Bacheloroppgave

NTNU
Norges teknisk-naturvitenskapelige universitet

Candidate: 10091

Allocentric processing, simulation sickness, and its relationship to immersion. A comparative study.

Bacheloroppgave i Psykologi Bahcelor
Veileder: Sebastian Thorp
Mai 2023

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Abstrakt

Virtual Reality (VR) har fått utrolig oppmerksomhet for dets potensiale til å tilrettelegge for ubegrensede 3D-miljøer. Denne studien utforsker bruken av VR-headsett (HMD) i forhold til mentale representasjoner knyttet til navigasjon og romlig forståelse. VR viser tegn til å forbedre psykomotoriske ferdigheter og forståelse av romlig visuell informasjon, men simulatorsyke (SS) utgjør en stort problem. Flere studier indikerer ødeleggende effekter av SS på generell ytelse i VR, samtidig sim varierende grad av «immersion» og manglende standardmål for kvaliteten på VR-opplevelser bidrar til usikkerhet rundt fordelen med VR. Denne studien søker derfor å undersøke ytelsen til forsøkspersoner i VR sammenlignet med en 2D-gruppe, samtidig som begrensningene rundt «immersion» tas hensyn for i eksperimentet.

Studien undersøkte forskjellen i allocentrisk ytelse mellom 62 forsøkspersoner som brukte en 24-tommers skjerm (2D) ($n = 30$) og en Meta Quest 2 VR HMD ($n = 32$). En uavhengig t-test viste ingen statistisk signifikant forskjell mellom gruppene, $t(60) = -1.43$, $p = .078$, men resultatet er nesten signifikant. Videre undersøkelser avdekket en betydelig positiv korrelasjon mellom rapportert simulatorkvalme og allocentrisk ytelse blant VR-deltakerne, $r(60) = .427$, $p = .015$. Denne korrelasjonen var imidlertid ikke signifikant innenfor 2D-gruppen. Ved vurdering av de aspektene av «immersion» som er mest forbundet med SS i dette eksperimentet, nemlig ustabilitet, begrenset mulighet for bevegelse og mangel på alternative bevegelsesmuligheter, indikerer de relevante analysene et tydelig negativt forhold mellom SS og AP i VR.

Abstract

Virtual Reality (VR) has gained significant attention for its potential to provide immersive and customizable 3D environments that can enhance navigation and visual-spatial learning. This study explores the use of VR head-mounted displays (HMD) relating to mental representations with regards to navigation and spatial understanding. While VR shows promise in psychomotor skills and understanding spatial visual information, simulation sickness (SS) poses a major obstacle to its widespread adoption. Several studies indicate detrimental effects of SS on general performance in VR, yet varying degrees of immersion and lack of standard measures for the quality of VR experiences contribute to inconsistent findings regarding the benefits of VR. This study therefore seeks to investigate the performance of subjects in VR compared to a 2D group, while considering the limitations to immersion present in the experiment.

The study examined the difference in allocentric performance between 62 subjects using a 24´monitor (2D) (n = 30) and in a Meta Quest 2 VR HMD (n = 32). An independent t-test revealed no statistically significant difference between the groups $t(60) = -1.43$, $p = .078$, although it is close to being significant. Further examination revealed a significant positive correlation between reported simulation sickness and allocentric performance among VR subjects, $r(60) = .427$, $p = .015$. This correlation however, was not significant within the 2D group. When considering the aspects of immersion most associated with SS present in this experiment, such as instability, limited degree of movement and a lack of alternative movement-options. The relevant analyses indicate a clear negative relationship between SS and AP in VR.

Introduction

Although modern computer screens today can provide an incredible degree of immersion, it is still significantly different from virtual reality (VR). VR head-mounted displays (HMD) free users from the familiar two-dimensional experience, and places them in an immersive completely customizable 3D-environment that responds in real-time to their head-movement (Anthes et al., 2016). Precisely for this reason, many hypothesize its potential use in applications involving navigation and visual-spatial processing (Epstein et al., 2017).

One way this might be examined is through the involvement of mental representations, as it is a crucial part of our visual-spatial processing system. The ability to generate mental representations of the environment, both in relation to self-position and objects or landmarks present, is referred to as egocentric- and allocentric processing (Ekstrom et al., 2014; Epstein et al., 2017). A closer examination of these may therefore provide valuable insight into the benefits of virtual reality in relevant applications.

The relevant studies indicate the use of VR HMDs to be beneficial in certain skill-acquisition; including psychomotor-skills related to head-movement, and understanding of spatial and visual information (Jensen & Konradsen, 2018; Molina-Carmona et al., 2018). There is one major obstacle, however. Use of VR HMDs is widely known to cause simulation sickness, and can in some cases even prove counterproductive compared to non-VR methods (Jensen & Konradsen, 2018; Rebenitsch & Owen, 2016). While this may be true, several of these studies are found to have used vastly different degrees of immersion (Jensen & Konradsen, 2018), and little seems to have been done to establish any concrete standard of measure regarding the quality of a VR experience (Grassini et al., 2021). In particular, the quality of the HMD and virtual environment utilized can have huge impact on the degree of SS experienced, and these are found to vary substantially between studies (Grassini et al., 2021; Jensen & Konradsen, 2018).

Based on this, although we hypothesize subjects in VR should outperform the 2D group. We propose that in this experiment, the data will instead indicate subjects in 2D outperforming the VR group, this likely being the result of limitations to immersion present in the experiment.

Theory

Immersion

Compared the commercial TV or computer screen subjects observe from a comfortable distance, VR systems are small head-mounted devices featuring a stereoscopic display and several sensors for tracking the users head movement (Anthes et al., 2016). When describing the differences between 2D and VR experiences, one often refers to the degree of "immersion" they offer. The term is a set of measurable aspects surrounding multimedia technology, specifically relating to how immersed a user is (Freina & Ott, 2015; Jensen & Konradsen, 2018). It is generally associated with a related concept called *presence*; although they refer to different things (Jensen & Konradsen, 2018; Rebenitsch & Owen, 2016). Presence, also called *sense of presence*, is the degree to which users actually feel "as if they are there" (Slater, 2003, as cited in Grassini et al., 2021). It is influenced by several different factors, however, it seems primarily moderated by how immersive the experience is (Grassini et al., 2021; Jensen & Konradsen, 2018; Servotte et al., 2020).

Technical measures of immersion typically include resolution of the HMD, display refresh rate, in-game latency, and tracking (Rebenitsch & Owen, 2016). Though generally overlooked and often more associated with presence, it should be important to include the quality of the VR application and its surrounding aspects (Freina & Ott, 2015; Servotte et al., 2020). Specifically, if it's a "virtual game-environment", a 360° video or a still 360° image, its quality of textures, the degree to which user can interact with the environment, autonomy of movement, and general stability (Brunnström et al., 2018; Grassini et al., 2021; Slater & Sanchez-Vives, 2016).

Simulation sickness

Simulation sickness (SS) is a phenomenon with many similarities to that of motion sickness (MS) where individuals experience nausea, disorientation, dizziness, and strain-like symptoms either during, after or both when in a simulated environment (Johnson, 2005; Kennedy et al., 1993). Compared to motion sickness where the subject is exposed to physical motion, the term simulation sickness is applied in virtually simulated settings where subjects experience visually induced symptoms of MS (Johnson, 2005; Rebenitsch & Owen, 2016). Although recent improvements in the technology grants users today far greater possibility of movement than available prior (Anthes et al., 2016), the vast majority of VR use, both private and in studies, feature subjects either stationary or contained to a small square, and not subjected to any physical motion (Jensen & Konradsen, 2018; Rebenitsch & Owen, 2016).

Also often referred to as "Cyber-sickness", or at times put forth as subclass of motion sickness (Arns & Cerney, 2005, as cited in Grassini et al., 2021), the phenomenon has been documented since the first iteration of a helicopter flight-simulator was put to use in the 1950´s (Johnson, 2005). To this day we still do not completely understand the phenomenon, however a number of theories have been proposed to both explain how and why simulation sickness happens (Brooks et al., 2010), the most cited being the Sensory conflict theory by (Reason & Brand, 1975).

Sensory conflict theory & Neural Mismatch Model

First proposed by Reason and Brand in 1975, the sensory conflict theory seems to be regarded as the most accepted theory of motion sickness (Arns & Cerney, 2005; Brooks et al., 2010; Cobb et al., 1999; Grassini et al., 2021; Warwick-Evans et al., 1998). It suggests that motion sickness is a consequence of incongruency between the visual input and the movement one experiences, as well as internal conflict between the vestibular systems responsible for motion, acceleration, and direction (Reason & Brand, 1975). Shortly after, Reason would also propose the Neural Mismatch Model to further elaborate on the occurrence of motion sickness. For it to occur, the sensory input should also conflict with one's own experience of motion in these environments (Reason, 1978). The more it is different or divergent from one's own expectations, the more likely sickness is to occur (Reason, 1978, as cited in Brooks et al., 2010;). Although these theories aim to explain motion sickness, they seem applicable for simulation sickness as well and are currently the most supported theoretical approach to it in recent works (Grassini et al., 2021).

Immersive aspects and associations with presence

Regardless of how comfortable one tries to make a VR experience, a certain degree of simulation sickness seems almost inescapable (Grassini et al., 2021; Jensen & Konradsen, 2018; Servotte et al., 2020). SS is often found associated with certain technical aspects regarding the immersive experience (Brunnström et al., 2018), as mentioned earlier. For instance, the presence of visual flickering, delay in perceived head-movement, and a low refresh rate can all cause SS (Grassini et al., 2021). Display quality/resolution however, does not seem to be of importance in SS (Rebenitsch & Owen, 2016). Studies rather indicate application design to be a more important tool for avoiding SS, granted other basic immersive requirements such as stability and latency are met (Brunnström et al., 2018; Grassini et al., 2021; Rebenitsch & Owen, 2016).

Arguably, one of the most important recent findings regarding SS is its connection to movement as the leading cause of SS (Caserman et al., 2021). Involuntary non-natural movement is highly likely to cause immediate nauseating SS symptoms, as is often found in roller coaster simulations and other high speed movement applications/videos (Caserman et al., 2021; Grassini et al., 2021; Servotte et al., 2020). The more users are able to smoothly control their movement, the less likely they are to experience symptoms, which led to the development of various movement types in VR (Rahimi et al., 2018; Sayyad et al., 2020). The most common methods today are direct teleportation and joystick movement (Buttussi & Chittaro, 2019). Direct teleportation is found better for distance estimation and spatial awareness, as well as invoking fewer SS symptoms (Keil et al., 2021; Rahimi et al., 2018), compared to joystick movement (Buttussi & Chittaro, 2019).

Other relevant studies have also indicated sense of presence to be negatively associated with simulation sickness (Almallah et al., 2021; Grassini et al., 2021). These, however, often mention presence in relation to objective aspects of immersion, such as details in environment and movement options (Almallah et al., 2021; Sayyad et al., 2020). Further highlighting the importance of awareness surrounding the various immersive aspects often overlooked or associated elsewhere.

SPATIAL PROCESSING

Cognitive map theory

The concept of a mental visualization of an environment was first introduced by (Tolman, 1948), when studying how rats appear to learn the spatial layout of a maze. When researchers blocked of the familiar path out of the maze, the rats who had already completed it once before it was blocked, found an alternative route faster than the rodents who had not completed it before (Tolman, 1948). Tolman theorized that the rats understand the spatial properties of the environment, akin to how we might get from reading a map (Tolman, 1948, as cited in Epstein et al., 2017).

Discoveries by (O'Keefe & Conway, 1978) would later bring support to this theory by highlighting how rats with lesions to their hippocampus were impaired in their ability to navigate a maze. They proposed that through firing of "place" cells in the hippocampus, the rodents produced a spatial representation of the environment. This representation was also hypothesized to exist in the form of a 3D-coordinate system allowing allocentric placement of landmarks (O'Keefe & Conway, 1978, as cited in Epstein et al., 2017).

Allocentric processing

Allocentric processing refers to a part of the visual-spatial processing system involved in mental representations of an environment (Ekstrom et al., 2014; Epstein et al., 2017; O'Keefe & Conway, 1978). Compared to egocentric processing where the position of oneself is the main reference, allocentric refers to mental representation through the present objects and or the environment itself, independent of self-position (Evensmoen et al., 2021). Studies aiming to identify the center of this process in the brain have considered the hippocampus and entorhinal cortex as the primary brain regions involved in allocentric representation (Epstein et al., 2017; Evensmoen et al., 2021).

A spatial map

fMRI studies of the hippocampus and entorhinal cortex indicate the existence of a spatial map, which together with frontal lobe mechanisms plan routes during navigation (Epstein et al., 2017). Within this map, distance relationships seem to be preserved, such that objects closer together in the environment are also close on the map (Ekstrom et al., 2017; Epstein et al., 2017). Additionally, a recent study by (Evensmoen et al., 2021) identified that accurate allocentric representation in the brain happens in multiple parts of the medial temporal lobe MTL, as well as the amygdala. Although recent literature all seem to indicate that allocentric processing cannot be traced to just one or two specific areas in the brain, its most crucial part still appear to be the hippocampus.

The hippocampus

As known by many, the hippocampus is crucial for long-term memory formation and retrieval (Eichenbaum et al., 1992). It is also a critical part in spatial processing, not through processing itself, but rather by organizing experiences in our memory (Eichenbaum, 2017). Considering this connection between allocentric processing and the hippocampus, it may be possible to infer a link between performance in an allocentric processing task, and how quickly one learns a spatial layout.

Challenges

Reviews of research on human behavior indicate that the vast majority of tasks given to measure allocentric representations, actually involve a combination of egocentric representations as well (Ekstrom et al., 2014). The use of either ego- or allocentric processing is not so easily identified, as it is both unconscious and varies between different persons. *"A mental representation of the environment can involve either allocentric or egocentric spatial* *representations, or most commonly, both."* (Ekstrom et al., 2014). Evidence has also recently emerged of egocentric processing relating to head-direction taking place in the hippocampus, (Wang et al., 2020), indicating its involvement in allocentric processing. Although they are separable, both interconnect in the hippocampus, and may therefore not be possible to truly separate in measurement (Ekstrom et al., 2014).

Given how this experiment aims to specifically measure allocentric processing by itself, it may be important to consider the possible involvement of egocentric processes.

The present study and hypotheses

Based on the relevant literature, VR-immersed subjects could be expected to perform better than those using a 2D computer monitor. I hypothesize this is the case, however, I do not believe this result is likely to occur in the data. Considering the general prevalence of simulation sickness in VR, as well as the amplifying effect that limitations in the immersive experience has on SS, (this due to limitations in the experiment application, which will be discussed later); it is likely there will be an opposite result. I propose the following hypotheses:

> H_1: "*There is a statistically significant difference between subjects preforming the same allocentric processing task on a 2D computer monitor, and those in a VR HMD.*"
>
> H_2: "*Subjects preforming the task on a 2D computer monitor have better allocentric performance scores than those in VR.*"

Following the reasoning above, I further propose that this difference in allocentric performance is fully mediated by the subjects experienced simulation sickness:

H_3: *“There is a significant indirect effect of simulation sickness on allocentric performance.”*

H_4: *“There is a competitive mediation between simulation sickness and immersion on allocentric performance”*

Method

Selection

The study consisted of a total of 62 participants, where 32 completed the experiment in VR using a head mounted display “HMD” (52%) and 30 completed in 2D using a standard LCD 24` computer monitor (48%). Participants age varied from 20 to 29 years old (M = 23.23, SD = 1.97), and consisted of 26 women (42%) and 36 men (58%).

The amount of people asked to participate in the study was not monitored, and neither was the number of canceled appointments. When selecting for subjects, a set of three criteria were demanded. *“Generally healthy, young adults between the age of (18-30)”*, “*No prior epilepsy diagnosis”*, and “*have normal to corrected vision”*.

Preparations

Beforehand, each of the 8 students in the bachelor-group were assigned to one of three responsibilities for the experiment. Three students were tasked with main recruitment and booking, including sending a reminder via email to each recruited participant the day prior to their appointment. Three others were tasked with lab-duty, assisting the lab supervisor before, during, and after the experiment procedures. Lastly, two were assigned to manually transfer data from the experiment into SPSS. Every student in the Bachelor-group was also tasked with gathering around 5 participants each to assist reaching the desired count of 60 subjects. Following this, a booking-calendar was created in a shared Word-document within the dedicated Microsoft Teams-group consisting of only the students, counselor, and his assistant.

Recruitment

Following creation of the booking-calendar, recruitment began shortly after starting January 15th, lasting until March 3rd. Each calendar day was split into five 2-hour timeframes ranging from 08:15-18:15. When subjects agreed to participate, name and email was noted down in the calendar timeframe best suited. Each timeframe would then be color coated to mark the student responsible for lab-duty that scheduled appointment. As the experiment progressed, lab-duty would be assigned to more students in the group to even out the amount of work for each.

Recruitment of participants was mostly done through convenience sampling of friends and known. One student responsible for recruitment and booking published a post on Facebook in a public group for gamers in Trondheim consisting of a description of the experiment as well as the three criteria for participants stated earlier. However, only four participants were recruited from this. On a few occasions, participants had to cancel their appointment just minutes prior to their scheduled time. To correct for this, the available lab-assistants managed to recruit a few individuals in the public halls just outside the Institute of Psychology on NTNU Campus Dragvoll.

Design

The main purpose of the experiment is to compare differences in allocentric performance between virtual reality and standard 2D imaging in a simulated environment.

Additionally, the experiment also measured the following relevant variables: simulation sickness, gaming experience, cognitive load, and sense of presence, as well as EEG analysis of each subject. For the purpose of this paper, the only variables of interest are immersion, simulation sickness, and allocentric processing.

The experiment was setup in a lab at the Institute of Psychology at NTNU Campus Dragvoll in Trondheim. Participants were seated in an office chair in front of two monitors, one displaying the game screen and the other a desktop background. The experiment utilized a commercial VR head mounted display “HMD” (Oculus/Meta Quest 2, 90Hz refresh rate, 1832x1920 resolution per eye, connected via cable) for 32 of the 62 participants. The rest completed using a standard (24´, 1920x1080p resolution) computer monitor. The simulated environment was run on a computer featuring (i7 8086K, Nvidia 1080ti, 16Gb RAM). To move around, participants in VR used the included Meta quest 2 controllers. Participants in 2D were given an Xbox Elite controller.

This simulated environment was made in an instance of popular video game Minecraft. The game provides a programmable foundation, while also allowing for additionally downloadable content (mods) to access more detailed objects. The in-game world features 3 parts; a starting area, the baseline box, and the main rooms. The starting area is a small walled of box with a tree and some grass where participants start and can walk around to familiarize with the controls, (see figure 1). The baseline box is a room made of only black blocks, featuring a large white cross in the middle of the room participants are directed to focus on when shown (see figure 2). It serves to obtain a baseline measurement of brain-activity prior to the cognitive work, as well as clearing working memory. The main rooms are a series of 10 rooms constructed in a large 7x7 grid, where seven of the tiles are occupied by different real-life objects from additionally downloaded mods. Each room is constructed equally and feature the same amount and type of figures; however, their position and rotation differ in every room (see figure 3).

Figure 1

Figure 2

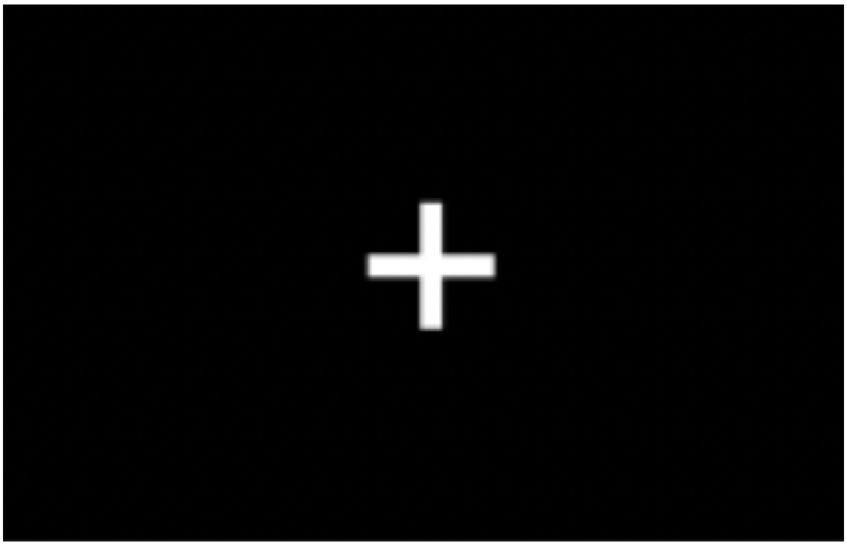


Figure 3

Participants were moved around using programmed “command-blocks” teleporting them to the different positions. Each sequence was manually started by prompting a “redstone block” to spawn on a set of six coordinates from 1-10, starting a cascade of timed teleports. Following each sequence, the participants were then asked to complete a series of odd-even tasks to further clear working-memory (see figure 4). After this, they were then asked to recall the position of each object by placing each figure in its corresponding position on a laminated paper sheet illustrating a top-down view of the 7x7 grid room the participants had just explored, shown in figure 5.

Figure 4

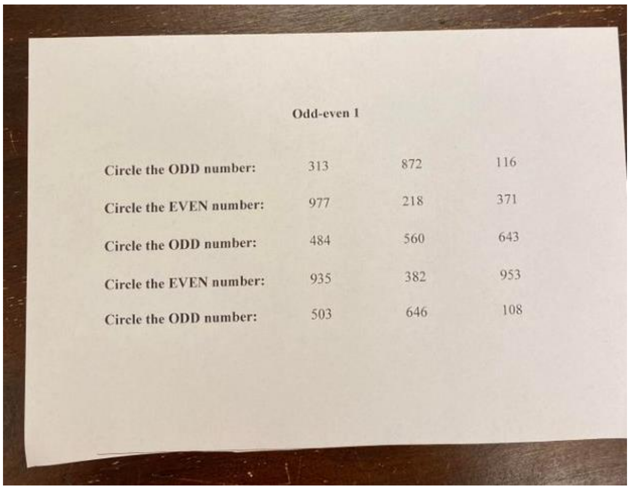
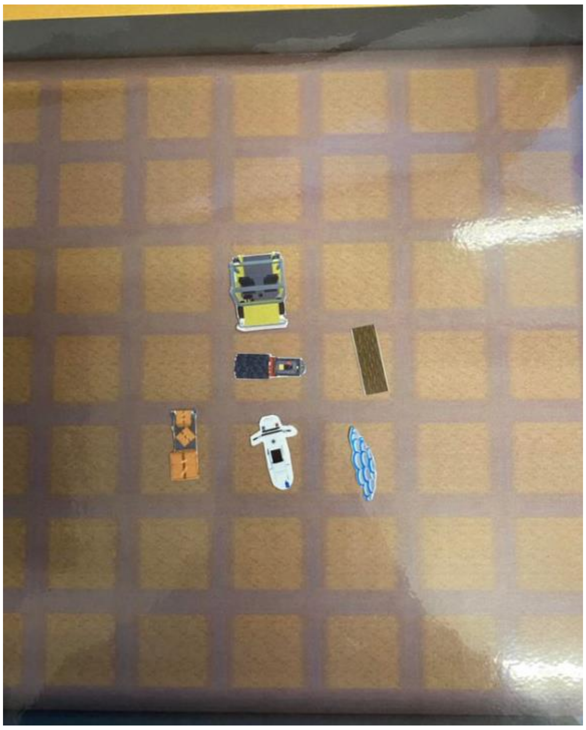


Figure 5



Procedure

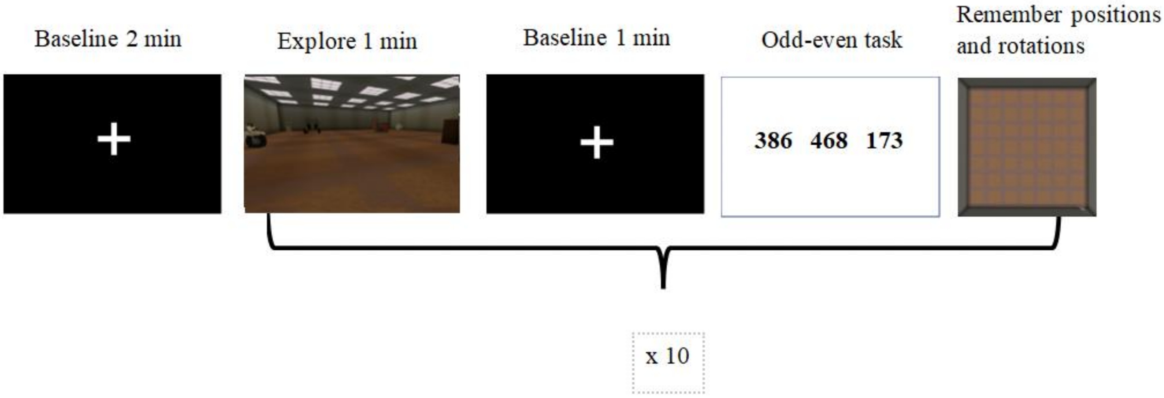
Participants upon entering the lab were asked to read an overview of the experiment containing information about its purpose, those responsible, voluntary involvement, personal privacy regarding their information and rights, followed by a consent form. After consenting to the experiment, participants answered a form to assess eligibility and prior gaming experience.

Participants were fitted an EEG cap connected to a laptop monitoring and recording the signal. To achieve adequate contact of (value < 20) with the scalp, conductive silicone gel was applied to each electrode using non-invasive disposable needles. Participants were then seated facing the desk with two 24´ computer monitors, and the paper sheet illustrating the 7x7 grid room the participants were about to enter. Participants were also presented seven laminated paper figures of each object they would encounter in the room. Following familiarization with the objects, each were informed of the experiment procedures about to occur.

The first 32 recruited completed the experiment using the VR. Before beginning, the lab-supervisor would assist participants in equipping the HMD as to not accidentally disrupt the EEG connections. They were then given the proprietary controllers and asked to familiarize themselves with walking and looking around in the VR starting room. When ready, the first command was entered, and the EEG analysis began recording.

On the first run, participants were moved to the baseline box for two minutes to establish a baseline EEG measurement, see figure 6. After this, they are teleported to the first main room to begin exploring. After one minute, they are brought back to the baseline box for just one minute. Once completed, they are returned to the starting area. Participants were then also assisted in removing the HMD, carefully making sure the cable connection is not accidentally severed. Upon the laminated 7x7 grid, a small sheet of paper containing an odd-even task was placed face down for them to flip over. Following the completion of this, participants were then asked to place each object in the correct location and with proper rotation on the 7x7 laminated grid. After one minute, they were told to stop, and a picture was taken of their result, ending the first run. The grid was then cleared, and a new odd even task placed face down. Participants then had the HMD re-equipped, and when ready, the same procedure would restart, although this time without the 2-minute baseline box.

Figure 6



On the following nine runs, participants were instead teleported directly to the next main-room corresponding to the run-number. Experiment procedure would then continue in the exact same way until all remaining rooms had been completed. Upon final completion, both the HMD and EEG cap was removed, and participants were asked to fill out a series of questionnaires regarding sense of presence, cognitive load, and simulation sickness. Once these were completed, they received a towel and access to a bathroom so they could wash away the silicone gel. After 32 participants had completed the experiment in VR, the lab transitioned over to 2D testing. Experiment procedure was exactly equal for the 2D participants, although without repeated removal and re-equipping of a HMD, and instead using an Xbox Elite controller to move.

All subsequent data was later manually processed and put into an SPSS dataset by the counselor and the assisting students tasked with data processing. One participant however, mistakenly put the objects on the line in between the grid. This was discovered too late, and therefore resulted in a non-score for allocentric performance. To correct for this, the empty value was replaced by the mean of the VR group (M = 2.62).

Instruments

Simulation sickness questionarie (SSQ)

The simulation sickness questionnaire was originally proposed by Kennedy et al (1993) to measure the quality of experience in virtual environments, and is currently the most utilized instrument for measuring simulation sickness (Balk et al., 2013). The questionnaire contains a series of 16 symptoms most associated with SS, where participants rate their subjective feeling on a 0-3 scale: 0 (none), 1 (slight), 2 (moderate), and 3 (severe). These are then further divided between three different groupings, nausea, oculomotor, and disorientation, based on symptom correspondence (Brunnström et al., 2018). The score for each category is then calculated by adding the corresponding reported values of symptomatic questions, and then multiplying by a set value for each category (Brunnström et al., 2018). In addition, there is also a total score containing the sum of all symptoms, which is used in this experiment.

Allocentric performance

This experiment measures allocentric processing by way of recall from a top-down perspective, identical to the procedure conducted in (Evensmoen et al., 2021). After exploring the virtual environment, participants attempt to recall the position of each object by placing the figures correspondingly on a birds-eye view of the 7x7 grid representative of their room.

A positional pattern is then created based on participants placements of these objects. It consists only of the object's positional accuracy in relation to each other and does not account for correct rotation or even the corresponding objects themselves. All participant patterns are then compared to the correct patterns by calculating distances between the difference in object placements, using root-mean square deviation. The resulting score is a measure of allocentric performance, where higher numbers correspond to bigger deviations from the correct pattern. The lower the score, the better allocentric performance.

Results

An independent samples t-test was conducted to compare the difference in allocentric processing between the VR and 2D participants. A non-significant Levene´s test, $p = .150$ is indicative of homogeneity of variance. There was a non-significant difference between participants in VR ($M = 2.62$, $SD = 1.74$) and 2D ($M = 2.06$, $SD = 1.33$), completing the same allocentric processing task, $t(60) = -1.43$, $p = .078$. Participants in 2D had on average higher scores, $\Delta M = -.56$.

These results both contradict the base hypothesized reasoning, as well as the suggested H_1 and H_2 hypotheses wrong, and must therefore be discarded. In addition, the non-significant difference between the groups provides no further support for the suggested secondary H_3 and H_4 hypotheses. As there is no significant difference between 2D and VR in allocentric performance, conducting a mediation analysis is therefore not relevant for purpose of this paper.

I hypothesized there would be a difference between immersion and AP, precisely because of a competitive mediation taking place. Conducting a mediation analysis now, even in the case of a significant interaction-effect, would not provide any useful insight, as there is no significant difference between the groups.

I will instead examine the different relationships between these variables by conducting further t-tests and a set of correlations.

Another independent samples t-test was conducted to compare the difference in self-reported simulation sickness between the VR and 2D participants. However, a significant Levene´s test, $p = .049$, is not indicative of homogeneity of variance. Equal variances is therefore not assumed. The analysis predictably revealed a significant difference between participants in VR (*M* = 54.93, *SD* = 35.10) and 2D (*M* = 30.29, *SD* = 27.31), experiencing SS, *t*(60) = -3.10, *p* = .002. Participants in VR reported higher scores of SS, Δ*M*= 24.64.

A split-file correlation analysis reveals a statistically significant positive moderate correlation between self-reported simulation sickness and allocentric performance among VR participants, *r*(60) = .427, *p* = .015. Additionally however, the analysis also revealed a non-significant negligible correlation between SS and AP among 2D participants, *r*(60) = .01, *p* = .944.

Discussion

This is study has examined whether there might a difference between subjects preforming the same allocentric processing task using a VR HMD or a commercial 2D computer monitor, and to what degree a difference can be explained by simulation sickness (SS).

Based on the relevant literature regarding, immersion, SS and its effects on general VR performance, the study proposed a reverse hypothesis from what studies on spatial processing in VR might indicate: 1) Subjects in 2D will outperform those in VR, followed by a set of secondary hypotheses: 2) This difference in performance is fully mediated by SS.

The primary analysis revealed a non-significant difference between the two levels of immersion. Facing this, both secondary hypotheses were discarded, and instead the relationships between relevant variables were further investigated.

As expected, VR participants reported significantly higher symptoms of SS. Additionally, there was moderate correlation between SS and AP in VR, but not between 2D participants. In relation to the findings from the primary analysis, I find these results both expected and unexpected.

Spatial processing and allocentric performance

A review of relevant works examining the use of VR HMDs in various applications identified the use of VR to be beneficial in situations involving spatial and visual information processing, and psychomotor skills relating to head-movement (Jensen & Konradsen, 2018). Both expectedly and unexpectedly, the primary analysis conducted seems to contradict these findings. It was found no significant difference in performance between the subjects preforming the same allocentric processing task in two completely different levels of immersion.

However, with a p-value of 0.78, the result is close to being significant. Compared to the demand of 5% random-error likelihood, the analysis calculated a 7.8% chance this difference in AP is the result of random errors. One could argue this should count as a significant finding, given discussion surrounding how strictly one should adhere to the set ($p < 0.05$) rule (Field, 2017). Nevertheless, it is possible that VR may simply not provide any benefit in spatial processing applications compared to using commercial 2D computer screens.

Concluding this, however, requires inferring a direct relationship between performance in an allocentric processing task and general spatial processing. Many studies indeed indicate allocentric processing to be essential for navigation and spatial processing, although none with specific regards to differing levels of immersion (Ekstrom et al., 2014, 2017). Still, it would not take into account the vast interacting networks of brain regions underlying human spatial navigation. The involvement of egocentric and allocentric and processes is indeed a central part of the equation (Ekstrom et al., 2017), but it may be a stretch to infer its involvement to be the "end-all be all" in regard to spatial processing, especially when deciding the efficacy of different levels of immersion.

Although recent studies indicate allocentric processing taking place across a vast array of brain areas, it is primarily rooted in the hippocampus (Eichenbaum, 2017; Epstein et al., 2017; Evensmoen et al., 2021). As was mentioned earlier, given what is known regarding the formation of long-term memory (Eichenbaum et al., 1992), and its critical part in spatial processing (Eichenbaum, 2017). Performance in an allocentric processing task may possibly be indicative of how quickly one is able to consolidate the spatial layout in the hippocampus. In other words, how quickly one learns the relevant environment.

Investigating this, the conducted experiment had measures put in place to reduce the involvement of working memory as much as possible. After exploring the main rooms, participants were asked to concentrate on the white cross in the baseline-box for 1 minute (see figure 2), immediately after, they had to solve five simple odd-even questions (see figure 4). Obtained results in allocentric performance may therefore provide accurate indicators of learning speed, potentially useful for indicating the efficacy of VR.

Finally, there might also be a certain involvement of egocentric processing in the experiment. As mentioned earlier, though despite efforts to isolate the processes, it may not be possible to separate in measurement (Ekstrom et al., 2014). How people might generate mental representations when navigating differs substantially, as some might use more egocentric techniques than others or vice versa (Ekstrom et al., 2014). And even regardless of this, the process of spatial navigation always involve a combination of the two (Burgess, 2006; Wang et al., 2020). Studies examining both egocentric and allocentric processes in the brain have revealed the firing of neurons relating to head-direction in egocentric processing (Wang et al., 2020). The use of VR may likely activate more head-direction neurons involved in egocentric processing, seeing as head-movement is a central part of the experience.

One could therefore expect this to show up in the data as a higher “total output” in allocentric performance for the VR group, possibly helping counteract the impact of simulation sickness, resulting in a non-significant difference between the groups.

Simulation sickness and immersion

Almost all studies conducted on virtual reality have had subjects reporting symptoms of simulation sickness, regardless of how immersive the experience is made (Jensen & Konradsen, 2018; Rebenitsch & Owen, 2016). As expected, a further analysis of the experiment data revealed a significant difference in self-reported SS between the levels of immersion. Based on pure mean-difference, participants in VR reported almost twice as much SS compared to the 2D group. It is likely that much of this can be attributed to a number of factors surrounding immersion in the experiment application itself (Caserman et al., 2021; Rebenitsch & Owen, 2016).

By itself, Minecraft in VR is generally a stable and enjoyable experience. However, likely due to the amount of installed third-party modifications, the experiment application seemed to suffer from a combination of both hardware and software limitations. As a result of this, customizing the VR experience for the experiment setting was made unnecessarily tedious, particularly height adjustment. Before giving participants the HMD, the lab-supervisor would have to stand on top of a chair in order to properly calibrate a correct point-of-view (POV) for participants seated height. And even so, the actual experience in VR would still be quite "off-putting" and not indicative of chair-height.

The application was also prone to crashing on multiple occasions and did generally not perform as smoothly as Minecraft in VR should be. Additionally, the HMD was required to be connected to the computer at all times with a rather easily removable cable. If accidently severed it would crash the whole application - forcing a restart, thereby rendering the current experiment useless. Participants were therefore always assisted in both equipping and removing of the HMD, and also asked to be mindful of the cable by preferably avoiding sudden and rapid head-movement when equipped. While complicating the general experiment procedure, this likely also affected participants.

In relevant light of these observations, it leads to the most likely contributor, namely movement. In a recent outlook on SS in VR HMDs, perceived movement is indicated to be the leading cause of simulation sickness (Caserman et al., 2021). Participants in VR moved around using artificial locomotion generated from a joystick they themselves operated. Although a standard movement-type in most 2D games, artificial locomotion in VR is strongly associated with SS compared to other movement options (Keil et al., 2021). This, in combination with a generally misaligned POV-height, results in a rather unnatural VR experience more similar to “flying” than of walking around. With a general lack of smoothness in game and participants limited possibility for head-movement, central aspects of the experiment application itself could likely explain the amount of SS in VR-group.

Associations between AP and SS

Interestingly, SS and AP is moderately correlated between participants in the VR group. This is consistent with findings regarding the effect of SS on general performance in VR (Jensen & Konradsen, 2018; Rebenitsch & Owen, 2016). As there is no correlation between these in 2D, it may be indicative of the proposed association between immersion and AP hypothesized in this paper. Additionally, this difference in correlation between the groups does little to explain the lack of a statistically significant difference in AP between 2D and VR. If anything, it indicates further support for the hypothesized benefits of VR - as even in the presence of a significantly higher degree of simulation sickness, there is still no statistically significant difference in AP.

Considering this difference in correlation between the groups, and the significant difference in reported SS, it may be possible to suggest that the difference in AP between the two levels of immersion are primarily a result of simulation sickness. Furthermore, following the observations listed prior, this in turn is likely explained by limitations in experiment application.

Limitations and suggestions for future research

There are several limitations to this study, and many of them have already been mentioned throughout the discussion above. The main research question was to examine if a possible difference between two groups completing the same allocentric processing task in VR and in 2D, could be the result of simulation sickness. The analysis suggests no significant difference between these two, this difference however is close to significant and arguably an indication of a difference. This may be the consequence of a rather low number of participants, which future research should be aware of.

As mentioned earlier, one should also be careful in deciding the potential benefits of VR compared to 2D in spatial applications, based purely on subjects' performance in an allocentric processing task. Additionally, because of allocentric relations to the hippocampus. The measure may be subject to the participants ability to either quickly consolidate long-memories, or their ability to hold information in working-memory despite preventative measures set in place.

On another note, the potential for involvement of egocentric processes should be kept in mind. Although it may not necessarily be a limitation, it is still something that should both be researched and accounted for in future experiments using allocentric processing.

An interesting suggestion for further research could be to compare allocentric performance between two groups in VR; one group is encouraged to move their head, and the other is asked to stay still. Such an experiment might provide insight into the involvement of egocentric aspects in AP.

As discussed in large part under simulation sickness, I believe much of the experiment application is full of limitations. Although economically resourceful, the use of heavily-modded Minecraft as the experiment application may not have proven particularly wise. General instability, tedious setup, off-putting POV-height, limited degree of movement, and lack of alternative movement-options are all aspects of immersion that heavily influence simulation sickness (Caserman et al., 2021; Grassini et al., 2021; Rebenitsch & Owen, 2016), and should therefore also be avoided in future research.

Additionally, the experiment might have been somewhat limited by the computer hardware. Though “high-end” in 2015, in the face of VR and multiple third-party mods it was likely pushed to its limits. Future research should therefore make sure the experiment computer is properly equipped to handle demanding virtual simulations.

Lastly, another relevant limitation in was the choice of HMD. Although competitive in almost every aspect, the Meta Quest 2 is primarily a standalone VR headset, thus lacking external sensor-tracking. Using a desktop-oriented HMD like the HTC Vive or a Valve Index would eliminate most issues not related to the desktop itself, thus removing several of the previously mentioned limitations.

Conclusion

The present study was aimed at exploring the possibility of using VR as a tool in applications associated with spatial processing, by examining if performance during an allocentric processing task significantly differs between subjects preforming the same task in either VR or on a 2D computer screen. Additionally, in the light of known effects of simulation sickness on general performance in VR, the study also aimed to examine if a present difference in allocentric performance was a result of simulation sickness.

The study did not find a statistically significant difference between allocentric performance in 2D and VR, suggesting the use of VR provides no benefit in spatial processing applications compared to using commercial 2D computer screens. This result, however, was close to significant.

Furthermore, the study found simulation sickness to be significantly correlated with allocentric performance in the VR group, but not the 2D group. Additionally, as expected, there was also significant differences in SS between the groups themselves, likely linked to limitations in immersion present in the experiment. These findings indicate a clear negative relationship between SS and AP in VR, regardless of a present non-difference in AP between the groups.

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