, 21: failure)

How hard did you have to work to accomplish your level of performance?
(1: very low, 21:very high)

How insecure, discouraged, irritated, stressed, and annoyed were you?
(1: very low, 21: very high)

APPENDIX D. APPROVAL FOR RESEARCH (IRB)

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office of Research Ethics
Vice President for Research
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Date: 11/12/2021

To: Stephen Gilbert

From: Office of Research Ethics

Title: Attention Task, Cybersickness, and Individual Differences Study

IRB ID: 21-345

Submission Type: Modification **Review Type**: Expedited

Approval Date: 11/12/2021 **Approval Expiration Date:** 03/21/2022