EXPLORING THE NEUROCORRELATES OF VIRTUAL REALITY IMMERSION USING EEG FREQUENCY DECOMPOSITION ANALYSIS

by

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A thesis submitted to the faculty of
The University of North Carolina at Charlotte
in partial fulfillment of the requirements
for the degree of Master of Arts in
Psychology

Charlotte

2020

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ABSTRACT

MATTHEW GRANSON. Exploring the neurocorrelates of virtual reality immersion using EEG frequency decomposition analysis. (Under the direction of DR. MARK FAUST)

Immersion is a psychological state resulting in the sensation of being enveloped in another reality or environment and is commonly experienced while using interactive media such as videogames. The goals of the present thesis project were to (a) test predictions of a recently proposed 3-dimension framework for psychological immersion (Nilsson et al., 2016), and (b) to explore the EEG neural correlates of an immersive experience. In 2 Experiments, participants played a driving simulator game where they drove on racetracks of 2 differing difficulty levels viewed through either a traditional flat computer screen, or a 3D virtual reality (VR) headset. EEG was recorded during the second experiment only. Experiment 1 yielded significantly greater self-reported challenge immersion for VR gameplay versus viewing a virtual room, both while using a 3D VR head-mounted display (VRHMD). Moreover, gameplay with the 3D VRHMD resulted in greater self-reported system/perceptual immersion than with the non-VR (NVR) 2D screen. Experiment 2 replicated the self-report immersion results extended to a 2 (viewing condition, NVR, VR) x 2 (difficulty: easy, medium) factorial design. Experiment 2 also revealed evidence of increased theta (4-8 Hz) amplitude for the 3D VR gameplay sessions versus the 2D screen. Both theta and beta (15-30 Hz) bands showed greater amplitude for 3D VR gameplay when just the first gaming session (i.e., the easier racetrack) was considered. The results were consistent with the prediction of separable dimensions of challenge and system/perceptual immersion. The results are also consistent with a small but growing literature suggesting that increased theta band activity is associated with increased immersion in games, movies, and narratives. However, order of viewing technology played a larger role in the EEG analysis than was anticipated, and gameplay-related motor movements, are a significant challenge to conducting this type of research.

Keywords: EEG, virtual reality, immersion, presence, frequency decomposition

TABLE OF CONTENTS

LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF ABBREVIATIONS	xi
CHAPTER 1: OVERVIEW	1
CHAPTER 2: INTRODUCTION	4
Defining Immersion	4
Differentiating Immersion from Similar Sensations	5
Flow	5
Cognitive absorption	6
Presence	7
3 Dimensions of Immersion Framework (Nilsson et al., 2016)	8
System (Perceptual) Immersion	12
Challenge Immersion	12
Virtual Reality/ Virtual Environments & Immersion	13
Electroencephalography (EEG), Oscillations and Frequency Decomposition	14
EEG, and Immersion Research	15
Frequency Bands, Cognition, and Computer Games	15
Beta & Theta Band & Immersion During 2D Videogame Play (Nacke et al., 2011)	16
Theta Band & Immersion During 3D Virtual Spatial Navigation (Slobounov et al., 2015)	17
Beta Band & Immersion During Film Viewing (Kruger, 2016)	19

Theta Band, Immersion & Virtual Architectural Spaces (Banaei et al., 2017) 20

Summary 20

CHAPTER 3: AIMS AND HYPOTHESES 22

Hypotheses: Immersion Survey Scores 23

Hypothesis 1: Challenge Immersion Manipulation Check 23

Hypothesis 2: System Immersion Manipulation Check 23

Hypotheses: EEG Results 23

Hypothesis 3: Average Frequency Band Amplitude Across Viewing Conditions 23

Hypothesis 4: Average Frequency Band Amplitude Across Difficulty Conditions 24

Hypotheses: Three-Dimensional Immersion Framework 24

Hypothesis 5: Separability/Independence of Immersion Dimensions 24

CHAPTER 4: EXPERIMENT 1 25

Method 25

Participants 25

Design 25

Driving Simulator & Hardware 26

Immersion Survey 26

Procedure 27

Computer Game Task 28

Results 29

Discussion 31

CHAPTER 5: EXPERIMENT 2 33

Method 33

Participants 33

Design 34

Materials and Apparatus 34

EEG Recording & Processing 34

Procedure 36

Computer Game Task 37

Results 38

Immersion Survey Results 38

EEG Results 40

Discussion 43

CHAPTER 6: GENERAL DISCUSSION 47

REFERENCES 55

APPENDIX A: GENERAL HEALTH AND HANDEDNESS QUESTIONNAIRE 59

APPENDIX B: EXPERIMENT 1 SURVEY (MODIFIED) 60

APPENDIX C: EXPERIMENT 2 SURVEY (MODIFIED) 61

APPENDIX D: EGAME FLOW SCALE 62

APPENDIX E: MULTIMODAL PRESENCE SCALE 63

APPENDIX F: MEAN CHALLENGE IMMERSION SCORES BY VIEWING CONDITION AND DIFFICULTY 64

APPENDIX G: MEAN OVERALL IMMERSION SCORES BY VIEWING CONDITION AND DIFFICULTY 65

APPENDIX H: MEAN PHYSICAL PRESENCE SCORES BY VIEWING CONDITION AND DIFFICULTY 66

APPENDIX I: MEAN THETA AMPLITUDE BY ORDER, VIEWING CONDITION & DIFFICULTY 67

APPENDIX J: MEAN BETA AMPLITUDE BY ORDER, VIEWING CONDITION & DIFFICULTY 68

LIST OF TABLES

TABLE 1: Taxonomy of Immersive Experience From Nilsson et al. (2016) Review 11

LIST OF FIGURES

FIGURE 1: Screenshot of "Easy difficulty" racetrack from Experiments 1 and 2 28

FIGURE 2: Mean immersion subscale scores by viewing condition (Experiment 1) 30

FIGURE 3: Mean immersion subscale scores by difficulty condition (Experiment 1) 31

FIGURE 4: Scalp map showing electrodes of interest (EoI) 36

FIGURE 5: Screenshot of "Medium difficulty" racetrack from Experiment 2 37

FIGURE 6: Mean immersion subscale scores by difficulty condition (Experiment 2) 39

FIGURE 7: Mean immersion subscale scores by viewing condition (Experiment 2) 40

FIGURE 8: Mean EEG frequency band amplitudes by viewing condition 41

FIGURE 9: Mean theta amplitude by viewing condition and order 42

FIGURE 10: Mean EEG frequency band amplitudes by viewing condition and easy 43

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CA	Cognitive Absorption
EEG	Electroencephalography
EoI	Electrodes of Interest
ERP	Event Related Potential
Hz	Hertz
HMD	Head Mounted Display
MPS	Multimodal Presence Scale
PFC	Prefrontal Cortex
PPC	Posterior Parietal Cortex
VR	Virtual Reality
VRHMD	Virtual Reality Head Mounted Display
NVR	Non-Virtual Reality
VE	Virtual Environment

CHAPTER 1: OVERVIEW

Humans have the ability to immerse themselves in their environments and engage with the physical and mental tasks these environments demand. Today, people immerse themselves with media such as novels, films, and video games (Gerrig, 1993; Kruger, Doherty, & Ibrahim, 2016). Video games are a media form that offers unique virtual environments (VEs) to create and explore. Modern video games exhibit photorealistic graphics, dynamic audio, and challenging gameplay that make them intensely immersive experiences. These experiences have been enriched with the advent of virtual reality (VR). Not much is known about the neural correlates that accompany the immersive experience. The present thesis research will add to a small but growing literature on this topic using electroencephalography (EEG) technology (Kruger et al., 2016; Nacke et al., 2011; Slobounov et a., 2015; Banaei, Hatami, Yazdanfar, Gramann, & Banaei, 2017).

Immersion literature across multiple research disciplines has produced a number of conceptualizations of immersion. This has led to some confusion as researchers using their own operationally defined constructs of immersion utilize different methodology and analysis when measuring for it. Additionally, there are sensations similar to immersion that are sometimes mistaken as synonymous, such as flow and presence (Jennette et al., 2008). It is important to have a clear and common definition of immersion and its properties so that future research is reproducible and consistent.

Nilsson, Nordahl, and Serafin (2016) present a taxonomy of immersion derived from existing immersion definitions across research domains. From this taxonomy, they constructed an integrative framework of immersion with 3 separable dimensions of immersion; system, challenge, and narrative immersion (Nilsson et al., 2016). They explain that system immersion is derived from the combination of the technology used to deliver the immersive experience and the user's perceptual response to that technology. Challenge immersion is modulated by the difficulty of the tasks being performed by the user. Finally, narrative immersion is produced by the user's engagement with a fictional narrative and the characters portrayed within (Nilsson et al., 2016). The three dimensions of the immersive experience are proposed by Nilsson et al. (2016) as three independent dimensions. The present thesis research is designed to manipulate multiple aspects of an immersive experience to verify the dimensions of this theory, especially the independent contributions of the dimensions as proposed by Nilsson et al. (2016).

Video games and their host platform (PC, console, or handheld) provide numerous avenues by which to engage users. The difficulty, narrative content, and overall presentation of a videogame can be altered to manipulate the user's immersive experience while playing it (Brown & Cairns, 2004; Desurvire, Caplan, & Toth, 2004). Videogames can be played in VR, further enriching the user's immersion by providing a more intense, 3D perceptual experience, than the traditional 2D screen viewing (Gramann, 2013; Slobounov, Ray, Johnson, Slobounov, & Newell, 2015). The current thesis includes 2 experiments designed to moderate system and challenge immersion dimensions by manipulating viewing technology (2D flat screen, 3D VR headset) and game difficulty level. Importantly, Experiment 2 included a factorial crossing of viewing technology and game difficulty to allow evaluation of the independence of the system and challenge immersion dimensions.

Prior research (Kruger et al., 2016; Nacke et al., 2011; Slobounov et a., 2015; Banaei et al., 2017) suggests that changes in theta (4-8 Hz) and beta (10-30 Hz) frequency band power/amplitude may be associated with aspects of immersion. Experiment 1 included manipulations of system immersion (2D screen vs. 3D VR headset) and challenge immersion (driving simulator gameplay vs. exploring a virtual room) to assess the validity of subscales chosen for the immersion survey used. Experiment 2 will be the first to simultaneously manipulate the challenge and system immersive properties of a video game experience in a 2 x 2 factorial design. To assess the independence of manipulation of system and challenge immersion in terms of immersion survey subscale scores, and EEG frequency band measures.

CHAPTER 2: INTRODUCTION

Peoples' natural ability to become "immersed" in their environments and the cognitive processes that generate said immersion seem to have provided significant evolutionary advantages and served a significant role in our development as a species (Riva et al., 2004). Today, humans are routinely immersed in a myriad of daily activities, pastimes like reading, playing games, or watching movies are among the most common examples. Being immersed when consuming such media has been found to have beneficial effects on memory (Georgiou & Kyza, 2018), route learning and spatial navigation (Henry & Polys, 2010), and general stress management (Reinecke, 2009).

Defining Immersion

Nilsson et al. (2016) posits that the term's broad usage throughout psychological research could be due to its appearance in *Hamlet on the Holodeck* (Murray, 1997; Nilsson et al., 2016) where immersion is used to describe, "the physical experience of being submerged in water… the sensation of being surrounded by a completely other reality" (Murray, 1997, p. 98). At its simplest conceptualization, immersion involves feeling as though you are surrounded by something (Witmer & Singer, 1998), and our perception of that "something" requires a significant portion of attentional resources to process. Building off this, Nilsson et al. (2016) suggested three additional factors that moderate one's subjective experience of immersion. First, the degree to which the user is isolated from external reality. Second, the sensation of "self-inclusion" within the environment and lastly; the ability to exhibit agency through interaction with the environment.

Whether users are enveloped in a VE or a challenging mental/physical task, it is almost always the case that full immersion results specifically in a lost sense of time or temporal dissociation (Brown & Cairns, 2004; Jennett et al., 2008). It should also be noted that immersion is not only a psychological state that one endeavors to obtain actively, but simply happens as a natural side effect of everyday cognitive activity. Whether they are playing games, reading books, watching movies, or daydreaming, it is almost inevitable that people will have an immersive experience at some point in their lives.

Differentiating Immersion from Similar Sensations

Unfortunately, the conceptual definition of immersion is broadly defined and largely contextual across many different domains of research. Numerous academic disciplines and scientific subfields such as narratology, ludology (the study of gaming experience), kinesiology, computer science, and psychology all present different conceptualizations of immersion (Nilsson et al., 2016). These areas of research all utilize "immersion" as a general term to describe entirely different procedures, constructs, and experiences. Other psychological states/sensations such as, flow, cognitive absorption (CA), and presence are sometimes confused (or assumed synonymous) with psychological immersion in academic research (Jennett et al., 2008). These phenomena are mental states that share some common characteristics with immersion, but they are distinctly separate from each other.

Flow

Flow is a rather extreme mental state in which irrelevant thoughts and perceptions are completely filtered out. To the person who has achieved a state of flow, "nothing else matters except the activity they are currently engaged in" (Csikszentmihalyi, 1990).

While flow and immersion share common attributes, such as environmental and temporal dissociation, it is erroneous to assume flow and immersion are the same psychological phenomenon. Being "immersed" is a graded experience that varies in intensity (Jennett et al. 2008), while being in a state of flow indicates visceral, razor sharp attention to a single activity which often results in a loss of self-consciousness (sense of self).

Flow and immersive experiences are generated by similar behaviors and activities, and it should be noted that immersion is often a precursor state the allows one to more readily achieve flow (Jennett et al., 2008). While they are distinctly separate cognitive phenomenon, they are not mutually exclusive. Consider this; it is common for an athlete to achieve a flow state while performing a sport or physical task, but it is not necessary for them to feel immersed (or "enveloped") in their environment to achieve said flow state. Likewise, the average reader does not need to achieve a state of flow, exhibiting hyper focus and heightened reflexes, to feel immersed in a fictional narrative. In either activity, both the reader and the athlete may begin to experience temporal and environmental dissociation (losing sense of time and place), common symptoms of both flow and immersion.

Cognitive absorption

Cognitive Absorption resembles flow as it literally describes a state of being absorbed in a task and, like immersion, CA often induces temporal dissociation. However, CA research is only concerned with peoples' motivations for using various information technologies and software (Agarwal and Karahana, 2000). CA research grades users' attitudes towards different information technology/software based on its perceived usefulness and ease of use, often using "curiosity" and "degree of focus" as scale metrics of user engagement with applications. In the case of CA, one's immersion specifically describes how well they engage with a product or software.

Presence

Presence is derived from immersion; it describes the sensation we feel when we are within an environment, real or artificial. Riva and colleagues (Riva, Waterworth & Waterworth, 2004) hypothesized that the earliest evolutionary purpose of presence, was to simply "provide a basis for the organism to separate events that occur only within the self from external events" (p. 414). In a later evolutionary form, presence manifested as the feeling of being situated within an "external, perceptible world." providing an organism the ability to recognize the conscious boundary of the "self" in relation to the world and events around it. They suggest that presence allows us to discriminate between reality and simulated experiences that take place in our minds (Riva et al., 2004).

With regards to interactive media, Slater et al. (1994) describes presence as a psychological sense of being in a virtual environment (VE) and measured the quality of this sensation via self-reports using metrics such as: realism, control, distraction, and sensory modality. The more realistic the VE and the more control a user experienced while immersed within it resulted in higher scores of presence. Witmer and Singer (1998), found that more natural, increasingly life-like, environments affected how much presence was reported while people explored them. Additionally, VEs in which the users' actions abided by the known laws of nature, meaning objects and their interactions reflect how they act in reality, also induced an enriched sense of presence (Zahorik & Jenison, 1998). However, unlike immersion, presence is not a temporal experience, it simply describes a sensation where one feels like they are literally present inside an environment (Waterworth & Waterworth, 2001).

There exist video games in which players experience being immersed, but do not feel present in the game world itself. Jennett et al. (2008) argues that Tetris is one such game. They state that while players can feel immersed in a game of Tetris, experiencing a loss of time and situational awareness, it is not likely that they feel they are literally present in a world consisting entirely of falling blocks. Most likely, the player does not feel that they are at risk of being physically crushed by a rouge “L” piece as it travels down the screen in front of them.

Alternatively, presence can be experienced without immersion. Jennett et al. (2008) propose that executing a boring task in VR can induce such a scenario. Although the players would likely report a high degree of presence, as they would be placed inside of the VE, the boring task would most likely fail to appropriately capture their attention. Thus, the players wouldn’t experience temporal dissociation or a decline in their awareness of external reality which are the hallmark symptoms of being psychologically immersed. This key difference between the feeling of simply “being present” in a location and the sensation of being enveloped within a perceptually engaging VE is what separates presence and immersion.

3 Dimensions of Immersion Framework (Nilsson et al., 2016)

Numerous studies within the past couple decades have studied immersion and its relation to presence. In these studies, researchers attempt to isolate and define immersion based on the core attributes of interactive media that provide the most immersive experience. Consequentially, since entertainment media can take many different forms, the immersive attributes researchers identify are unique to the specific medium being studied. Video games, music, novels, film, and art are all separate domains of interactive media and each have specific attributes that help generate a sense of immersion in their respective users (Nilsson et al., 2016). Researchers studying these domains provide theoretical frameworks that conceptualize immersion through the lens of their medium of choice. That is to say, the mechanisms that make video games immersive may be entirely different from those found in film or music. Thus, theories addressing immersion and presence in video games will not be applicable for other mediums.

The properties of an immersive experience are largely contextual and domain-specific, or dependent upon the media form being consumed. Thus, it is no surprise that there is some confusion in differentiating the unique properties of various immersive products or activities (i.e. movies, games, and music) across different domains of research (Nilsson et al. 2016). If one study were to compare music to movies while another compares video games to novels, they would find distinctly different immersive properties between them. For example, music is naturally immersive because the sound literally penetrates and surrounds the listener. It invokes an emotional response and draws the listener's attention to the piece being played (Dura, 2006). Meanwhile, novels rely on structured narrative elements that allow readers to mentalize the story characters, empathize with their actions, and visualize the world they exist in (Ermi & Mäyrä, 2005). While both music and novels can generate immersion, the methods by which researchers measure/assess the resulting immersive state in participants would be very different as reading novels and listening to music utilize completely different sensory modalities.

In recognition of the need for a unifying theoretical framework, Nilsson et al. (2016) conducted a systematic review of various literatures that have used aspects of immersion to motivate research in their respective subfields. They identified 4 aspects of immersion from the literature review (see Table 1): (a) immersion as a property of the technological system delivering the experience, (b) immersion as a subjective perceptual response, (c) immersion as a mental response to challenges, and (d) immersion as a cognitive response to the narrative characteristics of the experience.

Nilsson et al. (2016) argued that the technology used to deliver the immersive experience of a virtual world and the user's perceptual response could be best conceptualized as an integrated whole. They then proposed a three-dimensional framework for immersion: System (perceptual), challenge, and narrative. They proposed that these dimensions were separate and could be independently manipulated and studied. As system and challenge immersion are most applicable to the videogame technology used in the thesis research, a brief discussion of these 2 dimensions of immersion is included next.

Table 1

Taxonomy of Immersive Experience from Nilsson et al. (2016) Review

Aspects of Immersion	Terms & Description	Citations
A Property of System	**System Immersion**: The technology for presenting sensory information critically mediates the immersive experience.	Slater, Usoh, & Steed (1994)
A Perceptual Response	**Perceptual & Sensory Immersion**: Multimodal sensory envelopment of a virtual world (e.g., sights & sounds presented with screens and speakers).	Ermi & Mayra (2005), McMahan (2003), Witmer & Singer (1998)
A Response to Narratives	**Imaginal, Narrative & Psychological Immersion**: Mental absorption in a fictional world, as sense that characters and events have a reality.	Adams & Rollings (2006), Ermi & Mayra (2005), McMahan (2003)
A Response to Challenges	**Engagement & Ludic Immersion**: Focused attention and mental absorption when performing tasks requiring mental concentration, and possibly, application of motor skills, to meet task goals.	Adams & Rollings (2006), Ermi & Mayra (2005), McMahan (2003)

System (Perceptual) Immersion

The taxonomy developed by Nilsson et al. (2016) presented *system immersion* as a conceptualization of immersion that described the user's response to being surrounded by technology and the technology itself. The system immersion the user experiences is directly moderated by the quality of the VE being generated and the form (modality) in which the VE is delivered (i.e. multiple computer displays, VRHMD with high fidelity tracking, or audio only).

Other researchers have chosen to concentrate on the sensory characteristics (Ermi & Mayra, 2005) or perceptual response (McMahan, 2003) to the technological system used to provide the immersive experience. These two similar views of immersion overlap with each other in function and increase proportionally with system immersion (Nilsson et al., 2016). That is to say, the higher the quality of technology in a system, the more intense a user's perceptual/sensory response will be to it. Stronger computers coupled with higher resolution displays can render and present more realistic environments for users to experience. Nilsson et al. (2016) proposed that these two views, the system and sensory/perceptual aspects of immersion, could be conceptualized as just a single dimension of immersion, which they categorized as "system immersion".

Challenge Immersion

This form of immersion is generated by the performance of tasks, both physical and mental and is most intense when one is able to reach a balance of challenges and abilities (Ermi & Mayra, 2005). Prior to Ermi and Mayra, McMahan (2003) conceptualized immersion as a "love for games and the strategy it requires to play them". There is debate regarding immersion and the nature (sensorimotor or mental) of the tasks that generate it. There is an argument to be made that people experience a different form of immersion while performing physical tasks rather than mental ones. Adams and Rollings (2006), acknowledge these distinctions and present two additional conceptualizations of immersion, “strategic immersion” and “tactical immersion”. They argue strategic immersion centers around the optimization of choices while tactical immersion is experienced through chaotic action scenarios the demand attentional surrender (Adams & Rollings, 2006). It should be noted that almost every conceptualization of challenge-based immersion resemble flow in description. Like flow, these views of immersion are all characterized by intense focus, cognitive reaction, and sharp attention to the task/environment.

Challenge immersion is understandably influenced by media form, as the subject matter dictates the challenges being presented. The physical attributes of the media can moderate the intensity of challenge immersion (Nilsson et al., 2016). These attributes directly impact the user’s performance in video game media. Controller shape, screen size, loudness, and video resolution, all aspects of system immersion, play a role in the challenge immersion one experiences while playing video games.

Virtual Reality/ Virtual Environments & Immersion

When discussing VR and VE it is important to note that the term “VR” specifically references a type of interactive media or simulated experience while “VE” refers to a environment/rendering that is primarily experienced digitally, sometimes within VR (Psotka, 1995). New videogame creation tools, such as the Unreal engine, contain VR support and have provided content creators the ability to construct and explore virtually any artificial environment they can think of and literally place themselves within them. This technology has extreme customizability and it provides an excellent toolbox and platform for experimentation and study across multiple disciplines, especially for psychological science (Banaei et al., 2017; Jennett et al., 2008). VR technology has continually changed in form over time. Starting as a purely visual experience, early iterations of VR utilized wearable technology reminiscent of goggles. Contemporary iterations expanded upon the interactive quality of VR tech by incorporating other peripheral devices such as shoes, vests, and gloves, allowing users to physically interact with the virtual environment (VE) itself. Today, in conjunction with various other media devices, VR technology can produce an intense, multimodal, sensorimotor experience that can effortlessly mirror the likeness of reality.

Immersion levels have generally been found to increase when transitioning from 2D to 3D viewing and 3D viewing with view updated based on head movement tracking increases immersion levels further (Slater & Sanchez-Vivez, 2016). Kronqvist, Jokinen, & Rousi (2016) directly compared immersion ratings following viewing virtual scenes with a 2D screen, 3D glasses, and a 3D VR headset with motion updating and found that the glasses had greater immersion than the 2D screen, and the 3D headset had the greatest immersion.

Electroencephalography (EEG), Oscillations and Frequency Decomposition

EEG involves measuring changes in voltages on the scalp and separating out the portion of voltage changes due to neural activity in the brain from external noise (e.g., electromagnetic noise in the air or electrical wiring, or muscle fiber firing during movement). The neural activity related to the EEG signal naturally oscillates within narrow frequency bands depending on neural regions and types of information processing involved.

Brainwaves can be categorized into distinct frequency bands (measured in hertz) including, (delta [2-4 Hz], theta [4-8 Hz], alpha [8-12 Hz], beta [15-30], and gamma [30-50Hz]; Cohen, 2015). Each of these frequencies are associated with some cognitive function in the brain. Delta is mostly associated with deep sleep and unconsciousness (Cacioppo et al., 2007; Colrain et al., 2008). Theta seems to be connected to affective processing, navigation, attention, and memory (Aftanas & Golocheikine, 2001). Alpha appears associated to mental inactivity or idleness (Pfurtscheller, Zalaudek, & Neuper, 1998). Beta is most prominent in decision making, information processing, and general problem solving (Ray & Cole, 1985). Finally, gamma seems to be associated with attention, memory, and learning (Miltner et al., 1999).

EEG, and Immersion Research

Literature investigating EEG frequency band neurocorrelates of immersion is quite sparse. Only 4 such studies were identified during the initial literature search, and only 2 of these compared NVR and VR viewing. Each of these studies described below assessed EEG during the viewing experience and self-reported immersion directly following viewing. These studies provide the core literature motivating design of this study.

Frequency Bands, Cognition, and Computer Games

In a recent review, Palaus, Marron, Viejo-Sobera1, Redolar-Ripoll (2017) presented evidence that beta and theta band power changes with attention and cognitive workload during videogame play. They argued further that increased theta band power was generally associated with increased mental workload, and by contrast increased beta band power was associated with increased task complexity, during videogame play. Increased theta band power was reported by Pellouchoud, Smith, McEvoy, and Gevins (1999) during videogame play in relation to watching someone else playing the game, and sitting quietly with eyes closed. Recently, there has been increased interest in developing affordable EEG headsets that can be sold with videogames and allow events in the game to be driven by the EEG signals input to the game in real time. In testing a prototype EEG headset for gaming, Berta, Bellotti, De Gloria, Pranantha, and Schatten (2013) reported that the low beta band (12-15 Hz) was the best frequency band differentiator of EEG signals across 3 levels of game difficulty.

Beta & Theta Band & Immersion During 2D Videogame Play (Nacke et al., 2011)

Nacke et al. (2011), studied EEG frequency band neurocorrelates of immersion during video game play while playing an action shooter game where players must explore a variety of realistic locations. They produced 3 game levels (boredom, flow, immersion) using the modding tools native to the game. The boredom level provided mostly outside locations consisting of a simple linear path to traverse, with most of the combat opponents and obstacles removed. The flow level included a corridor with a row of rooms on a single sequential path (i.e., single entrance and exit doors for each room). To progress, all combat opponents must be defeated before the exit door would unlock allowing traversing to next room. This level emphasized game flow (similar to the challenge immersion dimension proposed by Nilsson et al., 2016). The immersion level had a complex path through varying indoor and outdoor locations, with less predictable combat opponent locations, and enhanced 3D lighting effects (e.g., shadows) meant to enhance perceptual and emotional engagement with the game. The VE design changes to create the immersion level in this study reflect changes in the system immersion dimension proposed by Nilsson et al. (2016), which, includes aspects of perceptual richness and explorational motivation.

In comparison to the boredom level, aspects of system and challenge immersion were increased. Nacke et al. (2011) reported significant increases in both theta (4-8 Hz) and beta (10-30 Hz) bands for the immersion level in comparison to the boredom level. Moreover, there were no significant frequency band differences in the boredom vs flow comparisons. These results suggest that system immersion may be expected to be related to theta and beta band increases, but frequency band neural correlates of challenge immersion remain elusive.

Theta Band & Immersion During 3D Virtual Spatial Navigation (Slobounov et al., 2015)

Slobounov et al. (2015) present a study in which two experiments compare 2D to 3D VR environments and investigate how these environments impact participant brain activity and sense of presence. To do this, researchers utilize EEG for both experiments to measure the frequency band power averages of participants performing a spatial navigation and balancing task in both viewing conditions (2D vs. 3D). After completing each experimental condition, participants were given self-report surveys on which they scored the sense of presence experienced in either condition.

In experiment 1, researchers presented participants a virtual corridor to navigate through. Prior to attempting the task, participants memorized a map showcasing a top-down view of the route they were going to navigate (encoding phase). While equipped with an EEG cap, participants would then navigate the virtual corridor (retrieval phase), presented in 2D or 3D. The system that showcased the VR corridor environment was a 3D television with two large black curtains on either side surrounding the participant. The television screen width was 65”and could switch between 2D and 3D viewing modes. Participants were instructed to stand 2.5 ft away from the screen, to ensure that the screen occupied the majority of their field of vision. Finally, viewing the screen for the 3D condition required the use of 3D stereo glasses to achieve the illusion of depth generated by the 3D television. Without these glasses, the picture on-screen would appear blurry and participants would find it hard to focus.

Results from EEG data analysis showed that theta power was significantly higher in the encoding phase of the navigation task for the 3D condition compared to the 2D condition. Within-subject t-tests revealed participants also exhibited higher navigation task success in the 3D condition as well. This theta power increase was seen in the right parietal area and left visual area of the brain (Slobounov et al., 2015).

Experiment 2 was similar to the first but focused more on the impact of viewing modality on physical performance, postural stability, and sensory processing. Researchers found that the 3D VR balancing task resulted in significantly higher theta band power averages in two areas of the brain. At the frontal region and central (midline) region.

With regards to my own research goals, this study by Slobounov et al. (2015) provides two things; First, it supports previous literature showing an increase in presence resulting from varying the form of immersion (specifically system immersion). Second, it shows significant differences in EEG activity patterns (theta power) resulting specifically from viewing condition. Thus, varying the immersive quality of a VR task seems to impact the neural activity of participants.

Beta Band & Immersion During Film Viewing (Kruger, 2016)

Kruger at al. (2016), conducted a study in which investigators sought to determine if beta band oscillations between frontal and parietal EEG electrode sites (beta coherence) can be used as an objective measurement of audience immersion while watching a film. Coherence measures correlated activity between 2 electrodes that have similar phase and amplitude of oscillations within a frequency band. Coherence measures functional connectivity across brain regions within said frequency band. In this study, researchers relied heavily upon narrative immersion as part of their experimental condition. Participants watched the first thirty minutes of a feature-length film, with and without subtitles, broken down into 12 scenes. Based on prior literature, Kruger et al. (2016) specifically looked at the functional connectedness of frontal electrode sites over prefrontal cortex (PFC) and posterior sites over parietal cortex (PPC). The PFC is believed responsible for the interpretation and modulation of affective states across other cortical regions while the PPC is argued to be associated with imagination (Shimamura, 2013).

They found that average beta coherence was reduced between the PFC and PPC for the subtitled version of the film. Kruger et al. (2016) suggested their findings were consistent with greater immersion for the subtitled film viewing experience (i.e., reduced beta coherence). However, they failed to find any significant difference in subscales of immersion between the subtitled and unsubtitled versions of the film. Kruger et al. (2016) did report that prior studies from their group had found significant increases in self-reported immersion following subtitled, as opposed to unsubtitled, viewing of media, so their interpretation of their beta coherence findings is consistent with previous studies using similar methodology in their lab.

Theta Band, Immersion & Virtual Architectural Spaces (Banaei et al., 2017)

Banaei et al. (2017) used a mobile EEG setup that allowed participants to walk while exploring virtual architectural spaces. Participants wore EEG and VR headsets, with recording computer and batteries carried in a backpack. The VR headset used sensors to detect motion of the participant and updated the view of the virtual world accordingly. Participants reported significant levels of physical presence in the virtual rooms during their explorations, and the results were dominated by theta band increases upon entering virtual rooms that was greatest when the room was pleasing and arousing in design.

Summary

Relatively little is known about EEG markers of immersive experience. My search of the literature yielded just 4 studies that conducted EEG frequency band analyses and tested for reliable immersion effects. Two of these studies (Banaei, 2017; & Slobounov et al.,2015) include 3D VR, only 1 included videogame play (Nacke et al., 2011), and none of these studies included both 3D VR and videogame play. The present thesis research was designed to test the effectiveness of manipulation of viewing technology (2D traditional screen, 3D VRHMD) and videogame difficulty on the system and challenge dimensions of immersion suggested by Nilsson et al. (2016). Both subjective immersion ratings and EEG frequency band analyses were utilized to verify the relationship of EEG frequency band markers of immersion. Moreover, Experiment 2 is the first study to simultaneously manipulate system and challenge immersion to assess the independence of immersion dimensions as assessed by self-report and EEG measures.

CHAPTER 3: AIMS AND HYPOTHESES

With the current thesis research, I was able to provide a more theoretically driven set of experimental manipulations than in prior studies. The recently proposed framework by Nilsson et al. (2016) integrates other known conceptualizations of immersion found through a review of literature across multiple research disciplines. While this framework proposed three dimensions of immersion, I chose system and challenge immersion as my manipulation targets because these dimensions are inherent to videogame media, more so than narrative immersion. Based on previous literature (Nilsson et al., 2016; Slobounov et al., 2015; Riva et al., 2004; and Witmer & Singer, 1998), the most effective way to manipulate the system immersion experienced through video games is to change the user's viewing modality. Thus, my system manipulation involved two different forms of visual technology, a 2D monitor and a 3D VRHMD. The visual presentation of these two pieces of technology exhibit clear differences in perceptual quality.

To manipulate challenge immersion simultaneously with system immersion, videogames were the ideal media as game difficulty is an inherent property of videogames (Nacke et al., 2011). Simultaneous manipulation of both these immersion dimensions in a 2 x 2 design allowed me to evaluate the independence of the immersion dimensions for possible synergistic interaction effects on user experience. I was also able to look for interaction effects between viewing condition and game difficulty to assess if difficulty amplified the immersive quality of one viewing condition over another. Additionally, manipulation of each dimension of immersion separately allowed me to evaluate the effectiveness of each manipulation on self-report scores to reveal the potential main effects of each manipulation discussed in the results section of each experiment.

Based on the studies by Nacke et al. (2011), Slobounov et al. (2015), and Kruger et al. (2016), I was able to verify theta and beta band neural correlates of system immersion. Additionally, with the more sophisticated design of Experiments 1 and 2, I produced results regarding the neural correlates of challenge immersion as well. With these goals in mind, I predicted the following hypotheses and analysis goals:

Hypotheses: Immersion Survey Scores

Hypothesis 1: Challenge Immersion Manipulation Check

I predict that mean challenge subscale scores will increase when moving from the baseline condition to the racing condition (for both NVR and VR, Experiment 1). I predict that mean challenge subscale scores will increase when moving from easy to medium racetrack conditions (for both NVR and VR, Experiment 2) based on Nilsson et al. (2016).

Hypothesis 2: System Immersion Manipulation Check

I predict that mean physical presence and overall immersion subscale scores will increase when moving from NVR to VR viewing conditions while racing a virtual car (Experiments 1 & 2) based on Nilsson et al. (2016).

Hypotheses: EEG Results

Hypothesis 3: Average Frequency Band Amplitude Across Viewing Conditions

I predict EEG analysis will show an increase in theta (potentially beta) band power for the 3D VR conditions compared to the 2D NVR viewing condition. (Based on Slobounov et al. 2015; Banaei et al. 2017).

Hypothesis 4: Average Frequency Band Amplitude Across Difficulty Conditions

I predict EEG analysis will show an increase in beta band power for the medium conditions compared to easy conditions. (Based on Nacke et al. 2011; Palaus et al. 2017).

Hypotheses: Three-Dimensional Immersion Framework

Hypothesis 5: Separability/Independence of Immersion Dimensions

By examining the 3-dimensional immersion framework via a 2 x 2 factorial design (Experiment 2), I predict that the 3 dimensions of immersion proposed by Nilsson et al. (2016) will not be entirely separate/independent of each other and interaction effects between challenge and system/perceptual immersion will be found.

CHAPTER 4: EXPERIMENT 1

The first experiment was designed to check the prediction of the Nilsson et al. (2016) 3-dimension framework of immersion. More specifically, I predicted that comparison of the VR baseline and VR gameplay conditions would only result in significant changes in self-reported immersion for the challenge, but not the overall immersion and physical presence subscales. I also predicted that comparison of the NVR gameplay and VR gameplay conditions would result in a significant increase of self-reported immersion scores for overall immersion and physical presence, but not the challenge, subscales. This pattern of results would be consistent with the proposal of separable, independent system/perceptual and challenge dimensions of immersion (Nilsson et al., 2016).

Method

Participants

Participants for the first experiment consisted of 30 UNCC students collected using the UNCC SONA research participant pool. All participants completed an IRB approved informed consent procedure, and participated for course credit. Participants were required to be right-handed, 18 years of age or older, speak fluent English, and have normal or corrected-to-normal vision using contact lenses. Eyeglasses were not permitted. 2 participants were dropped due to equipment failure for a final sample of 28 participants for data analysis (n = 28).

Design

For Experiment 1, the overall design consisted of two separate 2x2 sub-designs: 2 (block order: VR first, NVR first) x 2 (viewing condition: NVR gameplay, VR gameplay) sub-design and a 2 (block order: VR first, NVR first) x 2 (difficulty condition: VR baseline, VR gameplay) sub-design. The first sub-design allowed comparison of 2D NVR screen and 3D VR driving and the second allowed comparison of 2 levels of challenge i.e., passive observation of a virtual room vs. virtual racing using a driving simulator.

Driving Simulator & Hardware

Experiment 1 was performed using a PC laptop capable of running a VRHMD and accompanying game for extended periods smoothly, with minimal latency. The VRHMD used was an HTC Vive outfitted with a rigid-frame head strap with audio built-in. The VR game used was a racing simulator known as Project Cars 2 (2017) and was played using both a Logitech G920 Racing Wheel and a standard Xbox One controller depending on viewing condition.

Immersion Survey

I created a modified immersion survey (Appendix C) containing 13 items from the “challenge and “immersion” subscales in the “Egame Flow Scale” (see Appendix D), by Fong-Ling, Rong-Chang, & Sheng Chin (2009) and 5 items from the “physical presence” subscale of the “Multimodal Presence Scale” (MPS; Appendix E) by Makransky et al. (2017). The modified survey consists of 18 items allocated into three subscales: challenge (6 items), overall immersion (7 items), and physical presence (5 items). I also included 4 additional questions asking about the physical well-being of the participant after each condition.

To assess the challenge dimension of immersion proposed by Nilsson et al. (2016), I pulled items from the challenge subscale of the Egame Flow scale. These authors defined challenge immersion similar to what Nilsson et al. (2016) proposed, and the questions used in the challenge subscale of the Egame Flow scale (see Appendix C) were judged to have clear face validity for assessing challenge immersion as proposed by Nilsson et al. (2016). Fong-Ling et al. (2009) report acceptable validity and reliability for the Egame Flow scale.

Procedure

Since playing in VR can be an intense, multimodal sensory experience, some people develop motion sickness in response to the VR tech on their first time. The procedure began with a two-minute acclimatization period to better familiarize the student with the VR technology. The acclimatization period also served as a baseline condition in which players would simply sit with the VRHMD on their face situated in a virtual room resembling a one-room vacation home. Due to potential issues arising from user error and physical space constraints, participants were not allowed to get up while in VR and were not given to ability to physically interact with the objects in the VE using hand peripheries (controllers).

After the acclimatization period, participants were given the modified self-report survey on which they scored their baseline VR experience. Following the immersion survey, participants were prepped to play the racing game in either VR or NVR first. Viewing condition order was counterbalanced with half of the participants playing the game in VR first and the other half outside VR playing the game on a laptop first (NVR). Participants used the steering wheel attachment during the VR condition and a normal Xbox One controller for the NVR condition. This was due to spatial constraints in the test room and only being able to display the game on a single monitor, the laptop itself.

Consequently, using two different forms of controller input allowed for further manipulation regarding participant's system immersion.

Computer Game Task

The instructions were the same regardless of condition; drive around a beginner level (easy) racetrack for five minutes with an additional challenge that they maintain a consistent speed of 40 mph.

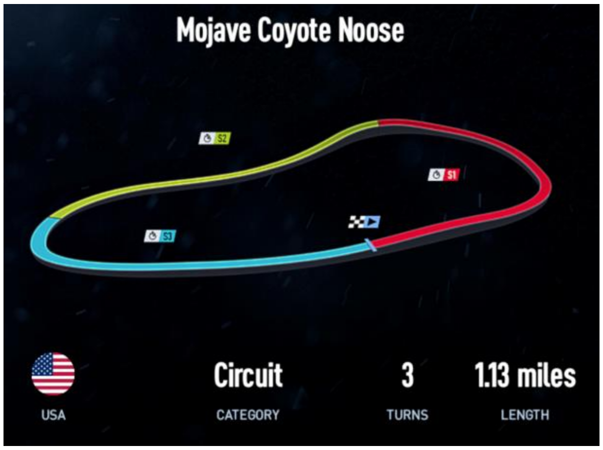

Figure 1. Easy difficulty track used in Experiment 1 and 2

This task served two purposes. First, it ensured that they would never be going fast enough to spin out or "fish tail" while driving. Reducing the possibility of incurring motion sickness while in VR and minimizing potential frustration that would result from crashing the car, regardless of experimental condition. Second, it generated an additional challenge to the task by providing the participants something to focus on maintaining while driving. Should the Ermi and Mayra (2005) conceptualization of immersion hold merit, adding this additional challenge to the experience should increase its immersive quality and would be reflected in the self-report surveys. Participants were given another self-report immersion survey at the conclusion of this first, five-minute task.

Following this second survey, participants switched viewing conditions (playing in VR to NVR and vice versa) and played the exact same track for another five minutes maintaining the same requested speed as before. At the completion of this last task, participants were provided the same survey for a third final time and then debriefed.

Results

To assess possible influences of order effects not controlled by counterbalancing the order of VR baseline and VR gameplay conditions across participants (VR baseline always came first), I checked for interactions between order and difficulty condition in 2-way ANOVA's. First, I conducted a 2 (order: NVR first, VR first) x 2 (viewing condition: NVR gameplay, VR gameplay) ANOVA, with order manipulated between participants, and viewing condition manipulated within participants, for each of the 3 immersion survey subscales (challenge immersion, overall immersion, and physical presence). I also conducted a 2 (order) x 2 (difficulty condition: VR baseline, VR gameplay) ANOVA with order manipulated between participants, and difficulty manipulated within participants, for the same 3 subscales (challenge immersion, overall immersion, and physical presence). Order did not interact significantly (both p's > .05) in either analysis. Thus, I collapsed across the control variable of order and reanalyzed reduced single factor repeated measures ANOVAs for each sub-design comparison (NVR gameplay vs. VR gameplay & VR baseline vs. VR gameplay).

With regard to viewing condition, analysis showed switching from NVR to VR resulted in a significant increase in mean immersion subscale scores (F (1, 27) = 53.90, $p < .001$; partial $\eta^2 = .67$) and physical presence subscale scores (F (1, 27) = 93.43, $p <$

.001; partial $\eta^2 = .78$). Results also showed that switching viewing conditions had no significant effect on mean challenge immersion subscale scores, p = .09.

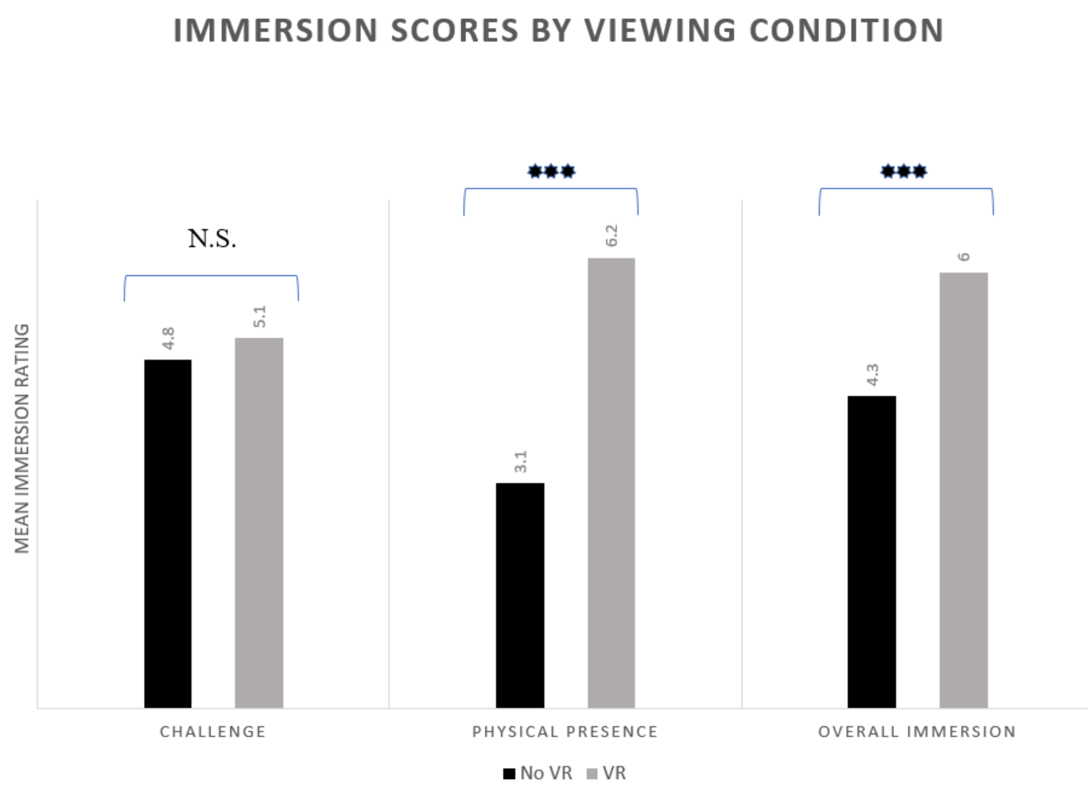

Figure 2. Mean immersions subscale scores by viewing condition (NVR gameplay, VR gameplay), *** p < .001, N.S. p >.05.

With regard to the difficulty comparison, analysis showed switching from VR baseline (VR with no task) to VR gameplay resulted in a significant increase in mean scores for all three subscales. Those being the challenge (F (1, 27) = 64.20, $p < .001$; partial $\eta^2 = .70$), overall immersion (F (1, 27) = 41.10, $p < .001$; partial $\eta^2 = .60$), and physical presence (F (1, 27) = 28.80, $p < .001$; partial $\eta^2 = .52$) scales respectively.

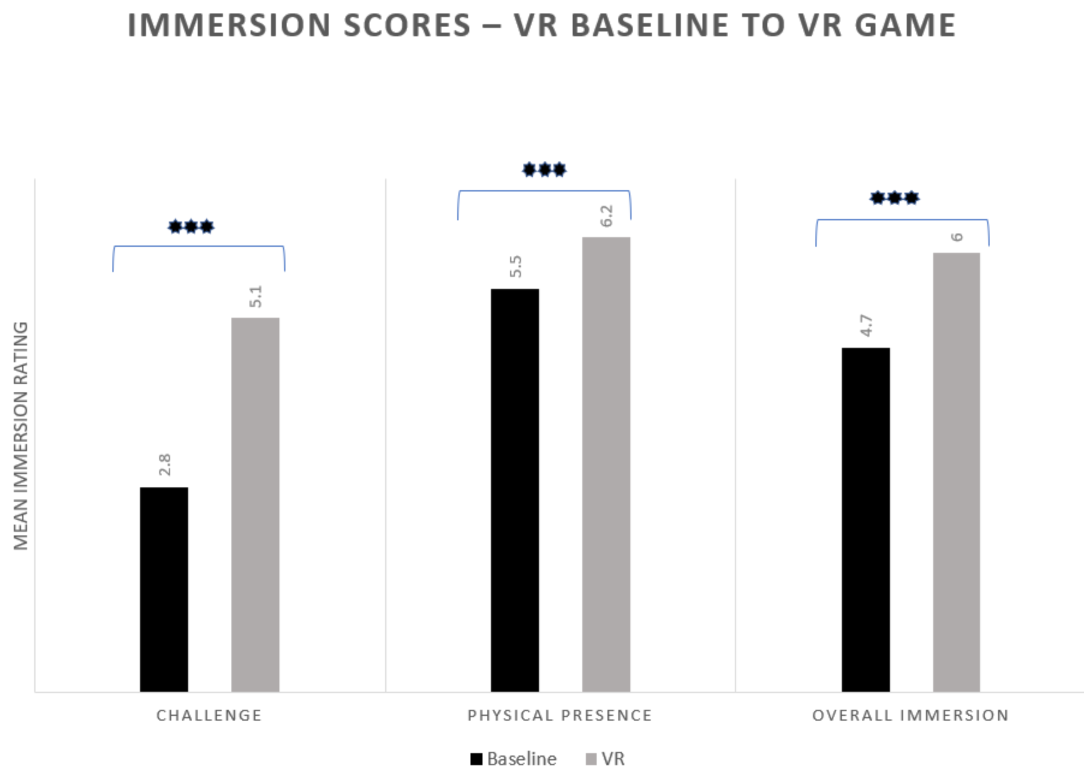

Figure 3. Mean immersions subscale scores by difficulty condition (VR baseline, VR gameplay), *** p < .001.

Discussion

In Experiment 1, manipulation of viewing and difficulty conditions were successful in modulating participant immersion while both inside and outside of VR. Figure 2 depicts the comparison of mean immersion subscale scores for the two viewing conditions. This comparison revealed that mean ratings increased from NVR gaming to VR gaming for the physical presence and overall immersion subscales, but not for the challenge subscale. This pattern is consistent with an effect modulation of the system dimension of immersion but not the challenge dimension. This reflects the proposal put forth by Nilsson et al. (2016) regarding the separate dimensions of immersion. Finally, due to limitations of the setup used in Experiment 1, the NVR and VR conditions differed in terms of controllers used (NVR condition utilized an Xbox One controller while the

VR condition utilized a steering wheel peripheral). The steering wheel is arguably more familiar (in terms of motor control) to the general populace than an Xbox controller and thus may accentuated the system immersion experienced by participants in the VR condition. This potentially confounding variable was removed in Experiment 2 by having participants use the steering wheel peripheral across all gameplay conditions.

Figure 3 depicts a comparison of the mean subscale scores of the VR baseline condition and the VR gameplay condition. There was a significant increase in the mean challenge immersion subscale scores, suggesting that moving from simply viewing a virtual room, to participating in a virtual car race presents a rather obvious jump in gameplay challenge/difficulty and thus increases the immersion of the experience. However, mean physical presence and overall immersion scores also increased significantly with this comparison. One reason for this may have been the significant change of perceptual complexity and sensory-motor demands when moving from the baseline condition (standard VR room) to the VR racetrack. The finding that this comparison resulted in significant change on all 3 immersion scales suggests that challenge and system/perceptual immersion may interact. To further explore this possibility, Experiment 2 was designed with a complete factorial crossing of the game difficulty and viewing dimensionality.

CHAPTER 5: EXPERIMENT 2

Experiment 2 was designed to replicate and extend the immersion survey results of Experiment 1 and add EEG measurement to assess neural correlates of the challenge and system (perceptual) dimensions of immersion. Experiment 1 included an empty VR room as an experimental condition for baseline acclimation. Experiment 2 included this same condition, again as a baseline acclimation period to the VR headset, but with no associated data collection. Challenge immersion was manipulated in Experiment 2 by including 2 levels of game difficulty (easy and medium) by introducing an objectively more challenging racetrack to the gameplay condition. This new “medium track” consisted of an increased length and number of turns per lap. This modification led to a 2 (viewing condition: NVR, VR) x 2 (difficulty: easy, medium) completely repeated measures design. As with Experiment 1, an additional control variable was added to the design. Viewing condition (NVR screen vs VR headset) order was counterbalanced across participants. However, within each level of viewing condition all participants played the easy then medium racetracks in that fixed order. Moreover, to remove the potential confound of different controller types for NVR and VR gameplay conditions (as in Experiment 1), participants used the steering wheel controller for all 4 gameplay conditions in the 2 x 2 design.

Method

Participants

Participants consisted of 11 UNCC students recruited from the UNCC SONA research participant pool. All participants completed an IRB approved informed consent procedure and participated for course credit. Participants were required to be right-handed, 18 years of age or older, speak fluent English, and have normal or corrected-to-normal vision using contact lenses. Eyeglasses were not permitted. One participant was unable to complete all four gameplay sessions due to gameplay equipment failure and was removed. Two other participants completed all gameplay sessions, but their EEG recordings were either incomplete due to electrode cap failure or included excessive movement artifact to effectively extract frequency band information. The resultant sample was $N = 10$ for immersion survey analysis, and $N = 8$ for EEG analysis.

Design

This design was a 2 (block order: NVR first, VR first) x 2 (viewing condition: NVR screen, VR) x 2 (difficulty: easy, medium) repeated measures design. Dependent variables include survey scores, and EEG frequency band amplitudes.

Materials and Apparatus

As mentioned above; most of the components used in this design are identical to those used in Experiment 1. However, for Experiment 2, I used the steering wheel attachment for both the VR and Non-VR conditions. Participants navigated a new racetrack in the game serving as the “medium difficulty” condition.

EEG Recording & Processing

EEG recordings were made using a Neuroscan 64-channel Quik-Cap connected to a Synamps amplifier with a 60 Hz notch filter, using Neuroscan Scan 4.5 data acquisition software. Electrodes on the cap were placed according to the expanded International 10-20 system. Standard filtering and analysis software routines were applied to the EEG continuous recordings using EEGLAB (Delorme & Makeig, 2004) software toolboxes MATLAB.

Continuous files were converted to EEGLAB format, referenced to average of right and left mastoid electrodes and high-pass filtered a .1 Hz then low-pass filtered at 50 Hz (12 dB per octave). Each 5 minute gameplay interval was parsed into 8 non-overlapping 30 second epochs starting 30 seconds in from the beginning of the gameplay interval. Epochs were visually examined for excessive muscle and eye movement artifacts and rejected. Epochs were also screened using an automated algorithm with a moving window designed to detect eye movement artifacts greater than 200 µV. Average frequency band amplitude was computed for theta (4-8 Hz), alpha (8-12 Hz), and beta (15-30 Hz) and transformed by adding 5 and taking the natural logarithm to normalize the data (resulting units are ln [5 + µV]). Electrodes of interest were selected to include frontal and parietal regions used in prior research (e.g., Banaei et al., 2017; Nacke et al., 2011), and to include the central top of the head where many attention and cognitive control EEG effects are typically observed (Cohen, 2015; Luck, 2014). Figure 4 presents the electrodes of interest, 5 rows covering most of the top of the head: (a) F3, F1, Fz, F2, F4; (b) FC3, FC1, FCz, FC2, FC4; (c) C3, C1, Cz, C2, C4; (d) CP3, CP1, CPz, CP2, CP4; (e) P3, P1, Pz, P2, P4. One participant's EEG data was removed from further analysis due to all 16 epochs being rejected in the non-VR viewing condition. Of the remaining data, all participants had at least 3 good epochs in all 4 of the gameplay sessions that each played, and no participant had more than one gameplay condition with fewer than 4 good epochs.

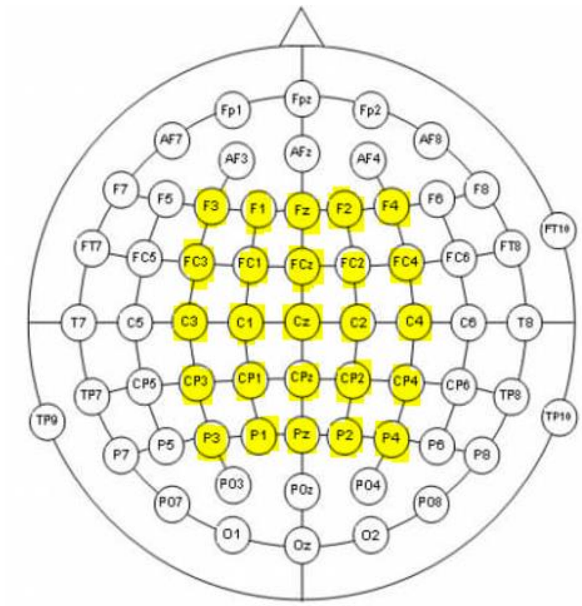

Figure 4. Scalp map showing the electrodes of interest (EoI) on a participant's scalp, covering the frontal and parietal regions (nose pointing up).

Procedure

Once participants arrive at the lab, they first completed informed consent forms, followed by a general health and handedness questionnaire, to determine eligibility. The questionnaire served as a screen to ensure participants met inclusion criteria (specifically, no history of epilepsy or seizures and being right-handed). After the questionnaire was completed, participants had an EEG cap placed on their head. This process was completed by two or three trained research assistants. The cap placement procedure includes preparation of the cap to measure neural activity. Research assistants filled the electrodes on the cap with an electrically conducive gel using blunt-tipped syringes. Once adequate impedances were achieved with the EEG cap, the participant proceeded with the testing process. All participants completed the computer game tasks in a counterbalanced order, with a baseline, acclimatization session preceding the test. The total testing time was approximately 1 ½ to 2 hours (5 – 10 minutes of consent and questionnaire; 20 – 45 minutes of cap placement; 30 – 40 minutes of cognitive testing; 10 – 20 minutes of clean up).

Computer Game Task

The computer game task consists of two conditions with identical objectives. Participants were instructed to drive a virtual car around two racetracks located in a simulated Mojave Desert setting for five minutes both inside and outside of virtual reality. The two racetracks differ in relative difficulty: with the "easy" track (identical to Experiment 1) being 1.13 mile(s) long, consisting of 3 turns and the "medium" track measuring 1.65 mile(s) long, consisting of 11 turns, making it an objectively more difficult track to complete. Figure 5 below depicts the overall layout of the medium track. Participants used a steering wheel peripheral for both viewing conditions. The only difference between conditions was the use of an HTC Vive VRHMD for the VR condition and a standard, 23-inch, computer monitor for the non-VR condition.

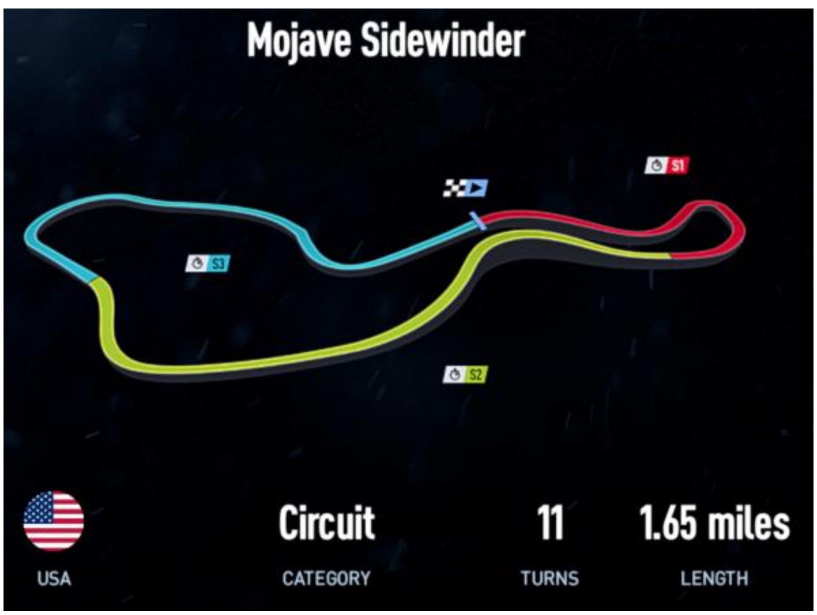

Figure 5. Medium difficulty track used in Experiment 2

Results

Immersion Survey Results

I first tested each subscale (challenge immersion, overall immersion, and physical presence) in a 2 (order: VR first, NVR first) x 2 (viewing condition: VR, NVR) x 2 (difficulty: easy, medium) repeated measures ANOVA to see if the experimental control variable of order significantly impacted the interpretation of effects involving viewing condition and difficulty. Results showed order effects in a three-way interaction between viewing condition, challenge, and order for each subscale, challenge ($F(1, 8) = 7.48$, $p = .026$; partial $\eta^2 = .48$), overall immersion ($F\ (1, 8) = 9.22$, $p = .016$; partial $\eta^2 = .54$), and physical presence ($F\ (1, 8) = 9.69$, $p = .016$; partial $\eta^2 = .55$). To investigate this, each three-way interaction was examined to confirm that the nature of the interaction did not require modification of our interpretation of the lower order main effects (see Appendices F – H). The 3-way interactions are depicted as separate viewing condition by difficulty condition interactions for each viewing order. Across the three 3-way interactions for the 3 immersion subscales (Challenge, overall immersion, and physical presence) the qualitative shape of the 2-way viewing condition by difficulty interactions were ordinal in all but one case. That is, in all but one case (NVR first, VR viewing, physical presence subscale dependent measure) the sample mean immersion subscale score increased from easy to medium gameplay. This pattern allowed us to collapse across the experimental control variable of order which we then re-ran the analyses as reduced model ANOVAs.

The three 2 (viewing condition: NVR screen, VR) x 2 (difficulty: easy, medium) repeated measures ANOVAs revealed a significant main effect of difficulty for mean challenge immersion scores ($F\ (1, 8) = 33.11$, $p \leq .001$; partial $\eta^2 = .79$; see Figure 6), a significant main effect of viewing condition for mean overall immersion scores (F (1, 8) = 13.33, p = .005; partial η^2 = .62; see Figure 7), and a significant main effect of viewing condition for mean physical presence scores (F (1, 8) = 16.35, p = .003; partial η^2 = .67; see Figure 7). No other main effects or interactions were significant (p > .05.). Most notably, there were no significant viewing condition by difficulty interactions. Implications of the finding of 3-way (order, viewing condition, difficulty) interactions for all of the immersion subscales will be covered in the Discussion.

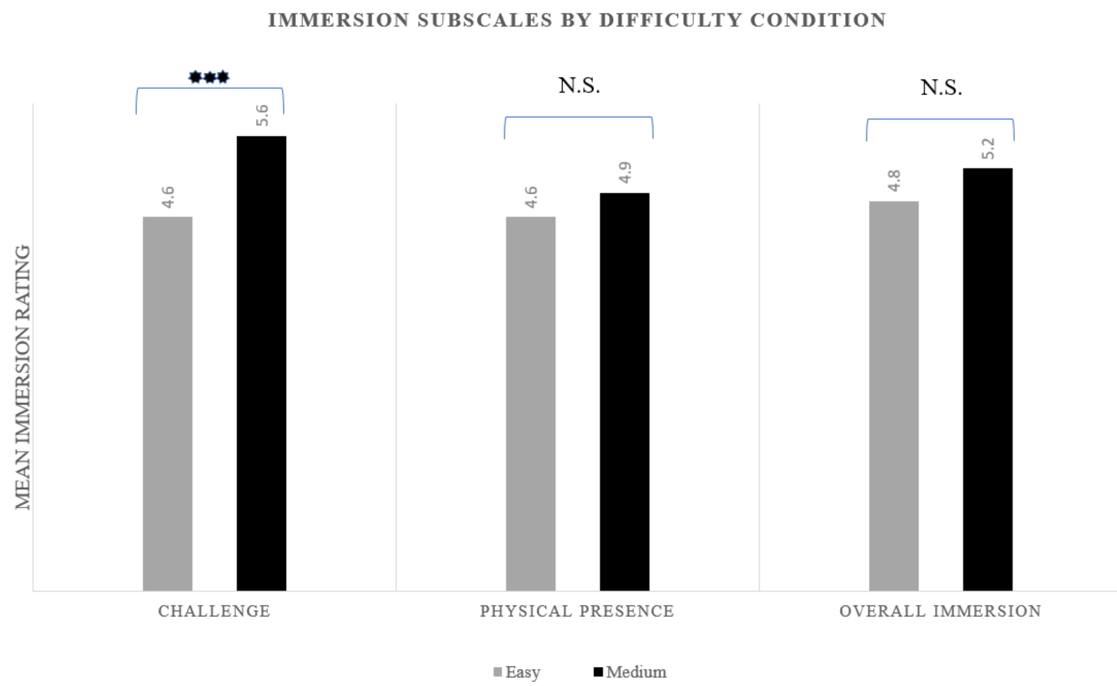

Figure 6. Mean immersion subscale scores by difficulty condition (Easy, Medium), *** p < .001, N.S. p >.05.

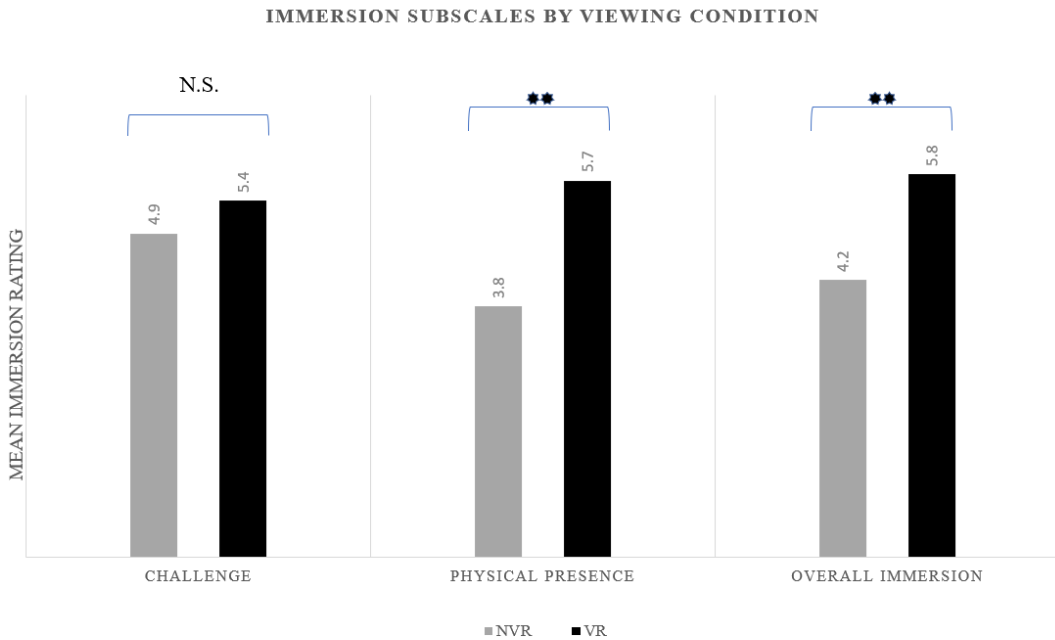

Figure 7. Mean immersion subscale scores by viewing condition (NVR, VR), **p < .01, N.S. p > .05.

EEG Results

Continuous EEG recordings during each of the four 5 minute gameplay sessions were parsed into eight 30-second epochs, and the average amplitude within each frequency band of interest (theta, 4-8 Hz; alpha, 8-12 Hz, and beta, 15-30 Hz) were computed (see EEG Recording & Processing subsection of Method). Average amplitude was logarithmically transformed to normalize the data (consistent with Nacke et al. 2011). The respective mean log amplitudes for each participant, in each of the 4 gaming sessions, were submitted to 2 (order: VR first, NVR first) x 2 (viewing condition: VR, NVR) x 2 (difficulty: easy, medium) mixed-model ANOVAs for each frequency band.

Significant three-way interactions between viewing condition, difficulty, and order were found for theta, $F(1, 6) = 7.26$, $p = .036$, and beta frequencies, $F(1, 6) = 6.13$, $p = .048$ (see Appendices I & J). Both of these significant 3-way interactions involve a crossover interaction of viewing condition (VR, NVR) and difficulty (easy, medium) that reverses across different orders of viewing condition (VR first, NVR first).

There was a main effect of viewing condition showing an increase in theta amplitude ($F(1, 6) = 5.97$, $p = .05$; partial $\eta^2 = .50$) going from NVR to VR (see Figure 8 below). Interpretation of this main effect is influenced by the significant interaction of viewing order and order condition, ($F(1, 6) = 7.05$, $p = .038$; partial $\eta^2 = .54$, see Figure 9). The mean theta amplitude was only larger for VR headset than for screen viewing when VR viewing came first, otherwise no change.

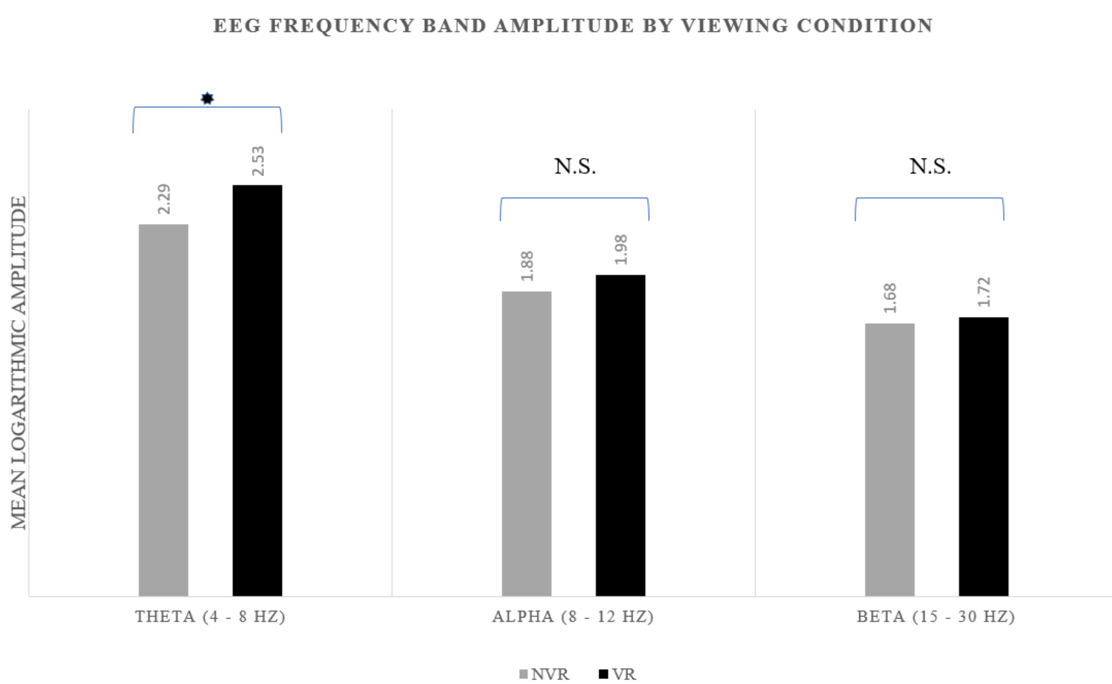

Figure 8. Mean EEG frequency band amplitudes by viewing condition (NVR, VR), *$p < .05$, N.S. $p > .05$.

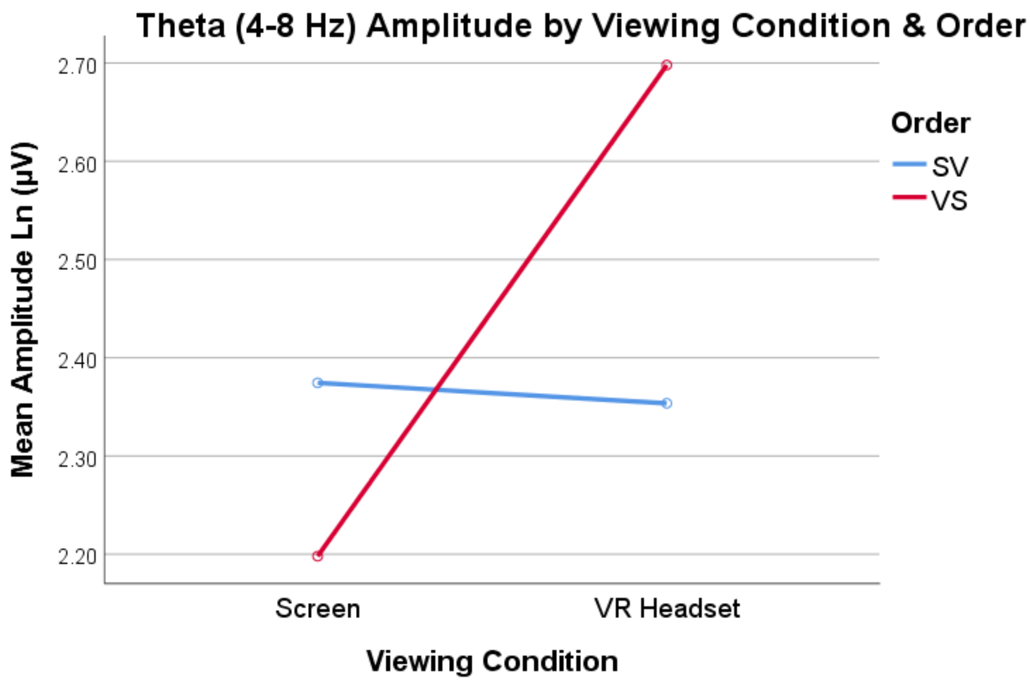

Figure 9. Mean theta amplitude by viewing condition and order.

Paired samples t-tests were performed for each frequency across viewing conditions for only the easy difficulty condition. The easy gameplay sessions were recorded first after baseline acclimation. Electrode impedances on EEG cap are checked between VR to NVR or NVR to VR transitions halfway through the experimental session. Moreover, examination of the significant 3-way interactions of order, viewing condition and difficulty for theta and beta bands (see Appendices I & J) reveal that the reversal of their component crossover 2-way interactions across order groups affect full interpretation of the results. However, the easy gameplay mean amplitudes do not reverse. Results determined that the transition from NVR to VR for the “easy” track produced a significant increase in amplitude of the theta frequency; NVR (M = 2.2, SD = .12) to VR (M = 2.6, SD = .46); t(7) = -2.63, p = .03 and beta frequency; NVR (M = 1.67, SD = .02) to VR (M = 1.73, SD = .06); t(7) = -3.0, p = .02 (see Figure 10 below). No significant change in mean amplitude was shown for alpha.

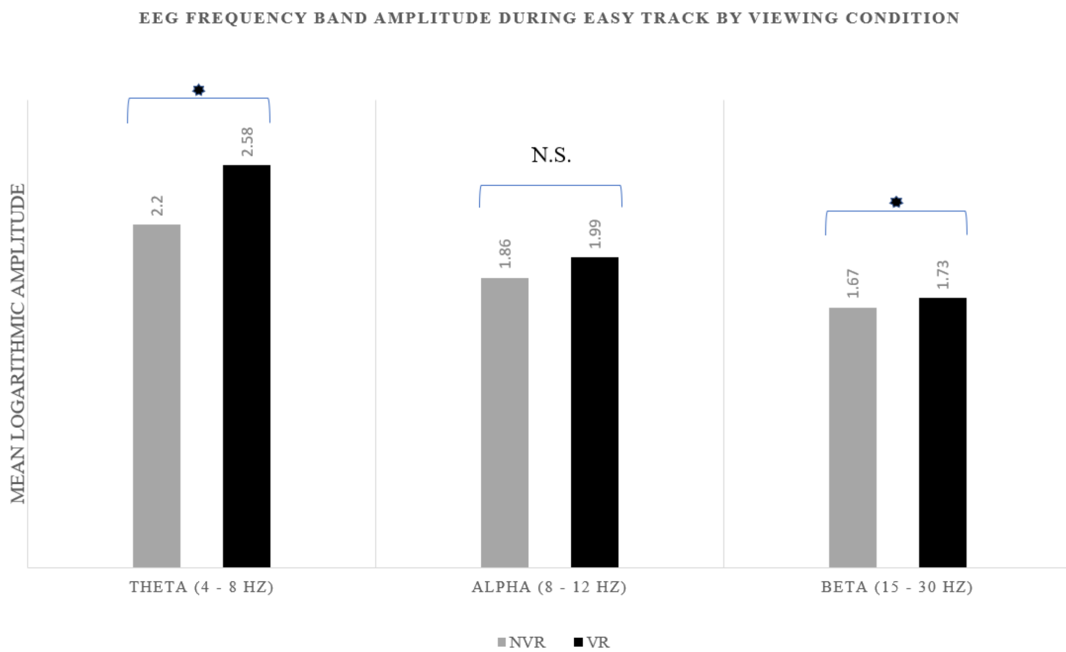

Figure 10. Mean EEG frequency band amplitudes while playing the easy difficulty track by viewing condition (NVR, VR), *p < .05, N.S. p > .05.

Discussion

One important finding of Experiment 2 is that manipulation of viewing technology and of game difficulty resulted in separable effects on self-report measures of immersion consistent with the prediction by Nilsson et al. (2016) of independent system/perceptual and challenge dimensions of immersion. I found that overall immersion and physical presence subscale means were greater for 3D VR gameplay than 2D gameplay, but challenge subscale means were not. I also found the reverse pattern for an increase in game difficulty where only the challenge subscale mean was significantly increased.

While there were significant 3-way order by viewing condition by game difficulty interactions for all of the immersion subscales (see Appendices F-H) the component 2-way interactions of viewing condition and game difficulty were primarily ordinal in nature, i.e., not disordinal crossover interactions, and do not require appreciable modification of any main effects of viewing condition or of game difficulty. As examination of the plots in Appendices F-H reveals, all but one of the 12 easy-difficulty comparisons yielded greater sample means for the medium gameplay condition. Additionally, all but one of the 12 viewing condition comparisons yielded greater sample means for the 3D VR conditions. The consistent pattern of viewing condition and game difficulty across the whole design support a straightforward interpretation of the main effects, as discussed in the preceding paragraph.

Overall, 3D VR gameplay conditions resulted in increased theta amplitude, relative to 2D NVR. This is consistent with Slobounov et al., (2015) and Banaei et al., (2017) papers (discussed at end of Chapter 2) who found theta increased for VR viewing conditions while performing virtual navigation learning and exploration of VR architectural spaces and mazes. However, interpretation of the significant main effect of viewing condition on theta amplitude was modified by the order by viewing condition interaction. The 3D VR advantage for theta amplitude was only observed for the VR first order group. While the small number of participants makes significance testing of the simple effects of this interaction of too low statistical power to rely upon, the pattern of observed sample means (see Figure 8) suggests that the increase in theta for 3D VR viewing was specific to the “VR first” ordering of view conditions.

Post-hoc comparison of the first (easy) gameplay session following a break (i.e., switching from 3D VR easy to 2D screen easy condition) revealed increased theta (4-8 Hz) and beta (15-30 Hz) for the 3D VR viewing condition. The finding of increased theta for the 3D VR viewing conditions is consistent with the non-gaming VR literature (Slater & Sanchez-Vives, 2016). Given that beta increases are not typically reported in the 3D VR literature (Slater & Sanchez-Vives, 2016; Slobounov et al., 2015) the increased beta for the 3D VR easy-gameplay condition may be attributable to an increase in perceptual complexity for 3D vs 2D viewing in a gaming environment that is more challenging. Beta band amplitude has been reported to increase with perceptual complexity in the gaming literature (Palaus et al., 2017).

There were significant 3-way interactions of order, viewing condition, and game difficulty for the theta and beta band analyses (see Appendices I & J). These 3-way interactions involved disordinal crossover interactions of viewing condition and game difficulty that varied for the viewing order groups (order of the viewing technologies, 3D VR vs. 2D NVR screen, was counterbalanced, but the order of game difficulty was not). While the low sample sizes (N = 3 & 5) lead to concerns that the 3-way interactions may not replicate, the pattern of interaction suggests habituation effects in the theta and beta band results. Inspection of the sample means for the theta and beta 3-way interactions depicted in Appendices I & J, respectively reveals that frequency band amplitude increased moving from easy to medium game difficulty levels in all cases for the first viewing condition (3D VR or 2D NVR screen) for the participants. The opposite is primarily true for the second viewing condition for each participant. This may be due to habituation of the EEG response during the medium gameplay sessions for the second viewing technology used. In fact, the 4th and final 5-minute gameplay session yielded the lowest sample mean frequency band amplitude (see Appendices I & J) in 3 out of 4 cases, and very nearly the lowest in the final case. This further supports a suspicion that the ability for aspects of immersion to trigger frequency band changes may habituate quite a bit during 20 minutes of repeated gameplay content.

CHAPTER 6: GENERAL DISCUSSION

The current thesis research revolves around 3 main components: the mental state of immersion, using VR to induce said immersion, and using EEG to record and examine the neural activity of an immersed participant. To further explores these components, I first had to (a) understand what psychological immersion is and its various conceptualizations that exist in the current research literature, (b) confirm that VR technology can provide a significantly higher quality of immersion than a traditional 2D screen, and (c) identify how EEG frequency bands were most likely to be affected by an immersive experience based on previous studies.

To help organize the myriad conceptualizations of immersion that exist in the literature, Nilsson et al. (2016) produced a taxonomy of immersion definitions ultimately categorized into three independent, separable dimensions: immersion as a property of a system (system/perceptual immersion), as response to narratives (narrative immersion), and as a response to challenges (challenge immersion). It is important to remember that Nilsson et al. defined system immersion as a combination of the technology that delivers the experience to the user and the user's perceptual response to it (Nilsson et al., 2016).

Survey results from both experiments show that when participants transitioned from viewing in 2D to 3D VR, mean immersion scores for the overall immersion and physical presence subscales (representing system/perceptual immersion dimension proposed by Nilsson et al., 2016) increased significantly. However, manipulating viewing technology (NVR screen to VRHMD) did not significantly impact participant challenge immersion scores. This pattern of results demonstrates that the manipulation of viewing technology was effective at changing the system/perceptual immersion dimension specifically. Additionally, for both experiments, moving from a lesser to greater VR gameplay challenge resulted in an increase in mean challenge subscale scores, consistent with the challenge immersion dimension proposed by Nilsson et al. (2016). But, in Experiment 1 only, there was also an increase in overall immersion and physical presence subscale scores.

For both experiments combined, the immersion survey results are consistent with experimental manipulations (i.e., viewing technology and gameplay challenge) that had effects primarily on their specific intended immersion dimension (i.e., system/perceptual and challenge). The fact that the 3D VR gameplay condition of Experiment 1 resulted increases in all 3 immersion subscales, and the comparison of easy and medium gameplay conditions in Experiment 2 yielded an increase in only the challenge subscale, indicates that the manner in which challenge is increased does matter. By holding nearly every variable of the virtual gameplay experience constant and simply extending the length and difficulty of the racetracks (Experiment 2), resulted in a specific increase in challenge subscale scores. However, the virtual experience differed in many ways for the VR baseline versus VR gameplay comparison of Experiment 1. Moving from passive viewing to a dynamic race environment resulted in increased challenge immersion, as evidenced by the increased challenge scores. But, the additional perceptual-motor requirements of the dynamic driving simulator may have also resulted in increased system/perceptual immersion, as evidenced by the increase in overall immersion and physical presence subscales. Some methods of increasing the challenge of a VE are likely to simultaneously increase perceptual immersive response.

However, it should be noted that the challenge and system dimensions of immersion are not entirely independent in my results. Experiment 2 was designed with a factorial crossing of viewing technology (3D VR, 2D NVR) and game difficulty (each, medium) that allowed testing for interactions that would be indicative of dependencies between system/perceptual and challenge immersion dimensions. While no direct viewing technology by game difficulty interactions were observed in the immersion survey or EEG results, the 3-way interaction of viewing order, viewing technology, and difficulty was significant for all of the immersion subscales and for 2 of 3 EEG frequency bands (see Appendices F-J). Each of the significant 3-way interactions indicates that the 2-way interaction of viewing technology and game difficulty differ significantly across order groups.

The component 2-way (viewing technology by game difficulty) interactions in the immersion subscale analyses were dominated by ordinal interactions with consistently higher means for 3D VR conditions, in relation to their 2D NVR comparison conditions, and also, consistently higher means for the medium, as opposed to easy, gameplay conditions. The pattern was one of modest quantitative variation in the magnitude of the effects of viewing technology and game difficulty manipulation, rather than any qualitative shift in the overall pattern of interaction. This suggests modest dependencies may exist between the system/perceptual and challenge immersion dimensions.
By contrast, the disordinal 2-way interactions in the theta and beta bands (see Appendices I & J) suggest either important synergistic combined effects of viewing technology and game difficulty on neural correlates of immersive experience, or habituation effects (see Discussion for Experiment 2).

Ultimately, participants in the VR condition reported higher immersion scores for each immersion subscale across both experiments. Playing in VR seems to result in a substantially more-intense perceptual experience, requiring more attentional resources and complex motor control to perform well in. This supports the findings of previous literature including McMahan (2003), Ermi and Mayra (2005), and Adams and Rollings (2006).

The findings from both Experiment 1 and 2 provide ample evidence suggesting that VR technology (specifically a VRHMD) reliably produces higher quality immersive experiences than its analogue counterparts. Based on previous studies utilizing EEG recording, such as Nacke et al. (2011), Kruger et al. (2016), and Slobounov et al. (2015), it was apparent that the transition from traditional non-VR to VR viewing caused an observable shift in the neural activity of the user, specifically the theta and beta band frequencies. Nacke et al. (2011) used a custom video game environment (consisting of three independent game levels of varying qualities challenge and immersion) that combined virtual combat against computer opponents with exploratory routes that must be navigated to complete each game level. However, the investigators did not use VR technology and presented the game on a standard computer monitor. They reported increased beta and theta for basic “immersion level” (atmospheric with complex navigation) vs “boredom level” (simple linear navigation and unexciting). They reported just a theta increase for the “flow level” (challenging and engaging) vs immersion level. Thus, their results are dominated by theta increases across game levels with just 2D viewing. While my results did not show evidence of theta increases with levels of challenge in the driving simulator, they did show theta increases were associated with changes in viewing technology.

Nacke et al. (2011) also reported a significant beta effect associated with immersion vs boredom levels. They attributed this effect to the additional challenge participants experienced as they went from walking down a straight path in a virtual outdoor environment (boredom level), to exploring a circuitous indoor and outdoor path with many unexpected opponents suddenly appearing (immersion level). The only significant beta effect found in my study, after post-hoc analysis, was associated with viewing condition (VR vs NVR) within the easy difficulty condition only. Given that Nacke et al. (2011) only used 2D viewing (monitor), the beta effect they observed in their study could not have resulted from changes in viewing technology, but most likely from the content of the game levels they produced. I may have found a beta effect in my study for similar reasons. While the content of the driving simulator racetracks was the same across both viewing conditions, the way in which participants perceived and process said content was entirely different. The beta effect found may be due to the added perceptual complexity (higher attention demand) of playing a driving simulator with VR headset versus a standard computer monitor.

An architectural study by Banaei et al. (2017) utilizing the same VR technology as in my study found that navigating a VR space resulted in an increase of theta band activity. The theta effect found in my study supports this finding as the only difference between the easy and medium difficulty conditions was the physical shape of the racetrack. Participants had to perceive and memorize an entirely different route as they navigated from start to finish. A review article by Slater & Sanchez-Vives (2016) produced a general finding that 3D VR typically results in greater theta activity most likely due to navigating new virtual spaces. Additionally, a separate review article by Palaus et al. (2017) found that beta generally tends to increase proportional to game difficulty/task complexity. This finding also supports the beta effect found in my study when considering the perceptual difference of viewing a computer monitor screen compared to having a fully encompassing, virtual reality projected around yourself.

The post-hoc analysis of just the easy gameplay sessions also yielded a similar theta increase that did not differ across viewing order groups. The driving simulator game used was specifically chosen to elicit a theta increase with viewing technology as non-gaming VR research has indicated that 3D VR viewing generally yields increased theta argued to be associated with the enriched spatial exploration and navigation that are afforded by 3D viewing of virtual worlds (Slater & Sanchez-Vives, 2016). Studies using implanted electrodes in animals and humans undergoing surgery have demonstrated increased theta due to spatial navigation in virtual environments. Recently, Liang, Starrett, and Ekstrom (2018) reported increased theta during real world navigation. These results suggest that the theta increases associated with increased system/perceptual immersion, in Experiment 2 are likely the result of the gameplay provided by the driving simulator.

The current study was not without limitations. Unfortunately, EEG analysis was somewhat hindered with the number of participants that provided viable data being far fewer than the initially desired amount. Although I had planned to run 30 participants, an unexpected disruption of participant recruitment, equipment failure, and noisy data left only ten viable participants for survey analysis and eight for EEG analysis in Experiment

2. To account for the increase in movement artifacts, which appeared more often later in the recordings, EEG analysis would be more focused on early section of the recordings collected during gaming sessions.

The early portions of the recording files consisted of participant neural activity patterns during the acclimation phase and their time playing the easy race track inside and outside of VR. These early parts of the recordings contained clearer data as participants were freshly equipped with the EEG and sat comfortably in their chairs with little movement. However, as time went on, participants began to itch/scratch their heads and shift in their seats. Naturally this disrupted EEG cap impedances and produced “noisy” data. Since the medium difficulty condition was always recorded last in both recording sessions, the later portions of the EEG recording files containing the medium difficulty track showed increasingly higher rates of movement artifacts. It was decided that data analysis would focus primarily on the participants’ easy difficulty condition.

Though I was able to find results that resembled the findings of previous studies, an increased sample size would help to strengthen the power of this study. Significant order effects show the immersive experience of a situation could be dependent on aspects of the current virtual experience, such as the nature of the challenge presented and technology of system used to deliver the virtual world, but also the nature of challenge and the perceptual experience you were having just prior to entering that virtual world. Additionally, future research of this nature would benefit from an EEG cap that is more robust to participant movement. While the cap used in the current study utilized gel to bridge the cap the participant’s scalp, a dry-fitting cap may reduce the discomfort participants may have felt during recording resulting in unconscious scratching/shifting of the cap.

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APPENDIX A: GENERAL HEALTH AND HANDEDNESS QUESTIONNAIRE

BIOGRAPHICAL INFORMATION FORM

STUDY: ________________________________ PARTICIPANT NUMBER: ________

GENDER: ________________ ETHNICITY (ASK): ___________________ AGE: _________

EDUCATION (YEARS): __________

Modified from Edinburgh Handedness Inventory (Revised)

Please mark the box that best describes which hand you use for the activity in question

	Always Left	*Usually Left*	*No Preference*	*Usually Right*	*Always Right*
Writing					
Throwing					
Toothbrush					
Spoon					

MEDICAL

Do you have a condition that would substantially reduce your performance reading words or images presented on a computer screen? Y / N

Have you ever experienced a seizure or lost consciousness due to injury? Y / N

Has a doctor every diagnosed you with a brain disorder? Y / N

Are you taking any medications that might affect your performance during computerized testing? Y / N

Do you need glasses to see a computer screen (Farsighted)? Y / N

If yes, is the participant wearing . . . GLASSES / CONTACTS / NONE

OTHER COMMENTS:

rev. 4/25/16

APPENDIX B: EXPERIMENT 1 SURVEY (MODIFIED)

Questionnaire

		Strongly disagree			Neither		Strongly agree	
	Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1C	The challenge is adequate, neither too difficult nor too easy.							
2C	My skill gradually improves through the course of overcoming challenges.							
3C	I am encouraged by the improvement of my skills.							
4C	The difficulty of the trials increased as my skills improve.							
5C	The trial provided new challenges with appropriate pacing.							
6C	The trials provide different levels of challenges that tailor to different players							
7*	I felt like I entered a state of flow during the trials. (In the zone)							
8*	I became focused on just the trial and nothing else.							
9I	I forgot about time passing while playing.							
10I	I became unaware of my external surroundings while playing.							
11I	I temporarily forgot worries about my everyday life while playing							
12I	I experienced an altered sense of time.							
13I	I can become (became) involved in the simulation.							
14I	I feel (felt) emotionally involved in the simulation.							
15I	I feel (felt) viscerally (instinctively) involved in the simulation.							
16P	The simulation seemed real to me.							
17P	I had a sense of acting within the simulation, rather than operating something from outside.							
18P	My experience in the simulation seemed consistent with my experiences in the real world.							
19P	While I was in the simulation, I had a sense of "being there".							
20P	I was completely captivated by the simulation.							

Sweat?

______

Motion sickness?

______

Claustrophobic

______

Uncomfortable?

______

APPENDIX C: EXPERIMENT 2 SURVEY (MODIFIED)

Questionnaire

The first part of the survey utilizes a 7-point likert scale with "1 = Strongly Disagree" and "7 = Strongly Agree". Mark your choices with an "X" or a check mark.

	Question	**1 SD**	**2**	**3**	**4 N**	**5**	**6**	**7 SA**
1	The challenge is adequate, neither too difficult nor too easy.							
2	My skill gradually improves through the course of overcoming challenges.							
3	I am encouraged by the improvement of my skills.							
4	The difficulty of the trials increased as my skills improve.							
5	The trial provided new challenges with appropriate pacing.							
6	The trials provide different levels of challenges that tailor to different players							
7	I forgot about time passing while playing.							
8	I became unaware of my external surroundings while playing.							
9	I temporarily forgot worries about my everyday life while playing							
10	I experienced an altered sense of time.							
11	I can become (became) involved in the simulation.							
12	I feel (felt) emotionally involved in the simulation.							
13	I feel (felt) viscerally (instinctively) involved in the simulation. (Acting on instinct)							
	Question	**1 SD**	**2**	**3**	**4 N**	**5**	**6**	**7 SA**
14	The simulation seemed real to me.							
15	I had a sense of acting within the simulation, rather than operating something from outside.							
16	My experience in the simulation seemed consistent with my experiences in the real world.							
17	While I was in the simulation, I had a sense of "being there".							
18	I was completely captivated by the simulation.							

Sweat?

_____

Motion sickness?

_____

Claustrophobic?

_____

Uncomfortable?

_____

APPENDIX D: EGAME FLOW SCALE

Factor	Item no.	Content
Concentration	*C1*	*The game grabs my attention*[a]
	C2	*The game provides content that stimulates my attention*[a]
	C3	Most of the gaming activities are related to the learning task
	C4	No distraction from the task is highlighted
	C5	Generally speaking, I can remain concentrated in the game
	C6	I am not distracted from tasks that the player should concentrate on
	C7	I am not burdened with tasks that seem unrelated
	C8	Workload in the game is adequate
Goal Clarity	G1	Overall game goals were presented in the beginning of the game
	G2	Overall game goals were presented clearly
	G3	Intermediate goals were presented in the beginning of each scene
	G4	Intermediate goals were presented clearly
	G5	*I understand the learning goals through the game*[a]
Feedback	F1	I receive feedback on my progress in the game
	F2	I receive immediate feedback on my actions
	F3	I am notified of new tasks immediately
	F4	I am notified of new events immediately
	F5	I receive information on my success (or failure) of intermediate goals immediately
	F6	*I receive information on my status, such as score or level*[a]
Challenge	*H1*	*I enjoy the game without feeling bored or anxious*[a]
	H2	*The challenge is adequate, neither too difficult nor too easy*[a]
	H3	The game provides "hints" in text that help me overcome the challenges
	H4	The game provides "online support" that helps me overcome the challenges
	H5	The game provides video or audio auxiliaries that help me overcome the challenges
	H6	*My skill gradually improves through the course of overcoming the challenges*[a]
	H7	*I am encouraged by the improvement of my skills*[a]
	H8	The difficulty of challenges increase as my skills improved.
	H9	The game provides new challenges with an appropriate pacing
	H10	The game provides different levels of challenges that tailor to different players
Autonomy	*A1*	*I feel a sense of control the menu (such as start, stop, save, etc.)*[a]
	A2	*I feel a sense of control over actions of roles or objects*[a]
	A3	*I feel a sense of control over interactions between roles or objects*[a]
	A4	*The game does not allow players to make errors to a degree that they cannot progress in the game*[a]
	A5	*The game supports my recovery from errors*[a]
	A6	*I feel that I can use strategies freely*[a]
	A7	I feel a sense of control and impact over the game
	A8	I know next step in the game
	A9	I feel a sense of control over the game
Immersion	I1	I forget about time passing while playing the game
	I2	I become unaware of my surroundings while playing the game
	I3	I temporarily forget worries about everyday life while playing the game
	I4	I experience an altered sense of time
	I5	I can become involved in the game
	I6	I feel emotionally involved in the game
	I7	I feel viscerally involved in the game
Social Interaction	S1	I feel cooperative toward other classmates
	S2	I strongly collaborate with other classmates
	S3	The cooperation in the game is helpful to the learning
	S4	The game supports social interaction between players (chat, etc)
	S5	The game supports communities within the game
	S6	The game supports communities outside the game
Knowledge Improvement	K1	The game increases my knowledge
	K2	I catch the basic ideas of the knowledge taught
	K3	I try to apply the knowledge in the game
	K4	The game motivates the player to integrate the knowledge taught
	K5	I want to know more about the knowledge taught

APPENDIX E: MULTIMODAL PRESENCE SCALE

Multimodal Presence Scale
MPS

Items

Physical Presence

PHYS_2	The virtual environment seemed real to me.	PR
PHYS_3	I had a sense of acting in the virtual environment, rather than operating something from outside.	NAPM
PHYS_4	My experience in the virtual environment seemed consistent with my experiences in the real world.	PR
PHYS_5	While I was in the virtual environment, I had a sense of "being there".	SBVE
PHYS_10	I was completely captivated by the virtual world.	NPARE

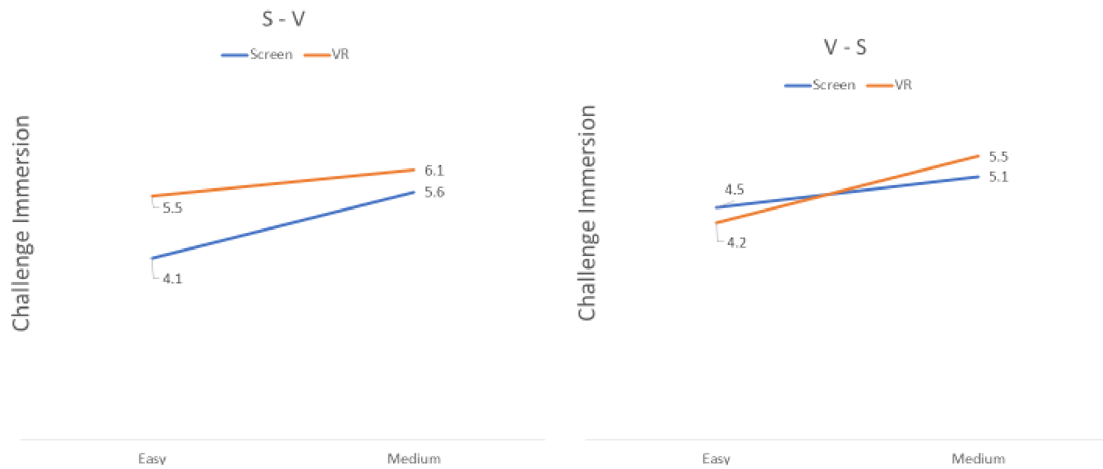
Social Presence

SOC_1	I felt like I was in the presence of another person in the virtual environment.	SC
SOC_2	I felt that the people in the virtual environment were aware of my presence.	HR
SOC_3	The people in the virtual environment appeared to be sentient (conscious and alive) to me.	HR
SOC_5	During the simulation there were times where the computer interface seemed to disappear, and I felt like I was working directly with another person.	SBE
SOC_7	I had a sense that I was interacting with other people in the virtual environment, rather than a computer simulation.	SBC

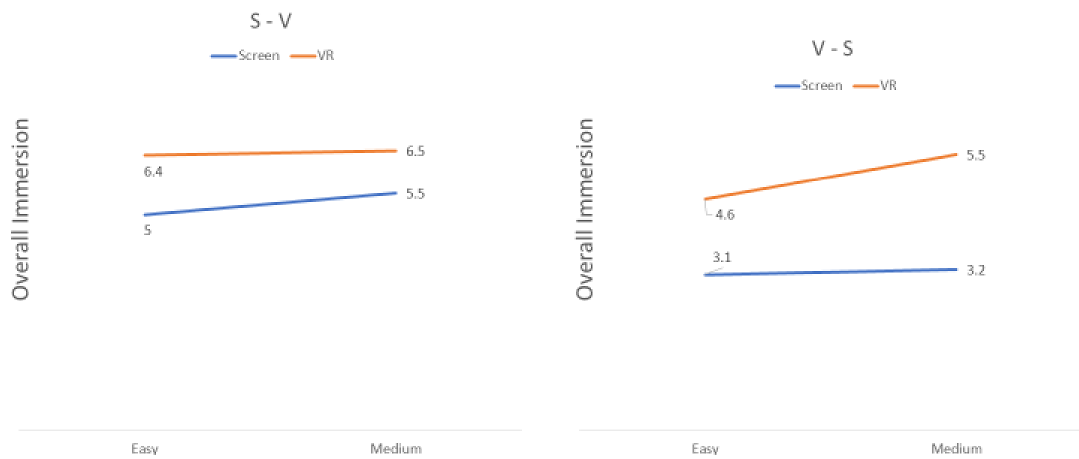
Self-presence

SELF_2	I felt like my virtual embodiment was an extension of my real body within the virtual environment.	SBE
SELF_3	When something happened to my virtual embodiment, it felt like it was happening to my real body.	SBC
SELF_4	I felt like my real arm was projected into the virtual environment through my virtual embodiment.	SBC
SELF_6	I felt like my real hand was inside of the virtual environment.	NASM
SELF_7	During the simulation, I felt like my virtual embodiment and my real body became one and the same.	NAASI

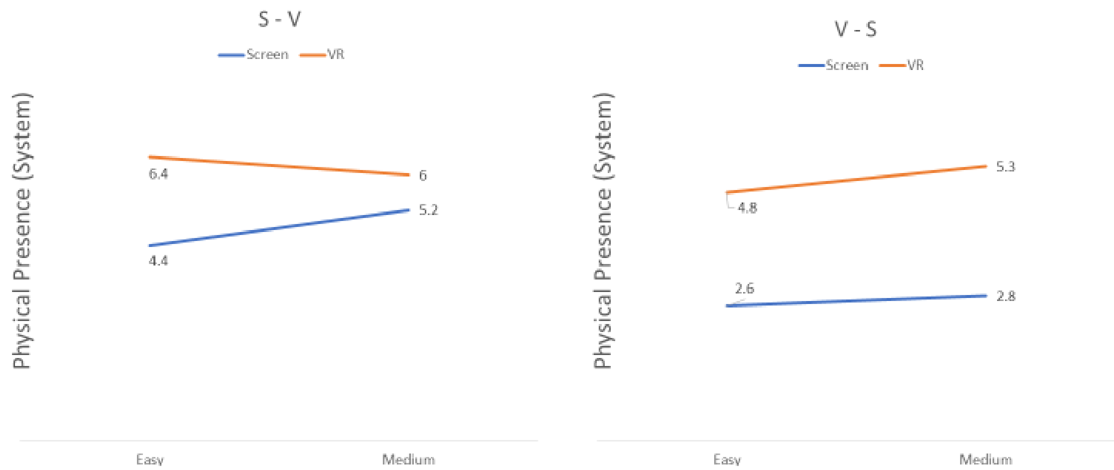
APPENDIX F: MEAN CHALLENGE IMMERSION SCORES BY VIEWING CONDITION AND DIFFICULTY



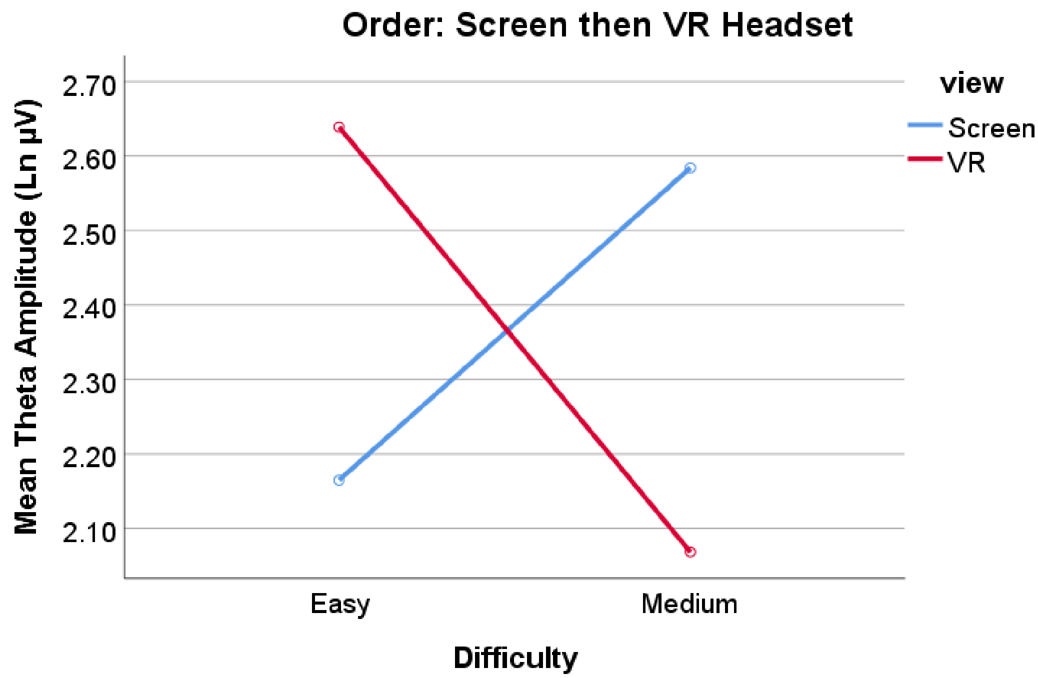
APPENDIX G: MEAN OVERALL IMMERSION SCORES BY VIEWING CONDITION AND DIFFICULTY

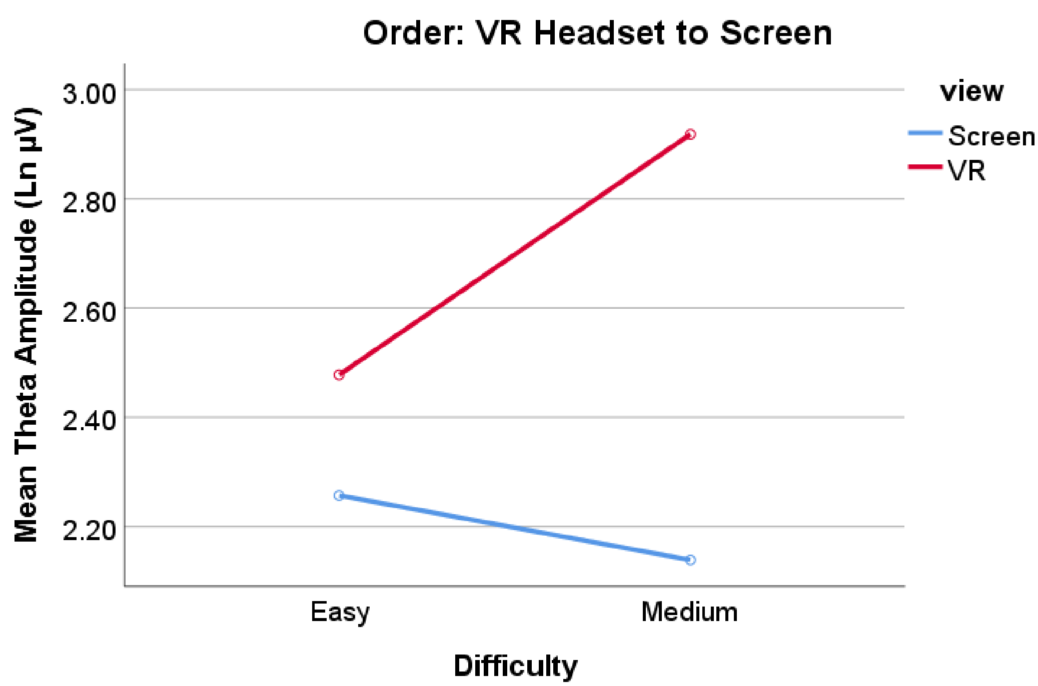


APPENDIX H: MEAN PHYSICAL PRESENCE SCORES BY VIEWING CONDITION AND DIFFICULTY



APPENDIX I: MEAN THETA AMPLITUDE BY ORDER, VIEWING CONDITION & DIFFICULTY





APPENDIX J: MEAN BETA AMPLITUDE BY ORDER, VIEWING CONDITION & DIFFICULTY