Measurements of Presence and Multisensory Stimulation

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Measurements of Presence and Multisensory Stimulation in Virtual Reality

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Abstract

Presence in virtual reality measures the extent to which users respond to a virtual experience as if they were present in it. Users experiencing presence will respond to the virtual environment as if it were real and ignore real-world stimuli to varying degrees. Studies show that incorporating additional multisensory stimuli along with the standard audio-visual stimuli may increase feelings of presence. Presence is typically measured via post hoc questionnaires or neurophysiological measurements. Although subjects who are immersed in virtual reality may exhibit neurophysiological reactions to virtual stimuli similar to those they would exhibit in the real world, subjects in some studies do not report feelings of presence in post-test questionnaires. This discrepancy may occur because the questionnaires are administered post-test when users have been removed from the experience that elicited feelings of presence. This study examined whether users experience higher levels of presence when additional sensory stimulation is integrated into a task-based virtual reality system and presence is measured during the experience. A modified repeated-measures experimental pre-test/post-test was conducted using task-based scenarios to measure presence and neurophysiological responses. This study manipulated timing and method of survey delivery as well as haptic and olfactory integration. The iGroup Presence Questionnaire (IPQ) and electroencephalography (EEG) activity were used to measure presence. Subjects also received a short qualitative survey post-test.

No statistically significant differences were found in EEG measurements or IPQ scores among subjects (*N=15*) who received different sensory treatments. This may be partially attributed to COVID campus requirements that subjects wear masks during the study. There was a significant difference in the F8 EEG band (placed over the frontal lobe) measurements for in-test survey with additional sensory stimulation compared to post-test survey with no additional sensory stimulation. Combining additional sensory stimulation and administering a survey in-test showed increased EEG activity in the frontal lobe, which may indicate higher levels of presence. Subjects answering a short qualitative questionnaire reported higher levels of presence when olfactory stimuli and olfactory stimuli in conjunction with haptic stimuli were

introduced during treatment. IPQ scores and EEG measurements do not support self-reports. A larger sample of subjects (N=35) who did not receive any additional sensory stimulation showed a statistically significant difference in the O2 EEG band (placed over the occipital lobe) measurements between groups that were administered a questionnaire in-test by a non-player character compared to groups where the questionnaire was administered in-test by a researcher or post-test on a computer (traditional method). Integrating a presence survey into a virtual reality experience (via NPC) may cause increased EEG activity in the occipital lobe, which may suggest higher levels of presence in users.

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Table of Contents

Abstract **2**

Acknowledgements **4**

Table of Contents **5**

Chapter 1: Introduction **9**

Cognitive Implications of Virtual Reality 16

Overview of Sensory Integration in Virtual Reality 20

Training and Education 24

Ethical Concerns About Creating Full Immersion 26

Methods for Measuring Presence 28

Research Questions and Specific Aims 31

Research Questions and Hypotheses 32

Chapter 2: Literary Review **34**

Measuring Presence 34

Multisensory Integration in Virtual Reality 46

Theories of Cognition 61

Body Ownership and the Ethics of Immersive Virtual Reality 74

Summation and Analysis 85

Chapter 3: Methodology **88**

Research Questions and Hypotheses 88

Methodology 89

Research Method 89

Operational Definitions 90

Variables 92

Population and Sampling Strategy 93

Tools 97

Methods 104

Chapter 4: Results and Data Analysis 108

Research Questions and Hypotheses 108

Data Analysis and Conversion 109

Statistical Hypotheses and Analyses 111

Small Sample Data Analysis and Results 112

Full Sample Data Analysis and Results 119

Qualitative results 127

Motion Sickness and Virtual Reality Sickness 130

Summary of Analyses and Results as related to the Research Questions and Hypotheses 130

Conclusion 135

Chapter 5: Conclusion 138

Research Goals 138

Research Questions and Hypotheses 139

R1 139

R2 139

Summary of Experimental Study 140

Sampling 140

Experiment Design 140

Methodology 141

Summary and Analysis of Results 142

Fisher's exact test 143

Qualitative results 143

T-tests, ANOVA, and Mann Whitney U Tests 145

Paired Sample T-test and Wilcoxon Signed Rank Test 147

Limitations of the Study 150

Conclusions that may be drawn from the data 154

Recommendations for further research 156

Conclusion 156

Appendix A: Recruitment, Subject Screening Questionnaires, COVID Precautions, Consent Form 160

Recruitment Letter: 160

Subject Screening Questionnaire 160

COVID 19 pretest Survey 161

COVID 19 Precautions 161

Appointment letter 162

Consent Form 163

Appendix B: Results 169

Full Sample Means – No Sensory Stimuli (N=35) 169

Decibel to Hertz conversion criteria 170

Table of Jarque-Bera test results 172

Small Sample Jarque-Bera test (N=15) 172

Full Sample Jarque-Bera test (N=35) 174

NPC-Researcher Jarque-Bera test (N=23) 175

Researcher-Posttest Jarque-Bera test (N=26) 176

NPC-Posttest Jarque-Bera test (N=21) 177

Table of Fisher's Exact Test Distributions 178

Tables of Results for Fisher's Exact Test Threshold I 180

Tables of Results for Fisher's Exact Test Threshold II 192

Tables of Results for Paired-Sample t-Test (N=15) 205

Tables of Results for Wilcoxon Signed Rank Test (N=15) 207

Tables of Results for Two-Independent-Sample t-Test (N=35) 215

Two-Independent-Sample t-Test NPC-Researcher (N=23) 215

Two-Independent-Sample t-Test NPC-Posttest (N=21) 221

Two-Independent-Sample t-Test Researcher-Posttest (N=26) 226

Tables of Results for One Way Within Subjects ANOVA (N=35) 233

Tables of Results for Mann Whitney U Test (N=35) 243

Mann Whitney U Test NPC-Researcher (N=23) 243

Mann Whitney U Test NPC-Posttest (N=21) 246

Mann Whitney U Test Researcher-Posttest (N=26) 248

Appendix C: Surveys 251

Qualitative Post-test Questionnaire 251

iGroup Presence Questionnaire (IPQ) 251

Virtual Reality Sickness Questionnaire (VRSQ) 252

Motion Sickness Susceptibility Questionnaire (MSSQ) 253

Appendix D: Figures 257

Bibliography 262

Chapter 1: Introduction

Virtual Reality

There have been many attempts to define virtual reality, ranging from simply a "computer generated world" (Pan & Hamilton, 2018) to a fully immersive system that involves all of the senses of the human body (Pope, 2018) to any system in which participants feel as though they have been transferred to a space other than their own. Most agree that virtual reality must involve more than mere computer worlds, as this would define almost all games and movies as "virtual reality." Furthermore, most systems labeled virtual reality do not engage all human senses, usually being limited to visual and auditory engagement. Some virtual reality systems involve haptic and olfactory senses, but this is far less common. The third listed definition is also too broad, as it would include books as well as several psychological disorders. ***For the purposes of this paper, virtual reality shall be defined as an immersive system that incorporates both hardware and software which engage multiple human senses.***

Reality

There are many philosophical theories regarding what defines reality. According to constructivists, reality exists as an extension of the human mind – objects and constructs exist and are real because people say they are (Schiappa, 2003). Others theorize that reality consists of entities that objectively exist and possess physical boundaries whereas virtual reality is more subjective and includes psychological constructs (Ma & Choi, 2007). Others posit that everything exists in both reality and virtuality. According to this theory, reality is comprised of objects as they exist, and virtuality refers to the concepts and thoughts pertaining to existing objects (Heim, 2000).

For the purposes of this paper, reality shall be defined as both physical and psychological constructs that exist outside of the virtual reality experience as defined above.

Immersion

Immersion refers to the degree of engagement a user experiences in a virtual reality system. The higher the degree of engagement, the higher the degree of immersion. There are many factors that affect immersion level in virtual reality including graphic quality and performance, runtime, amount of lag, field of view, and render speed. The better the quality and the more seamless the system, the higher the degree of immersion is achieved.

Immersion may also be affected by degree of interactivity present in the experience. The more interactive an experience is, the higher the degree of immersion. Furthermore, immersion intensifies when additional limbs are engaged and more sensory stimuli are added (Slater, 2018). Studies show that multisensory fidelity is important for producing an immersive experience. The more similar a virtual reality experience is to an experience in real life, the more immersive the experience appears to users (Cummings & Bailenson, 2015). Immersion may also be impacted by external stimuli that distract users from the virtual experience (Farda, 2021). Some use the terms "immersion" and "presence" interchangeably, but that is less accurate because presence describes a different feature of virtual reality (Slater, 2018).

Presence

Presence in virtual reality measures how much users respond as if they are actually present in a virtual experience. When users experience presence, they will respond to the virtual environment as if it were real and ignore real-world stimuli to varying degrees. The degree of presence experienced by users is affected by various factors. Sheridan pinpointed several categories that affect presence: sensory information, user ability to control sensors, and agency of users to affect physical environment (motor control) (Sheridan, 1992). Some of these factors include graphic quality, frame rate, audio quality, head tracking, and interaction modality (Schwind et al., 2019). Various studies identified other elements that influence presence including asymmetry (Jeong et al., 2020), motion parallax (Eftekharifar et al., 2020), gender, and age. Presence may also be referred to as a "virtually real experience" and may be linked to body ownership transfer, discussed later in this paper.

Some factors that affect how likely users of virtual reality are to experience presence include "context realism" and "perspectival fidelity". Context realism refers to how faithfully a virtual experience copies actual reality. The more contextually real an experience, the more likely users are to experience feelings of presence. Because everyone may interpret reality differently due to life experience and cultural bias, context realism may be comparatively subjective (Ramirez & LaBarge, 2018). Graphic and audio quality may not affect context realism (Slater, 2018). Perspectival fidelity refers to how faithfully a virtual experience matches the perspective of an average, neurotypical person. Users are more likely to respond to virtual reality experiences with higher levels of perspectival fidelity as if they were real (Ramirez & LaBarge, 2018). Audio and graphic quality, as well as presence of multisensory stimuli may affect perspectival fidelity (Slater, 2018).

Studies utilizing self-reporting questionnaires (Slater, Usoh, and Steed (SUS) and Witmer and Singer (WS) found that subjects cannot differentiate between presence in real life and virtual reality (Usoh et al., 2000). Studies utilizing neurophysiological methods of observing presence made similar observations (Petukhov et al., 2020). Physiological and neurophysiological studies of virtual reality generally concur that providing multisensory stimuli in and of itself is more important than the modus in which they are employed (Gentile et al., 2011) (Gentile et al., 2013) (Brozzoli et al., 2012) (Brozzoli et al., 2011) (Ehrsson, 2020) (Juliano et al., 2020).

History of Virtual Reality

It is difficult to pinpoint the exact historical beginnings of virtual reality, especially since the phrase “virtual reality” was not used until the 1980s. Some argue that virtual reality began with panoramic paintings in the 1800s, where the artists attempted to surround and transport their viewers to the world depicted in the paintings. Others suggest that virtual reality started with the photographic stereoscope created by Charles Wheaton in 1838 and its many offshoots (Pope 2018). The first flight simulator was not created until 1929, followed by Morton Heilig’s “Sensorama” in the 1950s. Heilig continued his work and patented the first head-mounted virtual reality system, the “Telesphere”, in 1960. Shortly afterward, two engineers created the first motion tracking system in 1961. All of these systems utilized cameras, but they were not truly interactive. It was not until 1968 that Ivan Sutherland created the first virtual reality headset that was connected to a computer. Myron Krueger coined the phrase “artificial reality” to describe his real-time computer-generated environments from 1969 to 1975. In 1982, “Sayer gloves” were invented, which connected finger-mounted sensors to a computer to track the movement of the hands. Jaron Lanier of VPL Research, a firm that sold HMD systems and gloves, popularized the term “virtual reality” in 1987. NASA began utilizing virtual reality as a training tool in 1989. The Mars Rover incorporated a virtual reality piloting system in 1991, the same year that virtual reality arcade games were released for the first time. In 1993, Sega developed a virtual reality headset to pair with their gaming systems, but it was never released to the public. The following year, Sega released a different virtual reality system, and Nintendo released Virtual Boy in 1995. Emory and Georgia Tech utilized virtual reality in groundbreaking PTSD research in 1997. In 2010, Google Street View converted to 3D and Oculus developed the prototype for the Rift, which was kickstarted in 2012. Facebook purchased Oculus in 2014, providing it with additional development capital. From 2016-2020 many virtual reality systems were released, including HTC Vive, Oculus Rift, and Google Glass (Menary, 2010) (Virtual Reality Society 2018). Virtual reality systems continue to develop and become more accessible to both developers and users.

Over time, many industries utilized visual and auditory equipment for various purposes, making them accessible and inexpensive. Equipment that incorporated other sensory stimulation, such as haptic, olfactory, and gustatory, was not historically as prevalent in other industries and remained costly, unsophisticated, or otherwise limited. Consequently, virtual reality research and development primarily utilized visual and auditory equipment. In more recent years, haptic and olfactory integration has become more prevalent in virtual reality research. Devices integrating these senses remain rudimentary compared to visual and auditory devices. Devices integrating multisensory stimulation are regularly studied in relation to presence, immersion, and other virtual reality related phenomena. Gustatory studies remain incredibly scarce and rarely examine associations to immersion and presence.

Societal perceptions of virtual reality have changed over time. Virtual reality vacillated between public popularity in the news and fading into the background of public thought. This may be because virtual reality devices were not consistently or readily available to the public. Whenever societal interest in virtual reality faded, funding for development of these systems became scarcer. Commercial industries do not want to allocate funding for projects that will not produce significant return on investment. When arcades were popular, commercial industry funded virtual reality machinery for the arcades. When home consoles became more affordable, public interest in arcades faded along with funding for arcade based virtual reality machines. In later years, producing and disseminating head-mounted audio-visual virtual reality displays became cheaper and easier, and they became the main interest of commercial research and production. Individual consumers are more likely to purchase low-cost systems that they can use at home or integrate with equipment they already own. Modern virtual reality arcades utilize these same low-cost systems to entertain their clientele.

Researchers, however, have maintained fairly consistent interest in virtual reality throughout history. Academics sought to overcome and understand its novel mechanics and limitations while government, military, and medical industries continued to research virtual reality to exploit its training potential.

Technological Aspects of Virtual Reality

Over the years there have been many technological advances in the field of virtual reality. As technology has advanced in both system speed, graphic quality, and incorporation of body movement, the degree of presence and immersion possible in virtual reality has increased.

Popular entertainment and industrial use motivated research and development of visual and auditory equipment including the stereoscope in 1833 and Cathode Ray Tube in 1897. Additional sensory stimulation in virtual reality requires specialized equipment, which may be costly, impractical, ineffective, difficult to obtain, and not easily employed or disseminated. Visual and auditory equipment was also historically bulky, expensive, and difficult to produce. The scarcity and costs involved in developing and maintaining such equipment limited it to academics and wealthy individuals with time and means to study it. Consequently, the expense restricted extensive development and experimentation. When visual and auditory equipment became cheaper, easier to use, and more readily available over time, they became the primary tools of virtual reality research and development. Although increasingly prevalent in research, olfactory and haptic devices remain relatively rudimentary or expensive. Most haptic and olfactory integrations are primarily research based and are not readily accessible otherwise. Even in research, gustatory integration remains incredibly rare.

Over time, studies have pinpointed various technological factors that affect presence and immersion in virtual reality. Seamless gameplay and higher frame rates provide better response times for users and so users are not forced to wait for the experience to catch up, which removes them from immersion and produces a break in presence. Interestingly, although a certain degree of graphic quality is required for higher levels of presence and immersion, graphics that are too realistic may detract from feelings of presence. This may be due to the “uncanny valley” theory, which claims that avatars and interactions that are too realistic are uncomfortable for users because they are still missing some component of realism (Rosenthal-von der Pütten et al., 2019). Another possibility is that people’s experience of the world is not always perfect (we do not always see and hear everything perfectly), making perfect graphics unrealistic.

Summary of some of the more popular virtual reality systems:

As virtual reality became more popular in the early twenty-first century, various systems were developed for commercial use and became relatively popular with the public. Of these systems, Google Cardboard, Oculus headsets, and HTC Vive are perhaps the most popular tools for developers because of their low price, easy access to developer support, and comparatively straightforward and accessible development tools.

Oculus

The founders of Oculus wanted to create virtual reality systems that everyone could develop for and use. The company developed their first lightweight head-mounted virtual reality display, the Oculus Rift, in 2013. The system utilized motion tracking cameras that were mounted in front of the user along with hand mounted controllers and a wired headset. Later, Oculus developed more streamlined systems including better iterations of the Rift and wireless systems named Quest and Go. The lower price point of the Oculus systems makes them very popular for both developers and users. Some Oculus systems still require a relatively powerful computer system (*Oculus | VR Headsets & Equipment*, n.d.) (DJSCOE, Vile - Parle (W), Mumbai et al., 2014).

HTC Vive

HTC developed a lightweight head mounted virtual reality system in 2015. Like the Oculus Rift, the HTC Vive requires a set of motion tracking cameras mounted at specific angles and distances from the user. The HTC Vive requires more floor space than the Oculus unless the user activates “standing mode” which does not allow moving around the room. The HTC Vive also utilizes hand-held controllers. Earlier iterations of the system were wired to a computer, but newer iterations are wireless. The HTC Vive costs more than double the price of the Oculus Rift but is still a popular choice for developers (*VIVE United States | Discover Virtual Reality Beyond Imagination*, n.d.).

Google Glass

Google Glass was first introduced in 2013 by Google. The Google Glass was a heads-up-display designed to look and be worn like a standard pair of eyeglasses. The device projected information and graphics over the user’s real environment. The price point was significantly higher than other head mounted systems, and the device was not made available other than to a select few developers. Production ceased in 2015. In 2017, Google released an updated version of the Google Glass, the Google Glass Enterprise. The Google Glass is generally used for training and therapy purposes (*Glass*, n.d.).

CAVE

A group of researchers at the University of Illinois, Chicago developed the first CAVE system in 1992. They wanted to create a virtual reality environment to display their work without forcing users to wear cumbersome, unwieldly equipment. A CAVE Automatic Virtual Environment (CAVE) is a system composed of large screens that surround and immerse users in virtual reality. Most CAVE systems integrate user interaction and tracking. Unlike many head-mounted systems, CAVE systems minimize image distortion. Typically they incorporate off-axis projectors to deliver stereo vision along with other techniques that minimize user shadow obstruction and provide more realistic interactions (Cruz-neira et al., 1993) (Cruz-Neira et al., 1992).

Variations of the CAVE system are used today, but most are primarily owned and used by institutions for training and research. Since they require a large amount of space and equipment, they are not typically accessible for public use and development.

Sony PlayStation VR

Sony released a head mounted virtual reality system for their PlayStation game systems in 2016. Although the cost of the system was relatively inexpensive, the system requires a PlayStation four or five in order to function. Moreover, the development tools are more expensive and difficult to use, which makes it less popular for independent developers (*PlayStation VR | Live the Game in Incredible Virtual Reality Worlds*, n.d.).

Google Cardboard

Google Cardboard or Google VR is a lightweight head mounted virtual reality system initially released in 2014 that attaches to a smart phone. The original Google Cardboard was made of cardboard with plastic lenses and a magnetic “button”, easy to assemble, and inexpensive. The system utilizes the smart phone gyroscope for location tracking and 3-axis magnetometer to detect “button” clicks. Other companies released inexpensive plastic and cardboard headsets that work with the Google Cardboard applications and other similar applications for smart phones. The low price point of the system is attractive to users and developers. Users and developers may also integrate accessories including handheld controllers (*Google Cardboard – Google VR*, n.d.).

Cognitive Implications of Virtual Reality

“4E Framework of Cognition”

User experience and behavior in virtual reality is frequently studied utilizing the 4E Framework of Cognition, a conglomeration of several concepts and theories in psychology, philosophy, and cognitive science (Kellmeyer, 2019). The 4E Framework consists of four classifications known as embodied cognition, enacted cognition, embedded cognition, and extended cognition (Menary, 2010). The theory of embodied cognition suggests that cognitive function is not limited to the central processes of the brain, instead involving extracranial cognitive processes throughout the body. These extracranial processes facilitate various cognitive functions including perception and spatial navigation. Embodied cognition requires that the brain dynamically interface with other areas of the body's system in real-time in order to interact with the external environment. Enacted cognition refers to the theory that cognition does not only entail extracranial activity, but also interaction with the external environment. Enacted cognition refers to various cognitive dependencies connected to the external environment and whether they produce a desire to act. Embedded cognition refers to how the body is embedded in its environment and how it interacts with its surroundings. If a cognitive process expands beyond the physical boundaries of the body, it is regarded as extended cognition (Newen, Gallagher, et al., 2018).

Functionalism theorizes that different parts of the brain and body perform distinct functions. According to this theory, cognitive functions occur solely in the brain. Although many traditional cognitive theories are based on functionalism, the 4E framework argues that numerous parts and processes of the body are integrated into cognition (Newen, De Bruin, et al., 2018).

"Body ownership and body memory"

According to various studies, establishing a stable and accurate mental self-representation of one's body, including its physical boundaries and where it exists in relation to other objects, is important for a healthy psyche. The ability to create a body self-image that is closely similar to one's physical body is referred to as "body ownership"(Kellmeyer, 2019a). Various factors may skew an individual's sense of body ownership as occurs in people with somatoparaphrenia or body dysmorphic disorders (Martinaud et al., 2017).

The "rubber hand illusion" and its connection to body ownership has been famously studied over the years. From 1998 to 2014, researchers conducted a series of experiments in which a rubber hand replaced the position of a participant's hand while their own is hidden from view. When researchers touched the rubber hand simultaneously with the participant's actual hand, individuals experienced the illusion that the rubber hand was their own. Some subjects even perceived agency over the rubber hand, believing that they could affect its movements (Kalckert & Ehrsson, 2014). Earlier iterations of this experiment examined how subjects moved their own hidden hand when presented with various moving objects including a wooden block, rubber hand, and real hand. The studies found that subjects responded least accurately when presented with a wooden block and most accurately when presented with a real hand (Holmes et al., 2006).

Body-related memories formed both indirectly and through direct activities are referred to as "body memory." Body memory may include tasks associated with muscle memory, such as playing a musical instrument, as well as the memory of physical perceptions, such as the sensation of water when entering a pool (Kellmeyer, 2019).

The literature implies that body ownership consists of a combination of current multisensory stimuli and prior knowledge, including body memory (Kilteni et al., 2012). When someone experiences a sense of body ownership for objects outside their actual body, it is called "body ownership transfer."

Some amputees experience a "phantom limb" phenomenon after undergoing an amputation. Persons undergoing this phenomenon feel as though their missing limb subsists and may even experience sensations of pain in their non-existent limb. This phenomenon occurs because the amputee's body memory and sense of embodiment still include a mental representation of the absent limb. To reduce the phantom limb sensation, the amputee must diminish their mental connection to the lost limb. On the other hand, the amputee should strengthen their connection to any prosthetic limb so that it may be properly integrated into body ownership and body memory (Blumberg & Dooley, 2017). People with lower limb amputations may also be more susceptible to cognitive impairment than the general population (Lombard-Vance et al., 2018).

Virtual body ownership and virtual body memory

As with body ownership, individuals engaging in virtual reality immersions form mental representations of their body in virtual space. Users immersed in virtual reality should experience agency over the virtual world — that their actions directly influence it. The physical manipulanda that influence interactions in virtual space are referred to as "virtual embodiment" (Spanlang et al., 2014). Many studies have been conducted to research and exploit these sensations and how they induce illusions of virtual body ownership as well as body ownership transfer to virtual bodies.

"Self, Identity, and Authenticity"

The Proteus Effect refers to an interesting behavior where computer game and virtual reality users identify with their in-game avatars and modify their behavior to match. Although it is still not well understood, studies examining the Proteus Effect observed that it is a relatively consistent phenomenon. Some believe that the "self-perception theory" may explain the Proteus Effect. The self-perception theory refers to the concept that individuals develop mental representations of themselves as if they are being seen by another person (Ratan et al., 2019). Some suggest that self-perception may be more common in users of virtual reality because of "deindividuation" resulting from the anonymity provided by virtual worlds, which may reduce individual self-focus. This causes individuals to focus on external appearances for their avatars, such as clothing and hair, which may in turn alter their own behavior and attitude (Yee & Bailenson, 2007).

Cognitive models of identification are used in various studies and assessments examining the effects of video games on self-perception. The general consensus among researchers is that theories of identification concerning interactive games and virtual environments are different than theories relating to non-interactive media, including television. Users are more likely to identify with material presented via interactive media and are also more likely to modify self-perception (Klimmt et al., 2009).

Virtually real experiences and Context Realism

"Virtual realism" is another term used to describe presence. In virtually real experiences, users feel as if they are actually transported to a new environment. Users can easily adopt modes of manipulation in virtual reality even if they are different from those they use in actual reality. Users treat these experiences as if they are real. Many current virtual reality experiences are not virtually real experiences because they lack sufficient perspectival fidelity and context realism, which removes the user from total immersion in the experience. Only virtual reality can create these experiences (Ramirez & LaBarge, 2018).

Context realism refers to how well the content of a virtual reality immersion matches a user's reality. The closer that the rules of the virtual reality match the rules of the user's actual reality, the higher degree of context realism. Simulations that require more gesture-based interaction are more "context real." (Ramirez & LaBarge, 2018). Because cultural upbringing and life experience may influence a person's interpretation of reality, context realism may be fairly subjective (Ramirez & LaBarge, 2018). Additionally, graphic and audio quality and equipment may not affect context realism (Slater, 2018).

Overview of Sensory Integration in Virtual Reality

Although historically, virtual reality was meant to incorporate all human senses, in practice, most modern applications only incorporate two – visual and auditory. This is in large part due to a historical interest in visual and auditory equipment for use in industries for mass circulation including popular entertainment. Once visual and auditory equipment became cheaper and more easily acquired, researchers and developers of all income levels quickly adapted them for virtual reality. Consequently, virtual reality utilizing visual and auditory stimulation is easily available and widely studied. Equipment for incorporating other sensory stimulation was not as appealing to mass distribution industries and remained costly and undeveloped outside of research and government institutions. Accordingly, such specialized equipment is not typically used and may be impractical or ineffective for various reasons including expense and difficult utilization. Haptic and olfactory integrations have become more prevalent in research and development as they become more affordable and obtainable but are still not readily accessible to the public. Gustatory integration is still incredibly rare, even in research. Studies researching multisensory integration in virtual reality suggest that the more senses that are engaged, the greater the likelihood of increasing feelings of presence. These studies also indicate olfactory stimulation may be more crucial to increasing presence than haptic integration, but that is not conclusive.

Haptic Integration

Haptic stimulation in virtual reality enhances immersion and presence as shown in multiple studies (Y. M. Kim et al., 2020) (George et al., 2020). Participants in a 2020 study were asked to perform virtual tasks using an avatar while immersed in virtual reality. Researchers measured the difference between simultaneous visual-haptic stimulation and nonconcurrent visual stimulation by touching participants on their backs (another example of impractical haptic integration). The study analyzed subject response in an attempt to quantify perceived self-location in virtual reality (Nakul et al., 2020).

Haptic feedback may be classified using several categories. The most common of these categories are “active” and “passive”. Active haptic feedback actively exerts force on the user by means of computer-controlled devices. Passive haptic feedback does not actively exert force on the user. Instead, devices are used to provide force feedback more passively. These devices may use bands that stretch with user movement or other mechanisms for providing resistance (Zenner & Kruger, 2017).

Many virtual reality devices, including the HTC Vive and Oculus Rift, offer simple haptic stimulation in the form of vibration. More complex haptic stimulation necessitates specialized equipment, which restricts development and distribution. Moreover, haptic devices and research thereof are not standardized or regulated – ranging from the incredibly complex to absurdly rudimentary (including researchers touching subjects, which is difficult to standardize). The lack of consistency may also limit the breadth of knowledge in the field.

Olfactory Integration

Although numerous studies integrated olfactory cues into virtual reality, many of these studies do not examine the relationship between olfactory cues and presence. Many studies that did examine the relationship between scent and presence tend to agree that presence is influenced when olfactory cues are integrated into the virtual reality system. Participants are more likely to experience presence when they can identify odors and when olfactory stimulation is administered simultaneously with matched auditory and visual cues (S. Jones & Dawkins, 2018) (Dinh et al., 1999) (Harley et al., 2018).

Human noses are very sensitive to scents and can detect certain odors (such as sulfur) even at very low concentrations. Interestingly, pungency is perceived via separate receptors than smell. Individuals with damaged or reduced olfaction may still be able to detect pungency. Malodors have been positively correlated with self-reported negative feelings including aggression, tension, depression, fatigue, and confusion. Furthermore, people may experience negative feelings and degraded mood when offered prospective malodor even if none is present (Dalton et al., 2020). Studies show that cognitive function may be affected by the presence of odors. Cognition is more likely impacted by unpleasant odors than pleasant odors (Nordin et al., 2017). Additionally, studies suggest that difficult cognitive tasks are more likely to be impacted by malodor than simple cognitive tasks (Dalton et al., 2020).

A series of virtual reality studies found that presence in task-based scenarios was significantly more impacted by unpleasant odors than pleasant odors. These studies observed higher levels of presence when users were exposed to odors that matched the virtual reality environment, as opposed to discordant odors. Additionally, these studies observed that pleasing scents affected user sense of reality but did not significantly impact feelings of presence. The studies utilized self-reporting questionnaire ITC Sense of Presence Inventory (ITC-SOPI) to measure sense of reality and presence (Baus & Bouchard, 2017) (Baus et al., 2019).

In a 2018 study, scents were dispensed from a custom device to examine how wind, thermal, and olfactory stimuli affect presence. Researchers measured presence using a Witmer and Singer based self-reporting questionnaire. Electrodermal activity and heart rate were also measured. Subjects were exposed to different arrangements of stimuli including 1) visual and audio only, 2) visual, audio, and olfactory, 3) visual, audio, and wind, 4) visual, audio, and thermal, and 5) audio, visual, olfactory, wind, and thermal. The study found the largest variations in physiological data and highest levels of presence when all five stimuli were deployed. A combination of audio, visual, and olfactory stimuli also produced significantly higher presence levels than any other partial combinations. This study utilized pleasant odors only (Ranasinghe et al., 2018).

Another study attempted to elicit emotional responses from subjects by incorporating olfactory cues into a video game. The results of this study showed that visual and auditory cues combined with olfactory stimulation produced greater emotional responses than audiovisual cues alone. This study also dispensed pleasant scents (Ranasinghe et al., 2019).

Currently, most olfactory devices necessitate specialized paraphernalia or substantial researcher interference and are not optimized for extensive utilization or portability. Consequently, research studying the effects of olfactory stimulation on presence in virtual reality is not well-regulated or uniform. Many olfactory studies use different evaluation criteria and different methods of deploying the scents. Some methods are hard to regulate and make uniform. For instance, some studies involve a researcher holding a vial in front of a subject's nose, while others use elaborate devices to dispense fragrances. Some even simulate scents utilizing electrical stimulation. Some olfactory research in virtual reality focuses on making the integration work more than studying presence or immersion. Furthermore, studies are conducted by researchers in varying fields, utilizing very different equipment, on subjects in varying countries on differing populations (age, gender, ethnicity, etc.), which makes it difficult to evaluate current literature for intersecting effects and corroborative evidence.

Gustatory Integration

Of all the sensory integrations in virtual reality, gustation is the least explored. One possible explanation for this is the inherent difficulty in developing a refillable mechanism that does not require continual replacement that is also acceptably hygienic. Various studies have attempted to integrate gustatory stimulation, but these often require unwieldy apparatuses, heavy researcher interaction, or consumables that are difficult to regulate. Many gustatory devices function using chemical, thermal, or electrical stimulation. While researchers have studied how various conditions in virtual reality are affected by gustatory stimulation and vice versa, taste has not been extensively studied for relationships to presence.

A comprehensive search yielded very few studies relating gustation to presence in virtual reality. One of the few such studies required subjects to eat real food to advance to the next level of a virtual reality game. User experience was measured using the Game Experience

Questionnaire (GEQ), which includes a limited section evaluating social presence (Arnold et al., 2018). The majority of gustatory virtual reality studies do not examine immersion or presence, focusing instead on development and analysis of delivery systems. Because most of the studies on gustation focus on implementation, evaluate factors other than presence and immersion, and are conducted by experts in varying fields, most of the information available on gustation in virtual reality is not readily correlated.

Training and Education

The Cognitive Theory of Multimedia Learning suggests that students absorb information better when exposed to multisensory modes of instruction than they do when receiving only one mode of sensory instruction. For instance, students learn better from a combination of words and images than from words alone (Mayer, 2014).

There have been numerous studies conducted on training and educational virtual reality applications to determine if the fields identified in virtual reality are generalizable to actual reality. Many of these studies, however, were conducted by experts in various fields including education and psychology. Because of this, a lot of these studies do not design or examine the participant experience utilizing the same methodology or instruments of analysis. Consequently, many of these studies seemingly contradict one another.

A 2018 study evaluated instruction given over standard computer screen versus instruction given over virtual reality. Subjects in the study were given self-reporting questionnaires on motivation and interest as well as tested for information retention. Participants who received instruction via virtual reality reported higher levels of motivation and interest, but lower rates of understanding and information retention (Parong & Mayer, 2018).

Although numerous studies reported positive associations for virtual reality and augmented reality learning in K-12 students, augmented reality produced more consistent positive learning outcomes than virtual reality studies. This effect may be due to overwhelming cognitive load (Papanastasiou et al., 2019).

Researchers use the VR Application Analysis Framework to assess virtual reality software for educational use. The framework analyzes these applications utilizing four classifications:

“purpose”, “communicative capability”, “immersive capacity”, and “cognitive load”. Cognitive Load is a well-studied educational theory that converts easily to virtual applications. The theory of Cognitive Load suggests that human brains have limited capacity for processing data acquired through multisensory sources. Excessive data may cause overload and may not be processed or maintained in memory. Cognitive Load explains why distractions may cause lower rates of information retention. One 2021 study tested the VR Application Analysis Framework on preexisting virtual reality educational software and found that it was an effective measure for analysis of educational applications (Frazier et al., 2021).

Researchers in a 2020 study observed that impaired cognition may be associated with virtual reality. Participants in the study were shown a sequence of eight 360-degree non-fiction films alternating between head-mounted virtual reality headsets and standardized computer screens. Subjects who were shown the films on the virtual reality headset reported higher levels of presence and exhibited more physiological symptoms related to presence. These participants, however, exhibited lower levels of information cognition and retention compared to viewing the films on the standard computer screen. The study also found that sequence of presentation modes affected results (Barreda-Ángeles et al., 2020).

Educational Environmental Narratives (EEN) are story-driven interactive environments created for educational purposes. A 2019 study utilized an Educational Environmental Narrative (EEN) to examine the role of narrative and interactivity on learning outcomes in virtual reality serious games. Subjects received self-reporting measures of presence (iGroup questionnaire, (Schubert, 2003)), engagement (Brockmyer et al., 2009), cognitive interest (Schraw et al., 1995), and post hoc assessments of information learned from the game. The study reported significant score differences for subjects who were allowed to choose their own path and when information remained onscreen (C. Ferguson et al., 2019). Other studies also suggest that information retention may be facilitated by immersive virtual reality (Feng et al., 2018) and that immersive virtual reality produces better memory recall than non-immersive virtual reality (Krokos et al., 2019).

Interestingly, studies do not agree on the value of virtual reality as an educational tool. Some studies found that information retention and cognition suffered in virtual reality compared to interactive learning applications on standard screens while other studies found that students retained information better when exposed to virtual reality applications. This may be explained by the fact that all these studies were conducted by researchers in different fields and were not standardized. Dissimilar equipment, subjects, and research methods may explain the disparity in results. Furthermore, studies suggest that level of immersion affects recall and retention. Some of the studies may have utilized less immersive virtual reality applications, which may also explain the differing observations.

Ethical Concerns About Creating Full Immersion

The goal of many virtual reality applications is to reproduce real-world experiences so that they are indistinguishable from actual reality. Because virtual reality is more immersive than other media, it also necessitates more moral and ethical scrutiny. The ethical and moral concerns related to virtual reality may also differ from those of other media. Discussions of ethical apprehensions regarding virtual reality largely concur that the medium must be evaluated differently than other varieties of media. Researchers in a 2018 study observed that users who treated their experiences as if they were real while immersed in virtual reality might later report that they knew that the experience was not real the entire time and did not believe that it was real (Ramirez & LaBarge, 2018). Furthermore, users' self-reports of presence do not always agree with physiological responses indicating that users are experiencing presence (Won et al., 2015).

While material portrayed in other media may be similar to material that is portrayed in virtual reality, virtual reality presents considerably higher levels of context realism, perspectival fidelity, and presence. This may be more ethical worrying for several reasons. Users subjected to a traumatic scenario in virtual reality may suffer psychological effects comparable to a real-life experience. Virtual reality elicits higher levels of presence and neurophysiological responses than other media. Consequently, some believe that virtual reality may be a more persuasive medium than other media. Because of the influential nature of virtual reality, some are concerned that the medium may be used unethically or convince users to behave in unethical ways. Virtual reality may also be used to encourage sexism, racism, and other morally objectionable opinions more intensely than other media (Slater et al., 2020).

According to the "equivalence principle", if it is unethical to do something to an individual in real-life, it is unethical to do it to them in virtual reality (Ramirez & LaBarge, 2018). Furthermore, some believe that permanent behavioral, psychological, or even biological changes in users may result from virtual reality experiences because of the higher levels of presence and embodiment offered by the medium (Madary & Metzinger, 2016) (Jouriles et al., 2019) (Rosenberg et al., 2013). Medary and Metzinger propose a system of ethics for research and therapy in virtual reality that suggests utilizing existing cognitive and psychological knowledge when designing experiences so that virtual experiences follow the same ethical rules as a real life experience might (Madary & Metzinger, 2016).

Aggression and violence in computer games and simulations have spurred many ethical discourses and studies on how they affect society and individuals. Some believe these ethical concerns are even more prominent in virtual reality (Geldenhuys Kotie, 2019) (Dholakia & Reyes, 2018) (Prescott et al., 2018) (Slater et al., 2020). Others contend that media depictions of aggression and violence, even in virtual reality, do not influence users negatively and may even constructively function as a nonharmful channel for violence or aggression (C. J. Ferguson & Wang, 2019) (Przybylski & Weinstein, 2019) (Zendle et al., 2018). The medium is even utilized to moderate and possibly treat some behaviors, including domestic violence (Seinfeld et al., 2018), bystander behavior (Jouriles et al., 2019), and certain psychological disorders that present aggressive or violent behavior (Dellazizzo et al., 2019). Virtual reality may be utilized for beneficial therapeutic purposes, which better immersion may improve.

A number of these ethical concerns may be addressed by developers by modifying perspectival fidelity, contextual realism, or virtual realism. These efforts may include modulating user perspective, regulating content or narrative, or purposely degrading visual or auditory quality. Some suggest educating users about potential risks and safeguards along with moderating use (Slater et al., 2020). Others endorse enacting legal policies including age restrictions, privacy directives for collection and use of data, standardized rating systems, and requirements for information and warning labels (Spiegel, 2018).

Interestingly, much of the literature discussing the ethical implications of virtual reality is published by authors from other fields who are not developers themselves. This may be because even otherwise ethical developers may be more interested in discovering and improving technological aspects of the medium and do not really consider the ethical implications of their work. Some developers may unconsciously or even consciously ignore possible ethical issues, being too engrossed in the next breakthrough or interesting technological challenge than any possible moral and ethical consequences of their work. This can be exploited by unscrupulous developers or corporations who utilize the medium in an unethical manner or present morally repugnant material in virtual reality. Furthermore, virtual content is difficult to regulate because users are easily able to connect to servers in other countries and download content that would otherwise be restricted or regulated in their home country.

Methods for Measuring Presence

Questionnaires

The most common method for measuring presence is the self-reporting questionnaire, which is typically administered to users post-test. The most commonly employed questionnaires are the Witmer and Singer (WS) (Witmer & Singer, 1994), Slater, Usoh, and Steed (SUS) (Usoh et al., 2000), and iGroup Presence (Schubert, 2003) questionnaires. Other presence questionnaires include the ITC Sense of Presence Inventory (ITC-SOPI), Temple Presence Inventory (TPI) (Schwind et al., 2019), and Spatial Presence Experience Scale (SPES) (Hartmann et al., 2016). Most of these questionnaires have been psychometrically evaluated and are generally considered satisfactory metrics of presence.

Self-reporting presence questionnaires have been criticized by some who feel that the use of a questionnaire itself may invalidate results. These critics feel that the introduction of presence questionnaires to users itself may trigger an occurrence of presence (Sanchez-Vives & Slater,

2005) (Graf & Schwind, 2020). Some also speculate that post-virtual-reality-experience questionnaires remove participants from the virtual reality experience and are therefore not good tools for measuring presence. Post-test questionnaires are typically administered using pen and paper, which further removes users from the virtual reality experience. Critics believe that these factors cause a break in presence, which may mean that users are not able to accurately self-report feelings of presence.

Some studies sought to bypass these concerns and obtain more accurate self-reports of presence by incorporating presence questionnaires inside virtual reality (Schwind, Knierim, Chuang, et al., 2017) (Schwind, Knierim, Tasci, et al., 2017) (Schwind et al., 2019) (Graf & Schwind, 2020) as well as other forms of media (Shute, 2011) (Frommel et al., 2015). Existing or modified post-test presence questionnaires were used in these studies. Participant adjustment time between the experience and the post-test questionnaire was reduced when questionnaires were integrated into the interactive virtual reality experience. Nevertheless, these studies still administered presence questionnaires post-test, which disconnects the participant from the actual experience and may cause a break in presence. One study transitioned the virtual experience into a segment that required subjects to shoot drones carrying the answer to the questionnaire (Tamaki & Nakajima, 2021). Accordingly, interactive integration may not adequately control for removal from experience. Furthermore, none of these studies controlled for the possibility that questionnaires themselves may trigger feelings of presence. As of the date of this paper, there are no published studies implementing questionnaire methodology for self-reporting of presence except as post-test measures.

Neurophysiological measurements of presence

Various tools for measuring physiological reactions to virtual reality experiences have been studied in numerous experiments. Over the years, researchers have attempted to identify which neural and physiological responses may indicate presence. Various tools are used to observe bioenergy disbursement, neurosynaptic activity, and other physiological responses of participants in virtual reality including Electroencephalography (EEG), electrocardiography (ECG), electrooculography (EOG), and electromyography (EMG). Electroencephalography (EEG) utilizes electrodes placed on the head to measure electrical activity in the brain.

Electrooculography (EOG) utilizes electrodes placed near the eyes to measure electrical activity and evaluate eye movements. Electrocardiography (ECG) uses electrodes placed on the arms and legs to measure electrical activity of the heart. Electromyography (EMG) utilizes electrodes inserted in the muscle or placed on the skin to measure electrical activity in the muscles.

Embodiment and presence were connected to activation of the bilateral ventral premotor cortex in fMRI and blood oxygenation level-dependent (BOLD) adaptation technique studies (Ehrsson, 2020). Increased activity in the frontal and parietal lobes of the brain associated with multisensory stimulation and virtual body ownership was shown in multiple neuroimaging studies (Bekrater-Bodmann et al., 2014) (Guterstam et al., 2013) (Brozzoli et al., 2011) (Grill-Spector et al., 2006) (Limanowski & Blankenburg, 2016).

A study comparing brain-computer-interfaces found significant differences between a head-mounted virtual reality brain-computer-interface and a brain-computer-interface that used standard computer screens. The study found a significant difference in the relationship between neurofeedback and embodiment and as well as neurofeedback and presence in virtual reality versus the computer screen when users were engaged in motor-driven tasks (Juliano et al., 2020). Another study compared electroencephalography measurements for subjects skiing down a slope in real life, skiing down a virtual reality slope with simulated ski equipment, and skiing down a slope on a two-dimensional desktop computer. Greater levels of bioenergy expenditure were identified in the real and virtual reality simulations than in the desktop simulation. Findings from these and other studies indicate that electroencephalography may be a satisfactory tool for measuring presence (Petukhov et al., 2020).

Studies that exploit neural and physiological metrics along with self-reporting measures to gauge feelings of presence are likely more accurate than studies that only utilize a single mode of detecting presence.

Research Questions and Specific Aims

Many researchers study the neurophysiological and cognitive associations of virtual reality. There have also been numerous studies on the effect of haptic and olfactory integration on immersion and presence in virtual reality. Research on the neurophysiological and perceptional implications of integrating senses other than visual and auditory, however, is more prefatory and non-standardized.

Various studies indicate that participants are more likely to experience presence when certain additional stimuli are introduced. Many studies integrate haptic and olfactory stimuli, but few integrate gustatory stimuli. Some studies indicate that olfactory cues may be more significant than haptic cues. Presence is typically measured via neurophysiological measures or post hoc via questionnaires. However, these studies are not as extensive or standardized as visual-audio only studies.

Most studies that integrate additional sensory stimuli rely heavily on questionnaires to gauge participant experience. Participants may report physiological symptoms like nausea or dizziness, but some studies did not find significant differences in reported physiological symptoms when olfactory or haptic cues were introduced compared to audio-visual stimulation alone. Studies indicate that certain sensory input, including temperature and olfaction, may be perceived differently by participants in post hoc questionnaires than audio-visual alone. An exhaustive search by this author yielded no published studies implementing questionnaires for measuring presence except as post-test measures.

A 2018 study found that participants experienced more variations in physiological data (measured by heart rate and electrodermal activity) when audio, visual, haptic (wind and temperature), and olfactory stimuli were integrated. The same study found the second highest indicators of presence when olfactory stimuli were integrated with visual and audio stimuli than any other combination of multisensory stimuli less than all five (Ranasinghe et al., 2018).

Virtual reality aims to create a virtual world that is indistinguishable from actual reality. Understanding the various factors that can contribute to or detract from that experience is important for both research and development purposes. Better understanding of the cognitive and perceptual aspects of virtual reality may lead to better control and use of the medium. This serves beneficial purposes including therapy and training.

Research Questions and Hypotheses

The purpose of this study was to examine whether users experience higher levels of presence when additional sensory stimulation is integrated into a task-based virtual reality system and presence is measured during the experience.

R1*: Are current Virtual Reality applications perceived differently because some senses are fully engaged, while others are not?*

H1: Users experience higher levels of presence when olfactory stimulation is integrated into a virtual reality system than when it is not.

H2: Users experience higher levels of presence when haptic stimulation is integrated into a virtual reality system than when it is not.

H3: Users experience higher levels of presence when both haptic and olfactory stimulation are integrated into a virtual reality system than when none or only one is integrated.

H4: Integrating additional sensory stimuli affects users' qualitative perception of virtual reality.

R2*: Are users better able to articulate presence when a survey is administered during an experience than when it is administered post-test?*

H1: Users report greater feelings of presence when a survey is administered by a researcher during a virtual reality experience.

H2: Electroencephalography (EEG) data supports user reports of presence when a survey is administered by a researcher during a virtual reality experience.

H3: Users report greater feelings of presence when a survey is integrated and administered as part of a virtual reality experience.

H4: Electroencephalography (EEG) data supports user reports of presence when a survey is integrated and administered as part of a virtual reality experience.

Chapter 2: Literary Review

Measuring Presence

Studies show that users who are immersed in virtual reality show similar physiological reactions to virtual stimuli as they would to stimuli in the real world. These assessments indicate that users are reacting to virtual experiences as if they were real experiences. Users in some of these studies, however, self-report that they were aware that the experiences were not real the entire time.

Presence in virtual reality is the degree to which users react to a virtual experience as if they were actually present within the virtual world. Users experiencing presence are typically able to block out external stimuli to varying degrees and respond to the virtual environment as if it were real. Many factors affecting the degree of presence achieved in virtual reality have been identified. Sheridan divided some of these factors into the following categories: sensory information, ability to control sensors, and agency to affect physical environment (motor control) (Sheridan, 1992). These factors include frame rate, graphic quality audio, interaction modality, and head tracking (Schwind et al., 2019). Other factors that affect presence have been identified in various studies and include motion parallax (Eftekharifar et al., 2020), asymmetry (Jeong et al., 2020), age, and gender.

Questionnaires

Self-reporting questionnaires are commonly used to measure presence. These questionnaires are regularly administered to participants either with paper and pen or on a computer and collected post-test. The most commonly used questionnaires have been evaluated for validity in various studies.

Building on previous research by Sheridan (Sheridan, 1992), Witmer and Singer developed a questionnaire of thirty-two-item with three subsets: “involvement/control”, “natural”, and “interface quality”. Although the Witmer and Singer presence questionnaire (WS) is cited the most on Google Scholar, it has received numerous validity critiques for including few items that directly assess presence and the subjectivity of its defined properties (Schwind et al., 2019).

Witmer and Singer later developed another questionnaire called the Immersive Tendencies Questionnaire (ITQ) This questionnaire included items related to how well participants felt able to control events in the virtual environment, awareness of, distraction by, and interference from hardware and related mechanisms during use, concentration, and completion of tasks, among other related questions (Witmer & Singer, 1994).

The second most cited questionnaire was developed by Slater, Usoh, and Steed (SUS) in several studies. This questionnaire includes six items on three themes: “the sense of being in the VE” (virtual environment), “the extent to which the VE becomes the dominant reality”, and “the extent to which the VE is remembered as a ‘place’” (Schwind et al., 2019).

A group of researchers developed a thirteen-item questionnaire called the iGroup presence questionnaire (IPQ) based on identified cognitive processes which make up the paradigm of presence. This questionnaire evaluated three subsets: “spatial presence”, “involvement”, and “experienced realism” (Schubert, 2003). A later study by the same group added one item for an “involvement” subset (Schwind et al., 2019).

Other less commonly used presence questionnaires include ITC Sense of Presence Inventory (ITC-SOPI) and the Temple Presence Inventory (TPI) (Schwind et al., 2019). Spatial Presence Experience Scale (SPES) is also sometimes used (Hartmann et al., 2016).

Critics of presence questionnaires argue that the use of a questionnaire itself invalidates the results since its introduction to participants might itself cause presence to occur (Sanchez-Vives & Slater, 2005) (Graf & Schwind, 2020). Critics also suggest that post-virtual-reality-experience questionnaires are not a good measure of presence because they inherently involve removing the participant from the virtual reality experience. Additionally, post-experience questionnaires are typically conducted using paper and pen, which requires disengaging from virtual reality and further remove participants from the virtual reality experience. These factors are believed to cause a break in presence which means that participants may not be able accurately self-report on presence (Schwind et al., 2019).

To avoid potential confounds and obtain more accurate self-reports of presence, several studies sought different methods to measure presence, integrating presence questionnaires inside the virtual reality experience itself. Presence questionnaires have been integrated in other forms of media (Shute, 2011) (Frommel et al., 2015) as well as in virtual reality (Schwind, Knierim, Chuang, et al., 2017) (Schwind, Knierim, Tasci, et al., 2017) (Schwind et al., 2019). These studies used existing or modified from existing post-test presence questionnaires. The virtual reality studies found that integrating the questionnaires into the interactive experience did reduce participant adjustment time between the experience and the post-test questionnaire. Integrating questionnaires also reduced distractions and decreased instances of break in presence. However, the questionnaire was administered post-test, which still removes the participant from the actual experience and may cause break in presence, so integration may not adequately control for removal. The 2019 study by Schwind and associates evaluated three common questionnaires (IPQ, WS, and SUS) and recommended the IPQ questionnaire for reliability in a limited time frame (Schwind et al., 2019).

Several studies examined the efficacy of integrating presence questionnaires in virtual reality. In one 2017 study, presences questionnaires were administered in virtual reality using the same virtual hands that were used to perform the virtual tasks in order to minimize disengagement (Schwind, Knierim, Tasci, et al., 2017). Another study evaluated two standard post-test presence questionnaires, IPQ and SUS, in both a lab setting and integrated in virtual reality. The study showed significant score differences depending on the test environment (Graf & Schwind, 2020). One study integrated a questionnaire into virtual reality by transitioning the virtual reality experience into a segment that required subjects to shoot drones carrying their answers (Tamaki & Nakajima, 2021). As of the date of this paper, there are no published studies implementing questionnaire methodology for self-reporting of presence except as post-test measures.

Physiological Monitoring for Measuring Presence

Over the years, researchers utilized various tools for monitoring physiological reactions to virtual reality stimuli. Studies have attempted to pinpoint which physiological responses may infer presence.

Electroencephalography (EEG), electrooculography (EOG), electrocardiography (ECG), and electromyography (EMG) may be used to observe neurosynaptic activity, bioenergy disbursement, and other physiological responses of participants in virtual reality. Electroencephalography (EEG) measures the electrical activity in the brain using electrodes placed on the head. Electrooculography (EOG) measures electrical activity using electrodes placed near the eyes to evaluate eye movements. Electrocardiography (ECG) measures electrical activity of the heart using electrodes placed on the arms and legs. Electromyography (EMG) measures electrical activity in the muscles using electrodes inserted in the muscle or placed on the skin.

A 2019 study observed a bidirectional relationship between presence and fear in a virtual reality simulation involving heights. Researchers monitored stress levels and observed physiological responses in height-fearful participants. Presence was manipulated in the simulation using degrees of realism (graphic and audio) and fear was manipulated by varying simulated circumstances (ground level vs. height). The study utilized skin electrodermal activity to measure skin conductance and an electrocardiogram to measure heart rate in participants. *Acrophobia Questionnaire* (AQ), *State-Trait Anxiety Inventory* (STAI), *Simulator Sickness Scale* (SSQ), and *MEC Spatial Presence Questionnaire* (MEC-SPQ) self-reporting questionnaires were used to evaluate participant's fear of heights and degree of anxiety and simulator sickness before the experiment (pre-test), and sense of presence post-test. The study found that higher levels of fear as indicated by physiological activity and self-report lead to significantly higher levels of presence. Presence, however, did not necessarily lead to significantly higher levels of fear. Nevertheless, researchers in this study suggest that a minimum level of presence is required in order to affect fear, which may not have occurred sufficiently in this study (Gromer et al., 2019).

Researchers have studied electrical activity of the cranial cortex to detect and evaluate neural responses to virtual reality using electroencephalography (EEG). Systems integrating electroencephalography with virtual reality (or other computer technology) are called brain-computer-interfaces (BCI). Brain-computer-interfaces have been used to facilitate rehabilitation for stroke sufferers (Badia et al., 2013) and people who have experienced brain injuries (Rose et al., 2005).

Researchers in a 2019 study compared two brain-computer-interfaces: one integrating electroencephalography and a head-mounted virtual reality system and the second integrating electroencephalography and a computer screen. The study evaluated healthy individuals for embodiment and presence while connected to the brain-computer-interface. Participants were asked to complete tasks using a virtual arm. The study found significant differences between the head-mounted virtual reality interface and the brain-computer-interface that used standard computer screens. Participants hooked up to the virtual reality brain-computer-interface experienced significantly higher instances of presence and embodiment. The study evaluated neurofeedback and used self-reporting questionnaires for presence (adapted from Witmer and Singer(WS)), embodiment (adapted from Bailey et al. and Banakou et al.), and simulator sickness (adapted from Kennedy et al.). The study suggests that neurofeedback was not significantly different between virtual reality and computer screen in early stages of the study because both engaged the participant in motor-driven tasks. The study did find that there was a significant difference in the relationship between embodiment and neurofeedback as well as neurofeedback and presence in virtual reality versus the computer screen (Juliano et al., 2020).

A 2020 study compared electroencephalography readings for participants skiing down an actual slope, skiing down a slope in virtual reality (with simulated ski apparatus for virtual manipulation), and skiing down a slope in a 2D desktop simulator. The study found that brain activity was relatively similar on the real slope and the virtual reality slope, but different for the desktop simulator. Higher levels of bioenergy expenditure were detected in the real and virtual reality sessions. Interestingly, there was increased activity in the frontal lobe in all test conditions. These findings indicate that electroencephalography may be a reasonable tool for measuring presence (Petukhov et al., 2020).

A rubber hand illusion study by Kanayama and associates compared electroencephalography (EEG) data between participants subjected to the rubber hand illusion experiment in real life with a dummy hand, in real life with no dummy hand, in virtual reality with a virtual hand, and in virtual reality with no visible hand. Like previous comparable studies, this study found significant differences in electroencephalography data when participants were shown a rubber hand versus when they were not shown a dummy hand. There were no significant differences between conditions for participants who were immersed in virtual reality. This may be because virtual reality itself altered perception and sensation for the participants (Kanayama et al., 2021).

Various neuroimaging studies show increased activity in the frontal and parietal lobes of the brain related to multisensory stimulation and virtual body ownership (Bekrater-Bodmann et al., 2014) (Guterstam et al., 2013) (Brozzoli et al., 2011) (Grill-Spector et al., 2006) (Limanowski & Blankenburg, 2016). fMRI and blood oxygenation level-dependent (BOLD) adaptation technique studies connected embodiment and presence with activation of the bilateral ventral premotor cortex (Ehrsson, 2020).

Activation of the intraparietal cortex and ventral premotor cortex was replicated in multiple studies involving the rubber hand illusion discussed below (Bekrater-Bodmann et al., 2014) (Guterstam et al., 2013) (Gentile et al., 2013) (Brozzoli et al., 2012) (Limanowski & Blankenburg, 2016) (Limanowski & Blankenburg, 2015) (Bekrater-Bodmann et al., 2012). Activation of the bilateral intraparietal cortex, bilateral inferior parietal cortex, bilateral ventral premotor cortex, and right cerebellum was also observed in some studies involving the rubber hand illusion

(Gentile et al., 2013). A few studies involving body ownership transfer observed activation of the extrastriate body area (EBA) of the brain — an area believed to process visual activity — and the cerebellum (Downing et al., 2001) (Brozzoli et al., 2011).

Cybersickness/Simulator Sickness/VR Sickness

Some users of virtual reality and other interactive media experience motion-sickness-like symptoms. This malady is sometimes called cybersickness, simulator sickness, or VR sickness. Symptoms of cybersickness include dizziness, nausea, vertigo, perspiration, and stomach awareness. The prevalent theories on motion sickness and cybersickness credit conflicts in sensory input for the ailment. The brain fails to adequately resolve discrepancies between what the eyes are seeing and what the body is feeling.

There are various popular tools for measuring cybersickness; the most popular of which are self-reporting questionnaires. The Nausea Profile (NP) questionnaire assesses various elements of nausea in varying situations. Nausea Profile questionnaire has been psychometrically evaluated and is generally considered a valid assessment of degree of nausea (Muth et al., 1996). Some studies on cybersickness use the Nausea Profile. The Motion Sickness Susceptibility Questionnaire (MSSQ) is occasionally used in conjunction with other cybersickness measurements to assess the predisposition of participants to experience motion sickness as a result of various forms of motion. The questionnaire was psychometrically evaluated and is generally highly rated for validity (Golding, 2006). The Simulation Sickness Questionnaire (SSQ) is one of the most commonly used assessments of cybersickness for conventional simulation users, game players, and virtual reality users. Although psychometric evaluations find the Simulation Sickness Questionnaire valid for screen-based game player assessment of simulation sickness, it is psychometrically questionable as a tool for Virtual Reality sickness assessment (Kennedy & Frank, 1985) (Kennedy et al., 1993) (Kennedy et al., 1992) (Kennedy et al., 2000) (Balk et al., 2013) (Sevinc & Berkman, 2020). The Cyber Sickness Questionnaire (CSQ) is a variant of the Simulation Sickness Questionnaire. Studies have found the Cyber Sickness Questionnaire more valid for evaluating virtual reality applications than the

Simulation Sickness Questionnaire, although that questionnaire is still very commonly used. Another commonly used variant of the Simulation Sickness Questionnaire is the Virtual Reality Sickness Questionnaire (VRSQ). Studies found the Virtual Reality Sickness Questionnaire more valid for evaluating virtual reality applications than the Simulation Sickness Questionnaire (Sevinc & Berkman, 2020).

Cybersickness and presence share some mechanisms of measurement. These devices include physiological measurement apparatus that gauge neural activity and skin conductance, as well as task performance measures, including reaction time and accuracy. Cybersickness is often measured though physiological tests that match neuroendocrine stress responses—increased heart rate, perspiration, nausea, etc. (Weech et al., 2019). Studies suggest that heightened stress levels during immersion may indicate higher levels of presence (Ling et al., 2013) (Bouchard et al., 2008). Interestingly, numerous studies found negative correlations between cybersickness and presence (Weech et al., 2019).

Numerous studies observed different factors that affect bother cybersickness and motion sickness including age and gender. Adults 60 years and older are more prone to cybersickness than younger adults. Women are more likely to experience cybersickness than men (Petri et al., 2020) (Munafo et al., 2017). Children of both genders are more likely to experience motion sickness than adults, although adult women reported less change since childhood than men (Propper et al., 2018) Some ethnic groups have higher instances of motion sickness than others. Individuals with certain health and mental health conditions, such as migraines and anxiety, are more prone to motion sickness (Paillard et al., 2013).

Gender

Various studies examined the effects of gender on presence. Some studies found that women are more likely to experience cybersickness, which reduces presence in virtual reality (Munafo et al., 2017) (Petri et al., 2020). Other studies show that women perform better on virtual reality tasks (Liang et al., 2019) (Allen et al., 2016). Some studies show no significant gender difference (Grassini et al., 2020), although some of these do not include a large enough sample ratio of women to men to draw conclusions.

Researchers in a 2017 study tested the effect of gender on presence in virtual reality. The study utilized three realistic models of hands and three non-realistic models of human hands: robot, abstract, and cartoon. Male and female participants were asked to complete a series of hand-centric virtual tasks and self-report presence using the Witmer & Singer Presence Questionnaire along with a seven-item questionnaire meant to measure how natural the participants felt using the avatar hands. The second questionnaire included items related to attractiveness, naturalness, eeriness, and likeability of the avatar hands. The questionnaires were administered in virtual reality using the same virtual hands that were used to perform the virtual tasks in order to minimize disengagement (one of the critiques of post-test presence questionnaires). The study found that women were less likely to experience virtual body ownership or body transfer to male hands. Men experienced virtual body ownership of male and female hands equally, but not with non-realistic hands. The study was almost equally split between male and female participants (Schwind, Knierim, Tasci, et al., 2017).

Lugrin and associates performed a study on virtual body ownership (linked to presence) utilizing different full-body avatars. Participants were inserted into a head mounted virtual reality system with accompanying hand controllers for a first-person timed task simulation. Self-reporting questionnaires were used to measure virtual body ownership (IVBO) and simulator sickness (SSQ). Skin conductance measurements gauged Galvanic skin response (GSR) to assess participants' stress level. Higher levels of stress are thought to indicate higher levels of presence. Body ownership transfer occurred equally frequently with the robot and cartoonlike human avatars and less frequently with the realistic human avatar. Researchers suggest this may be due to the Uncanny Valley theory which posits that people become more comfortable with non-human avatars and interactions the more realistic they are until they get too realistic and make people uncomfortable because they are still missing some element of realism (Rosenthal-von der Pütten et al., 2019). This study found no difference in body ownership transfer between the genders (Lugrin et al., 2015). Only 26% of participants in this relatively small study were female, which may not be a sufficient sample size to accurately test gender predisposition.

A 2020 study observed that virtual reality may impair cognition. Participants were shown a series of eight nonfiction 360-degree films via computer screens or a head-mounted virtual reality headset. Electrodermal activity (EDA) and heart rate variability were measured. Self-reporting questionnaires for presence (Spatial Presence Experience Scale (SPES)) were collected post-test. Information recognition and recall were also assessed post-test using methods devised by researchers in this study (Barreda-Ángeles et al., 2020). Cybersickness was measured post-test using a variant of the BOS questionnaire (Bos et al., 2010). The study found that participants who were shown the film using the headset experienced higher levels of presence but lower levels of information retention and cognition as compared to when they were shown the film on a standard computer screen. Researchers found increased electrodermal activity for participants in virtual reality but no significant relationship to cybersickness. Electrocardiogram (ECG) results showed significant variability in heart rate for participants viewing standard screens compared to when they were immersed in virtual reality. Researchers also found that the order in which participants were shown the different presentation modes made a difference to results. No significant association between heart rate variability and cybersickness was found in this study. (Barreda-Ángeles et al., 2020)

Summation and Analysis

Various physiological responses are believed to indicate feelings of presence including neurofeedback, heart rate, skin conductance, and blood oxygenation levels. Several studies indicate that increased stress levels may signify higher levels of presence. Users may be monitored for physiological symptoms that indicate stress, such as skin conductance and heart rate. Users may also experience physiological symptoms of cybersickness, which has been negatively correlated with presence. Electrodermal activity and increased heart rate may indicate feelings of fear, which is associated with increased feelings of presence. Users experiencing presence typically exhibit higher levels of neurofeedback, mostly frontal lobe activity. Electroencephalography (EEG) studies relate this increased activity to multisensory stimulation and virtual body ownership. Blood oxygenation level-dependent (BOLD) adaptation technique and fMRI research linked presence and embodiment with activity in the bilateral ventral premotor cortex. Various studies also observed increased activity in the intraparietal cortex, bilateral intraparietal cortex, bilateral inferior parietal cortex, bilateral ventral premotor cortex, right cerebellum, and the extrastriate body area (EBA) of the brain.

Many studies on presence in virtual reality test solely male subjects, do not include a significant number of female subjects, or do not record observed data that may be relevant to gender effects on presence. Accordingly, most studies may not report gender differences in data. Women and older users are also more likely to experience cybersickness, which negatively impacts feelings of presence. Because of gender disparity in the research, it is difficult to draw conclusions regarding gender effects on presence and immersion. A thorough search by this author yielded no studies conducted solely on female subjects.

Although people may exhibit physiological symptoms that indicate that they are experiencing presence, they may self-report otherwise. This contradiction may occur because users are always aware to some extent that they are interacting with a virtual environment. This awareness is called virtual lucidity. Virtual lucidity does not indicate lower levels of presence but may explain contradicting self-reports and physiological responses. Users may also experience cognitive distancing while immersed in the virtual environment – a phenomenon almost opposite to presence. This may occur when the virtual world presents situations that are too implausible, when psychological distractions appear, or when degraded graphic or auditory fidelity is present, among other reasons. Modern virtual reality applications typically require cumbersome equipment that may affect user perception of their experience. Even users who are immersed in a larger CAVE environment and not wearing heavy equipment can see the screens and other paraphernalia that make up the system. As virtual reality equipment becomes less and less burdensome to users, users will become less aware of the devices enabling their experience and this gap may close.

The most common tools for measuring presence are self-reporting questionnaires. The two most popular questionnaires were developed by Witmer and Singer, and Slater, Usoh, and Steed. Researchers may use a modified version or combination of several presence questionnaires. Although presence questionnaires have been criticized for accuracy and validity, they are still considered a reasonable qualitative gauge for measuring presence. Researchers also regularly use fMRI, Electroencephalography (EEG), electrooculography (EOG), electrocardiography (ECG), electromyography (EMG), and Galvanic Skin Response (GSR) to measure physiological and neural responses that may be linked to presence. Studies that utilize both self-reporting measures and neural and physiological metrics for detecting presence are likely more accurate than studies that only utilize a single methodology.

Multisensory Integration in Virtual Reality

Although historically, virtual reality was meant to incorporate all human senses, in practice, most modern applications only incorporate two – visual and auditory. Studies have been conducted exploring the integration of additional senses in virtual. Presence, immersion, and other theories related to virtual reality are regularly studied using multisensory systems that integrate haptic or olfactory stimulation. Gustatory research in virtual reality is incredibly unusual and typically does not assess connections to presence and immersion.

Starting with the stereoscope in 1833 and progressing to the Cathode Ray Tube in 1897, researchers focused on visual and auditory equipment for industrial use and as a means for popular entertainment. Integrating additional senses in virtual reality requires specialized equipment, which may not be practical, readily available, effective, or easily utilized and distributed. Historically, even visual and auditory equipment was expensive, bulky, and difficult to manufacture. Such equipment was typically only available to a very limited number of people, usually academics or wealthy men who had the time and resources to study it. The costs involved in developing such equipment inhibited widespread experimentation and development. Over time, visual and auditory equipment became more readily available, cheaper, and easier to use and disseminate. Although olfactory and haptic integrations have become more prevalent and affordable, most remain in the research stage and are not readily available to the public. Gustatory integration, even in research, is even more rare.

Some history

Some consider Morton Heilig's 1957 "Sensorama" the first instance of modern virtual reality. "Sensorama" incorporated visuals, audio, smell, wind, and vibration to immerse the user in its virtual world. "Sensorama", however, did not incorporate user response or interaction, which limited user experience of presence (Craig et al., 2009).

"Sketchpad", developed in 1963 by Ivan Sutherland, incorporated audio, visual, and haptic responses to user interaction (Craig et al., 2009). "Sketchpad" was one of the first visual human-computer interaction devices. It utilized the light pen, a predecessor of the mouse, that allowed users to point to objects on the screen and initiate interaction. "Sketchpad" required a specialized computer at MIT, which limited the amount of people who could access, study, and experiment with the system (I. E. Sutherland, 2003). Sutherland later proposed “The Ultimate Display”, in which he presented concepts for visual displays incorporating interactivity, audio, smell, taste, and force feedback (I. Sutherland, 1965).

In 1968, Sutherland developed a head mounted display (HMD) using stereo images to produce a three-dimensional (3D) experience. 3D stereo vision works by presenting a slightly different image in front of each eye to mimic the distance between human eyes. The head mounted display was composed of stereo glasses that magnified images shown by two miniature cathode ray tubes affixed to the user’s head and attached to the computer via a linkage system that measured head rotation and position. The computer adjusted the images according to head position and orientation. Movement, while considered fairly unconstrained at the time, was quite limited (I. E. Sutherland, 1968).

Researchers at the University of North Carolina developed GROPE, the first force feedback system, in 1971. GROPE utilized a hard surface system to provide force feedback to users in conjunction with visual virtual environment. In the initial system, the response time for force feedback was too long and users experienced a disconnect between stimuli. Over time, the same team continued development to add more surfaces and additional angles, providing force feedback and reduced response time. Response time continued to be an issue for the project through the 1990s (Mark et al., 1996).

Myron Krueger, considered by many to be one of the first virtual reality and augmented reality artists, experimented with human-computer interactions in various forms. Kreuger’s work formed the foundation for much of the current virtual reality technology and understanding of human-computer interaction. In 1969, Kreuger collaborated with artists from the University of Wisconsin on an art installation, “GlowFlow” (M. W. Krueger, 1977). GlowFlow operated using an Adage workstation, an expensive system for vector graphics. Adage workstations were seldom used because, in addition to the expense of the equipment, they also incurred a high per-hour cost of usage (M. Krueger, 2016). Krueger was unsatisfied with the GlowFlow project because, although user response was incorporated in the backend of the installation, response feedback was not displayed for the user. This dissatisfaction led to a series of studies on user response-feedback cycles including “Metaplay” (1970). Metaplay, using an Adage workstation and PDP-12 computer, a large and expensive machine, allowed users to use a finger to draw images and interact with users in another room, creating “interactive graffiti” and tricking users into believing that the responses they saw were computer generated (M. W. Krueger, 1977). Some argue that Metaplay, the first demonstrated gesture interface, was one of the first computer systems to initiate presence. Users who engaged in the Metaplay system could see their image interacting with the graphic system and expected the image to respond according to their own movements. Through experiments with Metaplay, researchers also realized that the image on the computer became an extension of the user. In creating Metaplay, a unified system combined telecommunications, film, and computers possibly for the first time ever (M. Krueger, 2016).

Later iterations of Kreuger’s work integrated computer responses with user behavior. “Psychic Space” detected user movement and position by utilizing a “sensing grid” on the floor (M. W. Krueger, 1991). The sensing grid was composed of a system of foam and window screen one foot squares laid out in a grid on the floor that revealed the user’s location to the computer (M. Krueger, 2016). With the sensing grid, Kreuger sought to integrate human-interaction without encumbering the user with specialized equipment to wear or hold (M. W. Krueger, 1991). A large screen displayed a graphic maze with a symbol controlled by the user’s movement along the room’s floor. The computer activated one of forty different response modes depending on the user’s interactions with the maze (M. W. Krueger, 1985). A number of the offered interactions attempted to encourage full-body user interaction. Psychic Space also used an Adage workstation and PDP-12 computer, both expensive pieces of equipment owned by the university (M. Krueger, 2016).

“Videoplace”, one of Kreuger’s most famous works, integrated live video within a computer graphic environment. The system incorporated computer graphic characters and objects that seemed to react to the user’s actions (M. W. Krueger et al., 1985). Videoplace is considered one of the first instances of virtual reality. Kreuger had actually proposed Videoplace in 1974, when he devised the term “artificial reality”, but was not able to fund and build the initial system until more than a year later. In the initial 1975 installation, users in separate rooms interacted with each other through images of themselves projected onto screens. In the 1985 iteration, users were able to draw on the screen with a pointed finger in real time. The computer would randomly choose one of twenty-five different interactive experiences, including shooting lasers from fingers and a dancing “Critter”. Videoplace was the first computer system capable of real-time responses to user interaction. In 1986, Krueger created Videodesk, a desktop version of Videoplace, which was later updated to create a groundbreaking telecommunication system for tutoring and assisting visually impaired people to understand maps. Over the next decade, Krueger continued to make iterations and improvements to Videoplace, enabling more interactions and functionalities. Some of these upgrades included “Small Planet”(which included a rudimentary flight simulator), “Tiny Dancer”, and “Voice Dancer”. (M. Krueger, 2016).

In 1987, James Foley developed a virtual cockpit for flight simulations for NASA consisting of a head mounted display, motion tracking gloves with tactile feedback, and microphone. Initially, the graphics were very rudimentary, but the system included head tracking and simulated visual depth for training. Tactile feedback allowed users to feel as if they were actually interacting with objects in the simulation (Foley, 1987).

Binocular-Omni-Oriented-Monitor (BOOM) was a head mounted display created by a company called FakeSpace in 1989. The designers sought to improve on previous head mounted displays by making BOOM more comfortable for the user. The system featured a stereoscopic display composed of two miniature cathode ray tubes an eye-width apart. The system was attached to the computer by a tractable metal armature but was not fastened to the user’s head. Instead, similar to the stereoscope, users could place their face close to the goggles and move the system with their hands (Bolas, 1994) (Mandal, 2013).

Kreuger followed VideoPlace with a series of augmented and virtual reality installations including "Step Lightly" (1990). Step Lightly incorporated a sensing grid on the floor with three-inch squares covered in the same carpet as the rest of the gallery, making it invisible to users. A laser graphic system mounted on the ceiling projected images on the floor that chased and interacted with people as they moved along the space (M. Krueger, 2016). Unwittingly working concurrently with NASA, Krueger developed an animated virtual reality system for graphically modeling the movement of gas particles in jet engines (M. W. Krueger, 1995). In contrast to the NASA animation system, which required significant effort from experienced users to operate and run, Kreuger's "Viser" system was user friendly and easy to operate using a gesture interface (M. Krueger, 2016).

In 1994, Krueger attempted to integrate olfactory stimuli for virtual reality for medical training (M. W. Krueger, 1996). At the time, only two other similar studies existed or were in progress: 1) a prototype olfactory system for training firefighters created by Denise Varner, and 2) a system by Cliff Bragdon, who was working on adding olfactory cues to vehicle simulation. Krueger's two-year study found that users felt that they were present in the scene when visual distance of an object was varied in conjunction with modified intensity of its corresponding odor. Users were better able to identify a scent when they were able to move their heads to find the source of the smell as opposed to experiencing virtual movement without body movement interaction. Participants were also better able to identify a scent when it was presented in conjunction with a matching or near matching graphic object than a non-matching graphic object (M. W. Krueger, 1996). The system utilized a head mounted olfactory display, which was cumbersome and limited user movement. The display graphic fidelity was fairly low; cameras with high-frame rates were not yet obtainable. Later in the study, researchers integrated a large CAVE system with olfactory stimulation and recommended designs for more advanced future devices (M. Krueger, 2016).

A CAVE Automatic Virtual Environment (CAVE) is a system of large screens surrounding and immersing the user in virtual reality. Typically, a CAVE incorporates some type of user tracking and interaction. The first CAVE was developed in 1992 by a group of researchers at the

University of Illinois, Chicago. The developers wanted to create a virtual reality environment for scientists and researchers to present their work while minimally burdening users with unwieldy wearable devices. The CAVE presented users with stereo vision using off-axis projectors and “synchronized shutter glasses” that matched the frame rate. The CAVE minimized image distortion, which is inherent in head mounted displays and Binocular-Omni-Oriented-Monitor (BOOM) displays. Developers also minimized user shadow interference on the screens by adjusting projector angle and controlled for visual occlusion by including a “guide” within the system to control user navigation. Head tracking cameras followed user position in the CAVE (Cruz-neira et al., 1993) (Cruz-Neira et al., 1992).

At this point in the early 1990s, most artificial reality systems were research prototypes. Although these prototypes were displayed at conferences and exhibitions, they were not readily available to the public aside from Virtuality’s arcade machines. It was also around this time that “virtual reality” became the more commonly used term than “artificial reality”. Head mounted displays were unwieldly and uncomfortable for users. Cheaper systems might not even display stereo vision and often provided poor graphic quality, constricted field-of-view, inaccurate tracking, and faulty equipment. Cheaper or less powerful equipment, such as desktop PCs, could not hope to provide real-time responses. In contrast research prototypes, like Videoplace, ran on powerful, expensive equipment that was not available to the average developer. Additionally, lack of consistent public interest in the idea inhibited widespread technological development. Instead, most research was conducted by academics engrossed in the novel challenges or government and medical organizations attracted to the training possibilities. Head mounted displays are now the most common form of virtual reality. Although the technology has advanced significantly, the use of any body-mounted device burdens and isolates the user (M. Krueger, 2016).

More Recent Tactile Studies and Best Practices

Studies show that haptic integration enhances presence and immersion (Y. M. Kim et al., 2020) (George et al., 2020). In a 2020 study, participants immersed in virtual reality were given an avatar and asked to perform virtual tasks. The study measured the difference between concurrent visual-haptic stimulation and asynchronous visual-haptic stimulation by touching participants on their backs. The study attempted to quantify perceived self-location in virtual reality based on participant response (Nakul et al., 2020).

There are several types of haptic feedback, the most recognized being “active” and “passive”. Active haptic feedback utilizes computer-controlled devices to actively exert force on the user. Passive active feedback devices do not actively exert force on the user. Instead, force feedback is provided more passively, using devices like bands that stretch with user movement or other forms of resistance (Zenner & Kruger, 2017). Dexmo, a relatively inexpensive haptic exoskeleton for force feedback, is an example of providing passive haptic feedback by blocking movement (Gu et al., 2016). Other passive haptic stimulation may utilize simple devices to simulate the feeling of holding a virtual prop, such as a sword or gun.

Examples of active haptic feedback devices include the PHANToM (Silva et al., 2009), Moog HapticMaster (Sidhik et al., 2019), which use end-effectors to provide haptic stimulation, or GyroTab, a rotatory haptic control (Yun & Kim, 2017). “Haptic revolver” is a rotating tactile virtual reality controller that moves and is tracked in conjunction with the virtual environment to provide matching texture and shape sensations (Whitmore et al., 2018). Other active haptic devices utilize haptic gloves, exoskeletons, or other devices to provide different measures of active haptic stimulation. These devices include the “Rutgers Master II” (Bouzit et al., 2002), CyberGrasp (*CyberGrasp*, n.d.), HGlove (Perret et al., 2017). Some devices even utilize electro-tactile technology to provide haptic stimulation (Hummel et al., 2016). Impacto (Hasso Platner Institute, Germany) incorporates electrical muscle stimulation (EMS) bands on various parts of the user’s the body to provide force feedback in virtual reality (Lopes et al., 2018).

The Virtual Mitten is a grip-based haptic interface where users could interact with virtual objects by moving the controls in both hands and modulating their grip strength to close or open a virtual mitten. Participants performed better on operation-based tasks when presented with both visual and haptic feedback (Achibet et al., 2014). “Ultrahaptics” uses audio to simulate haptic feelings while users are immersed in virtual. Integrated with Leap Motion technology, a hand tracking system, "ultrahaptics" utilize ultrasound speakers to make users feel like they are actually touching objects in virtual reality (*Haptics | Ultraleap*, n.d.). Other haptic integration devices include various haptic bodysuits, haptic controllers, haptic controllers that integrate electromyography (EMG) (M. Kim et al., 2020), TORC, a texture simulation device (Lee et al., 2019), a system that incorporates hetero-contact microstructure (HeCM) using wiring to recognize tactile interactions in virtual reality (Liao et al., 2019), a stretchable skin-like device for simulating temperature and tactile feedback in virtual reality (Lee et al., 2020), and other various tactile feedback systems (A. Jones, 2018).

Some tactile stimulation devices utilize combinations of passive and active feedback or even alternate approaches. "Shifty", a weight-shifting tactile device, provides "dynamic passive haptic feedback" to the user by fluctuating its internal weight distribution (Zenner & Kruger, 2017). Dexmo may also fall under this category since it utilizes a combination of haptic stimuli in an exoskeleton. "Robotic Graphics" (McNeely, 1993), "Torquebar" (Swindells et al., 2003), Listen Tree (haptic audio), and Morphees (Roudaut et al., 2013) are also examples of this type of integration.

Although many devices such as the Oculus Rift and HTC Vive provide simple haptic stimulation by means of vibration, more sophisticated haptic integration for virtual reality typically requires specialized equipment, which limits both development and dissemination. Researchers have attempted to bypass some equipment requirements by commandeering everyday objects to serve tactile functions in virtual and augmented reality with varying success rates. "Annexing Reality" is a real-time augmented reality system that recognizes objects in the real environment that match shapes for objects in the software and instructs users to touch them, providing matching haptic interaction (Hettiarachchi & Wigdor, 2016). Researchers have long attempted to integrate easily accessible objects in various forms of virtual and augmented reality (Daiber et al., 2020).

Temperature

Researchers have long known than temperature effects how people function and interact in actual reality (Stathopoulos et al., 2004) (Andrade et al., 2011) (Knez & Thorsson, 2006). Various studies examined the link between presence, immersion, and temperature in virtual reality. A 2020 study examined thermal comfort of participants while wearing five different head mounted virtual reality displays. Researchers measured temperature and humidity for the microclimate within the hardware and self-reporting measures were collected for discomfort. The study found that rising microclimate temperatures and humidity over time (caused in part by heat emitted from the devices themselves) increased discomfort in participants, which is consistent with other similar studies (Wang et al., 2020). Discomfort of all sorts in virtual reality, including temperature, is well documented and negatively correlates with presence (Weech et al., 2019) (Rourke, 2020) (Hamedani et al., 2019) (Cappellaro & Costa Beber, 2017) (J. Kim et al., 2020). Developers have attempted different methods to integrate temperature stimulation in virtual reality including Ambiotherm, a Bluetooth device that provides thermal and wind simulations for head mounted displays (Ranasinghe et al., 2017). Another recent prototype consists of a stretchable skin-like device integrated into a motion tracking glove for simulating temperature and providing haptic stimuli in virtual reality (Lee et al., 2020). Like most multisensory devices, most integratory temperature modulating devices require specialized equipment and are not typically available to most developers and users.

Olfactory studies and best practices

Numerous studies have integrated olfactory cues into virtual reality. Many of these studies, however, did not examine the impact of olfactory cues on presence. Studies that explored the influence of scent on presence mostly agree that presence is affected when scents are integrated into the system. Higher levels of presence are more likely achieved when participants can identify the scent and when it is administered in conjunction with matching visual and auditory cues. (S. Jones & Dawkins, 2018) (Dinh et al., 1999) (Harley et al., 2018).

A 2018 study examined how presence is affected by thermal, wind, and olfactory stimuli in a head mounted virtual reality weather simulation. Scents were dispersed using a custom device. Presence was measured using a self-reporting questionnaire based on Witmer and Singer. The study also measured heart rate and electrodermal activity. Researchers subjected participants to different combinations of stimuli including 1) visual and audio only, 2) visual, audio, and olfactory, 3) audio, visual, and wind, 4) audio, visual, and thermal, and 5) audio, visual, olfactory, wind, and thermal. Researchers found the highest levels of presence and variation in physiological data when all five stimuli were present. Audio, visual, and olfactory combination also resulted in significantly higher levels of presence than any of the other three combinations (Ranasinghe et al., 2018).

One 2019 study examined the effect of olfactory cues on presence and cybersickness on participants using a head mounted display for virtual training. The study utilized a SensoryCo SmX-4D forced air aroma system to dispense scents for some of the participants in the midst of training. Presence and cybersickness susceptibility were measured using self-reporting questionnaires (IPQ and SSQ). The study found that there was no significant effect of odor on cybersickness, but there was a significant effect of odor on presence and stress (as measured by a self-reporting questionnaire (Narciso et al., 2019)

Another study by the same group integrated olfactory stimuli and haptic wind stimulus to examine their effect on presence and cybersickness in participants using virtual reality to watch 360-degree films. The stimuli were administered via a compressed air hose and odor pump. Presence and cybersickness were measured post-test using self-reporting questionnaires (IPQ and SSQ). Participants exposed were shown the video with no other stimulus or exposed to the video in conjunction with smell or wind. Participants exposed to only smell showed a significant increase in presence compared to no smell, while wind alone produced no significant results. There was no significant effect on cybersickness from any condition (Narciso et al., 2020).

Researchers studied the effect of olfactory interactions, directionality, and intensity in a series of studies in “Smell Space”. Scents were administered to participants wearing head mounted virtual reality displays via a custom olfactory distribution device that could regulate intensity, type, and direction of scent using compressed air. The studies found that participants were more accurate and successful in completing tasks when scents were introduced. Participants were also able to accurately determine the directional source of a scent when administered in conjunction with corresponding visual cues as measured by participant head movements. Participants exhibited lower stress responses when exposed to integrated scents meant to moderate stress as measured by task accuracy. Emotional responses, especially stress responses, are linked to recall and presence in virtual reality (Maggioni et al., 2020).

Though some olfactory studies do not use established measures for analyzing games or presence, they may provide interesting ideas for delivery devices or data that is known to correlate to prevalent theories of presence and immersion. For instance, “Fragrance Channel” integrated olfactory cues in an educational digital board game about the spice trade. Scents were administered to participants by placing spices in front of fans blowing at participants. Data was collected from participants using self-reporting questionnaires for knowledge and engagement. Performance was higher on all tests for participants exposed to the fragrances (Covaci et al., 2018). A 2019 study integrated olfactory cues into a game and attempted to elicit emotional responses from players. The study found that olfactory cues combined with auditory and visual cues elicited greater emotional responses and enjoyment than visual and auditory cues alone. Scents were administered by spraying them in front of a fan. Responses were measured through qualitative self-reporting measures developed by the researchers (Ranasinghe et al., 2019). Several studies examined the effects of olfactory virtual reality cues on food cravings and found that participants were more likely to experience food cravings when exposed to both olfactory and visual cues (Martins & Guimarães, 2018) (Tuanquin et al., 2018).

There are various devices designed to integrate scents in virtual reality from researcher operated manual devices to more sophisticated devices like the one used in Smell Space. More recent iterations of these devices include Lotus, an olfactory delivery device that uses ultrasound to project scented mist for integrated virtual reality. Studies utilizing this device are ongoing (Y.-S. Chen et al., 2018). Another group of researchers developed a smart olfactory device that can release different scents on command or on a timer. The device utilizes fans to disperse scents (Tsaramirsis et al., 2020). Another group of researchers developed one version of a handheld olfactory device. The device is paired with a head mounted display that depicts virtual objects for users to pick up and smell. A scent is administered when the device is brought close to the head (Niedenthal et al., 2019). Most olfactory devices require specialized equipment or heavy researcher interaction and are not optimized for travel or widespread application.

Gustation

Gustation is perhaps the least explored sensory integration for virtual reality. This may be because generating a reusable device that does not need regular replenishment and is satisfactorily hygienic has proven more difficult than other sensory stimulation devices. Several studies have attempted to integrate taste stimulation in various ways. Although studies have been conducted on how taste affects various conditions in virtual reality and vice versa, gustatory stimulation devices are not regularly available and have not been extensively studied for relationships to presence.

Most gustatory devices employ chemical, thermal, or electrical stimulation. Devices providing chemical stimulation include devices that use flavor cartridges like “TasteScreen” and “BeanCounter”, apparatuses that dispense flavors like “LOLLio”, “TastyFloats”, and “TasteBud”, or food printers such as “EdiPulse”, which prints chocolate (Obrist, 2017). Gustatory devices that utilize thermal stimulation include various taste actuators, some of which include olfactory components (Cheok et al., 2015) (Ranasinghe & Do, 2016) (Ranasinghe et al., 2011) (Karunanayaka et al., 2018). Other devices utilize electrical stimulation to produce taste sensations. These devices include “Digital Lollipop”, “Virtual Lemonade”, “Thermal Sweet Taste Machine”, “Vocktail”, which use electrical actuation apparatuses, and “Augmented Gustation Using Electricity”, which uses electrolyte drinks and straws (Obrist, 2017) (Kerruish, 2019).

Other electrical devices include one developed by Sardo and associates that incorporates haptic stimulation (Sardo et al., 2018) and a thermal taste actuation technology by Karunanayake and associates (Karunanayaka et al., 2018). Other devices like "MetaCookie+" use visual and olfactory cues to change users' perception of taste (Narumi et al., 2011).

An exhaustive search by this author has yielded very few gustatory studies relating to presence in virtual reality. One of the few studies that remotely examines presence is a 2018 study that required participants to eat real food in order to progress to the next stage of a virtual reality game. The study utilized the Game Experience Questionnaire (GEQ) to measure user experience in game, which contains a small component that evaluates social presence (Arnold et al., 2018). Most gustatory virtual reality studies do not investigate presence or immersion.

Summation and Analysis

Diverse industries developed and used visual and audio equipment for numerous purposes over time. Widespread need for such equipment made it inexpensive and easy to procure. Many of these industries did not need or favor equipment for integrating other sensory stimulation, including olfactory, haptic, and gustatory. Therefore, systems incorporating other sensory input were not historically common and remained simplistic, expensive, or otherwise restricted. As a consequence, visual and auditory equipment became the primary means of virtual reality research and development. More recently, olfactory and haptic integration has become more common in virtual reality, but the equipment for incorporating these senses remains rudimentary and undeveloped in comparison to visual and auditory equipment. Presence, immersion, and other virtual reality phenomena are frequently studied using multisensory devices incorporating haptic and olfactory stimulation. Virtual reality gustatory research is still exceedingly rare and does not often assess relationships to presence and immersion.

Societal perceptions of virtual reality fluctuated over time between obscurity and public popularity. This vacillation of opinion may have occurred because virtual reality was not reliably available to the populace. Whenever virtual reality was popular with society, development and research flourished due to better funding. When these systems were less fashionable, developers had a more difficult time procuring funding to work on them. Without the promise of substantial return on investment, commercial businesses were hesitant to allocate capital for research and development. When societal interest in arcades peaked, companies funded virtual reality devices for arcade use. Later, home game consoles became more affordable and societal interest in arcades dwindled along with development capital for the virtual reality machinery they housed. Virtual reality systems were not yet readily available for home use, remaining costly and inefficient. Subsequently, as head-mounted virtual reality systems became more advanced, affordable, and easier to use, commercial research and production focused on developing such devices for home use. Consumers are more likely to buy inexpensive devices that integrate with systems that they already own at home. Contemporary arcades feature the same low-cost virtual reality systems for people who do not possess their own or who may want to test a system before buying.

In contrast to the general public, researchers maintained a consistent interest in development and testing of virtual reality systems. While military, medical, and other government offices sought to exploit the training potential of virtual reality, academics pursued the medium for its unique mechanics, challenges, and limitations. Many of these devices and studies incorporate multisensory stimulation with virtual reality.

Haptic feedback in virtual reality may be divided into active and passive categories. The devices used to integrate these stimuli vary widely from complex and expensive mechanical apparatuses, electrical muscle stimulation, and ultrasound speakers to rubber bands, researchers touching subjects, or asking subjects to hold simple objects. Olfactory integration devices for virtual reality are equally as varied. These devices range from elaborate electrical stimulation to automated fragrance dispensation contraptions to simple vials held in front of a subject by the researcher. Consequently, research studying the effects of haptic or olfactory stimulation on presence in virtual reality is not well-regulated or uniform. Many multisensory studies use different evaluation criteria and different research methods. A lot of these methods are difficult to regulate or make equivalent. Some multisensory research in virtual reality focuses on making the integration work more than on studying presence or immersion. Furthermore, studies are conducted by researchers in varying fields, utilizing very different equipment, on subjects in varying countries on differing populations (age, gender, ethnicity, etc.), which makes it difficult to evaluate current literature for intersecting effects and corroborative evidence. The rare gustatory studies are even more diverse, less focused, and non-uniform.

Theories of Cognition

Distributed Cognition is the idea that cognitive processes extend through the body and external environment. The 4E framework is a subset of Distributed Cognition (Anderson, 2020). The 4E Framework of Cognition refers to several intersecting theories and concepts related to the fields of psychology, cognitive science, and philosophy. These four classifications are known as embodied cognition, enacted cognition, embedded cognition, and extended cognition (Menary, 2010). The theory of embodied cognition posits that cognitive function does not involve only the central processes of the brain, but also cognitive processes throughout the body. These extracranial processes facilitate spatial navigation and perception among other cognitive processes. Embodied cognition necessitates dynamic real-time interaction of the cranial system with other branches of the body's system for interacting with the external environment (Newen, De Bruin, et al., 2018). The theory that cognition entails not only extracranial processes but also requires interaction with the external environment, is called "enacted cognition." Enacted cognition refers to both strong and weak cognitive dependencies related to the surrounding environment and whether or not they elicit a desire to act. Embedded cognition refers to the body's interactions with one's surroundings—how one is embedded in one's environs. A process which extends beyond the body's physical boundaries, is considered extended cognition (Newen, De Bruin, et al., 2018).

The 4E framework is more frequently employed in the study of user experience and behaviors in virtual reality than other cognitive archetypes (Kellmeyer, 2019). Many traditional cognitive theories are based on functionalism – the idea that different parts of the body and brain perform discrete functions and that cognitive functions are solely executed by the brain. The 4E framework argues that cognition integrates numerous parts of the body and processes therein (Newen, De Bruin, et al., 2018).

Embodied Cognition

Embodied cognition suggests that cognition integrates neural processes throughout the body, not just in the brain. Extracranial cognitive processes may be categorized as "strong" or "weak". "Strong" extracranial cognition is mostly comprised of and dependent upon extracranial processes. “Weak” extracranial cognitive processes are not fully dependent on or caused by extracranial processes. Extracranial processes can further be classified as “bodied” and “extrabodily”. Bodied processes integrate brain and body and extrabodily processes integrate brain, body, and environment. Cognitive processes can be classified as follows: “strongly embodied by bodily processes”, “strongly embodied by extrabodily processes”, “weakly embodied by bodily processes”, or “weakly embodied by extrabodily processes” (Newen, De Bruin, et al., 2018).

Mental Representations and Body Ownership

“Body ownership”, discussed more thoroughly later in this paper, falls under embodied cognition. Body ownership refers to one’s ability to create and maintain a mental representation of one’s body. Sometimes, one’s sense of body ownership may become distorted from actual reality. Various circumstances may trigger “body ownership transfer”—a sense of ownership for an object outside of one’s own body. Various studies examine the body ownership transfer phenomenon, which includes virtual body ownership. “The Rubber Hand Illusion”, an instance of body ownership transfer illusion has been repeatedly studied in various forms, including virtual (Bekrater-Bodmann et al., 2012) (Ward et al., 2015) (Kalckert & Ehrsson, 2014b) (Kilteni et al., 2012).

Enacted Cognition

Embodied cognition may be considered “enacted” if it actively engages with the exterior environment. Cognitive processes can be categorized as “strongly enacted” and “weakly enacted”. “Strongly enacted” processes are partially or wholly comprised by the inclination or capability to act. “Weakly enacted” processes are partially associated with the inclination or ability to act. Noe’s “theory of perception” is one example of enacted cognition. This theory posits that perception is not a passive process that happens to humans, it involves an explicit inclination to act that forms a “perceptual experience”. According to Noe, this type of cognition is demarcated and explained through inherent understanding of “sensorimotor contingencies.”

Whether this theory of perception should be classified as strong or weak enacted cognition is highly debated (Newen, Gallagher, et al., 2018).

Embedded Cognition and Extended Cognition

A cognitive process is considered "embedded" if it is weakly embodied by extrabodily processes. A cognitive process is considered "extended" if it is at least partially constituted of extrabodily processes (Newen, De Bruin, et al., 2018).

Much discussion exists concerning the differences between embedded and extended cognition. These discussions debate what processes may be counted as cognition, bearing "the mark of cognition". Proponents of embedded cognition posit that cognition is heavily reliant on interactions with the environment, but that all cognitive processes involved occur within the brain and its systems. For instance, when someone uses a calculator, the cognitive processes involved are still taking place in the brain. The calculator simply provides "scaffolding" or support for the mathematical processes taking place. According to the theory of embedded cognition, in this instance, the calculator serves a causal role in the cognitive processes that occur in the brain's systems (Kiverstein et al., 2018).

Supporters of extended cognition contend that, in particular situations, extrabodily processes and one's interactions with the environment may be considered part of cognition. Under certain conditions, mobile devices and technologies may be considered part of the cognitive network because they are so integrated in the cognitive process. According to this theory, external factors serve an integral or causal role in cognition. For instance, someone may lay a group of objects out in a specific order so that they may remember the order in which they need to use the objects. The memory of the order is now stored inside the placed objects, which are now integrated in the neural system. (Kiverstein et al., 2018).

"Radical" theorists of extended cognition go so far as to argue that all cognition must be extended whenever conditions in one system effect change in another system. Accordingly, the elements that comprise such a system may not be considered as two separate entities because they are so closely integrated (Kiverstein et al., 2018).

Supporters of the 4E Framework debate the significance of each assertion and may weigh the importance of each differently.

Why these theories are good for analyzing virtual reality

The 4E Framework examines the relationship between cognitive function and external environment in a more holistic way than many other approaches. Virtual reality developers and researchers strive to create more realistic experiences, hoping to perfectly replicate actual reality and elicit the same user responses and behaviors that are found in actual reality. Many theories in the 4E framework provide a relevant structure for analyzing and understanding virtual reality experiences and behaviors. Furthermore, the subsets of the 4E Framework interconnect well with each other and are not mutually exclusive. The embodiment theories of body ownership and body memory are particularly popular in virtual reality research. These theories are discussed in more detail later in this paper.

An electroencephalography(EEG) study by Juliano and associates found a significant correlation between embodiment and presence in virtual reality. Embodiment and neurofeedback were also positively correlated (Juliano et al., 2020). Researchers used self-reporting metrics to measures embodiment and presence. This study is discussed in detail later in this paper.

Most users experiencing embodiment clearly feel as if they control a virtual reality avatar and affect its actions. One interesting study attempted to reverse this experience and endeavored to influence users to perform certain actions utilizing a virtual reality avatar. Researchers formulated the experiments using a combination of computational cognition, mechanistic cognitive approach, causal inference (Körding et al., 2007) (Shams & Beierholm, 2010), and the 4E framework theories. Researchers exploited motor contagion, mimicry, and "motor retargeting" to visually guide participants' motor actions. Some participants were asked to move their arms matching the motion of the avatar through various spatial movements, while others were asked not to move. The avatars movements varied between gradual movement and sudden movement. Embodiment was measured post hoc using a self-reporting questionnaire (based on a previous study (Gonzalez-Franco & Peck, 2018)). Spatial measurements were also recorded for participant movement. The "self-avatar follower effect," in which a user subconsciously mimics an avatar's movements, was observed more frequently in participants when they were not allowed to move. The study found that lower levels of embodiment corresponded to fewer instances of the follower effect. Participants experienced higher levels of embodiment when the avatar moved gradually compared to when it moved suddenly (Gonzalez-Franco et al., 2020).

The Proteus Effect: Self-Perception and Identification

Users of computer games and virtual reality may start to identify with their avatars and change their behavior to match. This behavior is called the "Proteus Effect". Various studies examined the Proteus Effect and found it to be a fairly consistent, if not well understood, phenomenon.

Some believe the Proteus Effect may be explained by the "self-perception theory"; the concept that people form mental representations of themselves as if they are viewed by another person (Ratan et al., 2019). Self-perception may be more prevalent in virtual reality because of "deindividuation". Deindividuation is a result of the anonymity that virtual worlds provide so that people feel less self- focused. This leads them to focus on external imagery for their avatars, such as hair or clothing, which in turn alters attitude or behavior (Yee & Bailenson, 2007). Another theory suggests that the Proteus Effect is a result of the situational cues and actions in the virtual world that lead to a shift in behavior or thought (Peña et al., 2009) (Peña et al., 2016). Studies found that changes in avatar appearance caused behavioral differences in participants. Some studies observed that higher levels of embodiment (as measured by self-reporting questionnaires) led to more occurrences of the Proteus Effect. Some researchers speculate that the Proteus Effect may be impacted by or even a result of priming the participants. Therefore, some researchers lied to participants about the purpose of the study and still observed instances of the Proteus Effect (Yee & Bailenson, 2009) (Yee et al., 2009). Researchers have tested different beliefs about the Proteus Effect, modulating variables including participant demographics, avatar gender, and amount of interaction and control afforded to participants in the study. Causes for the phenomenon are still not well understood (Ratan et al., 2019) (Ratan & Dawson, 2015).

Various studies and assessments use cognitive models of identification to examine how video games alter self-perception. Researchers generally agree that theories of identification relating to interactive games and virtual environments may differ from beliefs dealing with non-interactive media such as television. Users exposed to interactive media may be more likely to identify with the media and possibly change their self-perception (Klimmt et al., 2009).

Stimulus-Organism-Response Model of Cognition

Some studies use the Stimulus-organism-response (SOR) model of cognition to evaluate user behavior in virtual reality. The Stimulus-organism-response theory attempts to explain the cognitive processes and causal relationship between inputs, internal processes, and outputs. This theory is often used for evaluating how customers make decisions about purchasing. A 2020 study used this model to evaluate how virtual tourists choose where to visit, how long to stay, and what kind of interactions to engage in (M. J. Kim et al., 2020).

Theory of Mind

There are various theories of how a person understands other people. Some of these theories may be categorized under the umbrella of Theory of Mind (TOM). Theory Theory (TT) suggests people understand others through “folk psychology,” which forms the basis of how humans perceive each other. Some claim that folk psychology is acquired from society and others argue that it is innate to human beings (Coninx & Newen, 2018). Simulation Theory (ST) is the theory of cognition that people understand others through simulation. For instance, when someone sees another person in pain, their pain system is activated, and they feel empathy (Goldman, 2006). Interaction Theory (IT) posits that neither of these theories is a valid way to evaluate how people apprehend others because both theories disregard social interaction and are dependent on observations by another person. Interaction theory posits that cognition is social; and suggests that people form “intersubjective” understandings of others through interactions with others. Studies on infants and neurological observations support these ideas (Hutto & Gallagher, 2008). The Narrative Practice Hypothesis (NPH) examines folk psychology and interpersonal cognition within the context of narratives. This hypothesizes that people form competencies in folk psychology while growing up through stories they hear and interactions with others (Hutto, 2008). The Person Model Theory (PMT) suggests that people develop "person models" of themselves, other people, and groups of people. Person models form the foundation of interpersonal comprehension by compositing a mental array of physical and mental properties perceived in others. According to this theory, people form "person schemata" and "person images" of others. Person schemata encompasses a set of sensory-motor functions and mental experiences belonging to a single person or group. Person images encompass a set of physical features and mental processes belonging to a single person or group (Coninx & Newen, 2018). These theories may be effective in understanding some social behaviors present in virtual reality.

Representational and Computational Model of Cognition

Representational and Computational Model of Cognition (RCC) was a foundational theory of cognitive science, which is not regularly used today. According to this theory, cognition synapses process information by manipulating "representational mental structures". This theory suggests that cognition is a series of processes that moderate perception and motor activity or calculation of mental representations, both symbolic (language of thought) and sub-symbolic (neural network activity). According to this theory, cognition only occurs in the brain (Newen, Gallagher, et al., 2018).

Mechanistic Approach to Cognition

According to some more recent schools of cognitive neuroscience, the 4E framework of cognition is too broad to adequately explain the processes of cognition. Miłkowski and associates contend that the 4E framework is no longer a useful way to understand distributed cognition because distributed cognition cannot be solely explained in terms of embodied, enacted, embedded, and extended cognition. They examine some of the cognitive sub-mechanisms in an effort to better understand cognitive processes. According to them, the 4E framework is a type of "wide cognition", which typically does not explain cognition as "intra-neural manipulation" of mental representations. In this context, "wide" refers to processes, which occur outside of the cranium. The 4E Framework depends profoundly on extrabodily processes as part of the cognitive network. Wide cognition theories typically concentrate on cognitive experiences of an individual. Other approaches to Distributed Cognition place even more importance on the environmental network than the 4E Framework. Some theories of Distributed Cognition claim that cognitive processes may be distributed through a group of people or even through time (Miłkowski et al., 2018).

The Mechanistic Approach to cognition seeks to understand and delineate the mechanisms of cognition. Miłkowski and associates suggest that trying to answer “yes or no” questions about cognitive processes and the variables affecting them cannot accurately explicate the mechanisms of cognition. Instead, they suggest adopting a wider outlook integrating all of the components that make up a cognitive phenomenon. Explanations that adopt this approach to understanding integratory mechanisms are called “constitutive explanations”. An explanation may “bottom out” when it is considered sufficiently robust to explain an observed mechanism. Mechanistic cognition may be used to explain specific emotions or behaviors – how and why cognitive phenomena occur. Looking at virtual reality through the lens of mechanistic cognition may allow developers and researchers to better analyze or even influence particular behaviors (Miłkowski et al., 2018).

Computationalism

The computational theory of cognition maintains that the brain functions as a computer and cognitive functions are mechanistic in nature. According to this theory, computation is universal; meaning that both brains and computers are versatile devices that can adapt processes to fit a particular task. By understanding the computational aspect of cognition, researchers are better able to understand the shared mechanisms and interactions of both systems and how to manipulate user experience (Miłkowski, 2018) (Kersten, 2017).

Situated Cognition

Situated cognition is often discussed in conjunction with embedded cognition and makes some of the same claims (Miłkowski et al., 2018). Situated cognition suggests that cognitive processes occur within the context of the surrounding environment. Situated cognition is often discussed when examining software affordances and how they can be exploited to elicit desired behaviors in users. This theory is often utilized for marketing or educational purposes (Chylinski et al., 2020). Virtual Reality Learning Environments [VLE] make routine use of certain affordances to produce optimal learning results in users. One study using self-reporting metrics identified presence interactivity, immersion, usability, embodiment, and empathy as key affordances for virtual reality learning environments (D.-H. Shin, 2017).

Social Neuroscience

Social neuroscience is an interdisciplinary methodology that attempts to understand and explain the neurological and biological functions that form social processes and behaviors. The mental processes involved in and related to social interactions, including memory, perception, engagement, and understanding social interactions is called “social cognition”. Virtual reality is considered a good tool for evaluating neuroscience and vice versa because of both the effectiveness of simulated social exchanges in mimicking reality and the social aspects of the medium itself (Parsons et al., 2017) (Kourtesis et al., 2020).

Virtual Lucidity

Similar to the concept of lucid dreaming, virtual lucidity refers to the awareness of users that they are immersed in a virtual environment. A 2018 study examined virtual lucidity by adapting methods and measures used to study lucid dreaming in an attempt to identify predicters for virtual lucidity. In the study, participants were exposed to a plank suspended over simulated height in virtual reality and asked to step off the plank. Self-reporting measures were used to measure virtual lucidity (adapted from lucid dreaming questionnaires), presence, fear of heights, mindfulness, lucid dreaming propensity, meditation experience, fear, distress, and anxiety. Researchers found that virtual lucidity predicted lower fear and higher levels of enjoyment. The study also determined that virtual lucidity does not indicate reduced presence. Virtual lucidity predicted behavior of the users; users who experienced virtual lucidity were more likely to step off the plank than users who did not experience virtual lucidity (Quaglia & Holecek, 2018).

Cognitive Distancing

While immersed in virtual reality, users are often aware that they are not actually present in the virtual environment. This awareness, almost opposite to presence, is called “cognitive distancing". Cognitive distancing may occur when users are presented with implausible situations in the virtual world, when the graphical or auditory fidelity declines, or psychological diversions occur, among other factors. Developers may purposely incite cognitive distancing in users for various reasons. Cognitive distancing serves several purposes in virtual reality. It allows users to self-regulate their responses, so they are not overtly affected by simulated situations while immersed. It may also allow users to disengage from content that is otherwise too upsetting and enjoy the experience because they are aware that it is not real. Cognitive distancing may result in "virtual lucidity" (Hartmann, 2021).

Virtual Reality for Learning

According to the Cognitive Theory of Multimedia Learning, students learn better when exposed to multisensory forms of instruction (typically words and images) than with a single sensory mode of instruction (usually words) (Mayer, 2014). One study compared instruction via virtual reality to instruction via standard computer screen. Participants were tested on the information and given self-reporting questionnaires on interest and motivation. In this study, participants who were exposed to virtual reality reported higher rates of interest and motivation, but lower rates of information retention and understanding (Parong & Mayer, 2018). Other studies that contradict this finding are discussed below.

Numerous studies report positive implications of using virtual reality and augmented reality for education K-12 students. More consistent positive learning outcomes were found in augmented reality studies than virtual reality studies, which may be due to overwhelming cognitive load (Papanastasiou et al., 2019). Many studies examined virtual reality as an educational tool with varying findings (Radianti et al., 2020).

The VR Application Analysis Framework is used to evaluate virtual reality applications for educational purposes. It analyzes applications using four categories: "purpose", "communicative capability", "immersive capacity", and "cognitive load". Cognitive load is a well-documented theory of learning in general that translates well to virtual applications. It suggests that the brain has finite capability to process data obtained from various multisensory sources. Too much data may cause an overload and may not be processed or retained. This theory explains why distractions may lead to lower information retention rates. A study tested the framework on existing language learning applications in virtual reality found the framework an effective metric for analyzing educational software (Frazier et al., 2021).

A 2020 study observed that virtual reality may be associated with impairment of cognition. Researchers showed participants a series of eight factual 360-degree films alternating between standard computer screens or a head-mounted virtual reality headset. This study utilized physiological and self-reporting measures which are discussed later in this paper. Participants who were shown the film using the headset experienced higher levels of presence, but lower levels of information retention and cognition compared to viewing films on a standard computer screen. Researchers also found that varying the order of presentation modes affected results (Barreda-Ángeles et al., 2020).

Ferguson and associates examined the role of interactivity and narrative on learning outcomes in virtual reality serious games using an Educational Environmental Narrative (EEN). Educational Environmental Narratives are story-driven interactive environments for the purposes of education. The study utilized self-reporting measures of presence (iGroup questionnaire (Schubert, 2003)), cognitive interest (Schraw et al., 1995), and engagement (Brockmyer et al., 2009) along with post-hoc tests of knowledge learned while playing the game. Researchers observed a significant difference in scores for participants when information remains on-screen and they were allowed to choose their own path (C. Ferguson et al., 2019). Various studies of immersive virtual reality for serious games show that immersive virtual reality may facilitate better information retention (Feng et al., 2018). Immersive virtual reality elicits better memory recall than non-immersive virtual reality (Krokos et al., 2019).

Summation and Analysis

The 4E Framework of cognitive psychology is the tool used most often to analyze user experience and behavior in virtual reality. This theory provides an effective analytical framework to understand virtual reality experiences because it examines cognition from a holistic approach. According to the 4E Framework, cognitive functions involve areas of the body outside of the brain as well as elements of the exterior environment. Researchers and developers of virtual reality want to provide the most realistic experience for users. Applications therefore seek to mimic the real world and provoke identical user behavior and response. The various Theories of Mind examine cognition as a development of social interaction. These theories may help understand how users interact with avatars and other players.

Virtual reality users easily experience embodiment and may even unconsciously mimic avatar movement, which is documented in numerous studies (many variations of the rubber hand illusion among others, (Maselli & Slater, 2013) (González-Franco et al., 2014) (Kondo et al., 2018) (Lee et al., 2019) (Hartmann, 2021)). Because of its interdisciplinary approach to cognition and how it integrates the external environment, the 4E Framework provides a good structure for analyzing virtual reality. The subcategories of the 4E Framework are not mutually exclusive and complement each other. The embodiment theories of body ownership and body memory are particularly useful in understanding presence and immersion in virtual reality.

The 4E Framework is considered a “wide” approach to cognition by some critics. According to these critics, the 4E Framework focuses on cognitive functions in individuals and does not accurately examine or explain more particularized details of cognitive processes or adequately address the social aspects of cognition. The mechanistic approach to cognition seeks to fill this gap by examining the minutiae of cognitive processes and how cognition may be distributed among a social group. The Stimulus-organism-response (SOR) model of cognition is used to explain why consumers make purchasing decisions. Virtual reality studies using this theory found that users follow expected patterns. This theory may be useful for understanding why users engage in particular behaviors or even to encourage or influence user behavior and purchasing decisions. Followers of this approach should be cautious not to violate ethical boundaries.

Other cognitive theories, including computationalism, social neuroscience, virtual lucidity, and various cognitive approaches to learning, may satisfy disparities of the 4E Framework’s wider approach to cognition. The theory of situated cognition is closely similar to embodied cognition and may be used in conjunction with the 4E Framework for analyzing virtual reality systems.

Intriguingly, researchers do not agree on the usefulness of virtual reality for educational purposes. While some studies observed a decrease in information retention and cognition in virtual reality educational applications compared to interactive educational applications on standard computers, other studies observed that user recall and retention was better in virtual reality learning systems. All of these studies were conducted by researchers in different fields and not standardized, which may explain this dichotomy. Disparate results may be explained by dissimilar subjects, equipment, research methods, and research goals. Additionally, the literature suggests that the amount of immersion present in a virtual reality system affects information recall and retention. Some studies may have provided less immersive virtual reality systems, which may also explain some of the differing results.

Body Ownership and the Ethics of Immersive Virtual Reality

Virtual reality aims to create a virtual world that is indistinguishable from actual reality. The level of immersion and presence in virtual reality is therefore much higher than other media. An additional element in immersion is the ways in which the cognitive theories of "body ownership" and "body memory" translate to "virtual body ownership" and "virtual body memory". A user's sense of "body ownership" can be exploited for better presence in virtual reality. This approach leads to some ethical concerns, which must be recognized and addressed by developers.

Psychological studies show that it is important for one to accurately and consistently view one's own body as it exists in the real world, including where it stands in relation to other objects in space, and where its boundaries lie. "Body ownership" refers to the ability to establish a stable mental self-representation of one's body that is near to its actual existence in physical space (Kellmeyer, 2019). A person's sense of body ownership may be skewed as, for instance, occurs in individuals with body dysmorphic disorders or Somatoparaphrenia (Martinaud et al., 2017). "Body memory" refers to body-related memories formed both obliquely and through direct activities. This may include tasks related to muscle memory, such as playing an instrument, as well as the memory of bodily sensations, such as the feeling of water before entering a pool (Kellmeyer, 2019). Literature suggests that body ownership utilizes a combination of prior knowledge, including body memory, and current multisensory input (Kilteni et al., 2012). Body ownership transfer occurs when someone experiences a sense of body ownership for another object outside of one's actual body.

Body Ownership Illusion

A group of researchers conducted a series of studies exploring body ownership transfer using a humanoid robot in which the user operated the robot's arm. In earlier experiments, operators utilized a head-mounted-display to manipulate the robot's arm. Researchers found that the shorter the time between operator command and robot's response, the higher instance of body ownership transfer. Using a brain-computer-interface, researchers manipulated the delay time between user commands and robot response. Using the brain-computer-interface, subjects experienced greater instances of body ownership transfer even with larger delayed response times (Alimardani et al., 2016).

Rubber Hand Illusion

In a series of studies researchers conducted from 1998 to 2014, a participant's hand is hidden from sight and a rubber hand is placed in view in the participant's sleeve. Researchers simultaneously touched the participant's actual hand and the rubber hand. Participants experienced the illusion that the rubber hand was their own and experienced a "sense of agency" over the rubber hand. (Kalckert & Ehrsson, 2014).

In an earlier series of experiments, researchers studied how participants moved their hidden hand when they were shown movements using a rubber hand, wooden block, or a real hand. Studies found that participants reached most accurately when shown a real hand and least accurately when shown a wooden block (Holmes et al., 2006).

Body Ownership Perceptual Rules

Various studies have been conducted to determine factors and conditions that contribute to the phenomena of body ownership and body ownership transfer. By understanding how body ownership occurs, researchers can exploit or mediate its effects. Wide-ranging multisensory integration is thought to adhere to several rules involving space and time perception. Research finds that body ownership phenomena basically adhere to the same rules as general sensory integration. These principles are the "temporal principal" and the "spatial principle". Essentially, these rules state that two or more signals from two or more different sensory systems will be integrated to elicit "multisensory perceptual unity." This, combined with other stimuli such as shape, orientation, and texture, form the basics of the body ownership phenomenon (Ehrsson, 2020).

"Temporal Rule"

The temporal rule states body ownership requires synchronous multisensory input. As discussed earlier, the rubber hand illusion utilizes visual and haptic sensory data to elicit a sense of ownership for a rubber hand. Temporal delays in visual or haptic feedback are less likely to elicit body ownership transfer. The touch on the real hand and rubber hand must be felt and seen at the same time in order to produce body ownership transfer (Ehrsson, 2020).

"Spatial Rules"

Successful body ownership transfer also depends on the spatial correlation of multisensory data including distance, peri-personal space (the space immediately surrounding the body), direction, and orientation (Ehrsson, 2020).

Distance Rule: Various studies of the rubber hand illusion examine the correlation between the position of the rubber hand relative to the participant and successful body ownership transfer. A 2007 study performed an experiment varying the horizontal distance of the rubber hand to the participants own hand. The study found that increased distance lessened the body ownership transfer (Lloyd, 2007). A 2014 study examined the effect of vertical distance on the classic rubber hand illusion and introduced a moving rubber hand. The study found that increased distance reduced body ownership transfer for both a static and moving hand. Researchers found that participants experienced agency over the moving hand regardless of distance, but distance affected feelings of agency in the static rubber hand. Furthermore, the classic "illusion" negatively correlates with distance (Kalckert & Ehrsson, 2014b). Further studies found that distance between the rubber hand, the participant's own hand, and the participant's torso affected the illusion. The horizontal position of the rubber hand in relation to the participant's own hand also affected body ownership transfer. These studies are consistent with current understandings of limb-specific processing for multisensory data and peri-personal spatial computation (including spatial relationship to participant's trunk and arm) (Ehrsson, 2020). Ehrsson further suggests that body ownership transfer to an extending virtual arm (Kilteni et al., 2012) is evidence that peri-personal space may extend outward as the virtual arm grows. Additionally, these studies suggest that peri-personal space is a fundamental component of body ownership (Ehrsson, 2020).

Orientation Rule: The rubber hand illusion is also affected by the rotation of the rubber hand (Ehrsson, 2020). When the rubber hand is rotated ninety or one-hundred-eighty degrees from the participant's own hand, the illusion is broken and there is no body ownership transfer. If the participant is shown a video of his/her own hand at a different angle than the rubber hand, the illusion does not occur (Gentile et al., 2013). Additionally, if the rubber hand is displayed at an angle that is anatomically implausible, the illusion does not occur (Ehrsson, 2020).

"Tactile Congruence Rule"

In order to achieve body ownership transfer, tactile congruence is necessary. In the example of the rubber hand illusion, this means that whatever is touching the participant's actual hand must be closely similar to what is touching the fake hand (Ehrsson, 2020). A 2015 study found that participants did not experience body ownership transfer when a pencil was used to touch the fake hand and a paintbrush was used to touch the real hand(Ward et al., 2015). When similar items with differences in texture were used, participants still experienced the rubber hand illusion. For instance, a paintbrush and mascara brush produced the same results (Ward et al., 2015). Likewise a sponge and piece of cotton generated the illusion (Schütz-Bosbach et al., 2009).

"Humanoid Shape Rule"

Studies suggest that items that more closely represent humanoid shapes are more likely to generate body ownership transfer. Following the Holmes and Spence study of 2006, researchers studied objects ranging from a wooden block to a realistic rubber hand and found that the closer the object resembled a human limb, the more likely participants were to experience body ownership transfer (Tsakiris et al., 2010). This theory has been tested with humanoid hands of varying colors and materials including metal, wood, and digital. Studies found that the color of hand does not matter so long as the shape of the static object closely resembles a human hand (Ehrsson, 2020). Similar studies were conducted with virtual hands and found that body ownership transfer can occur for any shape (including block) in some participants, but was most frequent in realistic humanoid shaped hands (Lin & Jörg, 2016).

Phantom Limb/Phantom Pain

After a limb is amputated, some amputees experience a "phantom limb" phenomenon. Someone experiencing this phenomenon feels as if their missing limb is still present and may even experience sensations of pain in their non-existent limb. This occurs because the person's sense of embodiment and body memory still includes a neural representation of the lost limb. The amputee must reduce his/her mental connection to the lost limb to eliminate or reduce phantom limb sensation. An amputee must strengthen the connection to a prosthetic limb in order to properly integrate it into their sense of body memory and body ownership (Blumberg & Dooley, 2017).

Virtual body ownership and virtual body memory

As with body ownership, individuals engaging in virtual reality immersions form mental representations of their body in virtual space (Kellmeyer, 2019). Users immersed in virtual reality experience a sense of "agency", meaning that their actions influence the virtual world directly. "Virtual embodiment" refers to the physical manipulanda that affect interactions in virtual space (Spanlang et al., 2014). Research has been conducted attempting to study and exploit these sensations and how they produce illusions of virtual body ownership and varying degrees of body ownership transfer to the virtual body.

A Very Long Arm

Researchers conducted a study of virtual body ownership utilizing a head-mounted stereo head-tracking virtual reality system. Users were immersed in first person perspective with control of a virtual arm of varying lengths. A virtual threat was introduced, and researchers measured how users reacted to the threat with the virtual arm. The study found that users experienced body ownership transfer to the virtual arm when it was up to three times the length of their actual arm. Instances of body ownership transfer decreased at four times the length (Kilteni et al., 2012).

Teleoperations

Teleoperations refers to the operation of remote mechanical systems by human workers. The goal of teleoperations is to minimize risk to humans. Some teleoperation systems utilize virtual reality in an attempt to mimic the actual task as closely as possible and increase accuracy. Virtual reality teleoperations systems sometimes result in incidences of body ownership transfer. In a 2020 study, researchers utilized virtual reality teleoperations systems to measure the effect of perceived threat on worker operations and accuracy. Researchers found that users who were immersed in the system with human arm avatars were more likely to experience body ownership transfer than users who were immersed in systems with robotic arm avatars. The same study also examined the relationship between perceived risk in the virtual system and task performance. Researchers found that users with higher levels of body ownership transfer reacted more strongly to perceived risk and accuracy in task performance was reduced as a result (M. Shin et al., 2021).

The effect of body ownership and agency on immersion

In a study at the University of Seigen, researchers sought to introduce body ownership and agency as predictors for immersion in virtual reality. In the study, participants utilized the HTC Vive headset and hand controllers to complete tasks in a virtual post office. Agency was measured using the controllers, and different hand avatars were used to measure perception of body ownership. Immersion was measured using a post-test survey adapted from Agarwal and Karahanna. Researchers found that a larger sense of agency positively affected immersion while larger instances of body ownership transfer did not significantly affect immersion (Freude et al., 2020)

Effect of Virtual Body Ownership on Empathy

A number of studies have been conducted on the effect of immersion and virtual body ownership on empathy. A 2018 study examined the effects of "perspective taking virtual reality experiences" on prosocial behaviors in participants. The study found that the virtual reality experiences increased empathy, but only toward the individual whose perspective the participant inhabited during the experience (Loon et al., 2018). In a study by Barbot and Kaufman, participants were exposed to a series of immersive "perspective taking virtual reality" experiences meant to encourage empathy. Researchers found a significant relationship between ownership and empathy (Barbot & Kaufman, 2020).

Invisible Hand Illusion

A 2013 study found that multisensory stimulus could generate the illusion of a hand in empty space in non-amputee participants. The researchers moved a brush in empty space in front of the participant while simultaneously moving brush in the same way touching the participant's hidden real hand. The study found that a combination of visual and tactile stimulus could generate the illusion of an invisible hand so long as the movements are sufficiently well-matched. In addition to the behavioral studies, researchers utilized an fMRI and found increased activity in parts of the brain that respond to multisensory stimuli of the body (Guterstam et al., 2013).

More virtual studies

A 2015 study examined the effect of different full body avatars to on virtual body ownership. The study utilized a robot avatar, cartoonlike human avatar, and male and female realistic human avatars. Participants were inserted into a head mounted virtual reality system with accompanying hand manipulanda for a first-person simulation. Participants were asked to catch as many virtual balls as they could within a specific time frame. Self-reporting questionnaires were used to measure virtual body ownership (IVBO) and simulator sickness (SSQ). Skin conductance measurements were used to measure Galvanic skin response (GSR) to measure participants' stress level. Higher levels of stress are considered to indicate higher levels of body ownership transfer. Task performance was measured by counting the number of balls caught during the simulation. Researchers found that body ownership transfer occurred with equal frequency with the robot and cartoonlike human avatars and with less frequency with the realistic human avatar. Researchers suggest this may be due to the Uncanny Valley (Lugrin et al., 2015). The Uncanny Valley is the theory that people become more comfortable with non-human avatars and interactions the more realistic they are until they get too realistic and make people uncomfortable because they are still missing some element of realism. Rosenthal-von der Putten and associates conducted an fMRI study examining the neural responses to virtual social partners. They found that ventromedial prefrontal cortex activity may be a good indicator of how people respond to the uncanny valley phenomenon (Rosenthal-von der Pütten et al., 2019).

Various virtual studies examined how body ownership may transfer to a full-body avatar (Lugrin et al., 2015) (Nakul et al., 2020), how body ownership effects perceived self-location in virtual reality (Nakul et al., 2020) (Petkova et al., 2011), and the role of plausibility in presence and body ownership transfer (Hofer et al., 2020). Researchers have also examined body ownership transfer in virtual reality as a means for understanding and possibly increasing empathy in participants (Bertrand et al., 2018). Some of these studies are discussed in more detail elsewhere in this paper.

Neural Responses to Multisensory Stimulation and How they Relate to Body Ownership

Studies utilizing fMRI show responses in the premotor cortex and intraparietal cortex to visual and haptic stimuli of certain body parts as well as visual stimuli in peri-personal space in human and non-human (primate) subjects (Ehrsson, 2020). In a series of studies, increased activation was observed in the cerebellum, ventral premotor cortex, inferior parietal cortex, and intraparietal cortex when visual stimuli was combined with tactile stimuli compared to tactile stimulation alone (Gentile et al., 2011) (Gentile et al., 2013). These studies pinpoint the areas of the brain that integrate visual and tactile stimulation. A series of studies utilized a “blood oxygenation level-dependent (BOLD) adaptation technique” to observe activation of intraparietal cortex, inferior parietal cortex and ventral and dorsal premotor cortex when visual stimuli were introduced to peri-personal space near the participant’s hand (Brozzoli et al., 2012) (Brozzoli et al., 2011). A series of neuroimaging studies utilizing fMRI and BOLD consistently showed that the premotor and parietal cortex are activated by multisensory stimulation in limbs and peri-personal space (Ehrsson, 2020). Juliano and associates conducted an electroencephalography study comparing head-mounted virtual reality brain-computer-interfaces and conventional computer screen brain-computer-interfaces. The study found a significant relationship between neurofeedback and embodiment for the virtual reality simulation, but no significant relationship for the computer screen simulation (Juliano et al., 2020).

Many of these studies also examined embodiment and body ownership transfer. Physiological and neural responses in users immersed in virtual reality are more likely to match real life responses when multisensory stimuli are employed. Embodiment and instances of body ownership transfer are more likely to occur under the same conditions and elicit the same physiological and neural responses. Studies of physiological and neurophysiological responses to virtual reality agree overall that the presence of multisensory stimuli in and of itself is more important than the manner in which they are applied.

Ethical Implications

Virtual reality applications have long sought to replicate real world phenomena so that the immersive experience is indistinguishable from actual reality. Because of the higher level of immersion present in virtual reality, the medium requires additional scrutiny for ethical and moral issues. The moral concerns may also be different from those of other media.

Discussions about ethical concerns surrounding virtual reality agree overall that virtual reality must be considered differently than other forms of media. In a 2018 paper by Ramirez and LaBarge, the authors report that although users indicated post hoc that they did not believe their experiences while immersed in virtual reality were real, in the moment their experience was treated "as if it was real" (Ramirez & LaBarge, 2018). Additionally, physiological responses indicating that users' experience presence do not always correspond with users' own reports (Won et al., 2015).

Several factors affect how likely users are to experience presence in virtual reality. Among these factors, "perspectival fidelity", "context realism", and "virtual realism" are often discussed in relation to ethical concerns for virtual experiences. Perspectival fidelity refers to how closely a virtual experience matches the perspective of an average, neurotypical, human. Users are more likely to treat virtual reality experiences with high levels of perspectival fidelity as if they were real ("virtually real experiences"). Multisensory equipment as well as graphic and audio quality may affect perspectival fidelity. Context realism refers to how close the content of a virtual experience is to actual reality. Users are more likely to experience presence when an experience is more contextually real. Context realism may be fairly subjective to users because each person's cultural upbringing and life experiences may cause them to interpret reality differently to some extent (Ramirez & LaBarge, 2018). Context realism may not be affected by equipment or graphic and audio quality (Slater, 2018). Virtual realism essentially refers to presence: the feeling users experience of actually being inside a virtual experience. Many studies examine presence, how it occurs, and factors that affect it.

Although some material presented in virtual reality may be similar to material presented on other visual media like television, virtual reality presents significantly higher levels of perspectival fidelity, context realism, and presence. This is more ethically concerning for multiple reasons. Users exposed to a traumatic experience in virtual reality may experience psychological effects more similar to a real-life experience. "The equivalence principle" posits that if it is unethical to do something to someone in actual reality, then it is unethical to do it to them in virtual reality (Ramirez & LaBarge, 2018). Some believe that the high level of presence and embodiment present in virtual reality may even lead to permanent psychological, behavioral, or even biological changes in users (Madary & Metzinger, 2016) (Jouriles et al., 2019) (Rosenberg et al., 2013). Madary and Metzinger suggest a code of ethics for virtual reality research and therapy that advises utilizing existing psychological and cognitive wisdom when designing experiences so that they are following the same set of ethics as a real life experience would (Madary & Metzinger, 2016). Higher degrees of presence and neurophysiological responses are observed for virtual reality than other media, and some believe that it may be a more influential medium than other media. Because virtual reality is a very persuasive medium, some worry that it will be used in an unethical manner or may persuade users to behave in unethical ways. It may also promote racism, sexism, and other morally repugnant views more strongly than other media (Slater et al., 2020).

There are many studies and discourses on the ethics of aggression and violence in games and simulation and how that effects individuals and society. Some believe that these concerns are even more pronounced for virtual reality (Geldenhuys Kotie, 2019) (Dholakia & Reyes, 2018) (Prescott et al., 2018) (Slater et al., 2020). Some argue that virtual reality or other media that depict violence or aggression do not negatively influence users and may even serve beneficial purposes by providing a nonharmful outlet for aggression and violence (C. J. Ferguson & Wang, 2019) (Przybylski & Weinstein, 2019) (Zendle et al., 2018). Others have attempted to utilize the medium to moderate or even treat some issues including bystander behavior (Jouriles et al., 2019), domestic violence (Seinfeld et al., 2018), and psychological disorders which may present in violent behavior (Dellazizzo et al., 2019). The medium serves a positive therapeutic use, which may be enhanced by better immersion.

James S. Spiegel discusses the mental and physical health risks of virtual reality immersion. He pinpoints four specific areas of ethical concern: "Depersonalization/Derealization Disorder"; neglect of physical health, wellbeing, and environment; virtual reality may record significantly more personal data than other media and violate user privacy; and lastly, the way that virtual reality distorts the boundary between reality and illusion is in itself ethically questionable (Spiegel, 2018). Although some studies observed disassociation in virtual reality (Aardema et al., 2010) (Aardema et al., 2006), it is not clear that some of these concerns are more likely to occur in virtual reality than in other media. Furthermore, because symptoms of cybersickness are more likely to occur and intensify over longer periods of immersion, it is unlikely that users will experience the same neglect of physical wellbeing that is found in other media like television or traditional computer games.

A 2019 article by Phillip Kellmeyer discusses the neurophysiological and ethical implications of virtual reality used as therapy tools. He suggests that the same immersive attributes of virtual reality that make it an effective therapy tool create psychiatric dangers. For instance, although virtual reality may be combined with electroencephalography (EEG) to assist paralyzed patients with communication, it can lead to a "disturbed sense of agency." Additionally, patients may become dependent on the virtual aides and lose some or all of their autonomy (Kellmeyer, 2019). Others are also concerned about the impact of virtual reality on vulnerable populations including children and people who experience psychosis (Slater et al., 2020).

Developers may attempt to address some of these ethical concerns by modulating perspectival fidelity, contextual realism, virtual realism. This may include purposely degrading audio or visual quality, modifying user perspective, or regulating content or narrative. Some recommend enacting legal policies implementing age restrictions, a standardized rating system, requirements for information and warning labels, and privacy directives for collection and use of data (Spiegel, 2018). Others suggest minimizing potential harm by moderating usage and educating users about potential risks and safeguards (Slater et al., 2020).

Summation and Analysis

Many studies examine how body ownership functions and the myriad ways it translates to virtual body ownership. These studies, including many virtual and analog variations of the rubber hand experiment, show that it is possible to feel embodiment for external objects even if they do not directly resemble a user's own body parts. Furthermore, neural and physiological studies show that users exhibit similar responses to virtual stimuli as they might to real life stimuli. Because virtual reality is more immersive than other media, additional ethical concerns arise. These concerns include psychological trauma, depersonalization, interrupted agency, privacy violations, physical neglect, and dependency. Some worry that these issues may affect the user permanently.

Many virtual reality applications aim to imitate real-world experiences so that they are identical to actual reality. The immersive nature of virtual reality, which is greater than that of other media, necessitates additional ethical and moral scrutiny from its developers. The ethical and moral concerns of virtual reality are also distinct from those of other media. The literature agrees overall that virtual reality must be appraised differently than other forms of media because of its immersive nature. Subjects' self-reports of presence do not always correspond to physiological and neurological indicators of presence.

Although material presented in virtual reality may be comparable to material presented in other forms of media, virtual reality offers substantially higher levels of context realism, perspectival fidelity, and presence. This may be more concerning ethically for several reasons. Users who are exposed to traumatic experiences in virtual reality may undergo psychological consequences similar to those of a real-life scenario. Because virtual reality produces greater levels of presence and neurophysiological reactions than other media, some believe that virtual reality may be more persuasive to users than other media. Some are concerned that the influential nature of virtual reality may be utilized unethically or influence users to behave in unethical ways. The medium may also be used to inspire sexism and racism along with other morally and ethically objectionable attitudes more powerfully than other media.

The “equivalence principle” asserts that acts toward others that are considered unethical in real life are also unethical in virtual reality (Ramirez & LaBarge, 2018). Moreover, some believe that the greater levels of presence and embodiment provided by virtual reality may cause permanent behavioral, psychological, or even biological changes in users (Madary & Metzinger, 2016) (Jouriles et al., 2019) (Rosenberg et al., 2013). Medary and Metzinger advise ethical policy for research and therapy in virtual reality utilizing existing psychological and cognitive knowledge when devising virtual reality applications so that virtual experiences obey the same ethical regulations as real-life experiences (Madary & Metzinger, 2016).

Violence and aggression in video games and computer simulations have generated numerous ethical conversations regarding how they may affect individuals and society. Some deem these ethical concerns more pronounced in virtual reality. Others argue that portrayals of violence and aggression in media including virtual reality do not negatively influence users and may even function beneficially as nonharmful channels for negative behavior. Virtual reality is used to moderate and plausibly treat some behaviors, including domestic violence, bystander behavior, and specific psychological conditions that present in violent or aggressive behavior. Better immersion may enhance beneficial therapeutic applications in virtual reality.

Developers may address some of these ethical concerns by modifying perspectival fidelity, contextual realism, or virtual realism. These endeavors may entail regulating content or narrative, modulating user perspective, or purposely degrading visual or auditory quality. Educating users about potential risks, safeguards, and responsible use may alleviate some potential ethical issues. Many users do not understand the nuances of virtual reality and may be ignorant of possible dangers to themselves or children. Like most animated media, many parents mistakenly believe that video games, including virtual reality video games, are automatically appropriate for children of all ages. Users may also unwittingly leave themselves open to breaches in privacy because they do not understand how companies collect and use their data. Legal policies including age restrictions, privacy directives for collection and use of data, standardized rating systems, and requirements for information and warning labels may be necessary to protect the public. Social media and the internet make it very easy for users, including young children, to access questionable content, including media sourced from other countries that may not follow the same moral or ethical guidelines. Educating parents and users about these risks may be the only way to temper these hazards.

Interestingly, a lot of the conversation about the ethical implications of virtual reality is not published by developers but by authors from other fields. This may occur because otherwise moral and ethical developers may be intent on discovering and improving the technological aspects of virtual reality and may not contemplate the ethical consequences of their work. Some developers may become too absorbed in interesting technological challenges and may unconsciously or even consciously ignore any potential ethical ramifications of their work. This can be exploited by unscrupulous developers or corporations who may use virtual reality for unethical purposes or who may communicate morally objectionable material using the medium. Virtual reality content is difficult to regulate because people are able to easily access servers in other countries and download content that would otherwise be regulated or restricted in their home country.

Chapter 3: Methodology

Studies indicate that people are more likely to experience presence when additional sensory stimuli is introduced to virtual reality experiences. These studies suggest that integrating olfactory and haptic stimuli are more likely to increase presence than audio-visual stimuli alone. Studies further suggest that olfactory stimuli may be more significant to presence than haptic stimuli (Ranasinghe et al., 2018). Moreover, studies suggest that introducing multisensory stimulus increases presence in participants regardless of the method used to employ them.

Participant experience in multisensory presence studies is typically gauged using presence questionnaires and neurophysiological measurements. Presence surveys are typically administered post-test after the subjects are removed from the experience. Consequently, subjects may not accurately articulate feelings of presence. Furthermore, subjects may even fail to articulate feelings of presence contrary to neurophysiological data. Some studies administered questionnaires in the virtual reality experience, but these questionnaires were still administered post-test. As of the date of this paper, no studies examining presence administered a survey during the experience.

Research Questions and Hypotheses

The purpose of this study is to examine whether users experience higher levels of presence when additional sensory stimulation is integrated into a task-based virtual reality system and presence is measured during the experience.

R1: Are current Virtual Reality applications perceived differently because some senses are fully engaged, while others are not?

H1: Users experience higher levels of presence when olfactory stimulation is integrated into a virtual reality system than when it is not.

H2: Users experience higher levels of presence when haptic stimulation is integrated into a virtual reality system than when it is not.

H3: Users experience higher levels of presence when both haptic and olfactory stimulation are integrated into a virtual reality system than when none or only one is integrated.

H4: Integrating additional sensory stimuli affects users' qualitative perception of virtual reality.

R2: Are users better able to articulate presence when a survey is administered during an experience than when it is administered post-test?

H1: Users report greater feelings of presence when a survey is administered by a researcher during a virtual reality experience.

H2: Electroencephalography (EEG) data supports user reports of presence when a survey is administered by a researcher during a virtual reality experience.

H3: Users report greater feelings of presence when a survey is integrated and administered as part of a virtual reality experience.

H4: Electroencephalography (EEG) data supports user reports of presence when a survey is integrated and administered as part of a virtual reality experience.

Methodology

Research Method

This study employed a modified repeated-measures experimental pre-test/post-test design conducted in a closed virtual reality lab. The study utilized task-based scenarios to measure neurophysiological responses and presence.

Pre-test/Post-test research design

The pre-test/post-test research design is a standard method wherein baseline measurements are recorded prior to researcher intervention on a single set of subjects. Measurements are taken again after the intervention and compared. This design is generally considered effective for a small sample size (*N <= 15*). Because there is no change in participants between the first test and last test, any change in measurements may be attributed to external factors and not to intervention (Gliner et al., 2017). To mitigate this concern and increase internal validity in this study, subjects were randomly assigned to conditions.

Repeated Measures Design/Within-subjects Randomized Experimental Design

Repeated measures design is also called within-subjects randomized experimental design. This is a standard method in which subjects are assigned to conditions in a random order. Subjects operate as their own control, which decreases error variance. This method is useful for comparisons to traditional treatments such as the standard administration of presence questionnaires in this study assumed to have no carryover effects. However, this type of design may result in “symmetrical transfer effects” – when the impact of one order is greater than another (Gliner et al., 2017). In an attempt to mitigate this issue, this study randomly assigned treatment order in all cases instead of randomly assigning subjects to two set orders of treatment.

Randomized experimental design

Due to unexpected complications, only fifteen subjects were able to complete the full multisensory pre-test/post-test repeated-measures experiment (small sample). Data was analyzed for thirty-five subjects who completed the study without any additional sensory stimulation (full sample). Subjects in the full sample had been randomly assigned to the control group (post-test survey) or one of two in-test treatments. Subjects in the full sample did not receive any other sensory treatment. Because treatment was randomly assigned, these experimental results may be considered reasonably valid.

Operational Definitions

IPQ Score: Total score of the iGroup Presence Questionnaire. Higher scores indicate higher levels of presence. Range of possible scores: 14-70

EEG measurements: Number of wave cycles per second, measured in decibels and converted to Hertz (Hz). Emotiv EPOC EEG samples twice per second.

EEG channel/band baseline: The average score of measurements taken in the first fifteen seconds of an EEG test. Measurements are taken twice a second on each channel.

EEG right baseline: The average score of measurements taken in the first fifteen seconds of an EEG test. Measurements are taken twice a second on each channel located on the right side of the brain. (EPOC channels: O2, P8, P4, T8, FC6, F4, F8, AF4)

EEG left baseline: The average score of measurements taken in the first fifteen seconds of an EEG test. Measurements are taken twice a second on each channel located on the left side of the brain. (EPOC channels: AF3, F7, F3, FC5, T7, P3, P7, O1)

EEG average baseline: Average of the channel baseline measurements taken in the first fifteen seconds of an EEG test. Measurements are taken twice a second on each channel.

EEG channel/band in-test: The average score of measurements taken from a 15 second segment 20 seconds into the activity portion of the EEG test, which is 50 seconds from the start of the test including a 30 second baseline measurement. Measurements are taken twice a second on each channel.

EEG right in-test: The average score of measurements taken from a 15 second segment 20 seconds into the activity portion of the EEG test, which is 50 seconds from the start of the test including a 30 second baseline measurement. Measurements are taken twice a second on each channel located on the right side of the brain. (EPOC channels: O2, P8, P4, T8, FC6, F4, F8, AF4)

EEG left in-test: The average score of measurements taken from a 15 second segment 20 seconds into the activity portion of the EEG test, which is 50 seconds from the start of the test including a 30 second baseline measurement. Measurements are taken twice a second on each channel located on the right side of the brain. Measurements are taken twice a second on each channel located on the left side of the brain. (EPOC channels: AF3, F7, F3, FC5, T7, P3, P7, O1)

Adult waking EEG: Average EEG waking measurement for a standard adult. Beta 13-30Hz indicates regular activity. (Alpha 8-12Hz indicates relaxed state, typically with eyes closed)

EEG sensor placement: Emotiv EEG sensors are placed on the head in a modification of the standard 10-20/MCN EEG electrode placement. Several of the electrodes are placed slightly differently than the (AF3, AF4, FC5, FC6)

Variables

This study manipulated three independent variables in two or three levels. These are: haptic stimulus (two levels), olfactory stimuli (two levels), and measuring presence during experience (three levels). This study aimed to measure one main dependent variable with two levels. The main dependent variable of this study is measures of presence with two levels: iGroup Presence Questionnaire (IPQ) score and electroencephalography (EEG) activity in various parts of the brain. The study also measured virtual reality sickness post-test.

This study identified several potential compounding variables, which were controlled for during selection. These variables are age, sex, ethnicity, motion sickness susceptibility, migraines, and anxiety.

Summary of Variables:

Independent Variables:

- Haptic stimulus
  - Level 1: haptic stimulus
  - Level 2: no haptic stimulus
- Olfactory stimuli
  - Level 1: olfactory stimulus

Level 2: no olfactory stimulus

Survey Measure of Presence during experience

Level 1: presence measured during experience verbally by researcher

Level 2: presence measured during experience by non-player character in game

Level 3: presence measured after experience using a traditional computer form

Measures of Presence (Dependent Variables):

iGroup Presence Questionnaire (IPQ) score

Overall EEG activity

Individual channel (band) EEG activity

Front side EEG activity

Back side EEG activity

Left side EEG activity

Right side EEG activity

Other dependent variable recorded and examined for interaction effects:

Virtual Reality Sickness Questionnaire score (VRSQ)

Potential confounding variables (controlled during sample selection):

Age

Sex

Ethnicity (randomized)

Motion Sickness Susceptibility Questionnaire score (MSSQ)

Migraines (self-report)

Anxiety (self-report)

Population and Sampling Strategy

Although the target population of this study is adults in the United States, the in-person nature of this study, pandemic safety precautions, and travel limitations affected the scope of sample recruitment. This study was limited to adults in the United States ages 18-35 who live in Maryland and were willing and able to travel to the study location. This study did not accept University of Baltimore students as subjects to avoid potential confounding factors. The study was conducted in a closed virtual reality computer lab on campus.

Age and Gender Studies that examine presence in virtual reality are primarily conducted on young male subjects. Some studies include female subjects, but many of these studies are still composed of a male majority (Schwind, Knierim, Tasci, et al., 2017) (Lugrin et al., 2015). A comprehensive search by this author found no studies on presence in virtual reality conducted solely on female subjects. This study attempted to recruit an equal number of female and male subjects, but some female subjects were unable to complete the study. One female subject's results needed to be removed from the sample because of data corruption. A second female subject experienced virtual reality sickness and needed to be disconnected from the equipment prior to completing the study. Due to unexpected complications, only fifteen subjects were able to complete the full multisensory repeated-measures experiment (small sample). Data was analyzed for thirty-five subjects who completed the study without any additional sensory stimulation (full sample). *See tables for full demographic data.*

Some users of virtual reality and other interactive media experience motion-sickness-like symptoms. This malady is sometimes called cybersickness, simulator sickness, or VR sickness. Symptoms of cybersickness include dizziness, nausea, vertigo, perspiration, and stomach awareness. The prevalent theories on motion sickness and cybersickness credit conflicts in sensory input for the ailment. The brain fails to adequately resolve discrepancies between what the eyes are seeing and what the body is feeling. Adults 60 years and older are more prone to cybersickness than younger adults. Women are more likely to experience cybersickness than men (Petri et al., 2020) (Munafo et al., 2017). Children of both genders are more likely to experience motion sickness than adults, although adult women reported less change since childhood than men (Propper et al., 2018) Some ethnic groups have higher instances of motion sickness than others. Individuals with certain physical and mental health conditions, such as migraines and anxiety, are more prone to motion sickness (Paillard et al., 2013). Users who experience cyber-sickness cannot remain immersed in virtual reality for prolonged periods of time. Furthermore, cybersickness is negatively correlated with presence and may also affect other aspects of a virtual reality experience.

There are various remedies thought to avoid or reduce the symptoms of motion sickness. Studies have found that individuals who control the motion of the vehicle (i.e. drivers) are less prone to motion sickness than passengers. Similarly, viewers of virtual media are more likely to experience cyber sickness than individuals who are playing the game and controlling the avatar (Y.-C. Chen et al., 2012). To mitigate possible virtual reality sickness, users in this study controlled a first-person avatar. This study also screened users for susceptibility to motion sickness, which is thought to indicate susceptibility to virtual reality sickness.

To control for some of these factors, subjects in this study were aged eighteen (18) to thirty-five (35). Subjects in that age range are less likely to experience adverse effects of prolonged immersion in virtual reality. People of this age range are less likely to experience other health conditions that may affect the study. Subjects were screened for motion-sickness propensity, anxiety, and migraines.

Subjects were recruited from Montgomery County, Howard County, Anne Arundel County, Baltimore County, and Baltimore City in Maryland. These counties are ethnically diverse. The census reports ethnic populations in these counties averaging at 51.28% white (non-Hispanic), 27.8% black, 5.97% Hispanic, 4.36% Asian, and 10.6% other (*Montgomery County, MD | Data USA*, n.d.) (*Anne Arundel County, MD | Data USA*, n.d.; *Baltimore County, MD | Data USA*, n.d.; *Baltimore, MD | Data USA*, n.d.; *U.S. Census Bureau QuickFacts*, n.d.). There was no differentiation in treatment of ethnicities in this study.

Census reported ethnic distribution

	White (non-Hispanic)	Black	Hispanic	Asian	Other/Mixed
Baltimore City	27.70%	61.30%	2.76%	2.57%	5.67%
Baltimore County	56.50%	28.70%	2.77%	6.05%	5.98%
Montgomery County	43.00%	18.10%	14.40%	9.05%	15.45%
Howard County	62.10%	14.40%	5.80%	0.30%	17.40%
Anne Arundel County	67.10%	16.50%	4.10%	3.82%	8.48%

Average	***51.28%***	***27.80%***	***5.97%***	***4.36%***	***10.60%***

Actual sample demographics

Age (2 groups)	18-25	26-35	N		
	21	13	35		
percentage	60%	37%			
Age (3 groups)	18-24	25-30	30-35	N	
	21	10	4	35	
percentage	60%	29%	11%		
Sex	Male	Female	N		
	20	15	35		
percentage	57%	43%			
Ethnicity/Race	White	Black	Hispanic	Asian	Other/Mixed
	10	3	7	1	14
percentage	28.57%	8.57%	20.00%	2.86%	40.00%

Small sample demographics

Age (2 groups)	18-25	26-35	N		
	11	4	15		
percentage	73%	27%			
Age (3 groups)	18-24	25-30	30-35	N	
	11	2	2	15	
percentage	73%	13%	13%		
Sex	Male	Female	N		
	8	7	15		
percentage	53%	47%			
Ethnicity/Race	White	Black	Hispanic	Asian	Other/Mixed
	4	1	6	0	4
percentage	14%	4%	21%	0%	14%

Because subjects were expected to wear multiple pieces of equipment on their heads, subjects were recruited with perfect eyesight or wear corrective contact lenses. Eyeglasses, which are worn on the face, may impede proper use of the equipment or modulate user experience.

Subject age and sex were recorded and examined for possible effect but were not the focus of this study.

Subjects were recruited through a widespread social media campaign on Facebook, email, and Discord. Recruitment strategies targeted local groups who might be able to participate in the study. Subjects were able to choose day or night sessions so subjects who worked during the day could participate and the sample was more likely to be diverse. People who answered the recruitment efforts were asked to complete a pretest survey. The survey tested for motion sickness susceptibility, anxiety, migraines, familiarity with virtual reality, computer literacy, and ability to participate in person.

Compensation

Subjects were compensated for participation with $20 digital gift cards at the end of the study. Subjects who started the in-person study but were unable to complete still received the same compensation.

Tools

Virtual Reality System and Experience Design

HTC Vive is a head mounted virtual reality display that comes with two handheld controllers. The HTC Vive requires a set of motion tracking cameras mounted at specific angles and distances from the user. The HTC Vive headset utilizes a Dual AMOLED 3.6'' diagonal screen with 1080 x 1200 pixels per eye resolution and an integrated microphone. The HTC Vive has a 110-degree field of view and a refresh rate of 90 Hz. Its sensors include SteamVR Tracking, G-sensor, gyroscope, and proximity sensor. Interpupillary distance and lens distance may be adjusted to provide eye-relief for users. The handheld controllers include SteamVR sensors, a multifunction trackpad, dual-stage trigger, system button, grip buttons, and menu button. A chaperoned play area and front facing camera provide additional safety for the user. When not in standing or sitting mode, the HTC Vive requires a 6’6” x 4’11” minimum and 11’5” x 11’5” maximum room size for use (*VIVE Specs & User Guide - Developer Resources*, n.d.).

The HTC Vive is relatively user friendly and popular for developers. In this study, the researcher developed custom virtual reality software for the HTC Vive using Unity, a 3D game engine. The task-based experience was presented within a realistically rendered 3D room. Subjects controlled a first-person human avatar with gender-neutral arms and were asked to carry and sort ten different items from the table to three bins on the opposite wall. The bins were labeled trash, recycling, and hazardous material with accompanying symbols. The virtual room had a window with curtains visibly blowing in the breeze. For some of the treatments, a realistically rendered non-player character asked the subject questions. *See figures 5-6 in Appendix D.*

Neurophysiological Measurements of Presence: Electroencephalography (EEG)

Several physiological responses are thought to indicate feelings of presence including heart rate, skin conductance, neurofeedback, and blood oxygenation levels. Various studies suggest that increased levels of stress may indicate increased levels of presence. Researchers may monitor subjects immersed in virtual reality for physiological responses that indicate stress, such as heart rate and skin conductance. Feelings of fear have also been linked to feelings of presence and may be indicated by electrodermal activity and heart rate. Virtual reality users may also experience symptoms of cybersickness, which is negatively correlated with presence. People who are experiencing feelings of presence typically display increased levels of neurofeedback – primarily frontal lobe activity. Electroencephalography (EEG) studies associate this amplified neural activity with virtual body ownership and multisensory stimulation (Kanayama et al., 2021) (Petukhov et al., 2020) tasks (Juliano et al., 2020) (Bekrater-Bodmann et al., 2014) (Guterstam et al., 2013) (Brozzoli et al., 2011) (Grill-Spector et al., 2006) (Limanowski & Blankenburg, 2016).

Electroencephalography (EEG) measures the electrical activity in the brain using electrodes placed on the head. Studies comparing electroencephalography readings for participants performing activities in actual reality and in virtual reality found that brain activity was relatively similar in both instances, but different for traditional computer screens (Petukhov et al., 2020) (Juliano et al., 2020). These findings indicate that electroencephalography may be a reasonable tool for measuring presence.

Emotiv EPOC EEG is a wireless electroencephalography system that connects to a desktop or laptop computer. The system contains fourteen (14) channels for whole brain sensing. The headset is lightweight and easy to use in conjunction with other head-mounted equipment. The system only takes about five minutes to set up, which reduces the amount of time subjects need to remain in all the head-mounted equipment necessary for the test. The headset uses saline-based electrodes, which are not wet sensors, and does not require gel application for use. The Emotive EPOC EEG headset is easy to sanitize and reuse. The system comes with its own software package for interpreting and analyzing results.

The Emotiv EPOC system utilizes a modified 10-20/MCN electrode placement. The electrodes are fixed in place on the headset but may be moved slightly for better positioning and conductivity. The headset uses replaceable felt sensors, which are saturated with a saline solution. Subjects were asked to wear long hair tied back against their head for easier electrode positioning and better conductivity. The Emotiv software package analyzes individual electrode connection in real-time so that positioning and sensor saturation may be adjusted before testing begins. Electrodes may also be readjusted during testing as necessary. *See figures 1-3 in Appendix D.*

Alienware Desktop Computers

The study utilized Alienware Desktop computers running Windows operating systems with Intel core i9 processors and NVIDIA GeForce GTX 1080 graphic cards. These computers are specially formatted to run virtual reality applications.

iGroup Presence Questionnaire (IPQ)

The Slater, Usoh, and Steed (SUS) presence questionnaire is the second most cited survey used to gauge presence. The questionnaire was developed over several studies and includes six items on three themes: “the sense of being in the VE” (virtual environment), “the extent to which the VE becomes the dominant reality”, and “the extent to which the VE is remembered as a ‘place’ ” (Schwind et al., 2019). A study using the Witmer and Singer (WS) and Slater, Usoh, and Steed questionnaires found that participants could not differentiate between presence in virtual reality and presence in actual life. The study asked two groups of participants to complete identical tasks either in real life or in a virtual environment. There were no significant differences in scores between the two groups (Usoh et al., 2000). A 2004 study evaluated Witmer and Singer questionnaire and the Slater, Usoh, and Steed Questionnaire for validity and reliability with 24 majority male subjects from 19 countries and found that the SUS questionnaire provided more consistent results (Nystad & Sebok, 2004).

The iGroup presence questionnaire (IPQ) was developed based on identified cognitive processes which make up the presence archetype. This questionnaire evaluated three subsets: “spatial presence”, “involvement”, and “experienced realism” (Schubert, 2003). A later study by the same group added one item for an “involvement” subset (Schwind et al., 2019).

The iGroup Presence Questionnaire uses many of the same measures as the Slater, Usoh and Steed and Witmer and Singer questionnaires. IPQ was psychometrically evaluated for validity and reliability in a Portuguese sample in 2016. The study found that IPQ maintained validity in the study when translated to Portuguese for a Portuguese sample of 478 subjects (Vasconcelos-Raposo et al., 2016). A 2019 study by Schwind and associates presented presence questionnaires post-test in virtual reality using virtual hands to answer the questionnaires. The study evaluated three common questionnaires (IPQ, WS, and SUS) in 36 subjects in the United States and recommended IPQ for reliability in a limited time frame when used in virtual reality (Schwind et al., 2019). This study utilized the iGroup Presence Questionnaire (IPQ).

Virtual Reality Sickness Questionnaire (VRSQ)

A number of virtual reality users experience motion-sickness-like symptoms when immersed in a virtual reality experience. These symptoms include nausea, sweating, headaches, dizziness, and vertigo. Cybersickness and presence are negatively correlated in multiple studies. Simulator Sickness Questionnaire (SSQ) is the most cited questionnaire for measuring motion-sickness-like symptoms in virtual reality. The Virtual Reality Sickness Questionnaire (VRSQ) was developed by Kim and Associates based on the Simulator Sickness Questionnaire (SSQ) after finding significant score differences on the SSQ between screen based simulation systems and virtual reality systems (H. K. Kim et al., 2018). Although researchers often use the Nausea Profile (NP), Simulation Sickness Questionnaire (SSQ), or Cyber Sickness Questionnaire (CSQ) to measure virtual reality sickness, studies found the Virtual Reality Sickness Questionnaire more valid for evaluating virtual reality. Although the Cybersickness Questionnaire (CSQ) performed better in multiple virtual reality studies than the Nausea Profile (NP), Simulation Sickness Questionnaire (SSQ), it did not correlate in studies as consistently as the Virtual Reality Sickness Questionnaire (VRSQ). Both the Virtual Reality Sickness Questionnaire (VRSQ) and Cybersickness Questionnaire (CSQ) have not been tested as diversely as some of the other surveys, which may limit psychometric validity, but they are generally considered a good measure for Virtual Reality Sickness (Sevinc & Berkman, 2020). This study utilized the Virtual Reality Sickness Questionnaire (VRSQ) post-test to determine if any subjects experienced virtual reality sickness, which may affect results.

Motion Sickness Susceptibility Questionnaire (MSSQ)

Motion sickness is characterized by feelings of illness brought on by motion. This may include feelings of vertigo, dizziness, nausea, and imbalance. Other symptoms may include sweating, headache, and hyperventilation. Roughly sixty percent of the human population experiences motion sickness.

According to current theories on motion sickness, it is caused by conflicting sensory data as they are processed by the brain. Information about body position and movement is provided to the brain by the vestibular (inner ear) system along with visual afferent (nerves) and somatosensory (physical sensation) input. Angular acceleration is registered in the vestibular system canals and linear acceleration stimulates other portions of the vestibular system (otolith organs: saccule and utricle). This includes the movement of the Earth. Afferent nerves in the vertebral column and neck muscles provide positional data of the head relative to the torso. Data from the joints and other muscles in the body is provided by their respective afferents, which are connected to the motor centers of the brain. Normally, all these sensory input systems provide information to the brain without contradiction. Motion sickness is caused when "kinetogenic sensory conflicts" occur. According to this theory, there are six categories of conflict that occur. (Koch et al., 2018). These conflicts often occur when people are engaged in multisensory interactive media, such as computer games and virtual reality immersions. Users who experience these symptoms are often unable to remain engaged in a virtual reality experience. These symptoms may also affect other aspects of a study.

The Motion Sickness Susceptibility Questionnaire (MSSQ) is sometimes used in conjunction with other cybersickness measurements to assess the predisposition of participants to experience motion sickness resulting from various forms of motion. The questionnaire was psychometrically evaluated and is generally highly rated for validity (Golding, 2006). This study screened potential subjects using the Motion Sickness Susceptibility Questionnaire (MSSQ) to make sure it did not affect the treatment or skew results.

Large electric fan

The study implemented a high-powered fan to simulate wind aimed at the subject. The researcher stood behind and away from the fan to reduce likelihood that particles may spread between people (COVID precaution).

Scent vials

Studies suggest that presence of odors may affect cognitive function. Unpleasant odors are more likely to affect cognition than pleasant odors (Nordin et al., 2017). Furthermore, studies imply that malodor is more likely to affect difficult cognitive tasks than simple cognitive tasks (Dalton et al., 2020). People are also affected more by odors that may indicate danger such as smoke indoors and harsh chemicals (Dalton et al., 2020).

Researchers conducted a series of task-based virtual reality studies and observed that presence was more impacted by unpleasant odors than by pleasant odors. Higher levels of presence were observed when subjects were exposed to scents that matched the virtual environment than when exposed to conflicting scents. These studies suggest that user sense of reality was affected by pleasant scents, but user feelings of presence were not significantly impacted by pleasant scents. Sense of reality and presence were measured using self-reporting questionnaire ITC Sense of Presence Inventory (ITC-SOPI) (Baus & Bouchard, 2017) (Baus et al., 2019). In most other studies examining olfaction and presence, users are provided with pleasant olfactory stimuli such as summer rain and fruit, which may still produce significant increases in feelings of presence (Ranasinghe et al., 2018) (Ranasinghe & Do, 2016) (Ranasinghe et al., 2019). Although studies suggest that integrating olfactory stimuli may increase presence in virtual reality, it is not clear whether the type of odor dispensed during the studies made consistent difference to user experience of presence. To control for this potential confounding variable, this study provided only unpleasant odors to participants. Odors were carefully selected so that, while typically considered unpleasant, they were not so unpleasant that they would distress subjects. Because subjects were required to wear masks on campus, strong odors were selected.

Some scents were reproduced using materials they represented. Other scents were procured in vials from Monell Chemical Senses Center. Vials were held approximately twelve (12) inches from the subject's nose for exactly as long as the subject's avatar was holding the corresponding virtual item. Subjects were able to smell the odor, but there was no prolonged exposure to unpleasant chemicals. All stimuli were either explicitly approved by the American Food and Drug Administration (FDA), European Medicines Agency (EMEA), or other agencies, signaling that the chemical or substance is considered safe by experts or were presented below their threshold of toxicological concern (TTC) (J. Mainland, personal communication, March 18, 2022).

Stimulus	Odor name	CAS	SMILES	PubChem CID	Solvent	Final []
apple core	ethyl isovalerate	108-64-5	CCOC(=O)CC(C)C	7945	propylene glycol	0.1

fish	trimethyl amine	75-50-3	CN(C)C	1146	ddH2O	0.005
batteries	1-Methylcyclohexane-1-carboxylic acid	1123-25-7	CC1(CCCCC1)C(=O)O	70744	N/A	1
moldy bread	2,4,6-tribromoanisole	607-99-8	COC1=C(C=C(C=C1Br)Br)Br	11839	diethyl pthalate	0.001
juice bottle	1-cyclohexylethyl acetate	13487-27-9	CC(C1CCCCC1)OC(=O)C	114533	propylene glycol	0.1

Stimulus	**Material Utilized**
wine bottle	red wine
matches	burnt cotton balls
can of beans	open can of beans
combustion engine	motor oil
rubber tire	rubber bands

Methods

Pre-test

Subject received a written explanation of the study via email prior to arriving at location including screening questionnaire, explanation of COVID precautions, and consent form to sign and return to the researcher. When subjects arrived on campus, they were met by researcher in the lobby outside the lab. Each subject was brought into the enclosed hallway outside the lab where researchers verbally explained the nature of the study. Subject was shown into the virtual reality lab where they were asked to complete the full Motion Sickness Susceptibility Questionnaire (MSSQ). Researchers showed and explained the equipment used for the study and answered any questions the subject posed. Subjects who were waiting for their turn were asked to wait in the lounge area outside the lab. Schedule of testing was optimized for minimal overlap between subjects.

See Appendix A

Test

Researcher verbally asked for subject consent to record and began recording video before starting the test. HTC Vive and Emotive system showed and explained to subject. Subject was asked if they have ever used a Vive or similar device before and given verbal operational instructions. Subjects were better able to express familiarity with equipment or similar equipment after seeing it.

Researcher verbally asked subject for consent again before placing equipment on subject's body. Subject was assisted to wear the EPOC EEG headset. EEG channel conductivity and signal strength were tested. Subject was then assisted to wear the Vive headset over the EPOC EEG headset and shown how to use and secure the Vive controllers. Adjustments were made to the equipment positioning and straps for user comfort. Subjects were asked to narrate their experience. Once all equipment was in place and subject expressed sufficient comfort level, subject EEG baseline measurements were recorded. EEG measurement recording was initialized.

Subject entered the virtual reality world and had several minutes to familiarize themselves with the controls, mitigate any possible nervousness, and make any equipment adjustments if necessary. Subject was asked if they would like a break and were given a five-minute break if necessary.

Subject was asked to narrate their experience. Subject then entered the first task-based test scenario. Subjects were presented with a realistically rendered room and were asked to carry and sort ten different items from the table to three bins on the opposite wall. The bins were labeled with symbols for trash, recycling, and hazardous material. Subject controlled a gender-neutral human avatar in first-person. The virtual room had an open window with curtains visibly blowing in the breeze.

Random subjects were presented with one of three randomized conditions.

> Condition 1: After two (2) minutes in the scenario, a non-player-character randomly asked the player a presence question from iGroup Presence Questionnaire. The subject was asked to answer the question out loud for the researcher to record.

Condition 2: After two (2) minutes in the scenario, the researcher randomly asked the player a presence question from iGroup Presence Questionnaire. The subject was asked to answer the question out loud for the researcher to record.

Condition 3: no questions were asked during the test. The iGroup Presence Questionnaire was given to subjects after the test.

Subjects were allowed ten (10) minutes to complete the first scenario. Most subjects completed their tasks well before time ran out. No subject went overtime. EEG measurements and task accuracy were recorded. Researcher observed and recorded subject body movements and speech.

Subjects were given a five (5) minute break in the virtual world. Subjects were asked if they would like a break without the equipment before the second test. No subjects asked for such a break.

After the break, subjects entered the second task-based test scenario. Subject was presented with the same realistically rendered room and asked to carry and sort ten different items from the table to three bins on the opposite wall. The bins were labeled with symbols for trash, recycling, and hazardous material. Subject controlled a gender-neutral human avatar in first-person. The virtual room had an open window with curtains visibly blowing in the breeze.

Subjects who experienced either condition in the first scenario may have experienced the same or different condition in the second scenario. Random subjects were presented with one of three randomized conditions, which are identical to the first test.

Condition 1: After two (2) minutes in the scenario, a non-player-character randomly asked the player a presence question from iGroup Presence Questionnaire. The subject was asked to answer the question out loud for the researcher to record.

Condition 2: After two (2) minutes in the scenario, the researcher randomly asked the player a presence question from iGroup Presence Questionnaire. The subject was asked to answer the question out loud for the researcher to record.

Condition 3: no questions were asked during the test. The iGroup Presence Questionnaire was given to subjects after the test.

Random subjects also received one of three new randomized conditions.

Condition 1: no additional sensory stimuli

Condition 2: olfactory stimuli were introduced to match the items the subject is sorting by holding scent vials under the subject's nose

Condition 3: haptic stimulus was introduced by turning on a large fan (wind)

Condition 4: both haptic and olfactory stimuli were introduced

Subjects were allowed ten (10) minutes to complete the first scenario. Most subjects completed their tasks well before time ran out. No subject went overtime. EEG measurements and task accuracy were recorded. Researcher observed and recorded subject body movements and speech.

Post-test

Researcher turned off EEG recording. Subjects were assisted to remove both headsets and controllers and asked to complete VRSQ and qualitative questions (outlined below). Subjects who received no questionnaire during testing were asked to complete the iGroup Presence Questionnaire on a computer.

Researcher turned off video recording.

Subject was thanked for their participation. Researcher walked subject to the waiting room and gave subject directions to exit. Subject received a $20 gift card after the study.

See Appendices A and C

Chapter 4: Results and Data Analysis

Research Questions and Hypotheses

The purpose of this study is to examine whether users experience higher levels of presence when additional sensory stimulation is integrated into a task-based virtual reality system and presence is measured during the experience.

R1: Are current Virtual Reality applications perceived differently because some senses are fully engaged, while others are not?

H1: Users experience higher levels of presence when olfactory stimulation is integrated into a virtual reality system than when it is not.

H2: Users experience higher levels of presence when haptic stimulation is integrated into a virtual reality system than when it is not.

H3: Users experience higher levels of presence when both haptic and olfactory stimulation are integrated into a virtual reality system than when none or only one is integrated.

H4: Integrating additional sensory stimuli affects users' qualitative perception of virtual reality.

R2: Are users better able to articulate presence when a survey is administered during an experience than when it is administered post-test?

H1: Users report greater feelings of presence when a survey is administered by a researcher during a virtual reality experience.

H2: Electroencephalography (EEG) data supports user reports of presence when a survey is administered by a researcher during a virtual reality experience.

H3: Users report greater feelings of presence when a survey is integrated and administered as part of a virtual reality experience.

H4: Electroencephalography (EEG) data supports user reports of presence when a survey is integrated and administered as part of a virtual reality experience.

Data Analysis and Conversion

In addition to the standard Electroencephalography (EEG) waveforms, Emotiv EEG software outputs a CSV file containing measurements from each channel. The raw voltage measurements are output from 14 or 16-bit ADC. The headset measures the deviation from the average signal level. Negative voltages indicate measurements less than the average while positive voltages indicate measurements greater than the average (subtracting the magni). The EEG signal occurs at approximately 4200 uV to allow for negative measurements. To remove the offset, the data was run through the Emotiv Analyzer tool which performs Fast Fourier Transform (FFT) and a high-pass filter to remove any possible confounding signals due to movement or other artifacts. The transformed data is output in decibel format, which must then be converted to Hz.

By default, the Emotiv analyzer segregates the EEG wavelengths into six smaller categories to make calculations easier. These divisions are not based on standard EEG frequencies. EEG measurements range from 0.5Hz to 70Hz and are divided into standard ranges that are classified with Greek letters. Alpha (8-12Hz) indicates relaxed state, typically with eyes closed. Beta (13-30Hz) indicates regular waking activity. Gamma (30-200Hz) indicates increased activity or concentration. These standard frequencies do not signify the same level of activity as a standard EEG in this dataset because the Emotiv Epoc outputs measurements of the deviation from the average signal, which differs for each subject. This study focused on deviations from the average EEG signal as a method of determining increased presence.

The raw EEG measurements were run through the Emotiv analyzer in several batches. The Emotiv analyzer can process frequencies ranging 0-64Hz. One processed batch used a slightly larger approximation of Beta (12-32Hz) range. A second batch used a larger range (8-40Hz). The approximate Beta range analysis did not capture a large enough range of activity to be used for this study. Batches that utilized ranges larger than 8-40Hz did not produce significantly different results in most subjects from the batch that utilized a range of 8-40Hz. Therefore, all of the statistical analyses were performed on the data translated by the Emotiv analyzer using an 8-40Hz frequency range. All EEG measurements are reported in Hertz.

All analyses utilized the rest of the recommended settings. Headset movements, electrostatic discharge from the user, and other artifacts can cause large voltage step changes between EEG signal samples. Voltage step changes can affect the filters used by the Emotiv analyzer and modify the resulting data. These issues are be mitigated by applying a slew limit, which restricts the influence of any step changes without significantly altering the EEG signal. Emotiv recommends a slew limit of 30. As recommended by Emotiv, the data was re-referenced according to the inquartile mean. The inquartile mean measures the central tendency of the data based on the mean of the inquartile range (the range of values in the middle of a set of scores). The filter parameters are set to the default filter coefficients for a second order high-pass filter of 3dB at 0.5Hz. The Emotiv analyzer divides the data into "Epochs" to better calculate the power of each EEG frequency band. The power was computed for each frequency by applying a Fourier transform to each Epoch. The sizes are set to the Emotiv recommendations.

Emotiv default wave analysis settings:	**Beta wave analysis settings:**	**Large Range Analysis settings:**
Slew limit 30	Slew limit 30	Slew limit 30
Inquartile mean referencing	Inquartile mean referencing	Inquartile mean referencing
Filter parameters:	Filter parameters:	Filter parameters:
A: [1,-1.96529337,0.96588546]	A: [1,-1.96529337,0.96588546]	A: [1,-1.96529337,0.96588546]
B: [0.98279471,-1.96558942,0.98279471]	B: [0.98279471,-1.96558942,0.98279471]	B: [0.98279471,-1.96558942,0.98279471]
Epoch:	Epoch:	Epoch:
Fourier transform window length: 256	Fourier transform window length: 256	Fourier transform window length: 256
Sliding window step size: 64	Sliding window step size: 64	Sliding window step size: 64
Band Frequencies (6):	Band Frequencies (one):	Band Frequencies:
1. Low Frequency (included): 4	Low Frequency (included): 12	Low Frequency (included): 8
High Frequency (omitted): 8	High Frequency (omitted): 32	High Frequency (omitted): 40
2. Low Frequency (included): 8		
High Frequency (omitted): 12		

3. Low Frequency (included): 12 High Frequency (omitted): 18 4. Low Frequency (included): 18 High Frequency (omitted): 25 5. Low Frequency (included): 25 High Frequency (omitted): 32 6. Low Frequency (included): 32 High Frequency (omitted): 40		

The Emotiv Analyzer returns values in decibels, which includes negative numbers. The values were converted from decibels to Hertz in Excel. Descriptive statistics for the baseline (first 15 seconds (30 measurements)) were calculated in Excel. Descriptive statistics for a 30 second segment 20 seconds into the activity portion of the EEG test, which is 50 seconds from the start of the test including a 30 second baseline measurement were calculated in Excel. See Appendix B for ranges for measurements and formulas used.

Descriptive statistics were also generated for several random 30 second samples in some subjects to verify that the in-test means did not differ significantly from the 50 second in-test mean.

Difference scores were calculated for the means of baseline and in-test measurements in Excel.

iGroup Presence Questionnaire (IPQ) contains some questions where the scale is reversed. Raw scores needed to be adjusted before performing statistical calculations to account for this. All scores shown are adjusted. *See Appendices B and C for full details.*

Statistical Hypotheses and Analyses

Due to unexpected complications, only fifteen subjects were able to complete the full multisensory EEG data set (small sample). Available data was also analyzed for all subjects who completed other portions of the study without any additional sensory treatments (full sample).

Jarque-Bera tests were performed on the datasets, and the EEG values for some bands were normally distributed (see Appendix B for full tables). A Jarque-Bera test also showed normal distribution for all IPQ test scores.

All EEG values are provided in Hertz (Hz).

Small Sample Data Analysis and Results

The small sample (N=15) consists of subjects that received one in-test survey and one post-test survey in a randomized order. No differentiation was made between subjects who received an in-test survey from a non-player character and those who received their in-test survey from a researcher.

Subjects received no extrasensory modifier in the first test, and some received a sensory modifier in the second test.

Small sample demographics

Age (2 groups)	18-25	26-35	N		
	11	4	15		
percentage	73%	27%			
Age (3 groups)	18-24	25-30	30-35	N	
	11	2	2	15	
percentage	73%	13%	13%		
Sex	Male	Female	N		
	8	7	15		
percentage	53%	47%			
Ethnicity/Race	White	Black	Hispanic	Asian	Other/Mixed
	4	1	6	0	4
percentage	14%	4%	21%	0%	14%

Fisher's exact test

The EEG values describe the deviation from the average EEG activity in Hz. Fisher's exact test requires nominal values. EEG values were categorized as Low, Moderate, or High using the range of values in the following table. The values in the table were based on a rounded percentage of all EEG values that fell into each category using two different thresholds. *See Appendix B for full tables of results and r code.*

For threshold one, 91.1% of band average EEG values deviate less than 1 Hz from 0. All percentages are shown in the second table. EEG values that deviate .2 or more from average activity may indicate increased presence. EEG values that deviate more than 1 Hz from average activity may indicate high levels of presence. *See Appendix B for full tables of score distribution.*

Presence	**(absolute value deviation from 0 in Hz)**	
Low	0	0.2
Moderate	0.2	1
High	1	6

Percentage of values in each category Threshold I

	Left	Right	Front	Back	Band Average
Low	39.3%	51.8%	41.1%	32.1%	42.9%
Moderate	48.2%	42.9%	46.4%	58.9%	48.2%
High	12.5%	5.4%	12.5%	8.9%	8.9%

For threshold two, 66.1% of band average EEG values deviate less than 1 Hz from 0. All percentages are shown in the second table. EEG values that deviate .2 or more from average activity may indicate increased presence. EEG values that deviate more than .4 Hz from average activity may indicate high levels of presence. *See Appendix B for full tables of score distribution.*

Presence	(absolute value deviation from 0 in Hz)	
Low	0	0.2
Moderate	0.2	0.4
High	0.4	6

Percentage of values in each category Threshold II

	Left	Right	Front	Back	Band Average
Low	39.3%	51.8%	41.1%	32.1%	42.9%
Moderate	19.6%	25.0%	25.0%	32.1%	23.2%
High	41.1%	23.2%	33.9%	35.7%	33.9%

Range of IPQ values

Max	60
Min	21
Range	39
Average	44.85714

Range of Possible IPQ values

Max	70
Min	14
Range	56

Fisher's exact test requires nominal values. IPQ values were categorized as Low, Moderate, or High using the range of values in the following tables. The values in the table are based on the range of possible values of the IPQ survey scores using two different thresholds.

Threshold I, high presence is indicated by scores that fall within the top 10% of possible values. Low presence is indicated by scores that fall in the bottom 45% of possible values. Moderate presence is indicated by scores that fall within the 45%-90% range of possible values.

IPQ Scores

Low	14	39
Moderate	39	63
High	63	70

Threshold II, high presence is indicated by scores that fall within the top 33% of possible values. Low presence is indicated by scores that fall in the bottom 33% of possible values. Moderate presence is indicated by scores that fall within the 33%-66% range of possible values.

IPQ Scores

Low	14	30
Moderate	30	46
High	46	70

Percentage of Values in each Category

	Threshold I	Threshold II
Low	16.1%	7.1%
Moderate	83.9%	42.9%
High	0.0%	50.0%

Fisher's Exact Test was run on the small sample size (N=15) using a 95% confidence interval.

Hypotheses:

H_0: the distribution is the same as expected (1:1:1:1)

H_1: the distribution is different than expected

No significant results were found in any of the EEG channels or in the iGroup Presence Questionnaire scores. The distribution of values is not significantly different than expected, and the null hypothesis cannot be rejected. *See Appendix B for full tables of results.*

Table Summary of Results for Fisher's Exact Test

	Threshold I	significance	Threshold II	significance
AF3	0.0597	Not Significant	0.1808	Not Significant
F7	0.2527	Not Significant	0.4655	Not Significant
F3	0.2674	Not Significant	0.093	Not Significant
FC5	0.0732	Not Significant	0.2284	Not Significant
T7	0.8527	Not Significant	0.6454	Not Significant
P7	0.4154	Not Significant	0.7243	Not Significant
O1	0.4154	Not Significant	0.7902	Not Significant
O2	0.0567	Not Significant	0.1137	Not Significant
P8	0.4877	Not Significant	0.1305	Not Significant
T8	0.135	Not Significant	0.4655	Not Significant
FC6	0.9233	Not Significant	0.6454	Not Significant
F4	0.9329	Not Significant	0.3826	Not Significant
F8	0.3011	Not Significant	0.3878	Not Significant
AF4	0.976	Not Significant	0.976	Not Significant
Left	0.7243	Not Significant	0.7962	Not Significant
Right	0.5397	Not Significant	0.2527	Not Significant
Front	0.1892	Not Significant	1	Not Significant
Back	0.7642	Not Significant	0.6546	Not Significant
Average	0.427	Not Significant	0.8527	Not Significant
IPQ	0.6374	Not Significant	1	Not Significant

Paired sample t-test

A paired sample t-test (two-tailed) was performed on the small sample size (N=15). Subjects received one in-test survey and one post-test survey. No differentiation was made between subjects who received an in-test survey from a non-player character and those who received their in-test survey from a researcher. Subjects received no extrasensory modifier in the first treatment, and some received a sensory modifier in the second treatment. No differentiation was made between types of sensory treatments. T-tests are valid statistical analyses for small sample sizes (N<30) when data is normally distributed.

Hypotheses:

H_0: The mean difference in a paired observation is 0 ($\mu_D = 0$)

H_1: The mean difference in a paired observation is not 0 ($\mu_D \neq 0$)

A Jarque-Bera test revealed that the F8 EEG band measurements were normally distributed. There was a significant difference in the F8 EEG band measurements for in-test survey with additional sensory stimulation (M = 0.297, SD = 0.356) and post-test survey with no additional sensory stimulation (M = 0.092, SD = 0.137) conditions; t(14) = 2.293, p = 0.038, d = 0.35.

The F8 EEG band rests on the frontal lobe of the brain. The frontal lobe is associated with higher mental functions including creativity, emotional expression, concentration, and judgement (Sukel, 2019). Increased EEG activity in the F8 channel may indicate higher levels of presence.

There was not a significant difference in any of the other EEG bands or the IPQ scores. See table for summary of results (EEG values in Hz).

	M in-test	***SD in-test***	***M post-test***	***SD post-test***	***df***	***t***	***p***	***d***
IPQ	43.600	11.513	45.730	8.844	14	-1.464	0.165	5.643
AF3	0.253	0.775	0.273	0.351	14	-0.081	0.936	0.946
F7	-0.114	1.358	0.222	0.462	14	-0.881	0.393	1.474
F3	0.380	0.490	0.115	0.507	14	1.390	0.186	0.750
FC5	0.492	0.905	0.347	0.471	14	0.512	0.617	1.099
T7	-0.233	1.642	0.351	0.578	14	-1.249	0.232	1.814
P7	-0.037	1.305	-0.041	0.967	14	0.011	0.991	1.491
O1	0.594	1.275	0.641	0.775	14	-0.110	0.914	1.649
O2	0.175	0.357	0.222	0.441	14	-0.332	0.745	0.549
P8	0.161	0.393	0.118	0.239	14	0.299	0.769	0.559
T8	0.106	0.617	0.098	0.185	14	0.045	0.965	0.725
FC6	0.251	0.337	0.179	0.255	14	0.644	0.530	0.432
F4	0.529	0.775	0.143	0.250	14	1.731	0.105	0.864
F8	0.297	0.356	0.092	0.137	14	2.293	0.038	0.346
AF4	0.493	0.522	0.017	0.729	14	1.717	0.108	1.073
Left	0.191	0.684	0.272	0.308	14	-0.393	0.700	0.801
Right	0.288	0.309	0.124	0.169	14	1.635	0.124	0.387
Front	0.177	0.442	0.105	0.289	14	0.541	0.597	0.515
Back	0.223	0.404	0.235	0.359	14	-0.089	0.931	0.507
Average	0.239	0.409	0.198	0.208	14	0.320	0.753	0.497

The null hypothesis may be rejected for the F8 EEG band because the results of the t-test are significant. The null hypothesis cannot be rejected for any of the other EEG bands or for the iGroup Presence Questionnaire scores because the results of the statistical analysis are not significant. *See Appendix B for the full table of results.*

Increased EEG activity in the frontal lobe may indicate higher levels of presence. It is possible that a combination of extrasensory stimulation and in-test survey administration leads to higher levels of presence. Additional research is recommended.

Wilcoxon Signed Rank Test

The Wilcoxon signed rank test is a nonparametric test that may be used in place of a paired sample t-test when data is not normally distributed, and the paired-sample size is greater than ten.

Wilcoxon signed rank test was run in SPSS for each pair of treatments with a 95% confidence interval.

H_0: The median difference is zero

H_1: The median difference is positive

The Wilcoxon signed rank test did not reveal significant results between pairs for the IPQ scores or in any EEG band. The null hypothesis cannot be rejected. See table for summary of results (EEG values in Hz). *See Appendix B for full tables.*

	Z	***p (two-tailed)***	***median test I***	***median test II***
IPQ	-1.298b	0.194	43	46
AF3	-.114c	0.91	0.179267369	0.265163917
F7	-.738b	0.46	0.137623565	0.155998336
F3	-1.420c	0.156	0.173093082	0.120312224
FC5	-.057c	0.955	0.142262214	0.244173308
T7	-1.022b	0.307	0.170339075	0.283474549
P7	-.568c	0.57	0.143694314	0.138952874
O1	-.568c	0.57	0.400680098	0.274863619
O2	-.227b	0.82	0.080011241	0.146156566

P8	-1.817c	0.069	0.214273345	0.116525884
T8	-1.193c	0.233	0.130559414	0.08363532
FC6	-1.022c	0.307	0.166000564	0.110550904
F4	-1.079c	0.281	0.069939294	0.083922536
F8	-1.874c	0.061	0.111570663	0.09243771
AF4	-1.647c	0.1	0.192232185	0.130951474
Left	-.057b	0.955	0.173782457	0.138513544
Right	-1.647c	0.1	0.211654783	0.169433041
Front	-.738c	0.46	0.13684221	0.157451491
Back	.000d	1	0.208477208	0.21315352
Average	-.625c	0.532	0.175070474	0.18736094

Full Sample Data Analysis and Results

A sample of thirty-five (35) subjects received no extrasensory stimuli during the test. These subjects were administered the survey three different ways: in-test by researcher, in-test by non-player character, and post-test on a standard computer screen (control).

Full sample demographics

Age (2 groups)	18-25	26-35	N		
	21	13	35		
percentage	60%	37%			
Age (3 groups)	18-24	25-30	30-35	N	
	21	10	4	35	
percentage	60%	29%	11%		
Sex	Male	Female	N		
	20	15	35		
percentage	57%	43%			
Ethnicity/Race	White	Black	Hispanic	Asian	Other/Mixed
	10	3	7	1	14
percentage	28.57%	8.57%	20.00%	2.86%	40.00%

Jarque-Bera tests were performed on the datasets, and the EEG values for some bands were normally distributed (see Appendix B for full table). A Jarque-Bera test also showed normal distribution for the IPQ test scores. Homogeneity of variance was assessed using Levene's Test for Equality of Variances. Equal variance was assumed for IPQ scores and all EEG bands except for the FC5 band in NPC-Researcher pair.

T-tests and one-way ANOVAs may still be considered reliable statistical analyses for a dataset that is not normally distributed as long as the sample is not too small ($N<25$). There is a slight increase in the chance of a Type I error when performing an ANOVA on a dataset that is not normally distributed (Cessie et al., 2020) (*One-Way ANOVA - Violations to the Assumptions of This Test and How to Report the Results | Laerd Statistics*, n.d.).

Two-Independent Sample t-tests

Two-independent sample t-tests were performed for each pair of treatments with a 95% confidence interval (CI) to compare the effects of timing on IPQ scores and EEG measurements.
H_0: the means are the same
H_1: the means are different

There was a significant difference in the O2 EEG band measurements, $t(21) = -3.17$, $p = 0.01$, $d = 0.47$, between subjects who were administered the survey by NPC ($M = -0.29$, $SD = 0.57$) as compared to subjects who were verbally administered the survey by a researcher ($M = 0.34$, $SD = 0.39$). The O2 EEG band rests on the occipital lobe of the brain, which is associated with vision and image processing. The O2 EEG data for this sample was not normally distributed, however, and t-test results may not be reliable. Limitations of these results will be discussed in the following chapter.

There was no significant difference in the IPQ scores or any of the other EEG band measurements between subjects who were administered the survey by NPC as compared to subjects who were verbally administered the survey by a researcher. See table for a summary of results (EEG values in Hz) and Appendix B for full tables.

NPC-Researcher summary of results

	NPC M	*NPC SD*	*Researcher M*	*Researcher SD*	*df*	*t*	*p*	*d*
IPQ	46.22	6.438	45.64	9.035	21	0.167	0.869	8.144
AF3	0.270954	0.78871	0.059398	1.491395	21	0.39	0.701	1.270393
F7	0.063634	0.549885	0.03247	1.143158	21	0.076	0.94	0.961336
F3	0.412479	1.254815	0.746399	1.390237	21	-0.583	0.566	1.340262
FC5	0.312036	2.039946	0.327276	0.424053	8.447	-0.022	0.983	1.302538
T7	0.177708	1.262163	-0.18124	1.630885	21	0.56	0.582	1.501137
P7	0.481795	1.717654	0.292064	1.533474	21	0.276	0.785	1.60613
O1	0.546266	0.95359	0.282813	0.868751	21	0.684	0.502	0.902012
O2	-0.29418	0.572426	0.338789	0.390191	21	-3.165	0.005	0.468056
P8	-0.01788	0.472956	0.294029	0.548154	21	-1.402	0.176	0.520789
T8	-0.08766	0.684343	0.232169	0.336447	21	-1.502	0.148	0.498481
FC6	0.130584	0.372467	0.291606	0.491789	21	-0.837	0.412	0.450079
F4	0.261755	0.656271	0.614584	0.950142	21	-0.971	0.342	0.850253
F8	0.176059	0.447797	0.245807	0.405547	21	-0.387	0.703	0.422141
AF4	0.565307	0.684129	0.72406	1.370427	21	-0.321	0.751	1.157978
Left	0.323553	0.875508	0.22274	0.847645	21	0.275	0.786	0.858366
Right	0.104855	0.274454	0.391578	0.49009	21	-1.593	0.126	0.421169
Front	-0.02106	0.929156	0.055504	1.113716	21	-0.171	0.866	1.04725
Back	0.179	0.632496	0.301924	0.517959	21	-0.51	0.615	0.564339
Average	0.214204	0.491543	0.307159	0.628868	21	-0.375	0.712	0.580398

There was a significant difference in the O2 EEG band measurements, $t(19) = -2.82$, $p = 0.01$, $d = 0.45$, between subjects who were administered the survey by NPC (*M =-0.29, SD = 0.57*) as compared to subjects who were administered the survey on a computer post-test (*M = 0.26, SD = 0.33*). The O2 EEG band is placed on the occipital lobe of the brain, which is associated with vision and image processing. The O2 EEG data for this sample was not normally distributed, however, and t-test results may not be reliable.

There was no significant difference in the IPQ scores or any of the other EEG band measurements between subjects who were administered the survey by NPC (as compared to subjects who were administered the survey on a computer post-test). *See table for a summary of results (EEG values in Hz) and Appendix B for full tables.*

NPC-Post-test summary of results

	NPC M	*NPC SD*	*Post-test M*	*Post-test SD*	*df*	*t*	*P*	*d*
IPQ	46.22	6.438	43.83	8.473	19	0.705	0.489	7.682
AF3	0.270954	0.78871	0.505067	1.08783	19	-0.546	0.592	0.973156

F7	0.063634	0.549885	0.650086	0.871829	19	-1.766	0.094	0.753236
F3	0.412479	1.254815	0.469048	0.986748	19	-0.116	0.909	1.107555
FC5	0.312036	2.039946	0.513632	0.834292	19	-0.311	0.759	1.468037
T7	0.177708	1.262163	0.492116	0.93625	19	-0.657	0.519	1.08547
P7	0.481795	1.717654	-0.02017	1.373936	19	0.745	0.465	1.528112
O1	0.546266	0.95359	0.643865	1.429697	19	-0.177	0.861	1.251505
O2	-0.29418	0.572426	0.263013	0.329151	19	-2.821	0.011	0.447985
P8	-0.01788	0.472956	0.194517	0.391218	19	-1.127	0.274	0.427543
T8	-0.08766	0.684343	0.180197	0.397819	19	-1.13	0.272	0.537414
FC6	0.130584	0.372467	0.244297	0.360807	19	-0.705	0.489	0.365762
F4	0.261755	0.656271	0.456952	0.863721	19	-0.565	0.579	0.783101
F8	0.176059	0.447797	0.27426	0.480913	19	-0.477	0.639	0.467255
AF4	0.565307	0.684129	0.322792	1.31846	19	0.501	0.622	1.097029
Left	0.323553	0.875508	0.464806	0.835802	19	-0.376	0.711	0.852745
Right	0.104855	0.274454	0.276576	0.539593	19	-0.87	0.395	0.44753
Front	-0.02106	0.929156	0.25739	0.778327	19	-0.747	0.464	0.845121
Back	0.179	0.632496	0.270306	0.691471	19	-0.31	0.76	0.667275
Average	0.214204	0.491543	0.370691	0.666228	19	-0.593	0.56	0.598919

There was no significant difference in IPQ scores or any of the EEG band measurements between subjects who were administered the survey verbally by researcher as compared to subjects who were administered the survey on a computer post-test. *See table for a summary of results (EEG values in Hz) and Appendix B for full tables.*

Researcher- Post-test summary of results

	Researcher M	***Researcher SD***	***Post-test M***	***Post-test SD***	***df***	***t***	***p***	***d***
IPQ	45.64	9.035	43.83	8.473	24	0.524	0.605	8.782
AF3	0.059398	1.491395	0.505067	1.08783	24	-0.857	0.4	1.321812
F7	0.03247	1.143158	0.650086	0.871829	24	-1.528	0.14	1.027729
F3	0.746399	1.390237	0.469048	0.986748	24	0.577	0.569	1.221956
FC5	0.327276	0.424053	0.513632	0.834292	24	-0.734	0.47	0.645308
T7	-0.18124	1.630885	0.492116	0.93625	24	-1.261	0.219	1.357378
P7	0.292064	1.533474	-0.02017	1.373936	24	0.543	0.592	1.462514
O1	0.282813	0.868751	0.643865	1.429697	24	-0.791	0.437	1.160025
O2	0.338789	0.390191	0.263013	0.329151	24	0.53	0.601	0.363489
P8	0.294029	0.548154	0.194517	0.391218	24	0.524	0.605	0.482602
T8	0.232169	0.336447	0.180197	0.397819	24	0.361	0.721	0.365856
FC6	0.291606	0.491789	0.244297	0.360807	24	0.275	0.785	0.43666
F4	0.614584	0.950142	0.456952	0.863721	24	0.44	0.664	0.91155

F8	0.245807	0.405547	0.27426	0.480913	24	-0.164	0.871	0.441689
AF4	0.72406	1.370427	0.322792	1.31846	24	0.757	0.456	1.346858
Left	0.22274	0.847645	0.464806	0.835802	24	-0.731	0.472	0.842237
Right	0.391578	0.49009	0.276576	0.539593	24	0.569	0.574	0.513372
Front	0.055504	1.113716	0.25739	0.778327	24	-0.527	0.603	0.974433
Back	0.301924	0.517959	0.270306	0.691471	24	0.133	0.895	0.603708
Average	0.307159	0.628868	0.370691	0.666228	24	-0.25	0.805	0.64626

One-way Within Subjects ANOVA

A one-way within subjects ANOVA was performed to compare the effect of timing on IPQ scores and EEG measurements with a 95% confidence interval.

H_0: group means do not vary
H_1: variance in population is greater than 0

The one-way ANOVA revealed that there was a statistically significant difference in the O2 EEG band measurements between at least two groups ($F(2, 32) = 6.707$, $p = 0.004$).

There were no significant differences in any of the other EEG band measurements or IPQ scores. See table for ANOVA results.

Tukey's HSD Test for multiple comparisons found that the mean value of O2 EEG band measurements was significantly different between NPC and Researcher ($p = 0.004$, 95% C.I. = -1.07966, -0.18629).

Tukey's HSD Test for multiple comparisons found that the mean value of O2 EEG band measurements was significantly different between NPC and Post ($p = 0.015$, 95% C.I. = -1.01822, -0.09617).

Tukey's HSD Test for multiple comparisons did not find a statistically significant difference between groups for any of the other EEG bands or for IPQ scores. See Appendix B for full results.

The null hypothesis may only be rejected for the O2 EEG band. Although the data for this band was not normally distributed, the ANOVA results may still be considered reliable because the sample size is larger than thirty (30). There is a slight increase in the chance of a Type I error (false positive). Limitations of these results will be discussed in the following chapter. *See table for a summary of results (EEG values in Hz) and Appendix B for full tables.*

one-way ANOVA

	between groups df	*within groups df*	*F*	*p*
IPQ	2	32	0.438	0.649
AF3	2	32	1.668	0.205
F7	2	32	0.258	0.774
F3	2	32	0.108	0.898
FC5	2	32	0.827	0.446
T7	2	32	0.294	0.748
P7	2	32	0.366	0.696
O1	2	32	6.707	0.004
O2	2	32	1.164	0.325
P8	2	32	1.385	0.265
T8	2	32	0.405	0.67
FC6	2	32	0.469	0.63
F4	2	32	0.13	0.878
F8	2	32	0.354	0.705
AF4	2	32	0.262	0.771
Left	2	32	1.04	0.365
Right	2	32	0.246	0.784
Front	2	32	0.114	0.893
Back	2	32	0.169	0.846
Average	2	32	0.253	0.778

Mann Whitney U test

The Mann Whitney U test is a nonparametric test that may be used in place of a two-independent sample t-test when data is not normally distributed.

A Mann Whitney U test was run in SPSS for each pair of treatments to compare the effect of timing on IPQ scores and EEG measurements with a 95% confidence interval.

H_0: The two populations are equal

H_1: The two populations are not equal.

The Mann Whitney U test did not reveal significant results between pairs for the IPQ scores or in any EEG band. The null hypothesis cannot be rejected. *See tables for a summary of results (EEG values in Hz) and Appendix B for full tables.*

NPC and Researcher

	Z	p (two-tailed)
IPQ	0	1
AF3	-0.315	0.753
F7	-0.063	0.95
F3	-0.189	0.85
FC5	-0.441	0.659
T7	0	1
P7	-0.693	0.488
O1	-0.567	0.571
O2	-2.835	0.005
P8	-0.819	0.413
T8	-0.693	0.488
FC6	-1.323	0.186
F4	-0.945	0.345
F8	-1.008	0.313
AF4	-0.441	0.659
Left	-0.882	0.378
Right	-1.512	0.131
Front	-0.252	0.801
Back	-0.567	0.571
Average	-0.315	0.753

NPC and Post

	Z	p (two-tailed)
IPQ	-0.821	0.412
AF3	-0.142	0.887
F7	-1.066	0.286
F3	-0.142	0.887
FC5	-0.213	0.831
T7	-0.711	0.477
P7	-1.635	0.102
O1	-0.284	0.776
O2	-2.772	0.006
P8	-0.213	0.831
T8	-0.142	0.887
FC6	-0.995	0.32
F4	-0.995	0.32
F8	-0.853	0.394
AF4	-0.569	0.57
Left	-1.066	0.286
Right	-0.64	0.522
Front	-0.64	0.522
Back	-0.071	0.943
Average	-0.995	0.32

Researcher and Post

	Z	p (two-tailed)
IPQ	-0.49	0.624
AF3	-0.772	0.44
F7	-1.029	0.304
F3	-0.206	0.837
FC5	-0.103	0.918
T7	-1.389	0.165
P7	-0.72	0.471
O1	-0.514	0.607
O2	-0.103	0.918
P8	-0.926	0.355
T8	-0.72	0.471
FC6	-0.154	0.877
F4	-0.154	0.877
F8	-0.051	0.959
AF4	0	1
Left	-0.051	0.959

Right	-0.617	0.537
Front	0	1
Back	-0.411	0.681
Average	-0.309	0.758

Qualitative results

Subjects were asked to complete a short qualitative survey post-test. The survey included scalar scores for ease of use of hardware, software, understanding tasks, and accomplishing tasks. The scale marked one (1) as very easy and five (5) as very difficult. The overall average ease score was 1.54. *See tables for results.*

Ease of use for software	
Average	1.79
Minimum	1
Maximum	4
Range	3

Ease of use for hardware	
Average	1.57
Minimum	1
Maximum	5
Range	4

Ease understanding tasks	
Average	1.29
Minimum	1
Maximum	5
Range	4

Ease accomplishing tasks	
Average	1.54
Minimum	1
Maximum	4
Range	3

Overall ease score	
Average	1.54
Minimum	1
Maximum	4.5
Range	3.5

These scores indicate that most subjects found it easy to use the hardware and software. Subjects also found it easy to understand and accomplish tasks. Based on these scores, it is unlikely that the experiment results (quantitative and qualitative) were unduly affected by faulty equipment or software.

Qualitative Impressions of Multisensory Integration and In-test Survey

The qualitative survey asked subjects "How did additional test conditions (haptic, olfactory, in-test questionnaire) affect your experience?"

Multisensory Integration

Seven subjects said that the olfactory stimulation made the virtual experience feel more real. One subject who experienced the olfactory treatment said “I caught myself holding the item closer to my face in order to ‘smell’ better. I knew it was a false object though. It made it seem realer.” Another subject said that scents “enhanced the experience and made it seem more real. The first scent I had (wine) helped me feel more in the virtual space than when there were no scents.” Two subjects who experienced the olfactory treatment said that it did not make a difference to their experience. The same two subjects commented that wearing masks made it difficult to smell, which may have impacted their experience. Two subjects did not like the olfactory integration. One stated that “the smells were a bit overwhelming. The other complained that although the smells made the experience more realistic, they did would prefer not to smell them.

Most subjects who received both olfactory and haptic treatments commented only on the olfactory treatment. When asked verbally after the treatment, two subjects said they did not notice the wind at all because they were too engrossed in the virtual world. One subject commented “sometimes, what I smelled was just like what I saw.” Another subject stated, “I believe that being able to use my sense of smell allowed me to understand more around what was going on around me.” A third subject said that “the smells enhanced my experience in the virtual world and contributed to my decision making.”

Several subjects also commented verbally to the researcher that the smells added to the virtual experience. It is clear from the survey and verbal comments that olfactory integration qualitatively affected the virtual reality experience. EEG data does not seem to support the qualitative results. Because subjects wore masks, it is possible that EEG measurements were impacted.

Two subjects who received the haptic only treatment commented that it enhanced their experience. One subject commented that “sound and wind in the surrounding environment enhanced my experience in the virtual reality environment.” Another said, “the wind did give a sense of realism to completing the tasks.” The other subjects who received haptic only treatments did not comment on the treatment until prompted, and two said that they did not notice the additional treatment at all.

In-test IPQ Survey

Most subjects who received the in-test IPQ survey said that they did not have a problem answering questions and multitasking. However, eight subjects skipped IPQ survey questions without noticing they had done so. That may have affected results. One subject stated that the researcher asking questions "distracted [them] from the virtual world." Another said that the experience "was not as realistic because of talking." Three subjects stopped sorting objects while the NPC asked questions and continued when the questions ceased. Two subjects sorted so quickly that they were finished before the survey began. All other subjects continued sorting while being asked questions.

Subjects who received the in-test questionnaire via NPC were more likely to skip questions than subjects who received the survey via researcher or post-test.

Subjects who received the in-test IPQ survey from an NPC did not get distracted from the game, but several of them also skipped questions. One subject completely disregarded the NPC and did not answer any questions. The same subject's EEG data was corrupted and was removed from the experimental data.

Table of treatments for subjects who skipped IPQ questions

treatment	*modifier*	*questions skipped*
NPC	olfactory	7
NPC	none	2
NPC	none	2
Researcher	none	1
NPC	none	2
NPC	olfactory	1
NPC	none	2
NPC	none	3

Subjects may be accustomed to ignoring NPC interactions in games, which may account for this discrepancy.

Motion Sickness and Virtual Reality Sickness

Subjects were screened for motion sickness susceptibility using the Motion Sickness Susceptibility Questionnaire (MSSQ). The highest MSSQ score possible is 144. All subjects fell below the acceptable range of motion sickness susceptibility. Subjects completed the Virtual Reality Sickness Questionnaire (VRSQ) post-test. Although one subject experienced virtual reality sickness and needed to be removed from the study, no other subjects experienced symptoms of virtual reality sickness. See tables below. The highest possible score for the VRSQ is 12. Most subjects fell below the acceptable range of virtual reality sickness except one. It is unlikely that results of the study were unduly affected by virtual reality sickness.

Range MSSQ Score	
Max	83
Min	0
Range	83
Average	11

Range VRSQ Score	
Max	11
Min	0
Range	11
Average	1.86

Summary of Analyses and Results as related to the Research Questions and Hypotheses

R1: Are current Virtual Reality applications perceived differently because some senses are fully engaged, while others are not?

H1: Users experience higher levels of presence when olfactory stimulation is integrated into a virtual reality system than when it is not.

H2: Users experience higher levels of presence when haptic stimulation is integrated into a virtual reality system than when it is not.

H3: Users experience higher levels of presence when both haptic and olfactory stimulation are integrated into a virtual reality system than when none or only one is integrated.

H4: Integrating additional sensory stimuli affects users' qualitative perception of virtual reality.

Hypotheses one, two, three were evaluated using Fisher's exact test (N=15).

H_0: the distribution is the same as expected (1:1:1:1)

H_1: the distribution is different than expected

No significant results were found in any of the EEG channels or in the iGroup Presence Questionnaire scores. The distribution of values is not significantly different than expected, and the null hypothesis cannot be rejected. Various factors may have affected these results, which will be discussed in the next chapter of this paper.

Hypothesis four was evaluated using surveys answered by participants and verbal discussion with participants.

Subjects reported higher levels of presence when olfactory stimuli and olfactory stimuli in conjunction with haptic stimuli were introduced during treatment although IPQ scores do not support self-reports and Fisher's exact test did not reveal significant differences in EEG activity. Some subjects who received the in-test survey administered by a researcher reported that it distracted from the virtual world and made the experience less realistic. Several subjects who received the in-test survey did not answer all IPQ questions.

R2: Are users better able to articulate presence when a survey is administered during an experience than when it is administered post-test?

H1: Users report greater feelings of presence when a survey is administered by a researcher during a virtual reality experience.

H2: Electroencephalography (EEG) data supports user reports of presence when a survey is administered by a researcher during a virtual reality experience.

H3: Users report greater feelings of presence when a survey is integrated and administered as part of a virtual reality experience.

H4: Electroencephalography (EEG) data supports user reports of presence when a survey is integrated and administered as part of a virtual reality experience.

Hypotheses one and three were evaluated using the iGroup Presence questionnaire (IPQ). ***Hypotheses two and four*** were evaluated using Electroencephalography (EEG) measurements.

Two-independent sample t-tests were performed for each pair of treatments (N=23, N=21, N=26) to compare the effects of timing on IPQ scores and EEG measurements.

Hypotheses for two-independent sample t-test:

H_0: the means are the same

H_1: the means are different

There was a significant difference in the O2 EEG band measurements, $t(21) = -3.17$, $p = 0.01$, $d = 0.47$, between subjects who were administered the survey by NPC (M =-0.29, SD = 0.57) as compared to subjects who were verbally administered the survey by a researcher (M = 0.34, SD = 0.39). The O2 EEG band rests on the occipital lobe of the brain, which is associated with vision and image processing. The O2 EEG data for this sample was not normally distributed, however, and t-test results may not be reliable.

There was no significant difference in the IPQ scores or any of the other EEG band measurements between subjects who were administered the survey by NPC as compared to subjects who were verbally administered the survey by a researcher.

A **one-way within subjects ANOVA** was performed to compare the effect of timing on IPQ scores and EEG measurements (N=35).

Hypotheses for one-way within subjects' ANOVA

H_0: group means do not vary

H_1: variance in population is greater than 0

The one-way ANOVA revealed that there was a statistically significant difference in the O2 EEG band measurements between at least two groups ($F(2, 32) = 6.707$, $p = 0.004$).

There were no significant differences in any of the other EEG band measurements or IPQ scores. See table for ANOVA results.

Tukey's HSD Test for multiple comparisons found that the mean value of O2 EEG band measurements was significantly different between NPC and Researcher ($p = 0.004$, 95% C.I. = -1.07966, -0.18629).

Tukey's HSD Test for multiple comparisons found that the mean value of O2 EEG band measurements was significantly different between NPC and Post ($p = 0.015$, 95% C.I. = -1.01822, -0.09617).

Tukey's HSD Test for multiple comparisons did not find a statistically significant difference between groups for any of the other EEG bands or for IPQ scores. *See Appendix B for full results.*

The null hypothesis may only be rejected for the O2 EEG band measurements.

A **Mann Whitney U test** was run in SPSS for each pair of treatments to compare the effect of timing on IPQ scores and EEG measurements (N=23, N=21, N=26).

Hypotheses for Mann Whitney U test

H_0: The two populations are equal

H_1: The two populations are not equal.

The Mann Whitney U test did not reveal significant results between pairs for the IPQ scores or in any EEG band. The null hypothesis cannot be rejected.

To examine whether there was any difference between subjects who received no additional sensory stimulation and received surveys post-test and subjects who received extrasensory stimulation and in-test surveys a **paired-sample t-test** and a **Wilcoxon signed rank** were run on the small sample (N=15). The analyses examined timing of survey only and method of delivery was ignored. Some subjects received sensory stimulation in the second treatment, ignoring the type of stimulation.

Hypotheses for paired sample t-test:

H_0: The mean difference in a paired observation is 0 ($\mu_D = 0$)

H_1: The mean difference in a paired observation is not 0 ($\mu_D \neq 0$)

There was a significant difference in the F8 EEG band measurements for in-test survey with additional sensory stimulation (M = 0.297, SD = 0.356) and post-test survey with no additional sensory stimulation (M = 0.092, SD = 0.137) conditions; $t(14) = 2.293$, $p = 0.038$, $d = 0.35$.

There was not a significant difference in any of the other EEG bands or the IPQ scores.

The results of the t-test are significant so the null hypothesis may be rejected for the F8 EEG band. The null hypothesis cannot be rejected for any of the other EEG bands or for the iGroup Presence Questionnaire scores because the results of the statistical analysis are not significant.

The F8 EEG channel is placed over the frontal lobe of the brain, which is linked to higher mental functions. Increased EEG activity in this area may indicate higher levels of presence. It is possible that some combination of extrasensory stimulation and in-test survey leads to higher levels of presence.

Hypotheses for Wilcoxon signed rank test:

H_0: The median difference is zero

H_1: The median difference is positive

The Wilcoxon signed rank test did not reveal significant results between pairs for the IPQ scores or in any EEG band. The null hypothesis cannot be rejected.

Various factors may have affected these results, which will be discussed in the following chapter.

Conclusion

For the most part, statistical analyses of the EEG data and IPQ scores did not reveal significant results. Fisher's exact test did not show significant differences between treatment groups in the small sample (*N=15*). These findings may have been affected by different factors including precautions that were implemented due to Covid 19.

Two-independent sample t-tests were performed for each pair of timing treatments with no extrasensory stimulus in the full sample (*N=35*). There was a significant difference in the O2 EEG band measurements, $t(21) = -3.17$, $p = 0.01$, $d = 0.47$, between subjects who were administered the survey by NPC ($M = -0.29$, $SD = 0.57$) as compared to subjects who were verbally administered the survey by a researcher ($M = 0.34$, $SD = 0.39$). There was a significant difference in the O2 EEG band measurements, $t(19) = -2.82$, $p = 0.01$, $d = 0.45$, between subjects who were administered the survey by NPC ($M = -0.29$, $SD = 0.57$) as compared to subjects who were administered the survey on a computer post-test ($M = 0.26$, $SD = 0.33$). The O2 EEG data for this sample was not normally distributed, however, and t-test results may not be reliable.

A one-way within subjects ANOVA was performed on the full sample (*N=35*) to compare the effect of timing on IPQ scores and EEG measurements with no extrasensory stimulus. The one-way ANOVA revealed that there was a statistically significant difference in the O2 EEG band measurements between at least two groups ($F(2, 32) = 6.707$, $p = 0.004$). Tukey's HSD Test for multiple comparisons found that the mean value of O2 EEG band measurements was significantly different between NPC and Researcher ($p = 0.004$, 95% C.I. = -1.07966, -0.18629). Tukey's HSD Test for multiple comparisons also found that the mean value of O2 EEG band measurements was significantly different between NPC and Post ($p = 0.015$, 95% C.I. = -

1.01822, -0.09617). Although the data for this band was not normally distributed, the ANOVA results may still be considered reliable because the sample size is larger than thirty (30).

The ANOVA results suggest that the two-independent sample t-tests may have produced reliable results.

The O2 EEG channel is placed on the occipital lobe of the brain, which is associated with vision and image processing. Increased EEG activity in this area may indicate higher levels of presence or may simply indicate intensified visual processing.

A Mann Whitney U test performed on the full sample (*N=35*) did not reveal significant results between pairs for the IPQ scores or in any EEG band. The populations are not sufficiently unequal according to these results.

A paired-sample t-test and a Wilcoxon signed rank were run on the small sample (N=15). The analyses examined timing only and method of delivery was ignored. Some subjects received sensory stimulation in the second treatment, ignoring type of stimulation. There was a significant difference in the F8 EEG band measurements for in-test survey ($M = 0.297$, $SD = 0.356$) and posttest survey with extrasensory stimulation ($M = 0.092$, $SD = 0.137$) conditions; $t(14) = 2.293$, $p = 0.038$, $d = 0.35$. There was not a significant difference in any of the other EEG bands or the IPQ scores.

The F8 EEG channel is placed over the frontal lobe of the brain. These results may indicate higher levels of presence when a survey is administered in-test and additional sensory stimulation is provided.

Subjects answering a short qualitative questionnaire reported higher levels of presence when olfactory stimuli and olfactory stimuli in conjunction with haptic stimuli were introduced during treatment. IPQ scores and most EEG measurements do not support self-reports. Some subjects who received the in-test survey administered by a researcher stated that the survey distracted from the virtual world and made the experience less realistic. Several subjects who received the in-test survey did not answer all IPQ questions. Subjects who were administered the survey via NPC were more likely to skip questions than subjects who were administered the survey via researcher.

Several confounding factors may have affected the results including COVID precautions and the unplanned removal of several subjects from the experiment. Limitations and implications of the results will be discussed in the following chapter.

Chapter 5: Conclusion

Research Goals

Various studies examine the cognitive and neurophysiological associations of virtual reality. Research on the neurophysiological and perceptional implications of integrating stimuli other than audiovisual, however, is more non-standardized and rudimentary. Studies suggest that subjects are more likely to experience presence when certain additional stimuli are introduced including haptic and olfactory. Research on integrating gustation is very rare. Some studies indicate that olfactory integration may have a larger effect than haptic integration.

Presence is typically measured via post hoc questionnaires or neurophysiological measurements. Most studies that incorporate additional sensory stimulation heavily rely on questionnaires to measure participant experience including reports of physiological symptoms like dizziness and nausea. Some studies did not find significant differences in reported physiological manifestations when additional sensory stimuli were introduced compared to audio-visual stimulation alone. Some studies found that subjects may perceive certain sensory stimulation such as smell and temperature differently than audio-visual alone when asked in post-test questionnaires. One study found that subjects experienced more variations in physiological data (heart rate and electrodermal activity) when audio-visual stimuli were integrated with haptic and olfactory. The same study found that olfactory stimuli produced the second highest indicators of presence compared to any other combination of stimuli less than all five (Ranasinghe et al., 2018). Although subjects who are immersed in virtual reality may exhibit similar neurophysiological reactions to virtual stimuli as they would in the real world, subjects in some studies do not report presence in questionnaires. An exhaustive search by this author yielded no published studies implementing questionnaires for measuring presence except as post-test measures.

Virtual reality aspires to create virtual worlds that are indistinguishable from actual reality. It is important for both research and developmental purposes to understand the various factors that contribute to or detract from a virtual experience. Better understanding of the perceptual and cognitive aspects of virtual reality may lead to better control and use of the medium, which serves beneficial functions including training and therapy.

Research Questions and Hypotheses

The purpose of this study was to examine whether users experience higher levels of presence when additional sensory stimulation is integrated into a task-based virtual reality system and presence is measured during the experience.

R1*: Are current Virtual Reality applications perceived differently because some senses are fully engaged, while others are not?*

H1: Users experience higher levels of presence when olfactory stimulation is integrated into a virtual reality system than when it is not.

H2: Users experience higher levels of presence when haptic stimulation is integrated into a virtual reality system than when it is not.

H3: Users experience higher levels of presence when both haptic and olfactory stimulation are integrated into a virtual reality system than when none or only one is integrated.

H4: Integrating additional sensory stimuli affects users' qualitative perception of virtual reality.

R2*: Are users better able to articulate presence when a survey is administered during an experience than when it is administered post-test?*

H1: Users report greater feelings of presence when a survey is administered by a researcher during a virtual reality experience.

H2: Electroencephalography (EEG) data supports user reports of presence when a survey is administered by a researcher during a virtual reality experience.

H3: Users report greater feelings of presence when a survey is integrated and administered as part of a virtual reality experience.

H4: Electroencephalography (EEG) data supports user reports of presence when a survey is integrated and administered as part of a virtual reality experience.

Summary of Experimental Study

Sampling

The study was restricted to adults in the United States ages 18-35 who live in Maryland. People in this age range are less likely to suffer from health conditions that may affect the study. They are also less likely to experience virtual reality sickness, which may affect results of the experiment. Subjects were screened for motion sickness susceptibility, anxiety, and migraines, which may also increase the risk of virtual reality sickness. Subjects were recruited through a wide-spread social media campaign on Facebook, email, and Discord.

Experiment Design

A modified repeated-measures experimental pre-test/post-test was conducted in a closed virtual reality lab on campus. Task-based scenarios were used to measure presence and neurophysiological responses.

A repeated-measures experimental design is a standard experimental method wherein subjects are randomly assigned to conditions in a random order. In this design, subjects act as their own control, which decreases error variance. This method is sometimes called within-subjects randomized experimental design. It is a useful method for comparing conventional treatments, such as a post-test questionnaire, that are assumed to have no carryover effects. Symmetrical transfer effects may occur in this design when the impact of one order is greater than another. To mitigate this possibility, all subjects were randomly assigned treatment order.

A pre-test/post-test is a standard research design in which baseline measurements are recorded prior to researcher intervention in a single set of subjects. Measurements are taken a second time after the intervention and compared to the baseline. Since there is no change in subjects between the control and intervention, changes may be credited to external causes. To address this concern, subjects were randomly assigned to conditions.

These research designs are considered effective for small sample sizes (N=15).

Due to unexpected complications, only fifteen subjects were able to complete the full multisensory pre-test/post-test repeated-measures experiment (small sample). Data was analyzed for thirty-five subjects who completed the study without any additional sensory stimulation (full sample). Subjects in the full sample had been randomly assigned to the control group (post-test survey) or one of two in-test treatments. Subjects in the full sample did not receive any other sensory treatment. Because treatment was randomly assigned, these experimental results may be considered reasonably valid.

Methodology

This study manipulated three independent variables in two or three levels. The main dependent variable of this study is measurements of presence with two levels: iGroup Presence Questionnaire (IPQ) score and electroencephalography (EEG) activity in various parts of the brain. Several potential compounding variables were identified and controlled for during selection. These variables are age, sex, ethnicity, motion sickness susceptibility, migraines, and anxiety.

Summary of Independent Variables:

- Haptic stimulus
  - Level 1: haptic stimulus
  - Level 2: no haptic stimulus
- Olfactory stimuli
  - Level 1: olfactory stimulus
  - Level 2: no olfactory stimulus
- Survey Measure of Presence during experience (timing treatment)
  - Level 1: presence measured during experience verbally by researcher

Level 2: presence measured during experience by non-player character in game

Level 3: presence measured after experience using a traditional computer form

Subjects were fitted with an Emotiv EPOC EEG headset under an HTC Vive virtual reality headset. Both headsets are light and reasonably comfortable. The researcher developed custom virtual reality software for the HTC Vive using Unity, a 3D game engine. The task-based experience was presented within a realistically rendered 3D room. Subjects controlled a first-person human avatar with gender-neutral arms and were asked to carry and sort ten different items from the table to three bins on the opposite wall. The bins were labeled trash, recycling, and hazardous material with accompanying symbols. The virtual room had a window with curtains visibly blowing in the breeze. For some of the treatments, a realistically rendered non-player character asked the subject questions.

In the first test, subjects were randomly assigned timing treatments for administration of the survey. No subjects received extrasensory treatment in the first test. In the second test, subjects were randomly assigned timing treatments as well as extrasensory treatments.

Haptic treatments were administered via a high-powered fan. Olfactory treatments were administered in vials that were held approximately twelve (12) inches from the subject's nose for exactly as long as the subject's avatar was holding the corresponding virtual item. Odors were carefully selected so that, while typically considered unpleasant, they were not so unpleasant that they would distress subjects. Because subjects were required to wear masks on campus, strong odors were selected. Some scents were reproduced using materials they represented. Other scents were procured in vials from Monell Chemical Senses Center.

Upon completing both tests, subjects were assisted to remove the headsets and asked to complete surveys on a computer.

Summary and Analysis of Results

The raw electroencephalography (EEG) measurements were run through the Emotiv Analyzer tool which performs Fast Fourier Transform (FFT) and a high-pass filter to remove any possible confounding signals due to movement or other artifacts while maintaining overall accuracy of EEG measurements. The transformed data was output in decibel format, which were then converted to Hz. Descriptive statistics for the baseline (first 15 seconds (30 measurements) were calculated in Excel. Descriptive statistics for a 30 second segment 20 seconds into the activity portion of the EEG test, which is 50 seconds from the start of the test including a 30 second baseline measurement were calculated. Difference scores were calculated for the means of baseline and in-test measurements.

Some questions in the iGroup Presence Questionnaire (IPQ) contain a reversed scale. IPQ scores were adjusted before performing statistical calculations.

Fisher's exact test

Research question 1: Hypotheses one, two, and three were evaluated using Fisher's exact test on the small sample (*N=15*). The small sample received both timing treatments and extrasensory treatments. Subjects received one in-test survey and one post-test survey in a randomized order. Subjects received no extrasensory modifier in the first test, and some received a sensory modifier in the second test. The EEG values describe the deviation from the average EEG activity in Hz. Fisher's exact test requires nominal values. EEG values were categorized as Low, Moderate, or High using the range of values in the following table. The values in the table were based on a rounded percentage of all EEG values that fell into each category using two different thresholds.

Hypotheses for Fisher's exact test:

H_0: the distribution is the same as expected (1:1:1:1)
H_1: the distribution is different than expected

Fisher's exact test did not show significant differences between treatment groups in any of the EEG channels or in the iGroup Presence Questionnaire scores. The null hypothesis cannot be rejected because the distribution of values is not significantly different than expected.

Qualitative results

Research question 1: Hypothesis four was evaluated by a short qualitative survey that subjects were asked to complete post-test. The survey included scalar scores for ease of use of hardware, software, understanding tasks, and accomplishing tasks. The scale marked one (1) as very easy and five (5) as very difficult. The overall average ease score was 1.54. These scores indicate that most subjects found it easy to use the hardware and software. Subjects also found it easy to understand and accomplish tasks. Based on these scores, it is unlikely that the experiment results were unduly affected by faulty equipment or software.

The post-test qualitative survey asked subjects how additional test conditions (haptic, olfactory, in-test questionnaire) affected their experience. Most subjects who received olfactory treatments said that the olfactory stimulation made the virtual experience seem more real. One subject stated that “I caught myself holding the item closer to my face in order to ‘smell’ better. I knew it was a false object though. It made it seem realer.” Two subjects said that olfactory integration made no difference to their experience. The same two subjects also commented that wearing masks made it difficult to smell anything. Two other subjects said that the odors made the experience feel more realistic, but they complained that the smells were overwhelming and unpleasant.

The majority of subjects who were administered both haptic and olfactory treatment only commented on the olfactory treatment. Two subjects said that they were too immersed in the virtual world and did not notice the haptic treatment at all. All subjects who experienced both extrasensory treatments said that it enhanced their experience and made the virtual world seem more real.

Verbal commentary and survey results make it clear that olfactory integration enhances the virtual reality experience and immersion. Although EEG data does not seem to support this outcome, this is possibly due to subjects’ decreased ability to smell because they were wearing masks.

Most subjects who received haptic treatment only did not comment on the haptic integration unless prompted. Two subjects stated that they did not notice the integration of the wind at all. Subjects who did notice the wind said that it did enhance their virtual experience and made it seem more realistic. It is possible that the haptic integration was not strong enough for all subjects to be noticeably affected. It is also possible that it was difficult for subjects to sufficiently feel the wind through their clothing, masks, and headset.

Subjects who were administered the in-test IPQ survey conveyed comfort with multitasking and answering questions. Eight subjects who received the in-test survey skipped questions without noticing. One subject stated that they were distracted from the virtual world by the researcher asking questions and another said that talking made the experience less realistic. Subjects who were administered the survey from a non-player character were more likely to skip questions that subjects who were administered the survey by a researcher.

T-tests, ANOVA, and Mann Whitney U Tests

Research question 2: Hypotheses one, two, three, and four were evaluated using two-independent sample t-tests for each pair of treatments (N=23, N=21, N=26) to compare the effects of timing on IPQ scores and EEG measurements. A one-way within subjects ANOVA was performed to compare the effect of timing on IPQ scores and EEG measurements (N=35). A Mann Whitney U test was run in SPSS for each pair of treatments to compare the effect of timing on IPQ scores and EEG.

Hypotheses for two-independent sample t-test:

H_0: the means are the same

H_1: the means are different

There was a significant difference in the O2 EEG band measurements, $t(21) = -3.17$, $p = 0.01$, $d = 0.47$, between subjects who were administered the survey by NPC ($M = -0.29$, $SD = 0.57$) as compared to subjects who were verbally administered the survey by a researcher ($M = 0.34$, $SD = 0.39$). The O2 EEG data for this sample was not normally distributed, however, and t-test results may not be reliable. There was no significant difference in the IPQ scores or any of the other EEG band measurements for subjects who were administered the survey by NPC as compared to subjects who were verbally administered the survey by a researcher.

Hypotheses for one-way within subjects ANOVA

H_0: group means do not vary

H_1: variance in population is greater than 0

The one-way ANOVA revealed that there was a statistically significant difference in the O2 EEG band measurements between at least two groups ($F(2, 32) = 6.707$, $p = 0.004$). There were no significant differences in any of the other EEG band measurements or IPQ scores. HSD Test for multiple comparisons found that the mean value of O2 EEG band measurements was significantly different between NPC and Researcher ($p = 0.004$, 95% C.I. = -1.07966, -0.18629). Tukey's HSD Test for multiple comparisons found that the mean value of O2 EEG band measurements was significantly different between NPC and Post ($p = 0.015$, 95% C.I. = -1.01822, -0.09617). Tukey's HSD Test for multiple comparisons did not find a statistically significant difference between groups for any of the other EEG bands or for IPQ scores. Although the data for the O2 EEG band was not normally distributed, ANOVA results are considered valid for samples greater than thirty (30) with a minor increase in the likelihood of a Type I error (false positive). The ANOVA results support the results of the two-independent sample t-tests, suggesting that they may also be valid despite the abnormal distribution of the data.

The O2 EEG channel is placed over the occipital lobe of the brain, which handles vision and image processing. Increased activity in this area may indicate increased presence or may merely indicate increased visual processing. Because almost the same visual stimulation is provided in all treatments, it is possible that these results indicate higher levels of presence.

Hypotheses for Mann Whitney U Test:

H_0: The two populations are equal

H_1: The two populations are not equal.

The Mann Whitney U test did not reveal significant results between pairs for the IPQ scores in any EEG band. The null hypothesis cannot be rejected, and the populations are not significantly different.

A paired-sample t-test and a Wilcoxon signed rank were run on the small sample (N=15). The analyses examined timing only and method of delivery was ignored. Some subjects received sensory stimulation in the second treatment, ignoring type of stimulation. There was a significant difference in the F8 EEG band measurements for in-test survey ($M = 0.297$, $SD = 0.356$) and posttest survey with extrasensory stimulation ($M = 0.092$, $SD = 0.137$) conditions; $t(14) = 2.293$, $p = 0.038$, $d = 0.35$. There was not a significant difference in any of the other EEG bands or the IPQ scores.

The F8 EEG channel is placed over the frontal lobe of the brain. These results may indicate higher levels of presence when a survey is administered in-test and additional sensory stimulation is provided.

Subjects answering a short qualitative questionnaire reported higher levels of presence when olfactory stimuli and olfactory stimuli in conjunction with haptic stimuli were introduced during treatment. IPQ scores and most EEG measurements do not support self-reports. Some subjects who received the in-test survey administered by a researcher stated that the survey distracted from the virtual world and made the experience less realistic. Several subjects who received the in-test survey did not answer all IPQ questions. Subjects who were administered the survey via NPC were more likely to skip questions than subjects who were administered the survey via researcher.

Paired Sample T-test and Wilcoxon Signed Rank Test

To examine whether there was any difference between subjects who received no additional sensory stimulation and received surveys post-test and subjects who received an in-test survey and additional sensory stimulation a **paired-sample t-test** and a **Wilcoxon signed rank** were run on the small sample (N=15). The analyses examined timing of survey only and method of delivery was ignored. Some subjects received sensory stimulation in the second treatment, ignoring type of stimulation.

Hypotheses for paired sample t-test:

H_0: The mean difference in a paired observation is 0 ($\mu_D = 0$)

H_1: The mean difference in a paired observation is not 0 ($\mu_D \neq 0$)

There was a significant difference in the F8 EEG band measurements for in-test survey with additional sensory stimulation (M = 0.297, SD = 0.356) and post-test survey with no additional sensory stimulation (M = 0.092, SD = 0.137) conditions; $t(14) = 2.293$, $p = 0.038$, $d = 0.35$.

There was not a significant difference in any of the other EEG bands or the IPQ scores.

The results of the t-test are significant so the null hypothesis may be rejected for the F8 EEG band. The null hypothesis cannot be rejected for any of the other EEG bands or for the iGroup Presence Questionnaire scores because the results of the statistical analysis are not significant.

The F8 EEG channel is placed over the frontal lobe of the brain, which is linked to higher mental functions. Increased EEG activity in this area may indicate higher levels of presence. It is possible that combining additional sensory stimulation and administering a survey in-test leads to higher levels of presence.

Hypotheses for Wilcoxon signed rank test:

H_0: The median difference is zero

H_1: The median difference is positive

The Wilcoxon signed rank test did not reveal significant results between pairs for the IPQ scores or in any EEG band. The null hypothesis cannot be rejected.

Summary

Most statistical analyses of the EEG data and IPQ scores did not reveal significant results. Fisher's exact test on the small sample (N=15) did not reveal a significant difference between treatment groups. A paired-sample t-test run on the small sample examined survey timing and additional sensory stimulation ignoring method of delivery and type of stimulation. There was a significant difference in the F8 EEG band measurements for in-test survey with extrasensory stimulation and post-test survey conditions with no additional sensory stimulation. There was not a significant difference in any of the other EEG bands or the IPQ scores.

The F8 EEG channel is placed over the frontal lobe of the brain. These results may indicate higher levels of presence when a survey is administered in-test and additional sensory stimulation is provided. Additional research is recommended.

Subjects answering a short qualitative questionnaire reported higher levels of presence when olfactory stimuli and olfactory stimuli in conjunction with haptic stimuli were introduced during treatment. IPQ scores and most EEG measurements do not support self-reports. Some subjects who received the in-test survey administered by a researcher stated that the survey distracted from the virtual world and made the experience less realistic. Several subjects who received the in-test survey did not answer all IPQ questions. Subjects who were administered the survey via NPC were more likely to skip questions than subjects who were administered the survey via researcher.

Two-independent sample t-tests performed for each pair of timing treatments with no extrasensory stimulus in the full sample ($N=35$) revealed significant results only for the O2 EEG band. However, O2 EEG data for this sample was not normally distributed, and t-test results may not be fully reliable. A one-way within subjects ANOVA performed on the full sample ($N=35$) revealed that there was a statistically significant difference in the O2 EEG band measurements between at least two groups. Tukey's HSD Test for multiple comparisons found that the mean value of O2 EEG band measurements was significantly different between NPC and Researcher as well as between NPC and Post-test. These findings suggest that the two-independent sample t-tests may have produced reliable results. ANOVA results may be considered reliable for data that is not normally distributed when the sample size is larger than thirty (30). There is a slight increase in the chances of a false positive Type I error.

The O2 EEG channel rests over the brain's occipital lobe. The occipital lobe is linked to image processing and vision. These results indicate increased brain activity in this area, which may suggest higher levels of presence or may only indicate increased visual processing.

A Mann Whitney U test performed on the full sample (*N=35*) did not reveal significant results between pairs for the IPQ scores or in any EEG band. The populations are not significantly unequal according to these findings.

Subjects who answered a short qualitative questionnaire reported increased presence when olfactory stimulation and olfactory stimulation together with haptic stimulation were administered during treatment. Most EEG measurements and IPQ scores do not support self-reports. Some subjects expressed that they were distracted from the virtual world when the in-test survey was administered by a researcher. Eight subjects who were administered the in-test survey did not answer all the IPQ questions. Subjects who received the survey from a non-player character in-test were more likely to skip questions than subjects who were given the survey by researcher.

A number of confounding variables may have affected the results including COVID precautions that required subjects to wear masks. The unplanned removal of several subjects may have also affected the experiment's results.

Limitations of the Study

Sampling Limitations

While the target population of this study was adults in the United States, the study was limited to adults ages 18-35 who live in Maryland and were willing and able to travel to the study location. This study did not accept University of Baltimore students as subjects to avoid potential confounding factors in the data. It is possible that children or adults of different ages may have produced different data. The study also controlled for uncorrected eyesight, motion sickness susceptibility, migraines, and anxiety, so results cannot be applied to people who experience any of the aforementioned conditions.

Even though the study attempted to recruit an even number of male and female participants, several female participants needed to withdraw from the study and the final sample was not equally divided between sexes. 57% of the sample was male and 43% was female. This is fairly close to the proportion of males to females in the general population, and results are likely not affected. There is a possibility, however, that an entirely equal sample may have produced different results.

Although the study recruited a variety of ethnic groups in the sample, the sample ethnic distribution was different than the ethnic population of the targeted area in Maryland. 28.57% of the study sample were white while the Maryland census reports 51.28% of the population is white. 40% of the sample indicated "other/mixed" as their ethnic identity while the Maryland census reports only 10.6% of the population as "other/mixed." *See table*. It is possible that this sample is not a good selection of the Maryland population and may also be more diverse than other states or countries. It is also possible that more ethnically homogenous populations may produce different results. Because the sample consisted of people in the United States, it is possible that people in other countries may have reacted differently or perceived the stimuli in other ways.

Census reported ethnic distribution and Study Sample ethnic distribution

	White (non-Hispanic)	Black	Hispanic	Asian	Other/Mixed
Baltimore City	27.70%	61.30%	2.76%	2.57%	5.67%
Baltimore County	56.50%	28.70%	2.77%	6.05%	5.98%
Montgomery County	43.00%	18.10%	14.40%	9.05%	15.45%
Howard County	62.10%	14.40%	5.80%	0.30%	17.40%
Anne Arundel County	67.10%	16.50%	4.10%	3.82%	8.48%
Average	***51.28%***	***27.80%***	***5.97%***	***4.36%***	***10.60%***
Study Sample	**28.57%**	**8.57%**	**20.00%**	**2.86%**	**40.00%**

The in-person nature of the study, pandemic safety precautions, pandemic safety concerns, and travel limitations affected the scope of sample recruitment. Only subjects who met campus COVID safety requirements were able to participate in the survey. This eliminated anyone who was not fully vaccinated or who did not want to wear a mask. Several potential subjects exhibited symptoms before their appointment and were not able to participate. Additionally, subjects who might have participated under other circumstances hesitated to do so because of pandemic concerns.

Limitations of olfactory integration while wearing masks

COVID regulations on campus required subjects to wear masks during all parts of the study including subjects who were administered olfactory stimulation. Although strong odors were chosen to mitigate this issue, subjects reported difficulty smelling some or all of the odors through their masks. While subjects reported that olfactory stimulation made the virtual experience seem more real, EEG measurements and IPQ survey scores did not show significant differences between subjects who received olfactory stimulation and subjects who did not. Masks may have impeded the full effect of the olfactory stimulation which may have caused this discrepancy.

Limitations of the Software and Hardware

Subjects controlled a first-person human avatar with gender-neutral hands in a realistically rendered 3D room. For some of the treatments, a realistically rendered non-player character asked the subject questions. Although the software was designed to present an appropriate level of realistic rendering so that the subjects could experience presence without experiencing the Uncanny Valley effect, it is possible that the rendered environment did not properly hit the target. Two subjects also experienced slight lag in the software's runtime, and one reported that the screen turned gray and "broke" during the test. Although it is not reflected in the overall qualitative survey, it is possible that these factors affected subject experience.

Subjects were required to wear two headsets and controllers during the test in addition to a face mask. Although none of the subjects complained, it is possible that wearing so much equipment was too burdensome and limited subjects from fully experiencing presence.

Although the Emotiv Epoc EEG headsets suit practical purposes of this study because they are light and portable, they are not nearly as accurate as medical grade EEG equipment. Additionally, although the Emotiv headsets were secured in place under the VR headset and tested at the start of the test, it is possible that electrodes may have shifted slightly while subjects moved about the room. Even though some of this was addressed during data analysis, it is possible that results were affected or that the analyzer overcorrected for movement.

Limitations of Data Analysis

Due to unexpected complications, only fifteen subjects were able to complete the full multisensory EEG data set (small sample). Available data were also analyzed for all subjects who completed other portions of the study without any additional sensory treatments (full sample).

In the small sample (*N=15*), treatment groups were uneven in size, and the sample was too small to employ certain standard statistical methods such as t-tests which would have allowed different comparisons of the data. Instead, Fisher’s exact test was used, which is a non-parametric test for small samples. Fisher’s exact test requires nominal data which meant that the data needed to be categorized as Low, Moderate, or High using a range of values based on two different thresholds. Fisher’s exact test assesses the distribution of the population and whether the data distribution differs significantly from an expected equal distribution. A larger sample would have allowed comparisons of means and variance in ratio data. It is possible that statistical analyses of a larger sample would have produced more significant results.

A paired sample t-test was run on the small sample to examine whether there was any difference between subjects who received no additional sensory stimulation and completed surveys post-test and subjects who received a survey in-test along with additional sensory stimulation. These analyses examined timing of survey and additional sensory stimulation. Method of survey delivery and type of stimulation were ignored. A significant difference was found in the F8 (frontal lobe) EEG measurements for in-test survey with additional sensory stimulation compared to post-test survey with no additional sensory stimulation. The F8 EEG data was normally distributed, so the t-test results are valid. However, this analysis does not provide any information about which survey delivery method or sensory stimulation produced the increased EEG activity.

In the full sample (*N=35*), subjects were not compared to themselves as the experiment was designed to do. Instead, the subjects were assigned treatment groups and compared to each other. The sample size was large enough to utilize standard statistical methods, but not all data was normally distributed. The two-independent sample t-test sample sizes were too small to account for this discrepancy in some of the EEG bands and a Mann-Whitney U test was performed. The Mann-Whitney U test does not require normally distributed data or large sample sizes and assesses whether the populations are equal. The Mann-Whitney U test did not show a significant difference in the population for any of the data. A one-way within subjects ANOVA supported the findings of the t-tests, however. Accordingly, it is possible that the t-tests were valid analyses despite the abnormal distribution of some of the data. When data is not distributed normally in an ANOVA, there is also a slight increase in the chance of a Type I error (false positive). Therefore, it is marginally possible that these significant results are not truly accurate.

The O2 EEG band rests over the brain's occipital lobe. The occipital lobe is responsible for vision and image processing. It is possible that increased activity in this area is only due to more substantial image processing and does not indicate increased presence. Because the imagery did not differ between tests, however, it is also possible that this increase in activity indicates some form of amplified presence.

Eight subjects did not answer all of the survey questions when they were presented in-test. It is possible that IPQ scores would have differed significantly if all subjects had answered all questions.

Conclusions that may be drawn from the data

There is a clear discrepancy between subjects' qualitative perception of olfactory integration in a virtual reality experience and their iGroup Presence Questionnaire (IPQ) score and electroencephalography (EEG) data. This discrepancy may be attributed to some of the limitations of the study previously discussed including masks and incomplete surveys. Because of the limited nature of this aspect of the study and the small sample size, the results should not be applied to the general population.

A paired sample t-test of the small sample (N=15) found a significant difference in the the F8 (frontal lobe) EEG measurements for in-test survey with additional sensory stimulation compared to post-test survey with no additional sensory stimulation. This analysis examined timing of survey and additional sensory stimulation. Method of survey delivery and type of stimulation were ignored. The F8 EEG data was normally distributed, so the t-test results are valid. However, this analysis does not provide any information about which survey delivery method or sensory stimulation produced the increased EEG activity. Some combination of additional sensory stimulation and administering a survey in-test may lead to higher levels of presence. The treatment groups were too small, and the interventions were not sufficiently separated to conclusively attribute these results to a specific combination of treatments. These results should not be applied to the general population.

A one-way within subjects ANOVA performed on the full sample (N=35) revealed significant difference in the O2 EEG channel in at least two groups. Tukey's HSD Test for multiple comparisons found that the mean value of O2 EEG band measurements was significantly different between NPC and Researcher as well as between NPC and Post-test. Although data for the O2 EEG band was not normally distributed, ANOVA results may be considered reliable because the sample size is larger than thirty (30). The chances of a false positive Type I error marginally increase in this instance. Because subjects were randomly selected and randomly assigned to treatment groups, this experimental design may be considered reasonably valid. Therefore, the results of this experiment may be applied to the general population.

Integrating a presence survey into a virtual reality experience (via NPC) increases EEG activity in the occipital lobe, which may suggest increased presence in users.

As was found in other studies, IPQ scores do not support this finding. However, eight subjects did not answer all the survey questions when they were presented in-test. IPQ scores may have differed significantly if all subjects had answered all questions.

Recommendations for further research

There is a blatant discrepancy between users' qualitative perception of olfactory integration and IPQ scores and EEG measurements. As discussed previously, the circumstances of the extrasensory study were less than ideal. A fresh study on a larger sample that accounts for some of the limiting factors, especially masks, may provide results that corroborate subjects' qualitative reports. A larger study should be designed so that statistical analyses may compare data that is not nominal.

Because so many subjects skipped questions during the in-test survey, the software should be redesigned so that this will not happen. The non-player character did not interrupt game play and was easy to ignore. In a future study, steps should be taken so that any non-player character that administers a survey will be harder to ignore while not significantly interrupting game tasks.

Conclusion

The purpose of this study was to examine whether users experience higher levels of presence when additional sensory stimulation is integrated into a task-based virtual reality system and presence is measured during the experience.

R1: Are current Virtual Reality applications perceived differently because some senses are fully engaged, while others are not?

H1: Users experience higher levels of presence when olfactory stimulation is integrated into a virtual reality system than when it is not.

H2: Users experience higher levels of presence when haptic stimulation is integrated into a virtual reality system than when it is not.

H3: Users experience higher levels of presence when both haptic and olfactory stimulation are integrated into a virtual reality system than when none or only one is integrated.

H4: Integrating additional sensory stimuli affects users' qualitative perception of virtual reality.

This study found an obvious discrepancy between iGroup Presence Questionnaire (IPQ) scores and electroencephalography (EEG) data and subjects' qualitative perception of olfactory integration in a virtual reality experience. This inconsistency may be ascribed to limitations of the study previously discussed including masks and incomplete surveys. Because of the limited nature of this aspect of the study and the small sample size, the results should not be applied to the general population.

This study was not able to prove hypotheses one, two, and three for research question one. Study findings support hypothesis four for research question one.

R2: Are users better able to articulate presence when a survey is administered during an experience than when it is administered post-test?

H1: Users report greater feelings of presence when a survey is administered by a researcher during a virtual reality experience.

H2: Electroencephalography (EEG) data supports user reports of presence when a survey is administered by a researcher during a virtual reality experience.

H3: Users report greater feelings of presence when a survey is integrated and administered as part of a virtual reality experience.

H4: Electroencephalography (EEG) data supports user reports of presence when a survey is integrated and administered as part of a virtual reality experience.

A one-way within subjects ANOVA performed on the full sample (N=35) revealed a significant difference in the O2 EEG channel in at least two groups. Tukey's HSD Test for multiple comparisons found that the mean value of O2 EEG band measurements was significantly different between NPC and Researcher as well as between NPC and Post-test. Although data for the O2 EEG band was not normally distributed, ANOVA results may be considered reliable because the sample size is larger than thirty (30). Because subjects were randomly selected and randomly assigned to treatment groups, this experimental design may be considered reasonably valid. Therefore, the results of this experiment may be applied to the general population.

Integrating a presence survey into a virtual reality experience (via NPC) increases EEG activity in the occipital lobe, which may suggest increased presence in users.

IPQ scores do not support this finding, which supports similar discrepancies in other studies. When survey questions were presented in-test, eight subjects did not answer the entire survey. If all subjects had answered all questions, IPQ scores may have differed significantly.

This study was unable to prove any of the hypotheses for research question two. This may be the result of various confounding factors including skipped survey questions.

Based on EEG measurements and IPQ scores, this study was not able to verify that users experience higher levels of presence when additional sensory stimulation is integrated into a task-based virtual reality system. However, users reported that their experience in the virtual world was enhanced by multisensory integration, especially olfactory. Statistical analyses indicate increased EEG activity when presence is measured during the experience by a non-player character. Although the occipital lobe processes visual data that is being activated by the visual aspects of the game, increased activity may indicate higher levels of presence because subjects are being presented with almost identical visual stimulation in both treatments. A paired sample t-test that compared subjects who received a presence survey post-test with no additional sensory stimulation to subjects who were administered additional sensory stimulation with an in-test survey found a significant increase in EEG activity in the second treatment. However, this test did not differentiate between survey delivery method and type of stimulus. These results indicate that a combination of in-test survey and multisensory stimulation may increase presence in users. Further research is recommended.

Appendix A: Recruitment, Subject Screening Questionnaires, COVID Precautions, Consent Form

Recruitment Letter:

You are being invited to participate in a research study about how people react when touch and smell are added to a virtual reality experience. The research study is being conducted at the University of Baltimore at the Universities at Shady Grove.

To participate in this study, you must be aged 18-35 and be willing and able to travel to the Universities at Shady Grove (9630 Gudelsky Dr, Rockville, MD 20850) or University of Baltimore (1420 N Charles St, Baltimore, MD 21202) (possible other campus locations) in person in November or December 2021 (possible other dates. Participation is confidential. The study will take about one (1) hour to complete.

If you are selected to complete this study, you will receive a $20 gift card. Please fill out this survey to determine your eligibility for this study.

Thank you for your time. If you have any questions feel free to contact me at ecahn@ubalt.edu.

Elka Cahn

Subject Screening Questionnaire

1. Name
2. Age
3. Sex at birth
4. Do you have any health conditions that may preclude you from completing an in-person study including migraines or anxiety?
5. Have you been vaccinated for COVID 19? If so, when did you receive your final vaccination?
6. Are you available for the following dates?
7. Will you be available for follow-up questions if necessary?
8. Motion Sickness Susceptibility survey (MSSQ)
9. Please rate your familiarity with head-mounted virtual reality systems
10. Do you have perfect eyesight or wear corrective contact lenses?

COVID 19 pretest Survey

(Taken from standard survey administered by medical offices to be completed the day before the study)

1. In the past 24 hours have you experienced any of the following? (Please check either "yes" or "no")
   If symptoms such as shortness of breath are due to a known, non-worsening chronic condition, mark "no".
   - Cough
   - Shortness of Breath
   - Fever (100.4°F or above)
   - Chills
   - Fatigue
   - Sore Throat
   - New Headaches
   - New Loss of Taste or Smell
2. In the past 14 days have you traveled outside of your hometown within the United States without following the recommendations or guidelines to prevent and control the spread of COVID 19 infection as established by applicable authorities in the area in which you were traveling (eg. adhering to social distancing standards and/or wearing personal protective equipment such as facemasks)?
3. In the past 14 days have you traveled to any foreign country or been in close contact with anyone person who has returned from a foreign country within the past 14 days?
4. In the past 14 days have you had close contact (within 6 feet) with any person with possible COVID 19 infection?

COVID 19 Precautions

(precautions are subject to change as campus guidelines are updated)

1. Subjects must be fully vaccinated and may be required to submit a recent negative COVID 19 test (within 14 days per USM guidelines)
2. Subjects and researcher will adhere to all COVID 19 guidelines including state, USM, and campus restrictions.
3. Subjects must complete a pretest health survey the day before they participate in the study that screens for common symptoms of COVID 19
4. Subjects will receive temperature checks using a no contact thermometer and be refused entry if measurement is above 100.4°F
5. Only one subject will be allowed in the lab at a time
6. Social distancing standards will be maintained at all times except when necessary to help the subject
7. Subjects will be staggered over time so they do not meet each other
8. There will be no more than three people in the lab at one time including subject, researcher, and observer (full lab capacity is 12)
9. Everyone will wear masks the entire time
10. Hand sanitizer and disinfectant wipes will be readily available in all areas
11. Virtual reality headsets, controllers, and Electroencephalography (EEG) head piece will be sanitized after use.
12. Lab will be sanitized after each subject using Lysol or equivalent, high contact surfaces will receive extra attention
13. Researcher will stand behind and away from the fan to reduce likelihood that particles may spread between people (COVID precaution).
14. Lab door will remain open to increase air circulation, although the hallway door may remain closed

Appointment letter

Hello ________,

Thank you for scheduling your appointment for the VR Research study for ___________ at ________. The study will take about one hour of your time and take place at the Universities of Shady Grove, 9630 Gudelsky Lane, Rockville, MD 20850 in Building I, Room 218B. I have attached a campus map for your convenience. Please let me know if you will need a parking voucher so that I can request one for you.

Please read, sign, and return the attached consent form before your appointment. Please be sure to check "yes" to allow us to record your session. All recordings will be destroyed at the conclusion of the study and will only be viewed by the researchers involved.

If you have long hair, please wear it in a low ponytail or bun at the nape of your neck. Please wear a mask to adhere to the campus rules. If you wear corrective contact lenses, please wear them for your appointment.

Please do not hesitate to contact me with any questions.

Elka Cahn

Consent Form

CONSENT FORM

TITLE OF STUDY: Measurements of Presence and Multisensory Stimulation in Virtual Reality

PRICIPAL INVESTIGATOR: Elka Cahn

STUDY PURPOSE/SUMMARY:

The purpose of this study is to examine how users react when touch and smell are added to a task-based virtual reality experience.

PROCEDURES

This is an in-person study. If you participate in this study, you will need to travel to a closed computer lab on campus. The study will take about one (1) hour to complete, but you should allot up to three (3) hours for completing the study. You will be asked to complete sorting tasks in a virtual reality environment in a limited time frame using a wearable virtual reality headset and controllers. You will also need to wear an electroencephalography (EEG) headset, which measures the electrical activity in the brain using saline-based electrodes. Both the virtual reality headset and EEG electrodes rest on your head and are not generally considered invasive or uncomfortable. You will not be asked to wear any equipment for more than fifteen (15) minutes at a time. Researchers may ask you questions verbally or ask you to fill out some questionnaires. Video and audio recordings will be taken throughout the duration of the study. Task time and accuracy will also be recorded. After completing the study, you will not be asked to return in person.

COVID precautions guided by the University System of Maryland and relevant local government will be followed at all times and equipment will be sanitized between use.

CONFIDENTIALITY

All personally identifiable data, such as names and email addresses, will remain confidential. Personally identifiable data will only be used by researchers to contact you for purposes of the study, such as scheduling your session. Code numbers will be used to identify subjects and all other data will be anonymous. Personally identifiable data will not be associated with data collected during the study and will be destroyed when data analysis is complete. Researchers will never share information or responses that could be linked to specific individuals.

Data collected in this study will be stored on a password protected external hard drive for analysis. The researcher will be the only person who knows the password. Any identifiable data will be destroyed when data analysis is complete. Deidentified and anonymous data may be maintained for future study or publication and will be password protected.

The gift card distribution service requires that you provide an email address where they can send your gift card. Your email address may be maintained for their records.

POTENTIAL BENEFITS

There are no direct benefits to you for participating in this research. You may, however, find it interesting to discuss your experience with others, and it may be beneficial to the field.

POTENTIAL RISKS AND DISCOMFORTS

Some users of virtual reality and other interactive media experience motion-sickness-like symptoms. This malady is sometimes called cybersickness, simulator sickness, or virtual reality sickness. Symptoms of virtual reality sickness include dizziness, nausea, vertigo, perspiration, and stomach awareness. Motion sickness susceptibility is thought to indicate susceptibility to virtual reality sickness.

If you are receiving this consent form, you have already been screened for motion sickness susceptibility and are unlikely to experience virtual reality sickness. If you experience any discomfort, please alert the researcher immediately so that you may be removed from the virtual reality experience. Discomfort typically subsides soon upon removal from virtual reality, but you will be asked to sit until you are feeling better. Depending on the severity of your discomfort, you may not wish to continue participating in the study. Researchers may ask you if you want to continue participating in the study and may also ask you not to continue participating. You can withdraw at any time and there is no penalty for doing so.

COMPENSATION

I will receive small financial compensation ($20 gift card) for my participation.

VOLUNTARY PARTICIPATION

Your participation is completely voluntary. You can withdraw from the study at any time. You do not have to answer any questions that you do not want to answer. If you choose not to participate, there will be no penalty or loss of any benefits for not participating. If you are a student, it will in no way effect your grade in the class.

WHO TO CONTACT WITH QUESTIONS?

If you should have any questions about the research, please feel free to call or email the Principal Investigator, Elka Cahn (ecahn@ubalt.edu, 301-738-6177), or Faculty Sponsor, Deborah Kohl (dkohl@ubalt.edu).

If you have questions regarding your rights as a research subject, or if problems arise which you do not feel you can discuss with the Investigator, please contact the UB Institutional Review Board at: irb@ubalt.edu 410-837-4057

SUMMARY

I understand the information that was presented and that:

I am 18 and older and my participation is voluntary.

Refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled.

I may discontinue participation at any time without penalty or loss of benefits.

I hereby give my consent to be the subject of the research.

I give permission to audiotape or videotaping my interview. Yes__ No___

Name (please print): ____

Signature: _______________________Date: ________________________

Interviewer Name (please print) __________________________________

Signature________________________ Date:________________________

Appendix B: Results

Full Sample Means – No Sensory Stimuli (N=35)

	All	***NPC***	***Researcher***	***Post***
n	35	9	14	11
Accuracy	2.85	2.56	3.07	2.82
IPQ	44.85	46.22	45.64	42.73
MSSQ Score	9.29	2.83	9.58	12.80
Ease Score	6.18	6.00	5.00	7.70
VRSQ	1.86	1.17	1.83	2.30
AF3	0.244744379	0.270954081	0.059397822	0.459195694
F7	0.196858594	0.063633674	0.032470246	0.515082334
F3	0.56356416	0.412478599	0.74639899	0.454480746
FC5	0.400927163	0.312036418	0.32727607	0.56739371
T7	0.172838439	0.177708325	-0.1812405	0.619499914
P7	0.271372227	0.481795224	0.292064116	0.072872824
O1	0.553045439	0.546266112	0.282813487	0.902523736
O2	0.140871151	-0.29418284	0.33878909	0.24492886
P8	0.170783377	-0.01788044	0.294028623	0.168287093
T8	0.119178587	-0.08765837	0.232169454	0.144602265
FC6	0.22323217	0.130583618	0.291606137	0.212014119
F4	0.461618075	0.261755232	0.614584484	0.430457699
F9	0.221369021	0.176058555	0.245807241	0.22733803
AF4	0.541549906	0.565306666	0.72406023	0.289826689
Left	0.343335772	0.323553205	0.222740032	0.513006994
Right	0.268371755	0.104854631	0.391577894	0.24535068
Front	0.112289073	-0.02105844	0.055504102	0.293663362
Back	0.284018048	0.178999514	0.301923829	0.347153128
Average	0.305853763	0.214203918	0.307158963	0.379178837

Decibel to Hertz conversion criteria

The Emotiv Analyzer returns values in decibels, which includes negative numbers. The values needed to be converted from decibels to Hertz using the following formula in Excel: 10^(value/10).

Descriptive statistics for the baseline (first 15 seconds (30 measurements) were calculated in Excel. The range for the baseline is $W$1:$AJ$31 (including line of headings)

Descriptive statistics for a 30 second segment 20 seconds into the activity portion of the EEG test, which is 50 seconds from the start of the test including a 30 second baseline measurement were calculated in Excel. The range for the in-test measurement is $W$101:$AJ$161 (no heading)

(In-test 15 seconds $W$101:$AJ$131)

Table of Jarque-Bera test results

Small Sample Jarque-Bera test (N=15)

	Count	*Skew*	*Kurtosis*	*Jarque-Bera test*	*p-value*	*Distribution*
AF3 test I	15	-1.791046585	5.784544869	67.08604195	2.70677E-15	Not Normal
F7 test I	15	-1.586133166	3.551832915	19.83646887	4.92681E-05	Not Normal
F3 test I	15	1.70806665	2.398384039	10.48883115	0.005276905	Not Normal
FC5 test I	15	2.612994993	7.420946528	235.0042827	9.32113E-52	Not Normal
T7 test I	15	-3.056338702	10.55729714	650.7114808	5.0095E-142	Not Normal
P7 test I	15	-2.27244729	7.221114047	168.2968792	2.84969E-37	Not Normal
O1 test I	15	0.737839103	4.263561174	6.185123135	0.045385547	Not Normal
O2 test I	15	-0.374947143	1.892020287	0.314536966	0.854474616	Normal
P8 test I	15	-3.095731261	11.12960436	741.9351982	7.7771E-162	Not Normal
T8 test I	15	-2.082792621	7.852843967	167.1960506	4.94127E-37	Not Normal
FC6 test I	15	2.294687184	6.477295572	138.0748016	1.04097E-30	Not Normal
F4 test I	15	1.547484211	1.541087294	3.554569009	0.169096706	Normal
F9 test I	15	1.258560706	0.990389245	0.971046853	0.615375009	Normal
AF4 test I	15	1.167445389	0.223975315	0.042732025	0.978860624	Normal
Left test I	15	-2.208762788	7.233441235	159.5394485	2.27221E-35	Not Normal
Right test I	15	0.170591602	-0.148189916	0.000399423	0.999800309	Normal
Front test I	15	-1.145444225	3.040922227	7.582956022	0.02256223	Not Normal
Back test I	15	-0.420155175	0.748528414	0.061818154	0.969563725	Normal
Average test I	15	-1.527106119	4.941745459	35.59419667	1.8656E-08	Not Normal
IPQ test I	15	-0.555362427	-0.061604761	0.00073158	0.999634277	Normal
AF3 test II	15	0.516183136	2.213938063	0.816241319	0.664898648	Normal
F7 test II	15	2.263418186	7.009668777	157.3274898	6.86704E-35	Not Normal
F3 test II	15	-0.811242543	2.945753467	3.569227639	0.167861873	Normal
FC5 test II	15	2.683224142	8.39157445	316.8697833	1.55812E-69	Not Normal
T7 test II	15	0.752000316	1.814710267	1.163940168	0.558796406	Normal
P7 test II	15	-3.05858095	10.66800091	665.4050067	3.2295E-145	Not Normal
O1 test II	15	1.016660908	0.375286202	0.090982415	0.955528004	Normal
O2 test II	15	0.31252762	2.055929106	0.258031719	0.878960026	Normal
P8 test II	15	0.007311988	0.637546223	1.35823E-05	0.999993209	Normal
T8 test II	15	0.55661646	2.11164057	0.863439876	0.649391221	Normal
FC6 test II	15	1.602677878	4.037869289	26.17441685	2.07156E-06	Not Normal
F4 test II	15	2.995560981	10.43782996	611.0219084	2.081E-133	Not Normal
F9 test II	15	-0.748228882	1.623378154	0.922121925	0.630614232	Normal

AF4 test II	15	-2.815812632	10.40592913	536.5982483	3.0142E-117	Not Normal
Left test II	15	0.270163494	- 0.847245724	0.032745537	0.983760537	Normal
Right test II	15	-0.589262813	- 0.478745492	0.049740195	0.975436616	Normal
Front test II	15	-1.570167196	3.626830435	20.26871986	3.9692E-05	Not Normal
Back test II	15	-0.112981066	-0.68835716	0.003780237	0.998111667	Normal
Average test II	15	-0.478084277	- 0.396925881	0.02250649	0.988809836	Normal
IPQ test II	15	-0.276423606	- 0.459081301	0.0100649	0.994980191	Normal

Full Sample Jarque-Bera test (N=35)

	Count	*Skew*	*Kurtosis*	*Jarque-Bera test*	*p-value*	*Distribution*
AF3	35	0.276502636	3.105769455	1.075458813	0.58407294	Normal
F7	35	-1.588776102	8.886186338	290.678581	7.58487E-64	Not Normal
F3	35	2.067522561	6.248784324	243.4155888	1.38988E-53	Not Normal
FC5	35	-1.235265343	9.051531382	182.314596	2.57566E-40	Not Normal
T7	35	-2.556221698	11.52124083	1264.888798	2.1522E-275	Not Normal
P7	35	-1.162322214	2.497074892	12.28493928	0.002149608	Not Normal
O1	35	0.312654801	1.262573796	0.227248251	0.892593396	Normal
O2	35	-1.003480012	4.685996111	32.2461673	9.95024E-08	Not Normal
P8	35	1.547374476	8.429611764	248.1205909	1.3222E-54	Not Normal
T8	35	-1.427960029	9.377820114	261.5126492	1.63399E-57	Not Normal
FC6	35	2.399895398	7.109382036	424.526821	6.53389E-93	Not Normal
F4	35	1.861739737	2.445511145	30.22971359	2.7271E-07	Not Normal
F9	35	1.529056357	2.836094579	27.42490977	1.10855E-06	Not Normal
AF4	35	1.381304734	4.407953016	54.06419198	1.82016E-12	Not Normal
Left	35	-0.065572157	4.207936057	0.111028381	0.945998599	Normal
Right	35	2.070057332	4.964644043	154.0273281	3.57594E-34	Not Normal
Front	35	-0.88383354	4.219275445	20.28025984	3.94637E-05	Not Normal
Back	35	0.898426699	2.285061854	6.146360401	0.046273761	Not Normal
Average	35	1.166938661	4.984620659	49.34203822	1.9298E-11	Not Normal
IPQ	35	-0.429784659	- 0.203217552	0.011124514	0.994453183184	Normal

NPC-Researcher Jarque-Bera test (N=23)

	Count	*Skew*	*Kurtosis*	*Jarque-Bera test*	*p-value*	*Distribution*
AF3	23	-0.397079253	1.585060876	0.379632058	0.827111285	Normal
F7	23	-2.982374409	11.94423912	1216.068113	8.5934E-265	Not Normal
F3	23	1.936438369	6.135018969	135.2557611	4.26172E-30	Not Normal
FC5	23	-1.534186177	8.678242781	169.8776783	1.2928E-37	Not Normal
T7	23	-2.790392986	10.71954644	857.4329289	6.4685E-187	Not Normal
P7	23	-1.467517703	3.285074974	22.2727511	1.45725E-05	Not Normal
O1	23	0.186719118	0.414945183	0.005752752	0.997127757	Normal
O2	23	-1.014370912	3.733592762	13.74561134	0.001035568	Not Normal
P8	23	1.455242511	8.928955726	161.803786	7.3241E-36	Not Normal
T8	23	-2.175436568	9.898495384	444.3731532	3.20329E-97	Not Normal
FC6	23	2.590292807	8.286872599	441.566012	1.30364E-96	Not Normal
F4	23	1.582802072	1.112535066	2.971647084	0.226315883	Normal
F9	23	1.205044387	2.14061274	6.376742715	0.04123898	Not Normal
AF4	23	2.194952046	5.570503297	143.2700915	7.74988E-32	Not Normal
Left	23	-1.289109672	2.735482135	11.91692191	0.002583886	Not Normal
Right	23	1.7509427	4.322059327	54.88351404	1.20836E-12	Not Normal
Front	23	-1.463665712	3.247436306	21.65118525	1.98841E-05	Not Normal
Back	23	0.20765917	1.123519808	0.052165129	0.974254647	Normal
Average	23	-0.076565869	2.496197584	0.035006198	0.982649191	Normal
IPQ	23	-0.603387511	0.275009492	0.026387886	0.986892716	Normal

Researcher-Posttest Jarque-Bera test (N=26)

	Count	*Skew*	*Kurtosis*	*Jarque-Bera test*	*p-value*	*Distribution*
AF3	26	0.328653077	2.69439974	0.849496447	0.65393441	Normal
F7	26	-1.68941575	8.449787706	220.76325	1.15311E-48	Not Normal
F3	26	2.787058383	8.427098683	597.5997378	1.7095E-130	Not Normal
FC5	26	2.247276448	4.814992391	126.842945	2.86025E-28	Not Normal
T7	26	-3.151725118	14.4529908	2247.8857	0	Not Normal
P7	26	-1.230133338	3.113991014	15.89648824	0.000353282	Not Normal
O1	26	0.292451435	1.436287706	0.191140407	0.908854555	Normal
O2	26	1.07864604	0.315199784	0.12522523	0.939307277	Normal
P8	26	2.802143239	9.166346636	714.7189918	6.3204E-156	Not Normal
T8	26	1.882735982	3.531592646	47.89411575	3.98038E-11	Not Normal
FC6	26	2.683224296	8.132182934	515.8106927	9.8431E-113	Not Normal
F4	26	1.761873832	1.960157711	12.92092922	0.001564069	Not Normal
F9	26	1.704822868	3.543635596	39.53836824	2.59629E-09	Not Normal
AF4	26	1.335185829	3.648976225	25.71506358	2.60642E-06	Not Normal
Left	26	0.636368743	4.845467757	10.30033149	0.005798444	Not Normal
Right	26	1.975459745	3.802614671	61.13122715	5.31524E-14	Not Normal
Front	26	-0.766295632	5.38147642	18.42288706	9.98897E-05	Not Normal
Back	26	1.282135261	2.830680302	14.26958819	0.00079689	Not Normal
Average	26	1.587473325	4.572788321	57.08699395	4.01529E-13	Not Normal
IPQ	26	-0.314496498	-0.310514396	0.010331353	0.994847643	Normal

NPC-Posttest Jarque-Bera test (N=21)

	Count	*Skew*	*Kurtosis*	*Jarque-Bera test*	*p-value*	*Distribution*
AF3	21	2.116186635	7.758684413	235.8805663	6.01431E-52	Not Normal
F7	21	1.047423324	2.147646863	4.427700923	0.109279063	Normal
F3	21	1.123643839	2.802651841	8.677681468	0.01305165	Not Normal
FC5	21	-1.191374015	5.834322586	42.27515187	6.60796E-10	Not Normal
T7	21	-0.042975825	0.81584695	0.001075657	0.999462316	Normal
P7	21	-0.863966426	2.090916814	2.855454836	0.23985339	Normal
O1	21	0.265687998	1.145406423	0.081034723	0.960292492	Normal
O2	21	-1.405946996	5.17321212	46.28779814	8.88653E-11	Not Normal
P8	21	-0.263205453	5.870028402	2.088710377	0.351918667	Normal
T8	21	-1.699355797	8.464075694	181.0238364	4.91104E-40	Not Normal
FC6	21	1.506755072	2.310296388	10.60300034	0.004984111	Not Normal
F4	21	2.558005895	6.829549931	267.0516735	1.02439E-58	Not Normal
F9	21	1.703318503	3.350436532	28.49722506	6.48494E-07	Not Normal
AF4	21	0.518401059	4.978117311	5.827336099	0.054276276	Normal
Left	21	0.424687455	5.959455311	5.604799132	0.06066432	Normal
Right	21	2.713109235	9.840239054	623.6686453	3.7331E-136	Not Normal
Front	21	0.094671753	4.46118879	0.156081022	0.924926956	Normal
Back	21	1.074457997	2.970943023	8.916113412	0.011584854	Not Normal
Average	21	1.78643562	9.089806642	230.7236334	7.92501E-51	Not Normal
IPQ	21	-0.44173973	-0.347744896	0.020647264	0.989729474	Normal

Table of Fisher's Exact Test Distributions

Distribution of Values Threshold I

	Low	***Moderate***	***High***
AF3	39.30%	37.50%	23.20%
F7	50.00%	35.70%	14.30%
F3	55.40%	26.80%	17.90%
FC5	46.40%	35.70%	17.90%
T7	35.70%	46.40%	17.90%
P7	35.70%	41.10%	23.20%
O1	32.10%	37.50%	30.40%
O2	50.00%	37.50%	12.50%
P8	46.40%	48.20%	5.40%
T8	64.30%	30.40%	5.40%
FC6	58.90%	32.10%	8.90%
F4	64.30%	23.20%	12.50%
F9	58.90%	33.90%	7.10%
AF4	57.10%	25.00%	17.90%
Left	39.30%	48.20%	12.50%
Right	51.80%	42.90%	5.40%
Front	41.10%	46.40%	12.50%
Back	32.10%	58.90%	8.90%
Average	42.90%	48.20%	8.90%

Distribution of Values Threshold II

	Low	Moderate	High
AF3	43.33%	23.33%	33.33%
F7	40.00%	20.00%	40.00%
F3	53.33%	13.33%	33.33%
FC5	46.67%	16.67%	36.67%
T7	30.00%	16.67%	53.33%
P7	40.00%	13.33%	46.67%
O1	30.00%	10.00%	60.00%
O2	46.67%	23.33%	30.00%
P8	46.67%	30.00%	23.33%
T8	56.67%	13.33%	30.00%
FC6	53.33%	26.67%	20.00%
F4	60.00%	10.00%	30.00%
F9	43.33%	30.00%	26.67%
AF4	50.00%	13.33%	36.67%
Left	46.67%	13.33%	40.00%
Right	46.67%	23.33%	30.00%
Front	40.00%	26.67%	33.33%
Back	26.67%	36.67%	36.67%
Average	40.00%	23.33%	36.67%

Tables of Results for Fisher’s Exact Test Threshold I

Table of Stimuli in Test II IPQ

	Low	Moderate	High	Total
I	0	3	0	3
II	2	3	0	5
III	0	3	0	3
IV	1	3	0	4
Total	3	12	0	15
p-value	0.6374			
r code				

```
input_mxn_table = structure(list(Low = c(0L, 2L, 0L,
1L), X.Moderate = c(3L, 3L, 3L, 3L), X.High = c(0L,
0L, 0L, 0L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II Average

	Low	Moderate	High	
I	1	1	1	**3**
II	3	1	1	**5**
III	0	2	1	**3**
IV	2	2	0	**4**
	6	**6**	**3**	**15**
p-value	0.7243			
r code				

```
input_mxn_table = structure(list(Low = c(1L, 3L, 0L, 2L), X.Moderate = c(1L, 1L, 2L, 2L), X.High = c(1L, 1L, 1L, 0L)), class = "data.frame", row.names = c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II Left

	Low	Moderate	High	Total
I	2	0	1	**3**
II	4	0	1	**5**
III	1	1	1	**3**
IV	2	2	0	**4**
Total	**9**	**3**	**3**	**15**
p-value	0.5397			
r code				

```
input_mxn_table = structure(list(Low = c(2L, 4L, 1L, 2L), X.Moderate = c(0L, 0L, 1L, 2L), X.High = c(1L, 1L, 1L, 0L)), class = "data.frame", row.names = c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II Right

	Low	Moderate	High	Total
I	0	2	1	**3**
II	3	2	0	**5**
III	1	1	1	**3**

IV	0	4	0	**4**
Total	**4**	**9**	**2**	**15**
p-value	0.1892			
r code				

```
input_mxn_table = structure(list(Low = c(0L, 3L, 1L,
0L), X.Moderate = c(2L, 2L, 1L, 4L), X.High = c(1L,
0L, 1L, 0L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II Front

	Low	Moderate	High	Total
I	2	0	1	3
II	3	1	1	5
III	1	2	0	3
IV	2	2	0	4
Total	8	5	2	15
p-value	0.7642			
r code				

```
input_mxn_table = structure(list(Low = c(2L, 3L, 1L,
2L), X.Moderate = c(0L, 1L, 2L, 2L), X.High = c(1L,
1L, 0L, 0L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II Back

	Low	Moderate	High	Total
I	0	2	1	3
II	3	2	0	5
III	0	2	1	3
IV	1	3	0	4
Total	4	9	2	15
p-value	0.427			
r code				

```
input_mxn_table = structure(list(Low = c(0L, 3L, 0L,
1L), X.Moderate = c(2L, 2L, 2L, 3L), X.High = c(1L,
0L, 1L, 0L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II AF3

	Low	Moderate	High	Total
I	1	0	2	3
II	4	1	0	5
III	0	2	1	3
IV	1	3	0	4
Total	6	6	3	15
p-value	0.0597			
r code				

```
input_mxn_table = structure(list(Low = c(1L, 4L, 0L,
1L), X.Moderate = 0:3, X.High = c(2L, 0L, 1L, 0L)),
class = "data.frame", row.names = c("I", "II", "III",
"IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II F7

	Low	Moderate	High	Total
I	1	0	2	3
II	3	1	1	5
III	2	1	0	3
IV	0	3	1	4
Total	6	5	4	15
p-value	0.2527			
r code				

```
input_mxn_table = structure(list(Low = c(1L, 3L, 2L,
0L), X.Moderate = c(0L, 1L, 1L, 3L), X.High = c(2L,
1L, 0L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II F3

	Low	Moderate	High	Total
I	1	1	1	3
II	4	1	0	5
III	2	1	0	3

IV	0	3	1	4
Total	7	6	2	15
p-value	0.2674			
r code				

```
input_mxn_table = structure(list(Low = c(1L, 4L, 2L,
0L), X.Moderate = c(1L, 1L, 1L, 3L), X.High = c(1L,
0L, 0L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II FC5

	Low	Moderate	High	Total
I	2	0	1	3
II	4	0	1	5
III	0	2	1	3
IV	1	3	0	4
Total	7	5	3	15
p-value	0.0732			
r code				

```
input_mxn_table = structure(list(Low = c(2L, 4L, 0L,
1L), X.Moderate = c(0L, 0L, 2L, 3L), X.High = c(1L,
1L, 1L, 0L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II T7

	Low	Moderate	High	Total
I	1	1	1	3
II	3	1	1	5
III	0	2	1	3
IV	2	1	1	4
Total	6	5	4	15
p-value	0.8527			
r code				

```
input_mxn_table = structure(list(Low = c(1L, 3L, 0L,
2L), X.Moderate = c(1L, 1L, 2L, 1L), X.High = c(1L,
1L, 1L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II P7

	Low	Moderate	High	Total
I	1	0	2	3
II	3	2	0	5
III	0	2	1	3
IV	2	1	1	4
Total	6	5	4	15
p-value	0.4154			
r code				

```
input_mxn_table = structure(list(Low = c(1L, 3L, 0L,
2L), X.Moderate = c(0L, 2L, 2L, 1L), X.High = c(2L,
0L, 1L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
```

fisher.test(input_mxn_table)

chisq.test(input_mxn_table)

Table of Stimuli in Test II O1

	Low	Moderate	High	Total
I	1	0	2	3
II	3	2	0	5
III	0	2	1	3
IV	2	1	1	4
Total	6	5	4	15
p-value	0.4154			
r code				

```
input_mxn_table = structure(list(Low = c(1L, 3L, 0L,
2L), X.Moderate = c(0L, 2L, 2L, 1L), X.High = c(2L,
0L, 1L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II O2

	Low	Moderate	High	Total
I	0	1	2	3
II	4	0	1	5
III	2	0	1	3
IV	1	3	0	4
Total	7	4	4	15
p-value	0.0567			

r code
input_mxn_table = structure(list(Low = c(0L, 4L, 2L, 1L), X.Moderate = c(1L, 0L, 0L, 3L), X.High = c(2L, 1L, 1L, 0L)), class = "data.frame", row.names = c("I", "II", "III", "IV")) input_mxn_table fisher.test(input_mxn_table) chisq.test(input_mxn_table)

Table of Stimuli in Test II P8

	Low	Moderate	High	Total
I	0	2	1	3
II	4	0	1	5
III	1	1	1	3
IV	2	1	1	4
Total	7	4	4	15
p-value	0.4877			
r code				
input_mxn_table = structure(list(Low = c(0L, 4L, 1L, 2L), X.Moderate = c(2L, 0L, 1L, 1L), X.High = c(1L, 1L, 1L, 1L)), class = "data.frame", row.names = c("I", "II", "III", "IV")) input_mxn_table fisher.test(input_mxn_table) chisq.test(input_mxn_table)				

Table of Stimuli in Test II T8

	Low	Moderate	High	Total
I	1	1	1	3
II	3	2	0	5

III	0	3	0	3
IV	3	0	1	4
Total	7	6	2	15
p-value	0.135			
r code				

input_mxn_table = structure(list(Low = c(1L, 3L, 0L, 3L), X.Moderate = c(1L, 2L, 3L, 0L), X.High = c(1L, 0L, 0L, 1L)), class = "data.frame", row.names = c("I", "II", "III", "IV"))

input_mxn_table

fisher.test(input_mxn_table)

chisq.test(input_mxn_table)

Table of Stimuli in Test II FC6

	Low	Moderate	High	Total
I	1	1	1	3
II	2	1	2	5
III	1	1	1	3
IV	3	1	0	4
Total	7	4	4	15
p-value	0.9233			
r code				

input_mxn_table = structure(list(Low = c(1L, 2L, 1L, 3L), X.Moderate = c(1L, 1L, 1L, 1L), X.High = c(1L, 2L, 1L, 0L)), class = "data.frame", row.names = c("I", "II", "III", "IV"))

input_mxn_table

fisher.test(input_mxn_table)

chisq.test(input_mxn_table)

Table of Stimuli in Test II F4

	Low	Moderate	High	Total
I	1	1	1	3
II	4	1	0	5
III	2	1	0	3
IV	2	1	1	4
Total	9	4	2	15
p-value	0.9329			
r code				

```
input_mxn_table = structure(list(Low = c(1L, 4L, 2L,
2L), X.Moderate = c(1L, 1L, 1L, 1L), X.High = c(1L,
0L, 0L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II F9

	Low	Moderate	High	Total
I	0	2	1	3
II	2	3	0	5
III	0	2	1	3
IV	3	1	0	4
Total	5	8	2	15
p-value	0.3011			
r code				

```
input_mxn_table = structure(list(Low = c(0L, 2L, 0L,
3L), X.Moderate = c(2L, 3L, 2L, 1L), X.High = c(1L,
0L, 1L, 0L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
```

```
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II AF4

	Low	Moderate	High	Total
I	1	1	1	3
II	3	2	0	5
III	2	1	0	3
IV	2	1	1	4
Total	8	5	2	15
p-value	0.976			
r code				

```
input_mxn_table = structure(list(Low = c(1L, 3L, 2L,
2L), X.Moderate = c(1L, 2L, 1L, 1L), X.High = c(1L,
0L, 0L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Tables of Results for Fisher's Exact Test Threshold II

Table of Stimuli in Test II IPQ

	Low	Moderate	High	Total
I	0	2	1	3
II	1	2	2	5
III	0	1	2	3
IV	1	1	2	4
Total	2	6	7	15
p-value	1			
r code				

```
input_mxn_table = structure(list(Low = c(0L, 1L, 0L,
1L), X.Moderate = c(2L, 2L, 1L, 1L), X.High = c(1L,
2L, 2L, 2L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II Average

	Low	Moderate	High	Total
I	1	1	1	3
II	3	1	1	5
III	0	2	1	3
IV	2	1	1	4
Total	6	5	4	15
p-value	0.8527			
r code				

```
input_mxn_table = structure(list(Low = c(1L, 3L, 0L, 2L),
X.Moderate = c(1L, 1L, 2L, 1L), X.High = c(1L, 1L, 1L, 1L)), class =
"data.frame", row.names = c("I", "II", "III", "IV"))
input_mxn_table
```

fisher.test(input_mxn_table)

chisq.test(input_mxn_table)

Table of Stimuli in Test II Left

	Low	Moderate	High	Total
I	2	0	1	3
II	4	0	1	5
III	1	0	2	3
IV	2	1	1	4
Total	9	1	5	15

p-value	0.7962
r code	

input_mxn_table = structure(list(Low = c(2L, 4L, 1L, 2L), X.Moderate = c(0L, 0L, 0L, 1L), X.High = c(1L, 1L, 2L, 1L)), class = "data.frame", row.names = c("I", "II", "III", "IV"))

input_mxn_table

fisher.test(input_mxn_table)

chisq.test(input_mxn_table)

Table of Stimuli in Test II Right

	Low	Moderate	High	Total
I	0	1	2	3
II	3	0	2	5
III	1	1	1	3
IV	0	3	1	4
Total	4	5	6	15

p-value	0.2527
r code	

```
input_mxn_table = structure(list(Low = c(0L, 3L, 1L,
0L), X.Moderate = c(1L, 0L, 1L, 3L), X.High = c(2L,
2L, 1L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II Front

	Low	Moderate	High	Total
I	2	0	1	3
II	3	1	1	5
III	1	1	1	3
IV	2	1	1	4
Total	8	3	4	15

p-value	1
r code	

```
input_mxn_table = structure(list(Low = c(2L, 3L, 1L,
2L), X.Moderate = c(0L, 1L, 1L, 1L), X.High = c(1L,
1L, 1L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II Back

	Low	Moderate	High	Total
I	0	1	2	3
II	3	1	1	5
III	0	1	2	3
IV	1	2	1	4

Total	4	5	6	15

p-value	0.6546
r code	

```
input_mxn_table = structure(list(Low = c(0L, 3L, 0L,
1L), X.Moderate = c(1L, 1L, 1L, 2L), X.High = c(2L,
1L, 2L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II AF3

	Low	Moderate	High	Total
I	1	0	2	3
II	4	0	1	5
III	0	2	1	3
IV	1	2	1	4
Total	6	4	5	15

p-value	0.1808
r code	

```
input_mxn_table = structure(list(Low = c(1L, 4L, 0L,
1L), X.Moderate = c(0L, 0L, 2L, 2L), X.High = c(2L,
1L, 1L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II F7

	Low	Moderate	High	Total
I	1	0	2	3
II	3	1	1	5
III	2	0	1	3
IV	0	1	3	4
Total	6	2	7	15

p-value 0.4655

r code

```
input_mxn_table = structure(list(Low = c(1L, 3L, 2L,
0L), X.Moderate = c(0L, 1L, 0L, 1L), X.High = c(2L,
1L, 1L, 3L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II F3

	Low	Moderate	High	Total
I	1	0	2	3
II	4	0	1	5
III	2	0	1	3
IV	1	3	0	4
Total	8	3	4	15

p-value 0.093

```
input_mxn_table = structure(list(Low = c(1L, 4L, 2L,
1L), X.Moderate = c(0L, 0L, 0L, 3L), X.High = c(2L,
1L, 1L, 0L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II FC5

	Low	Moderate	High	Total
I	2	0	1	3
II	4	0	1	5
III	0	0	3	3
IV	1	1	2	4
Total	7	1	7	15

p-value	0.2284
r code	

```
input_mxn_table = structure(list(Low = c(2L, 4L, 0L,
1L), X.Moderate = c(0L, 0L, 0L, 1L), X.High = c(1L,
1L, 3L, 2L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II T7

	Low	Moderate	High	Total
I	1	0	2	3
II	3	1	1	5
III	0	1	2	3

IV	2	0	2	4
Total	6	2	7	15

p-value	0.6454
r code	

```
input_mxn_table = structure(list(Low = c(1L, 3L, 0L,
2L), X.Moderate = c(0L, 1L, 1L, 0L), X.High = c(2L,
1L, 2L, 2L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II P7

	Low	Moderate	High	Total
I	1	0	2	3
II	3	1	1	5
III	0	1	2	3
IV	2	1	1	4
Total	6	3	6	15

p-value	0.7243
r code	

```
input_mxn_table = structure(list(Low = c(1L, 3L, 0L,
2L), X.Moderate = c(0L, 1L, 1L, 1L), X.High = c(2L,
1L, 2L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II O1

	Low	Moderate	High	Total
I	0	0	3	3
II	2	0	3	5
III	1	0	2	3
IV	2	0	2	4
Total	5	0	10	15

p-value	0.7902
r code	

```
input_mxn_table = structure(list(Low = c(0L, 2L, 1L,
2L), X.Moderate = c(0L, 0L, 0L, 0L), X.High = c(3L,
3L, 2L, 2L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II O2

	Low	Moderate	High	Total
I	0	0	3	3
II	4	0	1	5
III	2	0	1	3
IV	1	2	1	4
Total	7	2	6	15

p-value	0.1137
r code	

```
input_mxn_table = structure(list(Low = c(0L, 4L, 2L,
1L), X.Moderate = c(0L, 0L, 0L, 2L), X.High = c(3L,
1L, 1L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II P8

	Low	Moderate	High	Total
I	0	1	2	3
II	3	2	0	5
III	1	0	2	3
IV	1	3	0	4
Total	5	6	4	15

p-value	0.1305
r code	

```
input_mxn_table = structure(list(Low = c(0L, 3L, 1L,
1L), X.Moderate = c(1L, 2L, 0L, 3L), X.High = c(2L,
0L, 2L, 0L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II T8

	Low	Moderate	High	Total
I	1	0	2	3
II	3	1	1	5
III	0	1	2	3

IV	3	0	1	4
Total	7	2	6	15

p-value	0.4655
r code	

```
input_mxn_table = structure(list(Low = c(1L, 3L, 0L,
3L), X.Moderate = c(0L, 1L, 1L, 0L), X.High = c(2L,
1L, 2L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II FC6

	Low	Moderate	High	Total
I	1	0	2	3
II	2	1	2	5
III	1	0	2	3
IV	3	1	0	4
Total	7	2	6	15

p-value	0.6454
r code	

```
input_mxn_table = structure(list(Low = c(1L, 2L, 1L,
3L), X.Moderate = c(0L, 1L, 0L, 1L), X.High = c(2L,
2L, 2L, 0L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II F4

	Low	Moderate	High	Total
I	1	0	2	3
II	4	1	0	5
III	2	0	1	3
IV	2	0	2	4
Total	9	1	5	15

p-value	0.3826
r code	

```
input_mxn_table = structure(list(Low = c(1L, 4L, 2L,
2L), X.Moderate = c(0L, 1L, 0L, 0L), X.High = c(2L, 0L,
1L, 2L)), class = "data.frame", row.names = c("I",
"II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II F9

	Low	Moderate	High	Total
I	0	1	2	3
II	2	2	1	5
III	0	2	1	3
IV	3	0	1	4
Total	5	5	5	15

p-value	0.3878
r code	

```
input_mxn_table = structure(list(Low = c(0L, 2L, 0L,
3L), X.Moderate = c(1L, 2L, 2L, 0L), X.High = c(2L,
1L, 1L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
```

```
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Table of Stimuli in Test II AF4

	Low	Moderate	High	Total
I	1	0	2	3
II	3	1	1	5
III	2	0	1	3
IV	2	1	1	4
Total	8	2	5	15
p-value	0.976			
r code				

```
input_mxn_table = structure(list(Low = c(1L, 3L, 2L,
2L), X.Moderate = c(0L, 1L, 0L, 1L), X.High = c(2L,
1L, 1L, 1L)), class = "data.frame", row.names =
c("I", "II", "III", "IV"))
input_mxn_table
fisher.test(input_mxn_table)
chisq.test(input_mxn_table)
```

Tables of Results for Paired-Sample t-Test (N=15)

		Paired Differences					t	df	Significance	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				One-Sided p	Two-Sided p
					Lower	Upper				
Pair 1	AF3_Hz - AF3_Hz2	-0.01985	0.946496	0.244384	-0.54401	0.504298	-0.081	14	0.468	0.936
Pair 2	F7_Hz - F7_Hz2	-0.33532	1.473727	0.380515	-1.15144	0.480801	-0.881	14	0.197	0.393
Pair 3	F3_Hz - F3_Hz2	0.269137	0.749727	0.193579	-0.14605	0.684322	1.39	14	0.093	0.186
Pair 4	FC5_Hz - FC5_Hz2	0.145192	1.098825	0.283715	-0.46332	0.753701	0.512	14	0.308	0.617
Pair 5	T7_Hz - T7_Hz2	-0.58485	1.814094	0.468397	-1.58946	0.419766	-1.249	14	0.116	0.232
Pair 6	P7_Hz - P7_Hz2	0.004303	1.491493	0.385102	-0.82166	0.830264	0.011	14	0.496	0.991
Pair 7	O1_Hz - O1_Hz2	-0.0469	1.648542	0.425652	-0.95983	0.866031	-0.11	14	0.457	0.914
Pair 8	O2_Hz - O2_Hz2	-0.04707	0.548634	0.141657	-0.3509	0.256752	-0.332	14	0.372	0.745
Pair 9	P8_Hz - P8_Hz2	0.043189	0.559197	0.144384	-0.26648	0.352862	0.299	14	0.385	0.769
Pair 10	T8_Hz - T8_Hz2	0.008399	0.725089	0.187217	-0.39314	0.40994	0.045	14	0.482	0.965
Pair 11	FC6_Hz - FC6_Hz2	0.071817	0.431626	0.111445	-0.16721	0.310844	0.644	14	0.265	0.53
Pair 12	F4_Hz - F4_Hz2	0.38614	0.863766	0.223023	-0.0922	0.864477	1.731	14	0.053	0.105
Pair 13	F9_Hz - F9_Hz2	0.20508	0.346322	0.08942	0.013293	0.396867	2.293	14	0.019	0.038
Pair 14	AF4_Hz - AF4_Hz2	0.475711	1.073305	0.277126	-0.11867	1.070088	1.717	14	0.054	0.108
Pair 15	Left - Left2	-0.08118	0.800636	0.206723	-0.52456	0.362193	-0.393	14	0.35	0.7
Pair 16	Right - Right2	0.163323	0.386772	0.099864	-0.05086	0.37751	1.635	14	0.062	0.124
Pair 17	Front - Front2	0.071948	0.514911	0.132949	-0.2132	0.357096	0.541	14	0.298	0.597
Pair 18	Back - Back2	-0.01162	0.506924	0.130887	-0.29235	0.269105	-0.089	14	0.465	0.931
Pair 19	Average - Average2	0.04107	0.496578	0.128216	-0.23393	0.316065	0.32	14	0.377	0.753
Pair 20	IPQ Adj1 - IPQ Adj2	-2.133	5.643	1.457	-5.258	0.991	-1.464	14	0.083	0.165

Paired Samples Effect Sizes

			Standardizera	Point Estimate	95% Confidence Interval	
					Lower	Upper
Pair 1	AF3_Hz - AF3_Hz2	Cohen's d	0.946496	-0.021	-0.527	0.486
		Hedges' correction	0.972828	-0.02	-0.512	0.472
Pair 2	F7_Hz - F7_Hz2	Cohen's d	1.473727	-0.228	-0.737	0.289
		Hedges' correction	1.514728	-0.221	-0.717	0.281
Pair 3	F3_Hz - F3_Hz2	Cohen's d	0.749727	0.359	-0.17	0.876
		Hedges' correction	0.770585	0.349	-0.165	0.852
Pair 4	FC5_Hz - FC5_Hz2	Cohen's d	1.098825	0.132	-0.379	0.638
		Hedges' correction	1.129395	0.129	-0.368	0.621
Pair 5	T7_Hz - T7_Hz2	Cohen's d	1.814094	-0.322	-0.837	0.203
		Hedges' correction	1.864563	-0.314	-0.814	0.197
Pair 6	P7_Hz - P7_Hz2	Cohen's d	1.491493	0.003	-0.503	0.509

		Hedges' correction	1.532988	0.003	-0.49	0.495
Pair 7	O1_Hz - O1_Hz2	Cohen's d	1.648542	-0.028	-0.534	0.478
		Hedges' correction	1.694406	-0.028	-0.52	0.465
Pair 8	O2_Hz - O2_Hz2	Cohen's d	0.548634	-0.086	-0.591	0.423
		Hedges' correction	0.563898	-0.083	-0.575	0.411
Pair 9	P8_Hz - P8_Hz2	Cohen's d	0.559197	0.077	-0.431	0.583
		Hedges' correction	0.574754	0.075	-0.419	0.567
Pair 10	T8_Hz - T8_Hz2	Cohen's d	0.725089	0.012	-0.495	0.517
		Hedges' correction	0.745262	0.011	-0.481	0.503
Pair 11	FC6_Hz - FC6_Hz2	Cohen's d	0.431626	0.166	-0.346	0.673
		Hedges' correction	0.443635	0.162	-0.337	0.655
Pair 12	F4_Hz - F4_Hz2	Cohen's d	0.863766	0.447	-0.092	0.972
		Hedges' correction	0.887796	0.435	-0.09	0.946
Pair 13	F9_Hz - F9_Hz2	Cohen's d	0.346322	0.592	0.033	1.134
		Hedges' correction	0.355957	0.576	0.032	1.103
Pair 14	AF4_Hz - AF4_Hz2	Cohen's d	1.073305	0.443	-0.095	0.968
		Hedges' correction	1.103165	0.431	-0.093	0.941
Pair 15	Left - Left2	Cohen's d	0.800636	-0.101	-0.607	0.408
		Hedges' correction	0.822911	-0.099	-0.591	0.397
Pair 16	Right - Right2	Cohen's d	0.386772	0.422	-0.114	0.945
		Hedges' correction	0.397532	0.411	-0.111	0.919
Pair 17	Front - Front2	Cohen's d	0.514911	0.14	-0.371	0.646
		Hedges' correction	0.529236	0.136	-0.361	0.628
Pair 18	Back - Back2	Cohen's d	0.506924	-0.023	-0.529	0.484
		Hedges' correction	0.521027	-0.022	-0.514	0.471
Pair 19	Average - Average2	Cohen's d	0.496578	0.083	-0.426	0.588
		Hedges' correction	0.510393	0.08	-0.414	0.572
Pair 20	IPQ Adj1 - IPQ Adj2	Cohen's d	5.643	-0.378	-0.897	0.153
		Hedges' correction	5.8	-0.368	-0.872	0.149

a The denominator used in estimating the effect sizes.

Cohen's d uses the sample standard deviation of the mean difference.

Hedges' correction uses the sample standard deviation of the mean difference, plus a correction factor.

Tables of Results for Wilcoxon Signed Rank Test (N=15)

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum	Percentiles		
						25th	50th (Median)	75th
IPQ test I	15	43.6	11.513	21	60	38	43	53
AF3 test I	15	0.25277586	0.77495691	-2.07064196	1.29775348	0.0606027	0.179267369	0.93599735
F7 test I	15	-0.11352348	1.35815039	-3.68069564	2.13512347	0.01924455	0.137623565	0.33939
F3 test I	15	0.38364451	0.48953226	0.00762718	1.65099895	0.04309217	0.173093082	0.6292832
FC5 test I	15	0.49198911	0.90497601	-0.17502328	3.35200125	0.07705633	0.142262214	0.5470883
T7 test I	15	-0.23344547	1.64179812	-5.76790143	1.30848851	0.00793799	0.170339075	0.29459925
P7 test I	15	-0.03687559	1.30475546	-4.11605381	1.69900808	-0.00571456	0.143694314	0.45614069
O1 test I	15	0.59369797	1.27451945	-2.2013868	3.96126967	0.1297112	0.400680098	0.9624365
O2 test I	15	0.1751219	0.3573238	-0.69434856	0.82307798	0.03773874	0.080011241	0.46194188
P8 test I	15	0.16122779	0.3928282	-1.17543525	0.52445054	0.12137735	0.214273345	0.2762781
T8 test I	15	0.10631879	0.61695245	-1.82961411	1.15255901	0.0202614	0.130559414	0.29282553
FC6 test I	15	0.25119942	0.33694668	-0.12573152	1.28864861	0.05240274	0.166000564	0.31921073
F4 test I	15	0.52896872	0.77526349	-0.0551368	2.45220074	0.04078986	0.069939294	1.11554221
F9 test I	15	0.29734577	0.35625344	-0.06832727	1.16522703	0.0463984	0.111570663	0.6063191
AF4 test I	15	0.49288088	0.52161961	0.01200444	1.64043411	0.09086132	0.192232185	0.78214024
Left test I	15	0.19118042	0.68372796	-1.94936125	0.98016765	0.09053979	0.173782457	0.73530551
Right test I	15	0.28758047	0.30880846	-0.32208547	0.83041651	0.08562991	0.211654783	0.62004923
Front test I	15	0.17679342	0.44174645	-1.01843275	0.80417832	-0.02270502	0.13684221	0.56726122
Back test I	15	0.22329302	0.40419945	-0.57500753	0.91735568	0.10703778	0.208477208	0.32502762
Average test I	15	0.23938044	0.4086463	-0.94798408	0.81869749	0.15043051	0.175070474	0.54942852
IPQ test II	15	45.73	8.844	29	59	39	46	55
AF3 test II	15	0.27262931	0.35086642	-0.44302622	1.12356126	0.10770778	0.265163917	0.5129859
F7 test II	15	0.22179809	0.46192419	-0.36839507	1.66079205	-0.04859586	0.155998336	0.31069156
F3 test II	15	0.11450746	0.5066155	-1.2010388	1.02885095	0.00864661	0.120312224	0.22897144
FC5 test II	15	0.34679705	0.47054203	-0.08168348	1.86678823	0.05782108	0.244173308	0.36223894
T7 test II	15	0.35139982	0.57842071	-0.70391155	1.76496786	0.06384041	0.283474549	0.7473446
P7 test II	15	-0.04117838	0.96729145	-3.30646501	0.95079286	-0.06261162	0.138952874	0.38010191
O1 test II	15	0.64059894	0.77493647	-0.2115834	2.46488207	0.03430804	0.274863619	1.2521476
O2 test II	15	0.22219377	0.44149191	-0.71890607	1.24767834	0.01955754	0.146156566	0.48148063
P8 test II	15	0.11803868	0.23872887	-0.33160758	0.62052426	0.03075479	0.116525884	0.27772094
T8 test II	15	0.09791974	0.1850021	-0.28036229	0.52221865	0.01553847	0.08363532	0.1356514
FC6 test II	15	0.17938233	0.25502232	-0.15095204	0.90472518	0.02773121	0.110550904	0.29205717
F4 test II	15	0.14282899	0.25034029	-0.09646048	0.98464985	0.02678219	0.083922536	0.17310354
F9 test II	15	0.09226592	0.1373968	-0.23816534	0.33725911	0.0219164	0.09243771	0.17409852
AF4 test II	15	0.01716962	0.72900327	-2.41900337	1.05923549	-0.00673624	0.130951474	0.27313166
Left test II	15	0.27236461	0.30789131	-0.26986111	0.7337703	0.10279954	0.138513544	0.65674212
Right test II	15	0.12425701	0.16945704	-0.17389427	0.35735073	0.04023688	0.169433041	0.22807622

Front test II	15	0.10484495	0.28936464	-0.70078926	0.52025617	0.03743947	0.157451491	0.30569769
Back test II	15	0.23491325	0.35901938	-0.38178265	0.7894122	-0.01708919	0.21315352	0.61525437
Average test II	15	0.19831081	0.2075391	-0.22187769	0.47877577	0.10829401	0.18736094	0.41308758

Ranks

		N	Mean Rank	Sum of Ranks
IPQ Adj2 - IPQ Adj1	Negative Ranks	4a	5.63	22.5
	Positive Ranks	8b	6.94	55.5
	Ties	3c		
	Total	15		
AF3_Hz2 - AF3_Hz	Negative Ranks	6d	10.33	62
	Positive Ranks	9e	6.44	58
	Ties	0f		
	Total	15		
F7_Hz2 - F7_Hz	Negative Ranks	7g	6.71	47
	Positive Ranks	8h	9.13	73
	Ties	0i		
	Total	15		
F3_Hz2 - F3_Hz	Negative Ranks	10j	8.5	85
	Positive Ranks	5k	7	35
	Ties	0l		
	Total	15		
FC5_Hz2 - FC5_Hz	Negative Ranks	6m	10.17	61
	Positive Ranks	9n	6.56	59
	Ties	0o		
	Total	15		

T7_Hz2 - T7_Hz	Negative Ranks	5p	8.4	42
	Positive Ranks	10q	7.8	78
	Ties	0r		
	Total	15		
P7_Hz2 - P7_Hz	Negative Ranks	8s	8.75	70
	Positive Ranks	7t	7.14	50
	Ties	0u		
	Total	15		
O1_Hz2 - O1_Hz	Negative Ranks	9v	7.78	70
	Positive Ranks	6w	8.33	50
	Ties	0x		
	Total	15		
O2_Hz2 - O2_Hz	Negative Ranks	8y	7	56
	Positive Ranks	7z	9.14	64
	Ties	0aa		
	Total	15		
P8_Hz2 - P8_Hz	Negative Ranks	10ab	9.2	92
	Positive Ranks	5ac	5.6	28
	Ties	0ad		
	Total	15		
T8_Hz2 - T8_Hz	Negative Ranks	9ae	9	81
	Positive Ranks	6af	6.5	39
	Ties	0ag		
	Total	15		
FC6_Hz2 - FC6_Hz	Negative Ranks	9ah	8.67	78
	Positive Ranks	6ai	7	42
	Ties	0aj		

	Total	15		
F4_Hz2 - F4_Hz	Negative Ranks	9ak	8.78	79
	Positive Ranks	6al	6.83	41
	Ties	0am		
	Total	15		
F9_Hz2 - F9_Hz	Negative Ranks	9an	10.33	93
	Positive Ranks	6ao	4.5	27
	Ties	0ap		
	Total	15		
AF4_Hz2 - AF4_Hz	Negative Ranks	11aq	8.09	89
	Positive Ranks	4ar	7.75	31
	Ties	0as		
	Total	15		
Left2 - Left	Negative Ranks	7at	8.43	59
	Positive Ranks	8au	7.63	61
	Ties	0av		
	Total	15		
Right2 - Right	Negative Ranks	11aw	8.09	89
	Positive Ranks	4ax	7.75	31
	Ties	0ay		
	Total	15		
Front2 - Front	Negative Ranks	7az	10.43	73
	Positive Ranks	8ba	5.88	47
	Ties	0bb		
	Total	15		
Back2 - Back	Negative Ranks	7bc	8.57	60
	Positive Ranks	8bd	7.5	60

	Ties	0be		
	Total	15		
Average2 - Average	Negative Ranks	8bf	8.88	71
	Positive Ranks	7bg	7	49
	Ties	0bh		
	Total	15		

a IPQ Adj2 < IPQ Adj1

b IPQ Adj2 > IPQ Adj1

c IPQ Adj2 = IPQ Adj1

d AF3_Hz2 < AF3_Hz

e AF3_Hz2 > AF3_Hz

f AF3_Hz2 = AF3_Hz

g F7_Hz2 < F7_Hz

h F7_Hz2 > F7_Hz

i F7_Hz2 = F7_Hz

j F3_Hz2 < F3_Hz

k F3_Hz2 > F3_Hz

l F3_Hz2 = F3_Hz

m FC5_Hz2 < FC5_Hz

n FC5_Hz2 > FC5_Hz

o FC5_Hz2 = FC5_Hz

p T7_Hz2 < T7_Hz

q T7_Hz2 > T7_Hz

r T7_Hz2 = T7_Hz

s P7_Hz2 < P7_Hz

t P7_Hz2 > P7_Hz

u P7_Hz2 = P7_Hz

v O1_Hz2 < O1_Hz

w O1_Hz2 > O1_Hz

x O1_Hz2 = O1_Hz

y O2_Hz2 < O2_Hz

z O2_Hz2 > O2_Hz

aa O2_Hz2 = O2_Hz

ab P8_Hz2 < P8_Hz

ac P8_Hz2 > P8_Hz

ad P8_Hz2 = P8_Hz

ae T8_Hz2 < T8_Hz

af T8_Hz2 > T8_Hz

ag T8_Hz2 = T8_Hz

ah FC6_Hz2 < FC6_Hz

ai FC6_Hz2 > FC6_Hz

aj FC6_Hz2 = FC6_Hz

ak F4_Hz2 < F4_Hz

al F4_Hz2 > F4_Hz

am F4_Hz2 = F4_Hz

an F9_Hz2 < F9_Hz

ao F9_Hz2 > F9_Hz

ap F9_Hz2 = F9_Hz

aq AF4_Hz2 < AF4_Hz

ar AF4_Hz2 > AF4_Hz

as AF4_Hz2 = AF4_Hz

at Left2 < Left

au Left2 > Left

av Left2 = Left

aw Right2 < Right

ax Right2 > Right

ay Right2 = Right

az Front2 < Front

ba Front2 > Front

bb Front2 = Front

bc Back2 < Back

bd Back2 > Back

be Back2 = Back

bf Average2 < Average

bg Average2 > Average

bh Average2 = Average

Test Statistics

	Z	***p (two-tailed)***
IPQ	-1.298b	0.194
AF3	-.114c	0.91
F7	-.738b	0.46
F3	-1.420c	0.156
FC5	-.057c	0.955
T7	-1.022b	0.307
P7	-.568c	0.57
O1	-.568c	0.57
O2	-.227b	0.82
P8	-1.817c	0.069
T8	-1.193c	0.233

FC6	-1.022c	0.307
F4	-1.079c	0.281
F9	-1.874c	0.061
AF4	-1.647c	0.1
Left	-.057b	0.955
Right	-1.647c	0.1
Front	-.738c	0.46
Back	.000d	1
Average	-.625c	0.532

a Wilcoxon Signed Ranks Test

b Based on negative ranks.

c Based on positive ranks.

d The sum of negative ranks equals the sum of positive ranks.

Tables of Results for Two-Independent-Sample t-Test (N=35)

Two-Independent-Sample t-Test NPC-Researcher (N=23)

Group Statistics

	Treatment	N	Mean	Std. Deviation	Std. Error Mean
AF3	NPC	9	0.27095408	0.788710491	0.262903497
	Researcher	14	0.05939782	1.491394816	0.398592031
F7	NPC	9	0.06363367	0.549884747	0.183294916
	Researcher	14	0.03247025	1.14315755	0.305521707
F3	NPC	9	0.4124786	1.254814728	0.418271576
	Researcher	14	0.74639899	1.390236775	0.371556407
FC5	NPC	9	0.31203642	2.039945892	0.679981964
	Researcher	14	0.32727607	0.42405293	0.113332913
T7	NPC	9	0.17770833	1.262162749	0.420720916
	Researcher	14	-0.1812405	1.630884681	0.435872265
P7	NPC	9	0.48179522	1.71765386	0.572551287
	Researcher	14	0.29206412	1.533473961	0.409838155
O1	NPC	9	0.54626611	0.953590316	0.317863439
	Researcher	14	0.28281349	0.868750838	0.232183428
O2	NPC	9	-0.29418284	0.572426199	0.190808733
	Researcher	14	0.33878909	0.390190639	0.104282835
P8	NPC	9	-0.01788044	0.47295572	0.157651907
	Researcher	14	0.29402862	0.548154128	0.146500353
T8	NPC	9	-0.08765837	0.684342794	0.228114265
	Researcher	14	0.23216945	0.336446702	0.089919163
FC6	NPC	9	0.13058362	0.372467437	0.124155812
	Researcher	14	0.29160614	0.49178899	0.131436136
F4	NPC	9	0.26175523	0.656270981	0.218756994
	Researcher	14	0.61458448	0.950142021	0.253936137
F9	NPC	9	0.17605855	0.447796889	0.14926563
	Researcher	14	0.24580724	0.405546551	0.108386875
AF4	NPC	9	0.56530667	0.684129474	0.228043158
	Researcher	14	0.72406023	1.370427326	0.366262109
Left	NPC	9	0.3235532	0.875507727	0.291835909
	Researcher	14	0.22274003	0.847644645	0.226542561
Right	NPC	9	0.10485463	0.274454294	0.091484765
	Researcher	14	0.39157789	0.490090148	0.130982102

			-		
Front	NPC	9	0.02105844	0.92915557	0.309718523
	Researcher	14	0.0555041	1.113716233	0.297653184
Back	NPC	9	0.17899951	0.632495503	0.210831834
	Researcher	14	0.30192383	0.517958528	0.138430239
Average	NPC	9	0.21420392	0.491543256	0.163847752
	Researcher	14	0.30715896	0.628868073	0.168072062
IPQ Adj	NPC	9	46.22	6.438	2.146
	Researcher	14	45.64	9.035	2.415

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
		F	Sig.	t	df	Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						One-Sided p	Two-Sided p			Lower	Upper
AF3	Equal variances assumed	0.934	0.345	0.39	21	0.35	0.701	0.21156	0.54277	-0.91720	1.34031
	Equal variances not assumed			0.443	20.48	0.331	0.662	0.21156	0.47749	-0.78299	1.20610
F7	Equal variances assumed	0.263	0.613	0.076	21	0.47	0.94	0.03116	0.41073	-0.82299	0.88532
	Equal variances not assumed			0.087	19.86	0.466	0.931	0.03116	0.35629	-0.71237	0.77470
F3	Equal variances assumed	0.021	0.887	-0.583	21	0.283	0.566	-0.33392	0.57262	-1.52475	0.85691
	Equal variances not assumed			-0.597	18.51	0.279	0.558	-0.33392	0.55947	-1.50699	0.83915
FC5	Equal variances assumed	4.769	0.04	-0.027	21	0.489	0.978	-0.01524	0.55650	-1.17256	1.14208
	Equal variances not assumed			-0.022	8.447	0.491	0.983	-0.01524	0.68936	-1.59040	1.55992
T7	Equal variances assumed	0.02	0.888	0.56	21	0.291	0.582	0.35895	0.64136	-0.97482	1.69272
	Equal variances not assumed			0.593	20.12	0.28	0.56	0.35895	0.60580	-0.90423	1.62212
P7	Equal variances assumed	0.014	0.908	0.276	21	0.392	0.785	0.18973	0.68621	-1.23733	1.61679

	Equal variances not assumed			0.269	15.75	0.396	0.791	0.18973	0.70412	-1.30483	1.68430
O1	Equal variances assumed	0.154	0.698	0.684	21	0.251	0.502	0.26345	0.38538	-0.53799	1.06490
	Equal variances not assumed			0.669	16.01	0.256	0.513	0.26345	0.39363	-0.57097	1.09787
O2	Equal variances assumed	0.31	0.583	-3.165	21	0.002	0.005	-0.63297	0.19998	-1.04884	-0.21710
	Equal variances not assumed			-2.911	12.79	0.006	0.012	-0.63297	0.21745	-1.10352	-0.16242
P8	Equal variances assumed	0.001	0.978	-1.402	21	0.088	0.176	-0.31191	0.22251	-0.77463	0.15082
	Equal variances not assumed			-1.449	19.04	0.082	0.164	-0.31191	0.21521	-0.76228	0.13847
T8	Equal variances assumed	1.382	0.253	-1.502	21	0.074	0.148	-0.31983	0.21297	-0.76273	0.12308
	Equal variances not assumed			-1.304	10.52	0.11	0.22	-0.31983	0.24520	-0.86250	0.22285
FC6	Equal variances assumed	0.003	0.958	-0.837	21	0.206	0.412	-0.16102	0.19229	-0.56092	0.23888
	Equal variances not assumed			-0.891	20.29	0.192	0.384	-0.16102	0.18080	-0.53782	0.21578
F4	Equal variances assumed	2.666	0.117	-0.971	21	0.171	0.342	-0.35283	0.36327	-1.10829	0.40263
	Equal variances not assumed			-1.053	20.82	0.152	0.305	-0.35283	0.33517	-1.05022	0.34456
F9	Equal variances assumed	0.042	0.84	-0.387	21	0.351	0.703	-0.06975	0.18036	-0.44482	0.30533
	Equal variances not assumed			-0.378	15.93	0.355	0.71	-0.06975	0.18447	-0.46093	0.32143
AF4	Equal variances assumed	2.189	0.154	-0.321	21	0.376	0.751	-0.15875	0.49474	-1.18763	0.87012
	Equal variances not assumed			-0.368	20.12	0.358	0.717	-0.15875	0.43145	-1.05841	0.74090
Left	Equal variances assumed	0.002	0.965	0.275	21	0.393	0.786	0.10081	0.36673	-0.66185	0.86348
	Equal variances not assumed			0.273	16.79	0.394	0.788	0.10081	0.36945	-0.67938	0.88100
Right	Equal variances assumed	2.545	0.126	-1.593	21	0.063	0.126	-0.28672	0.17994	-0.66094	0.08749
	Equal variances not assumed			-1.795	20.75	0.044	0.087	-0.28672	0.15977	-0.61922	0.04577

Front	Equal variances assumed	0	0.995	-0.171	21	0.433	0.866	-0.07656	0.44743	-1.00705	0.85393
	Equal variances not assumed			-0.178	19.41	0.43	0.86	-0.07656	0.42956	-0.97436	0.82123
Back	Equal variances assumed	0.013	0.91	-0.51	21	0.308	0.615	-0.12292	0.24111	-0.62434	0.37850
	Equal variances not assumed			-0.487	14.7	0.317	0.633	-0.12292	0.25222	-0.66146	0.41561
Average	Equal variances assumed	0.831	0.372	-0.375	21	0.356	0.712	-0.09296	0.24797	-0.60864	0.42273
	Equal variances not assumed			-0.396	20.04	0.348	0.696	-0.09296	0.23472	-0.58251	0.39660
IPQ	Equal variances assumed	1.208	0.284	0.167	21	0.435	0.869	0.57900	3.47900	-6.65700	7.81500
	Equal variances not assumed			0.179	20.68	0.43	0.859	0.57900	3.23000	-6.14500	7.30400

Independent Samples Effect Sizes

		Standardizera	Point Estimate	95% Confidence Interval	
				Lower	Upper
AF3	Cohen's d	1.27039316	0.167	-0.674	1.003
	Hedges' correction	1.318132967	0.16	-0.65	0.967
	Glass's delta	1.491394816	0.142	-0.7	0.978
F7	Cohen's d	0.961336007	0.032	-0.805	0.869
	Hedges' correction	0.997461828	0.031	-0.776	0.838
	Glass's delta	1.14315755	0.027	-0.811	0.864
F3	Cohen's d	1.34026184	-0.249	-1.087	0.595
	Hedges' correction	1.390627226	-0.24	-1.048	0.573
	Glass's delta	1.390236775	-0.24	-1.078	0.607
FC5	Cohen's d	1.302537916	-0.012	-0.849	0.826
	Hedges' correction	1.351485684	-0.011	-0.818	0.796
	Glass's delta	0.42405293	-0.036	-0.873	0.802
T7	Cohen's d	1.501136734	0.239	-0.604	1.077
	Hedges' correction	1.5575476	0.23	-0.582	1.038
	Glass's delta	1.630884681	0.22	-0.626	1.058
P7	Cohen's d	1.606130062	0.118	-0.721	0.955

	Hedges' correction	1.666486448	0.114	-0.695	0.92
	Glass's delta	1.533473961	0.124	-0.717	0.96
O1	Cohen's d	0.902012041	0.292	-0.553	1.131
	Hedges' correction	0.935908541	0.281	-0.533	1.09
	Glass's delta	0.868750838	0.303	-0.548	1.143
O2	Cohen's d	0.468056141	-1.352	-2.27	-0.408
	Hedges' correction	0.485645114	-1.303	-2.188	-0.394
	Glass's delta	0.390190639	-1.622	-2.642	-0.562
P8	Cohen's d	0.520789018	-0.599	-1.449	0.264
	Hedges' correction	0.540359627	-0.577	-1.396	0.255
	Glass's delta	0.548154128	-0.569	-1.424	0.306
T8	Cohen's d	0.498481192	-0.642	-1.494	0.225
	Hedges' correction	0.5172135	-0.618	-1.44	0.217
	Glass's delta	0.336446702	-0.951	-1.848	-0.023
FC6	Cohen's d	0.450078791	-0.358	-1.198	0.491
	Hedges' correction	0.466992196	-0.345	-1.154	0.473
	Glass's delta	0.49178899	-0.327	-1.168	0.525
F4	Cohen's d	0.850253212	-0.415	-1.257	0.436
	Hedges' correction	0.882204678	-0.4	-1.211	0.421
	Glass's delta	0.950142021	-0.371	-1.214	0.485
F9	Cohen's d	0.42214083	-0.165	-1.002	0.676
	Hedges' correction	0.438004362	-0.159	-0.966	0.651
	Glass's delta	0.405546551	-0.172	-1.009	0.671
AF4	Cohen's d	1.157978304	-0.137	-0.974	0.703
	Hedges' correction	1.2014937	-0.132	-0.939	0.677
	Glass's delta	1.370427326	-0.116	-0.952	0.725
Left	Cohen's d	0.858365807	0.117	-0.722	0.954
	Hedges' correction	0.890622134	0.113	-0.696	0.92
	Glass's delta	0.847644645	0.119	-0.722	0.955
Right	Cohen's d	0.421169001	-0.681	-1.535	0.189
	Hedges' correction	0.436996012	-0.656	-1.48	0.182
	Glass's delta	0.490090148	-0.585	-1.441	0.292

Front	Cohen's d	1.0472497	-0.073	-0.91	0.765
	Hedges' correction	1.086604051	-0.07	-0.877	0.738
	Glass's delta	1.113716233	-0.069	-0.905	0.77
Back	Cohen's d	0.564339393	-0.218	-1.055	0.625
	Hedges' correction	0.585546571	-0.21	-1.017	0.602
	Glass's delta	0.517958528	-0.237	-1.075	0.609
Average	Cohen's d	0.580397806	-0.16	-0.997	0.681
	Hedges' correction	0.602208439	-0.154	-0.961	0.656
	Glass's delta	0.628868073	-0.148	-0.984	0.694
IPQ	Cohen's d	8.144	0.071	-0.767	0.908
	Hedges' correction	8.45	0.069	-0.74	0.875
	Glass's delta	9.035	0.064	-0.775	0.901

a The denominator used in estimating the effect sizes.

Cohen's d uses the pooled standard deviation.

Hedges' correction uses the pooled standard deviation, plus a correction factor.

Glass's delta uses the sample standard deviation of the control group.

Two-Independent-Sample t-Test NPC-Posttest (N=21)

Group Statistics

	Treatment	N	Mean	Std. Deviation	Std. Error Mean
AF3	NPC	9	0.27095408	0.788710491	0.262903497
	Post	12	0.5050672	1.087829797	0.314029413
F7	NPC	9	0.06363367	0.549884747	0.183294916
	Post	12	0.65008576	0.871828886	0.251675321
F3	NPC	9	0.4124786	1.254814728	0.418271576
	Post	12	0.46904762	0.986747915	0.284849587
FC5	NPC	9	0.31203642	2.039945892	0.679981964
	Post	12	0.51363183	0.834291649	0.240839254
T7	NPC	9	0.17770833	1.262162749	0.420720916
	Post	12	0.49211631	0.936249814	0.270272041
P7	NPC	9	0.48179522	1.71765386	0.572551287
	Post	12	-0.02016935	1.373936432	0.396621284
O1	NPC	9	0.54626611	0.953590316	0.317863439
	Post	12	0.64386452	1.429696504	0.412717831
O2	NPC	9	-0.29418284	0.572426199	0.190808733
	Post	12	0.26301328	0.329150633	0.095017603
P8	NPC	9	-0.01788044	0.47295572	0.157651907
	Post	12	0.19451717	0.391218226	0.112934974
T8	NPC	9	-0.08765837	0.684342794	0.228114265
	Post	12	0.18019726	0.39781867	0.114840358
FC6	NPC	9	0.13058362	0.372467437	0.124155812
	Post	12	0.24429715	0.360806777	0.104155945
F4	NPC	9	0.26175523	0.656270981	0.218756994
	Post	12	0.45695221	0.86372118	0.249334828
F9	NPC	9	0.17605855	0.447796889	0.14926563
	Post	12	0.27425972	0.480912693	0.138827536
AF4	NPC	9	0.56530667	0.684129474	0.228043158
	Post	12	0.32279212	1.3184604	0.380606733
Left	NPC	9	0.3235532	0.875507727	0.291835909
	Post	12	0.46480627	0.835801831	0.241275206
Right	NPC	9	0.10485463	0.274454294	0.091484765
	Post	12	0.27657556	0.5395933	0.155767168
Front	NPC	9	-0.02105844	0.92915557	0.309718523

	Post	12	0.25738983	0.77832688	0.224683617
Back	NPC	9	0.17899951	0.632495503	0.210831834
	Post	12	0.27030641	0.691471254	0.199610557
Average	NPC	9	0.21420392	0.491543256	0.163847752
	Post	12	0.37069091	0.666228454	0.192323589
IPQ	NPC	9	46.22	6.438	2.146
	Post	12	43.83	8.473	2.446

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
		F	Sig.	t	df	Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						One-Sided p	Two-Sided p			Lower	Upper
AF3	Equal variances assumed	0.07	0.794	-0.546	19	0.296	0.592	-0.2341	0.4291	-1.1323	0.6640
	Equal variances not assumed			-0.572	18.99	0.287	0.574	-0.2341	0.4096	-1.0913	0.6231
F7	Equal variances assumed	2.921	0.104	-1.766	19	0.047	0.094	-0.5865	0.3321	-1.2816	0.1087
	Equal variances not assumed			-1.884	18.58	0.038	0.075	-0.5865	0.3113	-1.2391	0.0662
F3	Equal variances assumed	0.363	0.554	-0.116	19	0.455	0.909	-0.0566	0.4884	-1.0788	0.9656
	Equal variances not assumed			-0.112	14.82	0.456	0.912	-0.0566	0.5061	-1.1363	1.0232
FC5	Equal variances assumed	1.661	0.213	-0.311	19	0.379	0.759	-0.2016	0.6473	-1.5565	1.1533
	Equal variances not assumed			-0.279	10.02	0.393	0.786	-0.2016	0.7214	-1.8085	1.4053
T7	Equal variances assumed	0.364	0.554	-0.657	19	0.26	0.519	-0.3144	0.4786	-1.3162	0.6874
	Equal variances not assumed			-0.629	14.21	0.27	0.539	-0.3144	0.5001	-1.3855	0.7566
P7	Equal variances assumed	0.149	0.703	0.745	19	0.233	0.465	0.5020	0.6738	-0.9084	1.9123
	Equal variances not assumed			0.721	15.01	0.241	0.482	0.5020	0.6965	-0.9825	1.9865
O1	Equal variances assumed	0.964	0.338	-0.177	19	0.431	0.861	-0.0976	0.5519	-1.2527	1.0575

	Equal variances not assumed			-0.187	18.82	0.427	0.853	-0.0976	0.5209	-1.1886	0.9935
O2	Equal variances assumed	1.366	0.257	-2.821	19	0.005	0.011	-0.5572	0.1975	-0.9707	-0.1437
	Equal variances not assumed			-2.614	11.93	0.011	0.023	-0.5572	0.2132	-1.0219	-0.0924
P8	Equal variances assumed	0.206	0.655	-1.127	19	0.137	0.274	-0.2124	0.1885	-0.6070	0.1822
	Equal variances not assumed			-1.095	15.37	0.145	0.29	-0.2124	0.1939	-0.6249	0.2001
T8	Equal variances assumed	0.97	0.337	-1.13	19	0.136	0.272	-0.2679	0.2370	-0.7639	0.2281
	Equal variances not assumed			-1.049	12.01	0.157	0.315	-0.2679	0.2554	-0.8243	0.2886
FC6	Equal variances assumed	0.173	0.682	-0.705	19	0.245	0.489	-0.1137	0.1613	-0.4513	0.2239
	Equal variances not assumed			-0.702	17.07	0.246	0.492	-0.1137	0.1621	-0.4555	0.2281
F4	Equal variances assumed	0.233	0.635	-0.565	19	0.289	0.579	-0.1952	0.3453	-0.9179	0.5276
	Equal variances not assumed			-0.588	18.99	0.282	0.563	-0.1952	0.3317	-0.8895	0.4991
F9	Equal variances assumed	0.013	0.91	-0.477	19	0.32	0.639	-0.0982	0.2060	-0.5294	0.3330
	Equal variances not assumed			-0.482	18.02	0.318	0.636	-0.0982	0.2038	-0.5264	0.3300
AF4	Equal variances assumed	0.267	0.611	0.501	19	0.311	0.622	0.2425	0.4837	-0.7700	1.2550
	Equal variances not assumed			0.547	17.26	0.296	0.592	0.2425	0.4437	-0.6925	1.1776
Left	Equal variances assumed	0.007	0.934	-0.376	19	0.356	0.711	-0.1413	0.3760	-0.9283	0.6458
	Equal variances not assumed			-0.373	16.92	0.357	0.714	-0.1413	0.3787	-0.9404	0.6579
Right	Equal variances assumed	0.458	0.507	-0.87	19	0.198	0.395	-0.1717	0.1973	-0.5848	0.2413
	Equal variances not assumed			-0.951	17.1	0.178	0.355	-0.1717	0.1806	-0.5527	0.2092
Front	Equal variances assumed	0.784	0.387	-0.747	19	0.232	0.464	-0.2784	0.3727	-1.0584	0.5015
	Equal variances not assumed			-0.728	15.51	0.239	0.478	-0.2784	0.3826	-1.0917	0.5348

Back	Equal variances assumed	0.023	0.881	-0.31	19	0.38	0.76	-0.0913	0.2942	-0.7072	0.5245
	Equal variances not assumed			-0.314	18.16	0.378	0.757	-0.0913	0.2903	-0.7009	0.5183
Average	Equal variances assumed	0.073	0.789	-0.593	19	0.28	0.56	-0.1565	0.2641	-0.7093	0.3963
	Equal variances not assumed			-0.619	19	0.272	0.543	-0.1565	0.2527	-0.6853	0.3723
IPQ	Equal variances assumed	0.538	0.472	0.705	19	0.245	0.489	2.389	3.387	-4.701	9.479
	Equal variances not assumed			0.734	18.99	0.236	0.472	2.389	3.254	-4.422	9.2

Independent Samples Effect Sizes

		Standardizera	Point Estimate	95% Confidence Interval	
				Lower	Upper
AF3	Cohen's d	0.97315613	-0.241	-1.105	0.63
	Hedges' correction	1.01379897	-0.231	-1.061	0.605
	Glass's delta	1.0878298	-0.215	-1.079	0.658
F7	Cohen's d	0.75323609	-0.779	-1.668	0.129
	Hedges' correction	0.7846942	-0.747	-1.601	0.124
	Glass's delta	0.87182889	-0.673	-1.567	0.249
F3	Cohen's d	1.10755458	-0.051	-0.915	0.814
	Hedges' correction	1.15381044	-0.049	-0.878	0.781
	Glass's delta	0.98674792	-0.057	-0.921	0.809
FC5	Cohen's d	1.46803668	-0.137	-1.001	0.73
	Hedges' correction	1.52934769	-0.132	-0.961	0.701
	Glass's delta	0.83429165	-0.242	-1.106	0.634
T7	Cohen's d	1.08546956	-0.29	-1.155	0.583
	Hedges' correction	1.13080306	-0.278	-1.109	0.56
	Glass's delta	0.93624981	-0.336	-1.204	0.547
P7	Cohen's d	1.52811189	0.328	-0.546	1.195
	Hedges' correction	1.59193187	0.315	-0.524	1.147
	Glass's delta	1.37393643	0.365	-0.52	1.235
O1	Cohen's d	1.25150497	-0.078	-0.942	0.788
	Hedges' correction	1.30377276	-0.075	-0.904	0.756
	Glass's delta	1.4296965	-0.068	-0.931	0.798
O2	Cohen's d	0.4479847	-1.244	-2.18	-0.281
	Hedges' correction	0.46669431	-1.194	-2.092	-0.27
	Glass's delta	0.32915063	-1.693	-2.781	-0.559
P8	Cohen's d	0.42754289	-0.497	-1.369	0.388

	Hedges' correction	0.44539877	-0.477	-1.314	0.372
	Glass's delta	0.39121823	-0.543	-1.424	0.361
T8	Cohen's d	0.53741374	-0.498	-1.371	0.386
	Hedges' correction	0.55985826	-0.478	-1.316	0.371
	Glass's delta	0.39781867	-0.673	-1.567	0.248
FC6	Cohen's d	0.36576184	-0.311	-1.177	0.563
	Hedges' correction	0.3810375	-0.298	-1.13	0.54
	Glass's delta	0.36080678	-0.315	-1.182	0.566
F4	Cohen's d	0.78310078	-0.249	-1.114	0.622
	Hedges' correction	0.81580616	-0.239	-1.069	0.597
	Glass's delta	0.86372118	-0.226	-1.09	0.648
F9	Cohen's d	0.46725535	-0.21	-1.074	0.659
	Hedges' correction	0.48676978	-0.202	-1.031	0.633
	Glass's delta	0.48091269	-0.204	-1.068	0.669
AF4	Cohen's d	1.09702903	0.221	-0.649	1.085
	Hedges' correction	1.1428453	0.212	-0.623	1.042
	Glass's delta	1.3184604	0.184	-0.688	1.047
Left	Cohen's d	0.85274547	-0.166	-1.029	0.702
	Hedges' correction	0.88835949	-0.159	-0.988	0.674
	Glass's delta	0.83580183	-0.169	-1.032	0.702
Right	Cohen's d	0.44752956	-0.384	-1.252	0.494
	Hedges' correction	0.46622017	-0.368	-1.201	0.474
	Glass's delta	0.5395933	-0.318	-1.185	0.563
Front	Cohen's d	0.845121	-0.329	-1.196	0.545
	Hedges' correction	0.88041659	-0.316	-1.148	0.523
	Glass's delta	0.77832688	-0.358	-1.227	0.527
Back	Cohen's d	0.66727497	-0.137	-1	0.73
	Hedges' correction	0.69514301	-0.131	-0.96	0.701
	Glass's delta	0.69147125	-0.132	-0.995	0.737
Average	Cohen's d	0.59891929	-0.261	-1.126	0.61
	Hedges' correction	0.62393253	-0.251	-1.081	0.586
	Glass's delta	0.66622845	-0.235	-1.099	0.64
IPQ	Cohen's d	7.682	0.311	-0.563	1.177
	Hedges' correction	8.003	0.299	-0.54	1.13
	Glass's delta	8.473	0.282	-0.596	1.148

a The denominator used in estimating the effect sizes.

Cohen's d uses the pooled standard deviation.

Hedges' correction uses the pooled standard deviation, plus a correction factor.

Glass's delta uses the sample standard deviation of the control group.

Two-Independent-Sample t-Test Researcher-Posttest (N=26)

Group Statistics

	Treatment	N	Mean	Std. Deviation	Std. Error Mean
AF3	Researcher	14	0.05939782	1.49139482	0.39859203
	Post	12	0.5050672	1.0878298	0.31402941
F7	Researcher	14	0.03247025	1.14315755	0.30552171
	Post	12	0.65008576	0.87182889	0.25167532
F3	Researcher	14	0.74639899	1.39023678	0.37155641
	Post	12	0.46904762	0.98674792	0.28484959
FC5	Researcher	14	0.32727607	0.42405293	0.11333291
	Post	12	0.51363183	0.83429165	0.24083925
T7	Researcher	14	-0.1812405	1.63088468	0.43587227
	Post	12	0.49211631	0.93624981	0.27027204
P7	Researcher	14	0.29206412	1.53347396	0.40983816
	Post	12	-0.02016935	1.37393643	0.39662128
O1	Researcher	14	0.28281349	0.86875084	0.23218343
	Post	12	0.64386452	1.4296965	0.41271783
O2	Researcher	14	0.33878909	0.39019064	0.10428283
	Post	12	0.26301328	0.32915063	0.0950176
P8	Researcher	14	0.29402862	0.54815413	0.14650035
	Post	12	0.19451717	0.39121823	0.11293497

T8	Researcher	14	0.23216945	0.3364467	0.08991916
	Post	12	0.18019726	0.39781867	0.11484036
FC6	Researcher	14	0.29160614	0.49178899	0.13143614
	Post	12	0.24429715	0.36080678	0.10415594
F4	Researcher	14	0.61458448	0.95014202	0.25393614
	Post	12	0.45695221	0.86372118	0.24933483
F9	Researcher	14	0.24580724	0.40554655	0.10838687
	Post	12	0.27425972	0.48091269	0.13882754
AF4	Researcher	14	0.72406023	1.37042733	0.36626211
	Post	12	0.32279212	1.3184604	0.38060673
Left	Researcher	14	0.22274003	0.84764465	0.22654256
	Post	12	0.46480627	0.83580183	0.24127521
Right	Researcher	14	0.39157789	0.49009015	0.1309821
	Post	12	0.27657556	0.5395933	0.15576717
Front	Researcher	14	0.0555041	1.11371623	0.29765318
	Post	12	0.25738983	0.77832688	0.22468362
Back	Researcher	14	0.30192383	0.51795853	0.13843024
	Post	12	0.27030641	0.69147125	0.19961056
Average	Researcher	14	0.30715896	0.62886807	0.16807206
	Post	12	0.37069091	0.66622845	0.19232359

IP Q	Researcher	14	45.64	9.035	2.415
	Post	12	43.83	8.473	2.446

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
		F	Sig.	t	df	Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						One-Sided p	Two-Sided p			Lower	Upper
AF3	Equal variances assumed	0.581	0.453	-0.857	24	0.2	0.4	-0.4457	0.5200	-1.5189	0.6276
	Equal variances not assumed			-0.878	23.463	0.194	0.389	-0.4457	0.5074	-1.4942	0.6029
F7	Equal variances assumed	0.25	0.622	-1.528	24	0.07	0.14	-0.6176	0.4043	-1.4521	0.2168
	Equal variances not assumed			-1.56	23.721	0.066	0.132	-0.6176	0.3958	-1.4351	0.1999
F3	Equal variances assumed	0.589	0.45	0.577	24	0.285	0.569	0.2774	0.4807	-0.7148	1.2695
	Equal variances not assumed			0.592	23.271	0.28	0.559	0.2774	0.4682	-0.6905	1.2452
FC5	Equal variances assumed	3.214	0.086	-0.734	24	0.235	0.47	-0.1864	0.2539	-0.7103	0.3376
	Equal variances not assumed			-0.7	15.757	0.247	0.494	-0.1864	0.2662	-0.7513	0.3786

T7	Equal variances assumed	0.073	0.789	-1.261	24	0.11	0.219	-0.6734	0.5340	-1.7755	0.4287
	Equal variances not assumed			-1.313	21.212	0.102	0.203	-0.6734	0.5129	-1.7393	0.3926
P7	Equal variances assumed	0.102	0.752	0.543	24	0.296	0.592	0.3122	0.5754	-0.8752	1.4997
	Equal variances not assumed			0.547	23.938	0.295	0.589	0.3122	0.5703	-0.8650	1.4895
O1	Equal variances assumed	2.199	0.151	-0.791	24	0.218	0.437	-0.3611	0.4564	-1.3029	0.5808
	Equal variances not assumed			-0.762	17.575	0.228	0.456	-0.3611	0.4735	-1.3577	0.6356
O2	Equal variances assumed	1.137	0.297	0.53	24	0.301	0.601	0.0758	0.1430	-0.2194	0.3709
	Equal variances not assumed			0.537	23.998	0.298	0.596	0.0758	0.1411	-0.2154	0.3669
P8	Equal variances assumed	0.206	0.654	0.524	24	0.302	0.605	0.0995	0.1899	-0.2923	0.4914
	Equal variances not assumed			0.538	23.312	0.298	0.596	0.0995	0.1850	-0.2829	0.4819
T8	Equal variances assumed	0.004	0.951	0.361	24	0.361	0.721	0.0520	0.1439	-0.2451	0.3490
	Equal variances not assumed			0.356	21.716	0.363	0.725	0.0520	0.1459	-0.2507	0.3547
FC6	Equal variances assumed	0.158	0.695	0.275	24	0.393	0.785	0.0473	0.1718	-0.3072	0.4018
	Equal variances not assumed			0.282	23.501	0.39	0.78	0.0473	0.1677	-0.2992	0.3938

F4	Equal variances assumed	0.958	0.337	0.44	24	0.332	0.664	0.1576	0.3586	-0.5825	0.8978
	Equal variances not assumed			0.443	23.898	0.331	0.662	0.1576	0.3559	-0.5770	0.8923
F9	Equal variances assumed	0.119	0.733	-0.164	24	0.436	0.871	-0.0285	0.1738	-0.3871	0.3302
	Equal variances not assumed			-0.162	21.681	0.437	0.873	-0.0285	0.1761	-0.3940	0.3371
AF4	Equal variances assumed	0.505	0.484	0.757	24	0.228	0.456	0.4013	0.5299	-0.6923	1.4948
	Equal variances not assumed			0.76	23.647	0.227	0.455	0.4013	0.5282	-0.6898	1.4923
Left	Equal variances assumed	0.021	0.886	-0.731	24	0.236	0.472	-0.2421	0.3313	-0.9259	0.4418
	Equal variances not assumed			-0.731	23.494	0.236	0.472	-0.2421	0.3310	-0.9259	0.4418
Right	Equal variances assumed	0.202	0.657	0.569	24	0.287	0.574	0.1150	0.2020	-0.3018	0.5318
	Equal variances not assumed			0.565	22.526	0.289	0.578	0.1150	0.2035	-0.3065	0.5365
Front	Equal variances assumed	0.619	0.439	-0.527	24	0.302	0.603	-0.2019	0.3833	-0.9931	0.5893
	Equal variances not assumed			-0.541	23.152	0.297	0.593	-0.2019	0.3729	-0.9731	0.5693
Back	Equal variances assumed	0.096	0.759	0.133	24	0.448	0.895	0.0316	0.2375	-0.4586	0.5218
	Equal variances not assumed			0.13	20.176	0.449	0.898	0.0316	0.2429	-0.4748	0.5380

Average	Equal variances assumed	0.263	0.613	-0.25	24	0.402	0.805	-0.0635	0.2542	-0.5883	0.4612
	Equal variances not assumed			-0.249	22.911	0.403	0.806	-0.0635	0.2554	-0.5920	0.4649
IPQ	Equal variances assumed	0.12	0.732	0.524	24	0.303	0.605	1.81	3.455	-5.321	8.94
	Equal variances not assumed			0.526	23.779	0.302	0.603	1.81	3.437	-5.288	8.907

Independent Samples Effect Sizes

		Standardizera	Point Estimate	95% Confidence Interval Lower	Upper
AF3	Cohen's d	1.32181174	-0.337	-1.111	0.443
	Hedges' correction	1.36499298	-0.326	-1.075	0.429
	Glass's delta	1.0878298	-0.41	-1.19	0.388
F7	Cohen's d	1.02772932	-0.601	-1.384	0.194
	Hedges' correction	1.0613034	-0.582	-1.341	0.188
	Glass's delta	0.87182889	-0.708	-1.519	0.13
F3	Cohen's d	1.22195615	0.227	-0.549	0.998
	Hedges' correction	1.26187528	0.22	-0.532	0.967
	Glass's delta	0.98674792	0.281	-0.505	1.055
FC5	Cohen's d	0.64530805	-0.289	-1.061	0.489
	Hedges' correction	0.66638912	-0.28	-1.028	0.474
	Glass's delta	0.83429165	-0.223	-0.995	0.558
T7	Cohen's d	1.35737805	-0.496	-1.275	0.292
	Hedges' correction	1.40172117	-0.48	-1.234	0.283
	Glass's delta	0.93624981	-0.719	-1.531	0.121
P7	Cohen's d	1.46251447	0.213	-0.562	0.985
	Hedges' correction	1.51029221	0.207	-0.544	0.954
	Glass's delta	1.37393643	0.227	-0.555	0.999
O1	Cohen's d	1.16002545	-0.311	-1.084	0.468
	Hedges' correction	1.19792142	-0.301	-1.05	0.453
	Glass's delta	1.4296965	-0.253	-1.025	0.531
O2	Cohen's d	0.3634886	0.208	-0.567	0.98
	Hedges' correction	0.37536312	0.202	-0.549	0.949
	Glass's delta	0.32915063	0.23	-0.552	1.002
P8	Cohen's d	0.48260219	0.206	-0.569	0.977

	Hedges' correction	0.49836795	0.2	-0.551	0.946
	Glass's delta	0.39121823	0.254	-0.529	1.027
T8	Cohen's d	0.36585571	0.142	-0.631	0.913
	Hedges' correction	0.37780756	0.138	-0.612	0.884
	Glass's delta	0.39781867	0.131	-0.645	0.901
FC6	Cohen's d	0.43666015	0.108	-0.664	0.879
	Hedges' correction	0.45092506	0.105	-0.643	0.851
	Glass's delta	0.36080678	0.131	-0.645	0.901
F4	Cohen's d	0.91155008	0.173	-0.601	0.944
	Hedges' correction	0.9413288	0.167	-0.582	0.914
	Glass's delta	0.86372118	0.183	-0.596	0.953
F9	Cohen's d	0.44168858	-0.064	-0.835	0.708
	Hedges' correction	0.45611776	-0.062	-0.809	0.685
	Glass's delta	0.48091269	-0.059	-0.829	0.714
AF4	Cohen's d	1.34685807	0.298	-0.481	1.07
	Hedges' correction	1.39085752	0.289	-0.466	1.037
	Glass's delta	1.3184604	0.304	-0.484	1.079
Left	Cohen's d	0.84223736	-0.287	-1.06	0.491
	Hedges' correction	0.86975175	-0.278	-1.026	0.475
	Glass's delta	0.83580183	-0.29	-1.064	0.497
Right	Cohen's d	0.51337197	0.224	-0.552	0.995
	Hedges' correction	0.53014292	0.217	-0.534	0.964
	Glass's delta	0.5395933	0.213	-0.568	0.984
Front	Cohen's d	0.97443253	-0.207	-0.978	0.568
	Hedges' correction	1.0062655	-0.201	-0.947	0.55
	Glass's delta	0.77832688	-0.259	-1.032	0.525
Back	Cohen's d	0.60370767	0.052	-0.719	0.823
	Hedges' correction	0.62342973	0.051	-0.697	0.797
	Glass's delta	0.69147125	0.046	-0.727	0.816
Average	Cohen's d	0.64625974	-0.098	-0.869	0.674
	Hedges' correction	0.66737189	-0.095	-0.841	0.653
	Glass's delta	0.66622845	-0.095	-0.865	0.679
IPQ	Cohen's d	8.782	0.206	-0.569	0.977
	Hedges' correction	9.069	0.2	-0.551	0.946
	Glass's delta	8.473	0.214	-0.567	0.985

a The denominator used in estimating the effect sizes.

Cohen's d uses the pooled standard deviation.

Hedges' correction uses the pooled standard deviation, plus a correction factor.

Glass's delta uses the sample standard deviation of the control group.

Tables of Results for One Way Within Subjects ANOVA (N=35)

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
IPQ	NPC	9	46.22	6.438	2.146	41.27	51.17	34	53
	Researcher	14	45.64	9.035	2.415	40.43	50.86	26	60
	Post	12	43.83	8.473	2.446	38.45	49.22	29	57
	Total	35	45.17	8.075	1.365	42.4	47.95	26	60
AF3	NPC	9	0.2710	0.7887	0.2629	-0.3353	0.8772	-1.3167	1.2978
	Researcher	14	0.0594	1.4914	0.3986	-0.8017	0.9205	-2.9754	2.9207
	Post	12	0.5051	1.0878	0.3140	-0.1861	1.1962	-0.4430	3.7730
	Total	35	0.2666	1.1906	0.2012	-0.1424	0.6756	-2.9754	3.7730
F7	NPC	9	0.0636	0.5499	0.1833	-0.3590	0.4863	-1.2411	0.7159
	Researcher	14	0.0325	1.1432	0.3055	-0.6276	0.6925	-3.6807	1.5203
	Post	12	0.6501	0.8718	0.2517	0.0962	1.2040	-0.1833	2.3262
	Total	35	0.2522	0.9497	0.1605	-0.0740	0.5785	-3.6807	2.3262
F3	NPC	9	0.4125	1.2548	0.4183	-0.5521	1.3770	-1.8180	2.6267
	Researcher	14	0.7464	1.3902	0.3716	-0.0563	1.5491	0.0102	5.1712
	Post	12	0.4690	0.9867	0.2848	-0.1579	1.0960	-0.4127	3.3665
	Total	35	0.5654	1.2031	0.2034	0.1522	0.9787	-1.8180	5.1712
FC5	NPC	9	0.3120	2.0399	0.6800	-1.2560	1.8801	-4.2638	3.3520
	Researcher	14	0.3273	0.4241	0.1133	0.0824	0.5721	0.0136	1.4059
	Post	12	0.5136	0.8343	0.2408	-0.0165	1.0437	-0.0817	2.5534
	Total	35	0.3873	1.1321	0.1914	-0.0016	0.7761	-4.2638	3.3520
T7	NPC	9	0.1777	1.2622	0.4207	-0.7925	1.1479	-2.1636	2.2879
	Researcher	14	-0.1812	1.6309	0.4359	-1.1229	0.7604	-5.7679	0.9503
	Post	12	0.4921	0.9362	0.2703	-0.1027	1.0870	-0.9091	2.4347
	Total	35	0.1419	1.3274	0.2244	-0.3141	0.5979	-5.7679	2.4347
P7	NPC	9	0.4818	1.7177	0.5726	-0.8385	1.8021	-3.4599	2.9626
	Researcher	14	0.2921	1.5335	0.4098	-0.5933	1.1775	-4.1161	2.3139
	Post	12	-0.0202	1.3739	0.3966	-0.8931	0.8528	-3.3065	2.6649
	Total	35	0.2338	1.4982	0.2532	-0.2808	0.7484	-4.1161	2.9626
O1	NPC	9	0.5463	0.9536	0.3179	-0.1867	1.2793	-0.7675	2.4159
	Researcher	14	0.2828	0.8688	0.2322	-0.2188	0.7844	-1.3768	1.8452
	Post	12	0.6439	1.4297	0.4127	-0.2645	1.5523	-2.2014	3.4057
	Total	35	0.4743	1.0911	0.1844	0.0995	0.8491	-2.2014	3.4057
O2	NPC	9	-0.2942	0.5724	0.1908	-0.7342	0.1458	-1.6419	0.2119
	Researcher	14	0.3388	0.3902	0.1043	0.1135	0.5641	-0.0316	1.0554
	Post	12	0.2630	0.3292	0.0950	0.0539	0.4721	-0.2017	1.0873
	Total	35	0.1500	0.4917	0.0831	-0.0189	0.3190	-1.6419	1.0873
P8	NPC	9	-0.0179	0.4730	0.1577	-0.3814	0.3457	-1.1754	0.4094
	Researcher	14	0.2940	0.5482	0.1465	-0.0225	0.6105	-0.2847	2.0791

	Post	12	0.1945	0.3912	0.1129	-0.0541	0.4431	-0.2490	1.2972
	Total	35	0.1797	0.4825	0.0816	0.0140	0.3455	-1.1754	2.0791
T8	NPC	9	-0.0877	0.6843	0.2281	-0.6137	0.4384	-1.8296	0.4456
	Researcher	14	0.2322	0.3364	0.0899	0.0379	0.4264	-0.1264	1.1526
	Post	12	0.1802	0.3978	0.1148	-0.0726	0.4330	-0.2804	1.2808
	Total	35	0.1321	0.4716	0.0797	-0.0299	0.2941	-1.8296	1.2808
FC6	NPC	9	0.1306	0.3725	0.1242	-0.1557	0.4169	-0.2296	0.9282
	Researcher	14	0.2916	0.4918	0.1314	0.0077	0.5756	-0.0510	1.8822
	Post	12	0.2443	0.3608	0.1042	0.0151	0.4735	-0.1510	1.2105
	Total	35	0.2340	0.4141	0.0700	0.0917	0.3762	-0.2296	1.8822
F4	NPC	9	0.2618	0.6563	0.2188	-0.2427	0.7662	-0.2765	1.8923
	Researcher	14	0.6146	0.9501	0.2539	0.0660	1.1632	-0.1124	2.4710
	Post	12	0.4570	0.8637	0.2493	-0.0918	1.0057	-0.0965	3.0029
	Total	35	0.4698	0.8414	0.1422	0.1808	0.7589	-0.2765	3.0029
F9	NPC	9	0.1761	0.4478	0.1493	-0.1681	0.5203	-0.4452	1.1652
	Researcher	14	0.2458	0.4055	0.1084	0.0117	0.4800	-0.4384	1.3224
	Post	12	0.2743	0.4809	0.1388	-0.0313	0.5798	-0.2382	1.5827
	Total	35	0.2376	0.4317	0.0730	0.0893	0.3859	-0.4452	1.5827
AF4	NPC	9	0.5653	0.6841	0.2280	0.0394	1.0912	-0.0614	1.9264
	Researcher	14	0.7241	1.3704	0.3663	-0.0672	1.5153	-0.5313	4.5544
	Post	12	0.3228	1.3185	0.3806	-0.5149	1.1605	-2.4190	3.5631
	Total	35	0.5457	1.1922	0.2015	0.1361	0.9552	-2.4190	4.5544
Left	NPC	9	0.3236	0.8755	0.2918	-0.3494	0.9965	-1.8643	1.0394
	Researcher	14	0.2227	0.8476	0.2265	-0.2667	0.7122	-1.9494	1.8202
	Post	12	0.4648	0.8358	0.2413	-0.0662	0.9958	-0.2699	2.9320
	Total	35	0.3317	0.8320	0.1406	0.0459	0.6175	-1.9494	2.9320
Right	NPC	9	0.1049	0.2745	0.0915	-0.1061	0.3158	-0.3221	0.5011
	Researcher	14	0.3916	0.4901	0.1310	0.1086	0.6745	-0.0514	1.7167
	Post	12	0.2766	0.5396	0.1558	-0.0663	0.6194	-0.1739	1.8606
	Total	35	0.2784	0.4658	0.0787	0.1184	0.4384	-0.3221	1.8606
Front	NPC	9	-0.0211	0.9292	0.3097	-0.7353	0.6932	-2.0572	0.7250
	Researcher	14	0.0555	1.1137	0.2977	-0.5875	0.6985	-3.0426	1.8746
	Post	12	0.2574	0.7783	0.2247	-0.2371	0.7519	-0.7008	2.5094
	Total	35	0.1050	0.9417	0.1592	-0.2185	0.4285	-3.0426	2.5094
Back	NPC	9	0.1790	0.6325	0.2108	-0.3072	0.6652	-1.0169	1.3533
	Researcher	14	0.3019	0.5180	0.1384	0.0029	0.6010	-0.5291	1.5032
	Post	12	0.2703	0.6915	0.1996	-0.1690	0.7096	-0.5750	2.1138
	Total	35	0.2595	0.5949	0.1006	0.0551	0.4638	-1.0169	2.1138
Average	NPC	9	0.2142	0.4915	0.1638	-0.1636	0.5920	-1.0320	0.5702
	Researcher	14	0.3072	0.6289	0.1681	-0.0559	0.6703	-0.9480	1.7685
	Post	12	0.3707	0.6662	0.1923	-0.0526	0.7940	-0.2219	2.3963
	Total	35	0.3050	0.5961	0.1008	0.1003	0.5098	-1.0320	2.3963

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
IPQ	Between Groups	34.535	2	17.267	0.253	0.778
	Within Groups	2182.437	32	68.201		
	Total	2216.971	34			
AF3	Between Groups	1.284	2	0.642	0.438	0.649
	Within Groups	46.909	32	1.466		
	Total	48.193	34			
F7	Between Groups	2.896	2	1.448	1.668	0.205
	Within Groups	27.768	32	0.868		
	Total	30.664	34			
F3	Between Groups	0.781	2	0.39	0.258	0.774
	Within Groups	48.433	32	1.514		
	Total	49.213	34			
FC5	Between Groups	0.293	2	0.146	0.108	0.898
	Within Groups	43.285	32	1.353		
	Total	43.578	34			
T7	Between Groups	2.945	2	1.473	0.827	0.446
	Within Groups	56.964	32	1.78		
	Total	59.909	34			
P7	Between Groups	1.375	2	0.688	0.294	0.748
	Within Groups	74.937	32	2.342		
	Total	76.312	34			
O1	Between Groups	0.905	2	0.452	0.366	0.696

	Within Groups	39.57	32	1.237		
	Total	40.475	34			
O2	Between Groups	2.428	2	1.214	6.707	0.004
	Within Groups	5.792	32	0.181		
	Total	8.22	34			
P8	Between Groups	0.537	2	0.268	1.164	0.325
	Within Groups	7.379	32	0.231		
	Total	7.916	34			
T8	Between Groups	0.603	2	0.301	1.385	0.265
	Within Groups	6.959	32	0.217		
	Total	7.562	34			
FC6	Between Groups	0.144	2	0.072	0.405	0.67
	Within Groups	5.686	32	0.178		
	Total	5.83	34			
F4	Between Groups	0.685	2	0.343	0.469	0.63
	Within Groups	23.388	32	0.731		
	Total	24.073	34			
F9	Between Groups	0.051	2	0.026	0.13	0.878
	Within Groups	6.286	32	0.196		
	Total	6.337	34			
AF4	Between Groups	1.045	2	0.523	0.354	0.705
	Within Groups	47.281	32	1.478		
	Total	48.326	34			
Left	Between Groups	0.379	2	0.19	0.262	0.771
	Within Groups	23.157	32	0.724		
	Total	23.536	34			

Right	Between Groups	0.45	2	0.225	1.04	0.365
	Within Groups	6.928	32	0.216		
	Total	7.378	34			
Front	Between Groups	0.456	2	0.228	0.246	0.784
	Within Groups	29.695	32	0.928		
	Total	30.151	34			
Back	Between Groups	0.085	2	0.042	0.114	0.893
	Within Groups	11.948	32	0.373		
	Total	12.032	34			
Average	Between Groups	0.126	2	0.063	0.169	0.846
	Within Groups	11.957	32	0.374		
	Total	12.083	34			

ANOVA Effect Sizesa,b

		Point Estimate	95% Confidence Interval	
			Lower	Upper
IPQ	Eta-squared	0.016	0	0.124
	Epsilon-squared	-0.046	-0.062	0.07
	Omega-squared Fixed-effect	-0.045	-0.061	0.068
	Omega-squared Random-effect	-0.022	-0.029	0.035
AF3	Eta-squared	0.027	0	0.158
	Epsilon-squared	-0.034	-0.062	0.105
	Omega-squared Fixed-effect	-0.033	-0.061	0.103
	Omega-squared Random-effect	-0.016	-0.029	0.054
F7	Eta-squared	0.094	0	0.274
	Epsilon-squared	0.038	-0.062	0.228
	Omega-squared Fixed-effect	0.037	-0.061	0.223
	Omega-squared Random-effect	0.019	-0.029	0.126
F3	Eta-squared	0.016	0	0.126
	Epsilon-squared	-0.046	-0.062	0.071
	Omega-squared Fixed-effect	-0.044	-0.061	0.069

	Omega-squared Random-effect	-0.022	-0.029	0.036
FC5	Eta-squared	0.007	0	0.079
	Epsilon-squared	-0.055	-0.062	0.021
	Omega-squared Fixed-effect	-0.054	-0.061	0.02
	Omega-squared Random-effect	-0.026	-0.029	0.01
T7	Eta-squared	0.049	0	0.205
	Epsilon-squared	-0.01	-0.062	0.155
	Omega-squared Fixed-effect	-0.01	-0.061	0.151
	Omega-squared Random-effect	-0.005	-0.029	0.082
P7	Eta-squared	0.018	0	0.133
	Epsilon-squared	-0.043	-0.062	0.079
	Omega-squared Fixed-effect	-0.042	-0.061	0.077
	Omega-squared Random-effect	-0.021	-0.029	0.04
O1	Eta-squared	0.022	0	0.146
	Epsilon-squared	-0.039	-0.062	0.093
	Omega-squared Fixed-effect	-0.038	-0.061	0.091
	Omega-squared Random-effect	-0.018	-0.029	0.047
O2	Eta-squared	0.295	0.042	0.48
	Epsilon-squared	0.251	-0.018	0.448
	Omega-squared Fixed-effect	0.246	-0.018	0.441
	Omega-squared Random-effect	0.14	-0.009	0.283
P8	Eta-squared	0.068	0	0.236
	Epsilon-squared	0.01	-0.062	0.188
	Omega-squared Fixed-effect	0.009	-0.061	0.184
	Omega-squared Random-effect	0.005	-0.029	0.101
T8	Eta-squared	0.08	0	0.253
	Epsilon-squared	0.022	-0.062	0.207
	Omega-squared Fixed-effect	0.022	-0.061	0.202
	Omega-squared Random-effect	0.011	-0.029	0.112
FC6	Eta-squared	0.025	0	0.153
	Epsilon-squared	-0.036	-0.062	0.1
	Omega-squared Fixed-effect	-0.035	-0.061	0.097
	Omega-squared Random-effect	-0.017	-0.029	0.051
F4	Eta-squared	0.028	0	0.162

	Epsilon-squared	-0.032	-0.062	0.11
	Omega-squared Fixed-effect	-0.031	-0.061	0.107
	Omega-squared Random-effect	-0.015	-0.029	0.057
F9	Eta-squared	0.008	0	0.088
	Epsilon-squared	-0.054	-0.062	0.031
	Omega-squared Fixed-effect	-0.052	-0.061	0.03
	Omega-squared Random-effect	-0.025	-0.029	0.015
AF4	Eta-squared	0.022	0	0.144
	Epsilon-squared	-0.04	-0.062	0.091
	Omega-squared Fixed-effect	-0.038	-0.061	0.088
	Omega-squared Random-effect	-0.019	-0.029	0.046
Left	Eta-squared	0.016	0	0.126
	Epsilon-squared	-0.045	-0.062	0.072
	Omega-squared Fixed-effect	-0.044	-0.061	0.07
	Omega-squared Random-effect	-0.022	-0.029	0.036
Right	Eta-squared	0.061	0	0.225
	Epsilon-squared	0.002	-0.062	0.177
	Omega-squared Fixed-effect	0.002	-0.061	0.172
	Omega-squared Random-effect	0.001	-0.029	0.094
Front	Eta-squared	0.015	0	0.123
	Epsilon-squared	-0.046	-0.062	0.068
	Omega-squared Fixed-effect	-0.045	-0.061	0.066
	Omega-squared Random-effect	-0.022	-0.029	0.034
Back	Eta-squared	0.007	0	0.081
	Epsilon-squared	-0.055	-0.062	0.024
	Omega-squared Fixed-effect	-0.053	-0.061	0.023
	Omega-squared Random-effect	-0.026	-0.029	0.012
Average	Eta-squared	0.01	0	0.102
	Epsilon-squared	-0.051	-0.062	0.046
	Omega-squared Fixed-effect	-0.05	-0.061	0.045
	Omega-squared Random-effect	-0.024	-0.029	0.023

a Eta-squared and Epsilon-squared are estimated based on the fixed-effect model.

b Negative but less biased estimates are retained, not rounded to zero.

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
IPQ	NPC	Researcher	0.579	3.528	0.985	-8.09	9.25
		Post	2.389	3.642	0.79	-6.56	11.34
	Researcher	NPC	-0.579	3.528	0.985	-9.25	8.09
		Post	1.81	3.249	0.844	-6.17	9.79
	Post	NPC	-2.389	3.642	0.79	-11.34	6.56
		Researcher	-1.81	3.249	0.844	-9.79	6.17
AF3	NPC	Researcher	0.2116	0.5173	0.9120	-1.0596	1.4827
		Post	-0.2341	0.5339	0.9000	-1.5461	1.0779
	Researcher	NPC	-0.2116	0.5173	0.9120	-1.4827	1.0596
		Post	-0.4457	0.4763	0.6220	-1.6161	0.7248
	Post	NPC	0.2341	0.5339	0.9000	-1.0779	1.5461
		Researcher	0.4457	0.4763	0.6220	-0.7248	1.6161
F7	NPC	Researcher	0.0312	0.3980	0.9970	-0.9469	1.0092
		Post	-0.5865	0.4108	0.3390	-1.5959	0.4230
	Researcher	NPC	-0.0312	0.3980	0.9970	-1.0092	0.9469
		Post	-0.6176	0.3665	0.2260	-1.5182	0.2829
	Post	NPC	0.5865	0.4108	0.3390	-0.4230	1.5959
		Researcher	0.6176	0.3665	0.2260	-0.2829	1.5182
F3	NPC	Researcher	-0.3339	0.5256	0.8020	-1.6256	0.9577
		Post	-0.0566	0.5425	0.9940	-1.3897	1.2765
	Researcher	NPC	0.3339	0.5256	0.8020	-0.9577	1.6256
		Post	0.2774	0.4840	0.8350	-0.9120	1.4667
	Post	NPC	0.0566	0.5425	0.9940	-1.2765	1.3897
		Researcher	-0.2774	0.4840	0.8350	-1.4667	0.9120
FC5	NPC	Researcher	-0.0152	0.4969	0.9990	-1.2363	1.2058
		Post	-0.2016	0.5129	0.9190	-1.4619	1.0587
	Researcher	NPC	0.0152	0.4969	0.9990	-1.2058	1.2363
		Post	-0.1864	0.4575	0.9130	-1.3107	0.9380
	Post	NPC	0.2016	0.5129	0.9190	-1.0587	1.4619
		Researcher	0.1864	0.4575	0.9130	-0.9380	1.3107
T7	NPC	Researcher	0.3589	0.5700	0.8050	-1.0418	1.7597
		Post	-0.3144	0.5883	0.8550	-1.7602	1.1313
	Researcher	NPC	-0.3589	0.5700	0.8050	-1.7597	1.0418
		Post	-0.6734	0.5249	0.4150	-1.9632	0.6165
	Post	NPC	0.3144	0.5883	0.8550	-1.1313	1.7602
		Researcher	0.6734	0.5249	0.4150	-0.6165	1.9632
P7	NPC	Researcher	0.1897	0.6538	0.9550	-1.4169	1.7964

		Post	0.5020	0.6748	0.7390	-1.1563	2.1602
	Researcher	NPC	-0.1897	0.6538	0.9550	-1.7964	1.4169
		Post	0.3122	0.6020	0.8630	-1.1671	1.7916
	Post	NPC	-0.5020	0.6748	0.7390	-2.1602	1.1563
		Researcher	-0.3122	0.6020	0.8630	-1.7916	1.1671
O1	NPC	Researcher	0.2635	0.4751	0.8450	-0.9041	1.4310
		Post	-0.0976	0.4904	0.9780	-1.3026	1.1074
	Researcher	NPC	-0.2635	0.4751	0.8450	-1.4310	0.9041
		Post	-0.3611	0.4375	0.6900	-1.4361	0.7140
	Post	NPC	0.0976	0.4904	0.9780	-1.1074	1.3026
		Researcher	0.3611	0.4375	0.6900	-0.7140	1.4361
O2	NPC	Researcher	-.632971933928996*	0.1818	0.0040	-1.0797	-0.1863
		Post	-.557196122054433*	0.1876	0.0150	-1.0182	-0.0962
	Researcher	NPC	.632971933928996*	0.1818	0.0040	0.1863	1.0797
		Post	0.0758	0.1674	0.8940	-0.3355	0.4871
	Post	NPC	.557196122054433*	0.1876	0.0150	0.0962	1.0182
		Researcher	-0.0758	0.1674	0.8940	-0.4871	0.3355
P8	NPC	Researcher	-0.3119	0.2052	0.2950	-0.8161	0.1923
		Post	-0.2124	0.2118	0.5800	-0.7328	0.3080
	Researcher	NPC	0.3119	0.2052	0.2950	-0.1923	0.8161
		Post	0.0995	0.1889	0.8590	-0.3647	0.5637
	Post	NPC	0.2124	0.2118	0.5800	-0.3080	0.7328
		Researcher	-0.0995	0.1889	0.8590	-0.5637	0.3647
T8	NPC	Researcher	-0.3198	0.1992	0.2580	-0.8094	0.1698
		Post	-0.2679	0.2056	0.4040	-0.7732	0.2375
	Researcher	NPC	0.3198	0.1992	0.2580	-0.1698	0.8094
		Post	0.0520	0.1835	0.9570	-0.3988	0.5028
	Post	NPC	0.2679	0.2056	0.4040	-0.2375	0.7732
		Researcher	-0.0520	0.1835	0.9570	-0.5028	0.3988
FC6	NPC	Researcher	-0.1610	0.1801	0.6480	-0.6036	0.2815
		Post	-0.1137	0.1859	0.8150	-0.5705	0.3431
	Researcher	NPC	0.1610	0.1801	0.6480	-0.2815	0.6036
		Post	0.0473	0.1658	0.9560	-0.3602	0.4548
	Post	NPC	0.1137	0.1859	0.8150	-0.3431	0.5705
		Researcher	-0.0473	0.1658	0.9560	-0.4548	0.3602
F4	NPC	Researcher	-0.3528	0.3653	0.6030	-1.2504	0.5447
		Post	-0.1952	0.3770	0.8630	-1.1216	0.7312
	Researcher	NPC	0.3528	0.3653	0.6030	-0.5447	1.2504
		Post	0.1576	0.3363	0.8860	-0.6688	0.9841
	Post	NPC	0.1952	0.3770	0.8630	-0.7312	1.1216
		Researcher	-0.1576	0.3363	0.8860	-0.9841	0.6688
F9	NPC	Researcher	-0.0697	0.1894	0.9280	-0.5351	0.3956
		Post	-0.0982	0.1954	0.8710	-0.5785	0.3821

	Researcher	NPC	0.0697	0.1894	0.9280	-0.3956	0.5351
		Post	-0.0285	0.1744	0.9850	-0.4569	0.4000
	Post	NPC	0.0982	0.1954	0.8710	-0.3821	0.5785
		Researcher	0.0285	0.1744	0.9850	-0.4000	0.4569
AF4	NPC	Researcher	-0.1588	0.5193	0.9500	-1.4349	1.1174
		Post	0.2425	0.5360	0.8940	-1.0746	1.5597
	Researcher	NPC	0.1588	0.5193	0.9500	-1.1174	1.4349
		Post	0.4013	0.4782	0.6820	-0.7738	1.5764
	Post	NPC	-0.2425	0.5360	0.8940	-1.5597	1.0746
		Researcher	-0.4013	0.4782	0.6820	-1.5764	0.7738
Left	NPC	Researcher	0.1008	0.3634	0.9590	-0.7923	0.9939
		Post	-0.1413	0.3751	0.9250	-1.0630	0.7805
	Researcher	NPC	-0.1008	0.3634	0.9590	-0.9939	0.7923
		Post	-0.2421	0.3347	0.7520	-1.0644	0.5803
	Post	NPC	0.1413	0.3751	0.9250	-0.7805	1.0630
		Researcher	0.2421	0.3347	0.7520	-0.5803	1.0644
Right	NPC	Researcher	-0.2867	0.1988	0.3320	-0.7752	0.2018
		Post	-0.1717	0.2052	0.6830	-0.6759	0.3325
	Researcher	NPC	0.2867	0.1988	0.3320	-0.2018	0.7752
		Post	0.1150	0.1830	0.8060	-0.3348	0.5648
	Post	NPC	0.1717	0.2052	0.6830	-0.3325	0.6759
		Researcher	-0.1150	0.1830	0.8060	-0.5648	0.3348
Front	NPC	Researcher	-0.0766	0.4116	0.9810	-1.0879	0.9348
		Post	-0.2784	0.4248	0.7910	-1.3223	0.7654
	Researcher	NPC	0.0766	0.4116	0.9810	-0.9348	1.0879
		Post	-0.2019	0.3790	0.8560	-1.1331	0.7294
	Post	NPC	0.2784	0.4248	0.7910	-0.7654	1.3223
		Researcher	0.2019	0.3790	0.8560	-0.7294	1.1331
Back	NPC	Researcher	-0.1229	0.2611	0.8850	-0.7644	0.5186
		Post	-0.0913	0.2694	0.9390	-0.7534	0.5708
	Researcher	NPC	0.1229	0.2611	0.8850	-0.5186	0.7644
		Post	0.0316	0.2404	0.9910	-0.5591	0.6223
	Post	NPC	0.0913	0.2694	0.9390	-0.5708	0.7534
		Researcher	-0.0316	0.2404	0.9910	-0.6223	0.5591
Average	NPC	Researcher	-0.0930	0.2612	0.9330	-0.7347	0.5488
		Post	-0.1565	0.2695	0.8310	-0.8189	0.5059
	Researcher	NPC	0.0930	0.2612	0.9330	-0.5488	0.7347
		Post	-0.0635	0.2405	0.9620	-0.6545	0.5274
	Post	NPC	0.1565	0.2695	0.8310	-0.5059	0.8189
		Researcher	0.0635	0.2405	0.9620	-0.5274	0.6545

* The mean difference is significant at the 0.05 level.

Tables of Results for Mann Whitney U Test (N=35)

Mann Whitney U Test NPC-Researcher (N=23)

Ranks

	Treatment	N	Mean Rank	Sum of Ranks
IPQ	NPC	9	12	108
	Researcher	14	12	168
	Total	23		
AF3	NPC	9	12.56	113
	Researcher	14	11.64	163
	Total	23		
F7	NPC	9	11.89	107
	Researcher	14	12.07	169
	Total	23		
F3	NPC	9	11.67	105
	Researcher	14	12.21	171
	Total	23		
FC5	NPC	9	12.78	115
	Researcher	14	11.5	161
	Total	23		
T7	NPC	9	12	108
	Researcher	14	12	168
	Total	23		
P7	NPC	9	13.22	119
	Researcher	14	11.21	157
	Total	23		
O1	NPC	9	13	117
	Researcher	14	11.36	159
	Total	23		
O2	NPC	9	7	63
	Researcher	14	15.21	213
	Total	23		
P8	NPC	9	10.56	95
	Researcher	14	12.93	181
	Total	23		
T8	NPC	9	10.78	97
	Researcher	14	12.79	179
	Total	23		
FC6	NPC	9	9.67	87
	Researcher	14	13.5	189

	Total	23		
F4	NPC	9	10.33	93
	Researcher	14	13.07	183
	Total	23		
F9	NPC	9	10.22	92
	Researcher	14	13.14	184
	Total	23		
AF4	NPC	9	12.78	115
	Researcher	14	11.5	161
	Total	23		
Left	NPC	9	13.56	122
	Researcher	14	11	154
	Total	23		
Right	NPC	9	9.33	84
	Researcher	14	13.71	192
	Total	23		
Front	NPC	9	12.44	112
	Researcher	14	11.71	164
	Total	23		
Back	NPC	9	11	99
	Researcher	14	12.64	177
	Total	23		
Average	NPC	9	12.56	113
	Researcher	14	11.64	163
	Total	23		

Test Statistics

	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)	Exact Sig. [2*(1-tailed Sig.)]
IPQ	63	168	0	1	1.000b
AF3	58	163	-0.315	0.753	.781b
F7	62	107	-0.063	0.95	.975b
F3	60	105	-0.189	0.85	.877b
FC5	56	161	-0.441	0.659	.688b
T7	63	168	0	1	1.000b
P7	52	157	-0.693	0.488	.516b
O1	54	159	-0.567	0.571	.600b
O2	18	63	-2.835	0.005	.003b
P8	50	95	-0.819	0.413	.439b
T8	52	97	-0.693	0.488	.516b
FC6	42	87	-1.323	0.186	.201b
F4	48	93	-0.945	0.345	.369b
F9	47	92	-1.008	0.313	.336b
AF4	56	161	-0.441	0.659	.688b

Left	49	154	-0.882	0.378	.403b
Right	39	84	-1.512	0.131	.141b
Front	59	164	-0.252	0.801	.829b
Back	54	99	-0.567	0.571	.600b
Average	58	163	-0.315	0.753	.781b

a Grouping Variable: Treatment

b Not corrected for ties.

Mann Whitney U Test NPC-Posttest (N=21)

Ranks

	Treatment	N	Mean Rank	Sum of Ranks
IPQ	NPC	9	12.28	110.5
	Post	12	10.04	120.5
	Total	21		
AF3	NPC	9	10.78	97
	Post	12	11.17	134
	Total	21		
F7	NPC	9	9.33	84
	Post	12	12.25	147
	Total	21		
F3	NPC	9	10.78	97
	Post	12	11.17	134
	Total	21		
FC5	NPC	9	11.33	102
	Post	12	10.75	129
	Total	21		
T7	NPC	9	9.89	89
	Post	12	11.83	142
	Total	21		
P7	NPC	9	13.56	122
	Post	12	9.08	109
	Total	21		
O1	NPC	9	10.56	95
	Post	12	11.33	136
	Total	21		
O2	NPC	9	6.67	60
	Post	12	14.25	171
	Total	21		
P8	NPC	9	10.67	96
	Post	12	11.25	135
	Total	21		
T8	NPC	9	10.78	97
	Post	12	11.17	134
	Total	21		
FC6	NPC	9	9.44	85
	Post	12	12.17	146
	Total	21		
F4	NPC	9	9.44	85
	Post	12	12.17	146
	Total	21		

F9	NPC	9	9.67	87
	Post	12	12	144
	Total	21		
AF4	NPC	9	11.89	107
	Post	12	10.33	124
	Total	21		
Left	NPC	9	12.67	114
	Post	12	9.75	117
	Total	21		
Right	NPC	9	10	90
	Post	12	11.75	141
	Total	21		
Front	NPC	9	12	108
	Post	12	10.25	123
	Total	21		
Back	NPC	9	10.89	98
	Post	12	11.08	133
	Total	21		
Average	NPC	9	12.56	113
	Post	12	9.83	118
	Total	21		

Test Statistics

	Mann-Whitney U	*Wilcoxon W*	*Z*	*Asymp. Sig. (2-tailed)*	*Exact Sig. [2*(1-tailed Sig.)]*
IPQ	42.5	120.5	-0.821	0.412	.422b
AF3	52	97	-0.142	0.887	.917b
F7	39	84	-1.066	0.286	.310b
F3	52	97	-0.142	0.887	.917b
FC5	51	129	-0.213	0.831	.862b
T7	44	89	-0.711	0.477	.508b
P7	31	109	-1.635	0.102	.111b
O1	50	95	-0.284	0.776	.808b
O2	15	60	-2.772	0.006	.004b
P8	51	96	-0.213	0.831	.862b
T8	52	97	-0.142	0.887	.917b
FC6	40	85	-0.995	0.32	.345b
F4	40	85	-0.995	0.32	.345b
F9	42	87	-0.853	0.394	.422b
AF4	46	124	-0.569	0.57	.602b
Left	39	117	-1.066	0.286	.310b
Right	45	90	-0.64	0.522	.554b
Front	45	123	-0.64	0.522	.554b
Back	53	98	-0.071	0.943	.972b

Average	40	118	-0.995	0.32	.345b

a Grouping Variable: Treatment

b Not corrected for ties.

Mann Whitney U Test Researcher-Posttest (N=26)

Ranks

	Treatment	N	Mean Rank	Sum of Ranks
IPQ	Researcher	14	14.18	198.5
	Post	12	12.71	152.5
	Total	26		
AF3	Researcher	14	12.43	174
	Post	12	14.75	177
	Total	26		
F7	Researcher	14	12.07	169
	Post	12	15.17	182
	Total	26		
F3	Researcher	14	13.79	193
	Post	12	13.17	158
	Total	26		
FC5	Researcher	14	13.36	187
	Post	12	13.67	164
	Total	26		
T7	Researcher	14	11.57	162
	Post	12	15.75	189
	Total	26		
P7	Researcher	14	14.5	203
	Post	12	12.33	148
	Total	26		
O1	Researcher	14	12.79	179
	Post	12	14.33	172
	Total	26		
O2	Researcher	14	13.36	187
	Post	12	13.67	164
	Total	26		
P8	Researcher	14	14.79	207
	Post	12	12	144
	Total	26		
T8	Researcher	14	14.5	203
	Post	12	12.33	148
	Total	26		
FC6	Researcher	14	13.71	192
	Post	12	13.25	159

	Total	26		
F4	Researcher	14	13.29	186
	Post	12	13.75	165
	Total	26		
F9	Researcher	14	13.57	190
	Post	12	13.42	161
	Total	26		
AF4	Researcher	14	13.5	189
	Post	12	13.5	162
	Total	26		
Left	Researcher	14	13.43	188
	Post	12	13.58	163
	Total	26		
Right	Researcher	14	14.36	201
	Post	12	12.5	150
	Total	26		
Front	Researcher	14	13.5	189
	Post	12	13.5	162
	Total	26		
Back	Researcher	14	14.07	197
	Post	12	12.83	154
	Total	26		
Average	Researcher	14	13.07	183
	Post	12	14	168
	Total	26		

Test Statistics

	Mann-Whitney U	*Wilcoxon W*	*Z*	*Asymp. Sig. (2-tailed)*	*Exact Sig. [2*(1-tailed Sig.)]*
IPQ	74.5	152.5	-0.49	0.624	.631b
AF3	69	174	-0.772	0.44	.462b
F7	64	169	-1.029	0.304	.322b
F3	80	158	-0.206	0.837	.860b
FC5	82	187	-0.103	0.918	.940b
T7	57	162	-1.389	0.165	.176b
P7	70	148	-0.72	0.471	.494b
O1	74	179	-0.514	0.607	.631b
O2	82	187	-0.103	0.918	.940b
P8	66	144	-0.926	0.355	.374b
T8	70	148	-0.72	0.471	.494b
FC6	81	159	-0.154	0.877	.899b
F4	81	186	-0.154	0.877	.899b

F9	83	161	-0.051	0.959	.980b
AF4	84	162	0	1	1.000b
Left	83	188	-0.051	0.959	.980b
Right	72	150	-0.617	0.537	.560b
Front	84	162	0	1	1.000b
Back	76	154	-0.411	0.681	.705b
Average	78	183	-0.309	0.758	.781b

a Grouping Variable: Treatment

b Not corrected for ties.

Appendix C: Surveys

Qualitative Post-test Questionnaire

1. Ease of use for hardware
2. Ease of use for software
3. Ease accomplishing tasks
4. Ease understanding tasks
5. How did additional test conditions (haptic, olfactory, in-test questionnaire) affect your experience

iGroup Presence Questionnaire (IPQ)

Please answer on a scale of one to five

1. In the computer generated world I had a sense of "being there"
    a. 1 = “not at all”, 5 = “very much”
2. Somehow I felt that the virtual world surrounded me.
    a. 1 = “fully disagree”, 5 = ”fully agree”
3. I felt like I was just perceiving pictures.
    a. 1 = “fully disagree”, 5 = ”fully agree”
4. I did not feel present in the virtual space.
    a. 1 = “did not feel present” 5 = “felt present”
5. I had a sense of acting in the virtual space, rather than operating something from outside.
    a. 1 = “fully disagree”, 5 = ”fully agree”
6. I felt present in the virtual space.
    a. 1 = “fully disagree”, 5 = ”fully agree”
7. How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?
    a. 1 = “not aware at all” 3 = “moderately aware” 5 = “extremely aware”
8. I was not aware of my real environment.
    a. 1 = “fully disagree”, 5 = ”fully agree”

9. I still paid attention to the real environment.
    a. 1 = “fully disagree”, 5 = ”fully agree”
10. I was completely captivated by the virtual world.
    a. 1 = “fully disagree”, 5 = ”fully agree”
11. How real did the virtual world seem to you?
    a. 1 = “completely real” 5 = “not real at all”
12. How much did your experience in the virtual environment seem consistent with your real world experience ?
    a. 1 = “not consistent” 3 = “moderately consistent” 5 = “extremely consistent”
13. How real did the virtual world seem to you?
    a. 1 = “About as real as an imagined world” 5 = “Indistinguishable from the real world”
14. The virtual world seemed more realistic than the real world.
    a. 1 = “fully disagree”, 5 = ”fully agree”

Virtual Reality Sickness Questionnaire (VRSQ)

Please rate on a scale of 0-3 where 0 is “not at all” and 3 is “very”

1. Oculomotor
    a. General discomfort
    b. Fatigue
    c. Eyestrain
    d. Difficulty focusing
2. Disorientation
    a. Headache
    b. Fullness of head
    c. Blurred vision
    d. Dizzy (eyes close)
    e. Vertigo

Motion Sickness Susceptibility Questionnaire (MSSQ)

Survey was provided as a matrix of choices with the following options for each question about how often they traveled or experienced: “never”, “1 to 4 trips”, “5-10 trips”, “11 trips or more”

The following options were provided for how often they felt sick or nauseated and how often they vomited: “Never”, “Rarely”, “Sometimes”, “Frequently”, “Always”

For each of the following types of transport or entertainment please indicate:

1. As a CHILD (before age 12), how often you Traveled or Experienced: [Cars]
2. As a CHILD (before age 12), how often you Traveled or Experienced: [Buses or Coaches]
3. As a CHILD (before age 12), how often you Traveled or Experienced: [Trains]
4. As a CHILD (before age 12), how often you Traveled or Experienced: [Aircraft]
5. As a CHILD (before age 12), how often you Traveled or Experienced: [Small Boats]
6. As a CHILD (before age 12), how often you Traveled or Experienced: [Ships, e.g. Channel Ferries]
7. As a CHILD (before age 12), how often you Traveled or Experienced: [Swings]
8. As a CHILD (before age 12), how often you Traveled or Experienced: [Roundabouts: playgrounds]
9. As a CHILD (before age 12), how often you Traveled or Experienced: [Amusement Park rides]
10. As a CHILD (before age 12), how often you Felt Sick or Nauseated: [Cars]
11. As a CHILD (before age 12), how often you Felt Sick or Nauseated: [Buses or Coaches]
12. As a CHILD (before age 12), how often you Felt Sick or Nauseated: [Trains]
13. As a CHILD (before age 12), how often you Felt Sick or Nauseated: [Aircraft]
14. As a CHILD (before age 12), how often you Felt Sick or Nauseated: [Small Boats]
15. As a CHILD (before age 12), how often you Felt Sick or Nauseated: [Ships, e.g. Channel Ferries]
16. As a CHILD (before age 12), how often you Felt Sick or Nauseated: [Swings]
17. As a CHILD (before age 12), how often you Felt Sick or Nauseated: [Roundabouts: playgrounds]

18. As a CHILD (before age 12), how often you Felt Sick or Nauseated: [Amusement Park rides]
19. As a CHILD (before age 12), how often you Vomited: [Cars]
20. As a CHILD (before age 12), how often you Vomited: [Buses or Coaches]
21. As a CHILD (before age 12), how often you Vomited: [Trains]
22. As a CHILD (before age 12), how often you Vomited: [Aircraft]
23. As a CHILD (before age 12), how often you Vomited: [Small Boats]
24. As a CHILD (before age 12), how often you Vomited: [Ships, e.g. Channel Ferries]
25. As a CHILD (before age 12), how often you Vomited: [Swings]
26. As a CHILD (before age 12), how often you Vomited: [Roundabouts: playgrounds]
27. As a CHILD (before age 12), how often you Vomited: [Amusement Park rides]
28. Over the last ten (10) years, how often you Traveled or Experienced: [Cars]
29. Over the last ten (10) years, how often you Traveled or Experienced: [Buses or Coaches]
30. Over the last ten (10) years, how often you Traveled or Experienced: [Trains]
31. Over the last ten (10) years, how often you Traveled or Experienced: [Aircraft]
32. Over the last ten (10) years, how often you Traveled or Experienced: [Small Boats]
33. Over the last ten (10) years, how often you Traveled or Experienced: [Ships, e.g. Channel Ferries]
34. Over the last ten (10) years, how often you Traveled or Experienced: [Swings]
35. Over the last ten (10) years, how often you Traveled or Experienced: [Roundabouts: playgrounds]
36. Over the last ten (10) years, how often you Traveled or Experienced: [Amusement Park rides]
37. Over the last ten (10) years, how often you Felt Sick or Nauseated [Cars]
38. Over the last ten (10) years, how often you Felt Sick or Nauseated [Buses or Coaches]
39. Over the last ten (10) years, how often you Felt Sick or Nauseated [Trains]
40. Over the last ten (10) years, how often you Felt Sick or Nauseated [Aircraft]
41. Over the last ten (10) years, how often you Felt Sick or Nauseated [Small Boats]

42. Over the last ten (10) years, how often you Felt Sick or Nauseated [Ships, e.g. Channel Ferries]
43. Over the last ten (10) years, how often you Felt Sick or Nauseated [Swings]
44. Over the last ten (10) years, how often you Felt Sick or Nauseated [Roundabouts: playgrounds]
45. Over the last ten (10) years, how often you Felt Sick or Nauseated [Amusement Park rides]
46. Over the last ten (10) years, how often you Vomited [Cars]
47. Over the last ten (10) years, how often you Vomited [Buses or Coaches]
48. Over the last ten (10) years, how often you Vomited [Trains]
49. Over the last ten (10) years, how often you Vomited [Aircraft]
50. Over the last ten (10) years, how often you Vomited [Small Boats]
51. Over the last ten (10) years, how often you Vomited [Ships, e.g. Channel Ferries]
52. Over the last ten (10) years, how often you Vomited [Swings]
53. Over the last ten (10) years, how often you Vomited [Roundabouts: playgrounds]
54. Over the last ten (10) years, how often you Vomited [Amusement Park rides]

Section A: Your CHILDHOOD experience only (before 12 years of age)

For each of the following types of transport or entertainment please indicate:

As a CHILD (before age 12), how often you Traveled or Experienced:

	Never	1 to 4 trips	5 to 10 trips	11 trips or more
Cars	○	○	○	○
Buses or Coaches	○	○	○	○
Trains	○	○	○	○
Aircraft	○	○	○	○
Small Boats	○	○	○	○
Ships, e.g. Channel Ferries	○	○	○	○
Swings	○	○	○	○
Roundabouts: playgrounds	○	○	○	○
Amusement Park rides	○	○	○	○

As a CHILD (before age 12), how often you Felt Sick or Nauseated:

	Never	Rarely	Sometimes	Frequently	Always
Cars	○	○	○	○	○
Buses or Coaches	○	○	○	○	○
Trains	○	○	○	○	○
Aircraft	○	○	○	○	○
Small Boats	○	○	○	○	○
Ships, e.g. Channel Ferries	○	○	○	○	○
Swings	○	○	○	○	○
Roundabouts: playgrounds	○	○	○	○	○
Amusement Park rides	○	○	○	○	○

As a CHILD (before age 12), how often you Vomited:

	Never	Rarely	Sometimes	Frequently	Always
Cars	○	○	○	○	○
Buses or Coaches	○	○	○	○	○
Trains	○	○	○	○	○
Aircraft	○	○	○	○	○
Small Boats	○	○	○	○	○
Ships, e.g. Channel Ferries	○	○	○	○	○
Swings	○	○	○	○	○
Roundabouts: playgrounds	○	○	○	○	○
Amusement Park rides	○	○	○	○	○

Figure 1 survey matrix of choices

Appendix D: Figures

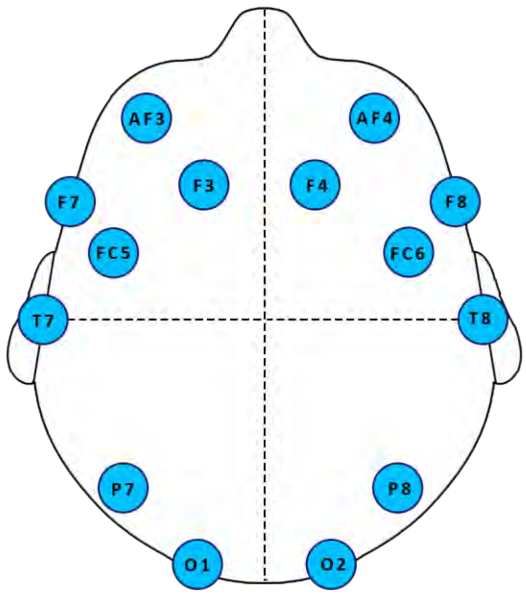

Figure 2 Emotiv Epoc electrode placement (illustration by author based on diagrams from Emotiv guide)

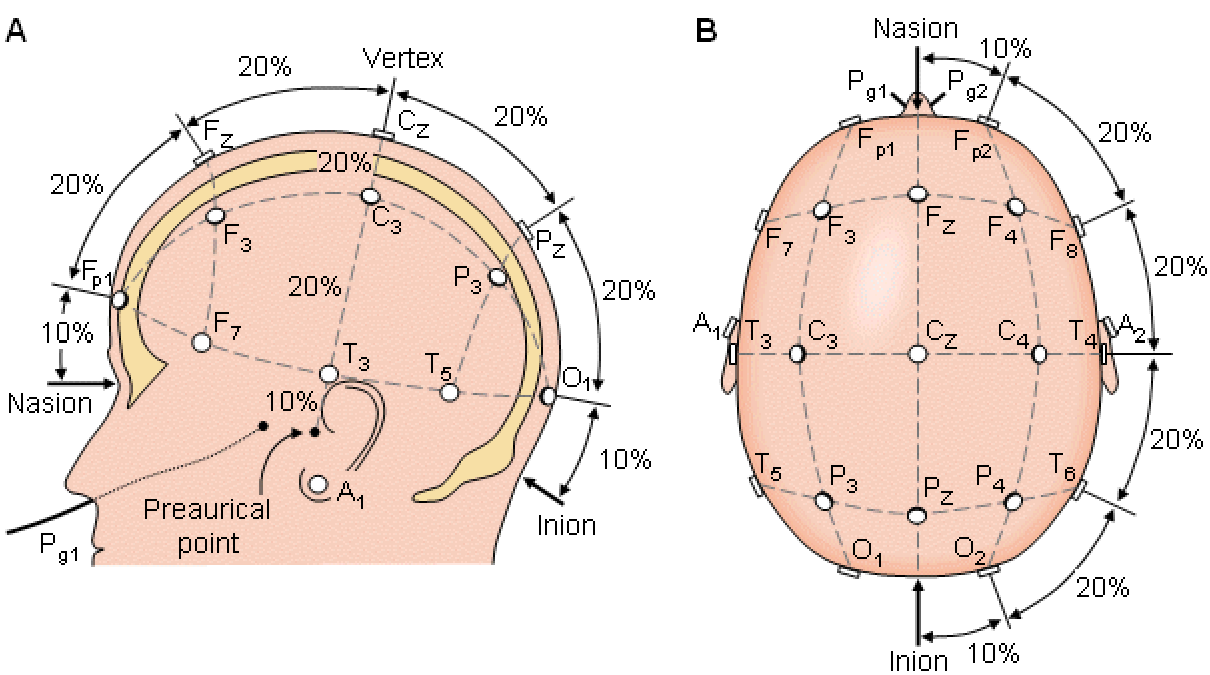

Figure 3 EEG 10-20 Electrode Placement (Shriram, 2012)

Figure 4 Emotiv EPOC headset("EMOTIV EPOC X 14 Channel Mobile Brainwear®," n.d.)

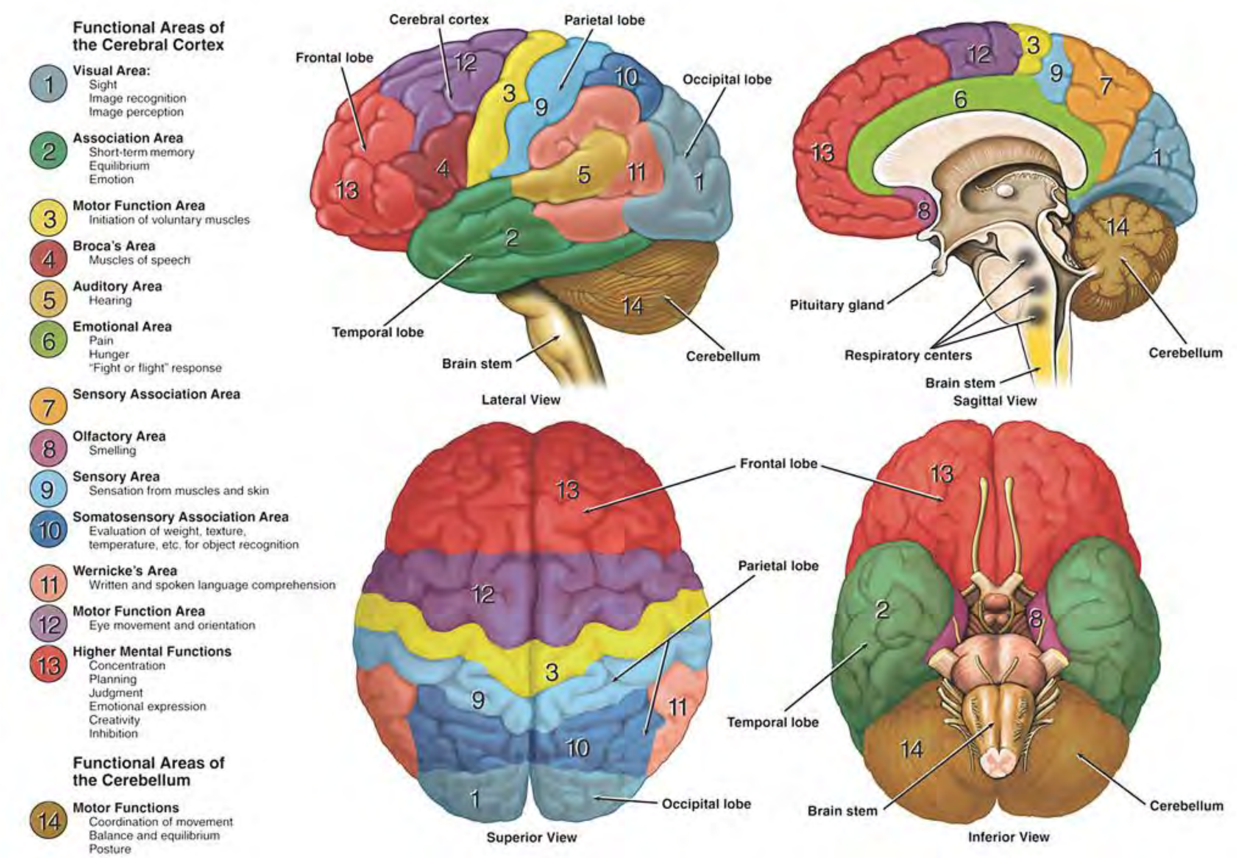

Figure 5 functions of areas of the brain (Sukel, 2019)

*Figure 6 HTC Vive headset (*VIVE United States | Discover Virtual Reality Beyond Imagination*, 2023)*

*Figure 7 HTC Vive controllers (*VIVE United States | Discover Virtual Reality Beyond Imagination*, 2023.)*

Figure 8 subject wearing EEG and VR headset performing sorting task

Figure 9 subject wearing EEG and VR headset performing sorting task

Figure 10 virtual table with sorting objects

Figure 11 virtual sorting bins

Figure 12 non player character

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