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An Analysis of Presence and User Experiences Over Time

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An Analysis of Presence and User Experiences Over Time

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Accepted by:
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Abstract

This manuscript presents the result of a series of studies intended to shed light on understanding how trends regarding user experiences in VR changes over time when engaging with VR games.

In my first study, I explored how user experiences compared when playing Minecraft on the desktop against playing Minecraft within an immersive virtual reality port. Fourteen players completed six 45 minute sessions, three sessions were played on the desktop, and three in VR. The Gaming Experience Questionnaire, i-Group presence questionnaire, and Simulator Sickness Questionnaire were administered after each session, and players were interviewed at the end of the experiment. Survey data showed substantial increases in presence and positive emotions when playing Minecraft in VR while multiple themes emerged in participant interviews: participants' heightened emotional experiences playing Minecraft in VR was closely linked to feelings of immersion and improved sense of scale; participants overall enjoyed using motion controls, though they felt indirect input was better for some actions; and players generally disliked traveling via teleportation, as they found it disorienting and immersion-breaking.

In my second study, I identified temporal shifts in user perceptions that had taken place within the first two years that consumer VR devices had become available. To consider what could be learned about the long-term use of consumer VR devices, I analyzed online forums discussions devoted to specifically VR. I gathered posts made on the /r/Vive subreddit from the first two years after the HTC Vive's release. Over time, users moved from passive to active as their attitudes and expectations towards presence and simulator sickness matured. The significant trends of interest found to influence this was game design implementation and locomotion techniques.

In my third study, again, I examined the data taken from the /r/Vive subreddit forum posts to gain further insights into the scope of what "lingering effects" users had reported experiencing

after using VR and the progression of these effects over time. After identifying search terms designed to discover comments made about lingering effects, I found three significant categories of lingering effects (besides simulator sickness) during my qualitative analysis: perceptual effects, behavioral effects, and changes in dreams. The perceptual and behavioral categories were further divided into sub-themes; including disruption of body ownership and proprioception, loss of a sense of depth in the real world, visual after effects, the need to verify the reality of the natural world through touch, hesitation when moving in the real world, and attempts to apply VR interaction metaphors to real-life interactions. After identifying these categories of effects, I mapped out how these effects progressed concerning time. In particular, I coded data according to four temporal concepts: 1) how long must be spent in VR to trigger an effect, 2) how long before the onset of an effect upon exiting VR, 3) the duration of any specific effect, and 4) the total duration that all effects can continue to occur overall.

In my fourth study, I examined how user experiences and trends regarding presence changed throughout a single gaming session. Participants were immersed in a virtual experience called 'The Secret Shop' and given instructions to explore their surroundings with no guided direction. After their experience ended, users performed an After Action Review (AAR) while watching a recording of their recent experience, followed by a semi-structured interview. I graphed each user's feelings of presence over time from second to second using the results of the After Action Review. Presence was shown in these graphs to both rise and fall, gradually and rapidly, throughout the course of each user's experience. The analysis of both the graphs and the interviews then showed that presence was significantly impacted by user expectations, affordance inconsistencies, and the intensity of engagement experienced throughout the session.

In my final study, I loaned out VR headsets to local novice users to track their perceptions of presence across the span of four weeks. Users were given the freedom to explore any VR games and applications of interest to them off-site to simulate regular VR consumer experiences. In this study, I analyzed how over time, novice users gradually evolved in their understanding of presence and what became most important to them in order to maintain and create it in the form of visual appeal, interaction techniques, and locomotion. I also found that the levels of engagement experienced across games were shown to be linked to whether users experienced lingering effects, how their perceptions of time spent within VR had been altered, and whether or not they retained any interest in investing in future VR-related purchases.

Dedication

"For the Lord giveth wisdom: out of his mouth cometh knowledge and understanding"

Proverbs 2:6

First and foremost, I would like to dedicate this work to the God I serve. He has brought me through numerous trials and tribulations along this academic journey and has continuously graced me with even more blessings and miracles along the way. Without his wisdom, guidance, and love, I would not have been able to make it to where I am today, and I thank him for all the amazing people he has brought into my life and what each of them has taught me along the way.

Next, I equally dedicate this work to my mother, Andrea M. Porter, and my father, Bishop John J. Porter Jr. I thank God every day for blessing me with a mother who knew how great I was before I even knew myself. She nurtured and raised me to always reach for the best, showing me what God defines as a virtuous woman. She is always eager to sacrifice anything she has to make sure I would not be slowed down in my journey for knowledge and nurtured my desire to reach out and lead people with my unique skills and gifts. Likewise, I thank God for my father because while my mother nurtured me, he raised me to be a strong vessel, wise in the ways of man and fearful of the Lord, even when it was uncomfortable or I didn't understand. Even at a young age, I can remember that he has always possessed vision, showing me the marks that an honorable man of God should be looking to accomplish with the finite time that he has on this planet. Alongside these two, I want to dedicate this to the two women who raised them, my grandmothers. Marjorie L. Ruffin showed me the power of prayer, and how through faith and patience, I can tear down strongholds and change lives for the better through God's might, even if I don't have it all figured

out myself. Mary L. Taliferro introduced me to so many things that I still love today and showed the importance of living for the moment and being courageous and honest in how you carry yourself. My grandfather, John J. Porter Sr., of whom I continue the legacy, taught me the importance of taking risks because sometimes it's the only way to either get what you want or learn a lesson you need, and I dedicate this work to him as well. Next, I dedicate this work to the two people who for so long stood behind me but now walk to stand beside me, my sister, Alexis S. Porter, and my brother, Joshua I. Porter. Alexis makes me appreciate who I am and what I represent, not only as her brother but as an individual. She showed me the importance of not being afraid to say what's on my mind if I feel slighted or manipulated, but I should always be willing to put in my fair share even when the times get rough. Joshua showed me the importance of perseverance and the diversity of those I may soon be teaching and mentoring. Through my many conversations with him, I've learned that to get through difficult times, sometimes you have to try, even on days you don't feel like trying, because that's what real love looks like. I would, of course, also like to formally dedicate this work to all my aunts, uncles, great uncles, great aunts, and cousins, of whom I hope I have made genuinely proud in this accomplishment showing that through God, anything is possible.

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Table of Contents

Title Page . . . . . **i**

Abstract . . . . . **ii**

Dedication . . . . . **iv**

Acknowledgments . . . . . **vii**

List of Tables . . . . . **xi**

List of Figures . . . . . **xii**

1 Introduction and Motivation **1**

2 Related Work **4**
2.1 Longitudinal Studies and Virtual Reality 4
2.2 Comparisons of Non-Immersive and Immersive Gameplay 4
2.3 Input and Travel for Immersive VR Games 5
2.4 Online Forums 6
2.5 Varying Degrees of Presence 6
2.6 Factors that Influence Presence 7
2.7 Measuring Presence 8
2.8 Presence and Exposure to Virtual Environments 10

3 Study 1: Guidelines on Successfully Porting Non-Immersive Games to Virtual Reality: A Case Study in Minecraft **11**
3.1 Experimental Design 12
3.2 Quantitative Results 15
3.3 Semi-Structured Interviews 18
3.4 Discussion 27
3.5 Conclusion 29

4 Study 2: An Analysis of Longitudinal Trends in Consumer Thoughts on Presence and Simulator Sickness in VR Games **31**
4.1 Experimental Design 32
4.2 Qualitative Analysis 34
4.3 Discussion 45
4.4 Conclusions and Future Work 47

5 Study 3: Lingering Effects Associated with Virtual Reality: An Analysis Based on Consumer Discussions Over Time **48**
5.1 Experimental Design 49

5.2 Qualitative Analysis 51
5.3 Conclusions and Future Work 65

6 Study 4: Changes in Presence over the Short-term: An Analysis using After Action Reviews 67
6.1 Experimental Design 68
6.2 Results 73
6.3 Discussion 80
6.4 Conclusion 81

7 Study 5: Changes in Presence over the Long-term: An Analysis of the relationship between Presence and Time 83
7.1 Experimental Design 84
7.2 Interview Findings 85
7.3 Conclusion 92

8 Conclusion 94
8.1 Introduction 94
8.2 Overview 95
8.3 Final Conclusion 96
8.4 Contributions 98

Bibliography 100

List of Tables

3.1 Modality parameters for the linear mixed model for the GEQ items. Estimate reports the average change in score when moving from the desktop to VR. Effect sizes are reported as r^2; by convention, effect sizes < 0.1 are small, between 0.1 and 0.3 are moderate, and > 0.3 are large. 16

3.2 Modality parameters for the linear mixed model for the presence factors. Estimate reports the average change in score when moving from the desktop to VR. Effect sizes are reported as r^2; by convention, effect sizes between < 0.1 are small, between 0.1 and 0.3 are moderate, and > 0.3 are large. 18

3.3 Modality parameters for the linear mixed model for the SSQ factors. Estimate reports the average change in score when moving from the desktop to VR. Effect sizes are reported as r^2; by convention, effect sizes between < 0.1 are small, between 0.1 and 0.3 are moderate, and > 0.3 are large. 18

7.1 Participant quotes that highlight a variety of lingering effects that were experienced 90

List of Figures

3.1 Examples of performing various activities in Vivecraft. Note the changing hand and tool positions in the different images. The Vivecraft interface can also be seen, which floated in front of the player low in their field of view. 13
3.2 Average scores for the GEQ factors, divided by session number (Order) and by Modality (Desktop or VR). Error bars represent 95% confidence intervals. Significant differences were observed for all factors except Tension/Annoyance. 17
3.3 Average scores for the presence factors, divided by session number (Order) and by Modality (Desktop or VR). Error bars represent 95% confidence intervals. Significant differences were observed for all factors. 17
3.4 Average scores for the simulator sickness factors, divided by session number (Order) and by Modality (Desktop or VR). Error bars represent 95% confidence intervals. Significant differences were observed for all factors. An order effect was also observed for Disorientation, such that the participants felt significantly more disoriented after the second session in VR. 17

4.1 The plot shows total posts returned for each search term, by month. It also reports the total number of posts made in each month (in hundreds). While the number of posts containing our keywords decline over time, it can be seen that this decline is representative of a decrease in the number of total posts, not decreased interest in these topics. 34

6.1 The Secret Shop 68
6.2 Each participant's gameplay was recorded and replayed to them on a monitor after leaving the experience. While watching the video, participants seamlessly reported the amount of presence they felt moment to moment indicated by the position of the pointer added at the bottom of their video (right is high, left is low) 71
6.3 These graphs visualize the amount of presence over time each participant reported using the AAR interface. The various colored lines show the start of a particular event in the data for each participant. The red line indicates when the long break event was administered, while the pink line indicates when the short break event was administered. The blue line indicates when a participant encountered or engaged with the in-game Jack-in-the-Box, of which some participants engaged multiple times. . . 72
6.4 Expected events that occurred during every participant's journey around the Secret Shop. The long break event showed a significant decrease in presence ($p = 0.0122$), with the short break event showing no significance ($p = 0.161$). The jack-in-the-box event trended towards a significant increase in presence (0.0519), but with a low median, signifying not all participants recorded this change. 74

Chapter 1

Introduction and Motivation

The consumer virtual reality (VR) space has undergone a massive transformation since the release of the Oculus Rift CV1 and HTC Vive in early 2016. Whereas previously, VR was primarily confined to laboratories and training facilities, millions of headsets are now used in homes for entertainment and other applications. A significant consequence of the widespread availability of VR is that more people are experiencing VR and for more extended periods of unsupervised time. When VR was confined to the laboratory, few people had the opportunity to spend any meaningful amount of time in VR. Now, it is not uncommon for users to spend hours in VR for weeks on end. As such, it is more important than ever that we understand how prolonged exposure to VR affects the people who use it.

The larger question driving this dissertation is "*What's most important/concerning to users in regards to their VR gaming experiences?*". From the research outlined in this manuscript, we address three significant areas of interest in answering this question. The first, simulator sickness, or VR's equivalent of motion sickness, has already been researched extensively by the VR community. The second, "lingering effects," relates to various changes in a user's behavior and/or mental framing of the natural world due to increased exposure to VR. Finally, the last is "Presence," or the feeling that you're actually in the virtual world which causes users to suspend disbelief and believe they are actually in the virtual environment, reacting to stimuli as if they were in the real world. My dissertation seeks to look into the two latter mentioned points by answering the questions "*How does extended exposure to a VR game affect the user's experience?*" and "*How is presence affected as a result of this increased exposure?*"

When considering how long-term exposure to VR affects people, it is crucial to recognize the distinction between studies that conduct longitudinal research *on* VR, and studies that conduct longitudinal research *using* VR. Studies in the first category inform us about how users with more experience using VR technology will respond to VR differently than users with less experience. Studies in the second category tell us about how users who have gone through a structured program using VR will be different from users who have not, in some other context (such as phobias or performance).

While many longitudinal studies *using* VR have been conducted, very little longitudinal research has been conducted *on* VR. There are many challenges associated with longitudinal research, especially when this research must be conducted in laboratory settings, as opposed to in the field [60, 100, 98]. The only aspect of VR that has received a significant amount of longitudinal research is how users' response to simulator sickness changes over time, as they gain experience using VR technology (though this research has largely been conducted in the context of military training simulations) [40, 24]. Almost every other longitudinal study involving VR has focused on the *application* of VR to a specific context, such as phobia [59] or PTSD treatment[50], training behavior [20], or social behavior [56]. While controlled, experimental longitudinal studies are essential for answering some questions, we argue that other methods can also be used in conjunction to gain insights about how users' responses *about* VR evolves over time as they gain experience with the technology.

Users have generated large quantities of data about their experiences with VR in online forums devoted to VR games. I used these forums as a lens to investigate how community beliefs and attitudes towards VR evolved over time. They also provide other researchers the opportunity to identify self-reported information about how a particular user's response to VR has evolved. There are limitations with this method, notably a lower degree of control than experimental studies, and the results of the study pertain to the community's beliefs as a collective, which may differ from actual relationships. However, this approach can enable research that would be nearly impossible to conduct experimentally due to either the rarity of the phenomenon or the number of participants required.

In my investigation, I used multiple methodologies to outline trends found in user experiences related to VR gaming. From the information gathered using these methods, I then analyzed and verified the findings surrounding user experiences regarding extended time spent playing VR games. This investigation was conceived following a logical and rational approach based on the series of

studies presented in this dissertation document.

In my first study, I found that feelings of presence are directly associated with preferences of how motion controls are implemented [62]. This finding was analyzed using one-on-one interviews and survey data gathered in a traditional laboratory setting, where games played on standard desktop scenarios were compared to those ported to immersive virtual environments (IVEs).

In my second study, using online forum discussions, I found that user perceptions, attitudes, and understandings of presence can change over time based on crucial game design choices, given affordances, and the amount of time spent in VR [63].

In my third study, more user experiences were again analyzed using online forums surrounding extended exposure to VR games. From this study, I found that extended exposure to VR can affect a user's perceptions and behaviors outside of VR as well, alerting the community of the powerful effect that VR can have on our mental state.

In my fourth study, I used the After Action Review (AAR) technique to capture changes in presence over time throughout a user's single gaming experience and observed how those moment-to-moment changes in presence better inform us of a person's overall VR experience. In this study, I found that presence changes both gradually and rapidly throughout a user's experience and can be heavily impacted by a user's expectations, the affordance inconsistencies of the application, and the level of engagement they are experiencing at any given second.

Finally, in my fifth study, I loaned out VR headsets to local novice users in order to track their perceptions of presence across the span of four weeks. Each participant conducted two interviews, one near their initial receipt of the headset and one near its return. Users were given the freedom to explore any VR games and applications of interest to them off-site at times convenient to them to simulate a regular VR consumer experience.

The results from these five studies led to many over-arching themes that surround how and why users' experiences and perceptions regarding presence can change as a result of time as they become more involved in VR gaming.

Chapter 2

Related Work

2.1 Longitudinal Studies and Virtual Reality

The goals of longitudinal research are to understand the "development of interacting processes over time" [32]. Aside from simulator sickness topics, little longitudinal research has been conducted in VR. Concerning this, our approach has been informed by published work in other related fields, in both descriptive and analytic terms [8, 25, 52, 30]. A number of longitudinal research studies have been conducted exploring consumer engagement with other forms of media, including video games [29, 3, 54, 2, 110, 10, 95], television [111, 34], smartphones [53, 33], and touchscreens [57]. Of these studies, research investigating engagement with video games is most relevant to consumer engagement with VR because of the similarities in content and their similar interactive nature. Several of these studies have evaluated natural behavior in online virtual worlds, such as *Second Life* [108] and *World of Warcraft* [75], and have examined a range of questions.

2.2 Comparisons of Non-Immersive and Immersive Gameplay

Relatively few studies have compared user experience when playing games in non-immersive and immersive settings. Tan et al. explored how playing Half-Life 2 on the Oculus Rift DK1 affected player experience, compared to playing on a desktop [97]. Players used an XBox 360 controller in

both conditions. Playing the game in VR resulted in more intense experiences, but also stronger feelings of cybersickness. Players also experienced a weaker sense of control over their motion and their aiming in VR, but an increase in flow. Martel et al. evaluated the effect of different head-based control schemes on user experience in a VR version of Team Fortress 2 [48]. Players performed best in the non-VR condition. However, they experienced the highest level of immersion in VR when using a control scheme where viewing direction was controlled by the HMD and targeting was controlled by the mouse. A blended control scheme that used both the HMD and the mouse position for movement and targeting resulted in improved VR performance, but reduced immersion. Shelstad et al. compared non-VR and VR versions of Defense Grid 2 [78]. The VR version resulted in moderate increases in player enjoyment and aesthetic appreciation. Seibert and Shafer investigated how VR and motion controls affected spatial presence, naturalness, and cybersickness while playing Half-Life 2 for a brief 20 minute session (motion controls were enabled using the Razor Hydra) [76]. Playing in VR increased feelings of spatial presence, however the use of motion controls actually *decreased* perceived naturalness.

2.3 Input and Travel for Immersive VR Games

Some research has considered new input and travel techniques for VR games (without comparisons to non-VR equivalents). Martel et al. considered how to blend HMD input (facing direction) and mouse input for maximum effectiveness, and found that immersion and performance were highest when HMD was used exclusively for controlling the view and steering of the avatar, while the mouse is decoupled and used separately to perform interactions [49]. Shewaga et al. found that room-scale travel increased immersion in a serious game for epidural preparation, as compared to a seated VR experience [80]. Bozgeyikli et al. found that teleportation compared favorably to two other travel techniques (walking in place and joystick control) [15]. Burgh and Johnsen considered whether users should be scaled to a homogeneous size when playing a game, or should be left as their natural size (which could give larger players an advantage over smaller players) [17]. Normalizing players scale had no effect on the game that was tested, and evoked diverse responses from users (some favorable, some negative), underscoring that whether or not to scale has no simple answer, and the implications of which should be carefully considered before implementing.

2.4 Online Forums

People often use online forums as a way to get answers to questions, tell stories, get access to expertise, offer their experiences, as well as read about the experiences of others [58]. Additionally, people have often sought advice from others using online discussion boards [105, 55]. Concerning the most visited sites on the web, Reddit is currently ranked as #6 in the United States, and #21 globally to date[1]. The site describes itself as a "home to thousands of communities, endless conversation, and authentic human connection" where there are currently over 330 million active users, over 138 thousand active communities, and 14 billion monthly screenviews[2]. On Reddit, users can submit textual content directly as submissions, allowing for others to comment, as well as create their own subcommunities named "subreddits." These subreddits are independent, dedicated to a specific topic, and moderated by other volunteer 'Redditors' - a neologism combining 'Reddit' and 'editor'. Within these subreddits, users generally stay within their own community [16], and are often vetted by bots, moderators, and other redditors when posting content or answers in their respective forums. This signifies a generally cohesive and trustworthy base of information that can be gathered from these users. Currently, some longitudinal research concerning Reddit posts has been done, though only relating to Reddit data as a whole, not focusing on any one particular subreddit [81].

2.5 Varying Degrees of Presence

The effects, variations, and experiences of presence have been well surveyed [83]. In terms of self-presence Biocca et al. describe short-term and long-term presence as the effect of the virtual environment on one's body, physiological state, emotional state, perceived traits, and identity [9]. Regarding the after-effects of presence, Stanney et al. demonstrate that the post-experience of presence can produce lingering effects such as dizziness and vertigo. This work also highlights the need to standardize measurement approaches for measuring these after-effects [91, 93].

Another method of measuring varying degrees of presence was to assess "breaks" of presence [83]. Slater and colleagues utilized physiological measures and self-report measures to measure the "time" in breaks [85, 86]. Additionally, Garau et al. created breaks during an experience in the virtual environment then asked questions about the breaks through semi-structured interviews [28].

[1] https://www.alexa.com/siteinfo/reddit.com
[2] https://www.redditinc.com/

This literature and the majority of scholarship revolving around interactivity has focused on research lab settings. However, Porter and Robb demonstrated over a two-year span that consumer attitudes and expectations surrounding presence could shift from passive to active, signaling a "maturity" of their understanding, triggers, and reactions to experiencing presence in VR [63]. A similar finding by Bailenson and Yee also demonstrates longitudinally that presence ratings can be substantially different over a period of time [5], specifically that repeated use of the system led to varying changes in presence. This study suggests that initial feelings of presence during the first few experiences in the virtual environment are generally higher compared to later in the experience. These two studies highlight that additional factors may influence presence over time and that presence, as a result, decreases after repeated exposure.

2.6 Factors that Influence Presence

Interactions and events within the virtual environment have been known to influence one's subjective experience of presence [74]. Varying factors within the environment can increase and decrease one's experience of presence. For example, Welch et al. demonstrate increases in presence when compared to delayed visual feedback [104], showing that visual feedback delay was the key cause to decrease presence. Slater et al. showed that body movement could also positively affect presence [87]. Several other pieces of scholarship [66, 35, 88] also demonstrate that interactivity within the environment has a significant effect on presence. Regarding experiments which replicate consumer activities (e.g., games, entertainment), Steed et al. demonstrated that when users were placed in a virtual bar using a consumer HMD (e.g., Samsung Gear VR, Oculus Go), they had positive feelings of presence when using an avatar but presence decreased when interacting within the environment [94]. This decrease in presence via interaction could be linked to a few things within the environment, such as visual features (e.g., fidelity) or emotion. For example, Gilbert demonstrated that the perceived realism of a virtual environment could be more dependent on the users' expectations of the environment [31], and Riva and colleagues have also demonstrated that emotionally charged environments have a greater feeling of presence [68]. With these considerations in mind, plausibility and realism can lead to realistic behaviors within the environment [84], which can effect presence.

2.7 Measuring Presence

Presence as a construct has been traditionally assessed summatively via self-report, behavioral, and physiological measures, with self-report being assessed "after-the-fact" [104]. Each measure has distinct advantages and disadvantages over the other, but each also presents an interesting and creative methodology for assessing and understanding presence.

Self-report measures are generally referred to as presence questionnaires, typically completed by the participant after the experiment. The Slater-Usoh-Steed questionnaire was the first form of a self-report questionnaire [89], later updated to another version [101], mainly focused on reporting feelings of being 'in' the virtual environment (e.g., place presence). Kim and Biocca et al. created a self-report measure for general media use involving the feelings of arrival (e.g., feeling in the environment) and departure (e.g., feeling outside the environment) [39]. This adaptation to other media use signifies the vast flexibility of "place presence." Another self-report scale that emerged by Witmer and Singer focused on control, sensory, distraction, and realism [107]. In this questionnaire emerged another popular self-report measure, the immersive tendencies questionnaire (ITQ). This measured one's tendency to become involved in everyday activities, which then assessed their likelihood to experience presence in a virtual environment. Additionally, qualitative post measures have been used to assess presence. In particular, Mai and Hußmann introduce a post-experience drawing method to collect temporal measures of presence [47]. One key highlight of this work is how participants can provide a *descriptive model* that creates distinct points relating to the phase at which a participant perceives presence within the environment.

As technological advancements continued *presence* as a concept evolved to more complex forms. For example, Lombard et al. describe presence as six facets: social richness, realism, transportation, immersion, social actor via medium, and medium as the social actor [46], this resulted in a 103-item questionnaire. To date, many other self-report measures have also been created to measure various aspects of presence [6, 13, 71, 109, 73, 44, 42].

Behavioral Measures are commonly referred to as responses to threatening stimuli or socially conditioned behaviors [79]. One example was done with Slater et al., who used the gesture of pointing to demonstrate participants' presence within the environment via [90]. In another example, Thie and Van Wijk used "comeback rate" as a methodology to evaluate presence by stating that participants who came back more often had more attributes in their experience involving social

presence [99]. Regenbrecht et al. demonstrated that using emotional responses could be a strong measure of presence, in which they designed an experiment to elicit fear of heights [67]. Freeman et al. attempted to examine presence by examining the posture participants were in when viewing a video; however, there was no significant relationship between presence and postural response [26]. Behavioral measures are synchronous and have advantages such as being a non-intrusive way to measure presence as well as an "objective" measurement rather than a "subjective" post-experiment measurement (i.e., self-report).

Physiological measures are commonly measured using skin conductance response, electrocardiogram data, and electrodermal activity [44]. However, in another study, the effects of emotional media and display size on presence did not correlate with physiological metrics and presence [23]. Therefore other technologies such as fMRIs have been measured to assess presence by Bouchard et al. [12, 14, 70] and Baumgartner et al. [7]. While Bouchard et al. asserted that the parahippocampus is the brain region most associated with "the feeling of presence", Baumgartner et al. pointed to the dorsolateral prefrontal cortex as the region for presence, although the difference between the two may be based on their different methodologies. Heart rate has also been a measurement used to measure presence. Meehan et al. used skin temperature to assess presence and found that a participant's heart rate increased when they viewed a visual cliff significantly correlating with a self report presence questionnaire [51], and Skarbez et al. used heart rate in combination with surveys as well to assess presence [82]. However it should be noted that Meehan et al.'s work was different from previous scholarship, where the use of physiological metrics was used to measure *breaks* in presence [85, 82] or incidental changes [86]. Where physiological measures have benefits over self-report and behavioral measures is shown in how they are truly objective measures and can be both synchronous and continuous. However, they are not fully reliable at capturing the entirety of a user's experience. For example, if a threatening or surprising event was not occurring, a participant could still feel high levels of presence and it not be captured through this method. Even so, there is also not an obvious method of appropriately equating a physiological reading to how present a person was feeling at the time of the event.

2.8 Presence and Exposure to Virtual Environments

There has been some research done where the duration of exposure in a virtual environment has been shown to correlate with peoples' sense of the presence but there is some uncertainty as to what the nature of the correlation is and should be [91]. It was also shown that presence and duration of VR exposure were positively correlated in an investigation exploring virtual navigation tasks and training tasks [38]. Researchers have explained this positive correlation by speculating that longer durations in the virtual environment have led people to adapt, understand, and become more familiar with their virtual environment, ultimately causing them to perceive higher levels of presence [92]. Venkatakrishnan et. al, proved that by affording control to a user in a virtual environment, feelings of presence can be also be amplified [103]. They also found that experiencing cybersickness has the potential to significantly lower one's feelings of presence. They believe this to be accounted to users becoming more internally focused as a result of cybersickness, thereby rendering them less able to process aspects of the virtual environment.

Chapter 3

Study 1: Guidelines on Successfully Porting Non-Immersive Games to Virtual Reality: A Case Study in Minecraft

This study begins to answer the first of the leading questions, "*How does extended exposure to a VR game affect the user's experience?*" by gathering data from users who were asked to play a single VR game over the course of 3 week study. The themes gathered here strengthened the notion that although multiple gaming sessions can have different sub-goals in mind, there are certain commonalities in the game's design that the users expects in order to enjoy their experience. The question of "*How is presence affected as a result of this increased exposure?*" is also given more light as a result of this study due to the data that suggests that the amount of time it takes to feel present is reduced after repeated exposures to the same environment. Furthermore, we can see from the results of this study that high levels of presence can be maintained for the same game as long as certain criteria are met, as outlined in the results below.

In this study, we explored how user experiences changed when comparing game play while playing Minecraft on a desktop PC and experiencing an immersive virtual reality port. Fourteen players completed six 45 minute sessions, three sessions played on the desktop and the remaining three in VR. The Gaming Experience Questionnaire, the i-Group presence questionnaire, and the Simulator Sickness Questionnaire were administered after each session, and players were interviewed at the end of the experiment. Overall, participants strongly preferred playing Minecraft in VR, despite frustrations with using teleporation as a travel technique and feelings of simulator sickness. users also reported their enjoyment in using the motion controls afforded by VR, while still continuing to use indirect input under needed circumstances. However, using the indirect input controls did not appear to negatively impact feelings of presence.[1]

3.1 Experimental Design

3.1.1 Experiment simulation and setup

A separate Minecraft world was created for each participant. To ensure that participants received comparable experiences, each world was initialized with the same world seed (-3734132139203251714). This seed was selected by randomly generating worlds until one was found that was near a village and close to several different biomes. The standard Minecraft texture pack was used, and graphic settings were set to high. Headphones were worn while playing the game. Participants played on normal difficulty, and in survival mode.

Participants in the desktop modality played on a desktop computer equipped with a i7 processor and an Nvidia GTX 1080. Participants were seated at a desk with a 22" 1080p monitor and standard keyboard/mouse. The same computer was used for the VR modality. Participants in the VR modality played using the HTC Vive in a 15' by 15' space. The Vive chaperone bounds were configured to create a safe space within which participants could walk freely without the risk of running into obstacles.

3.1.2 Participants

Fourteen people participated in our study (10 males). Ages ranged from 18 to 31 ($\mu = 21.07, \sigma = 3.79$). Thirteen of our participants reported having 50+ hours of prior experience with

[1]Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play, Pages 405–415

(a) Mining (b) Building (c) Teleporting (d) Fighting

Figure 3.1: Examples of performing various activities in Vivecraft. Note the changing hand and tool positions in the different images. The Vivecraft interface can also be seen, which floated in front of the player low in their field of view.

Minecraft; the remaining player reported having 10 to 20 hours of prior experience. We specifically recruited participants with prior experience playing Minecraft so as to avoid learning effects related to Minecraft itself. Twelve participants identified as avid gamers, having been playing video games for 10+ years. Six participants reported prior experience with virtual reality; one reported 20+ hours of VR experience, another 5 to 10 hours, three had 1 to 3 hours, and the last had less than 1 hour of prior experience.

3.1.3 Methodology

Upon enrollment in the experiment, we explained the study procedures to participants and requested their informed consent. After consenting, participants completed a demographic survey about their time spent playing Minecraft and other video games, time spent in VR, and a battery of standard personality surveys. Participants were then assigned to either the VR-first condition or the Desktop-first condition. Participants completed three 45 minute sessions playing Minecraft on a standard desktop computer and three 45 minute sessions playing Minecraft in immersive VR using the HTC Vive. Multiple sessions were included in the experiment to ensure that participants received a significant amount of exposure to playing Minecraft in VR, and to allow us to explore whether any longitudinal effects could be observed. Participants were not given specific tasks to complete in these sessions, but instead were encouraged to play freely. Participants completed all sessions in one modality before switching to the other. The order in which modalities were presented was counterbalanced.

Before beginning the VR sessions, participants received a 15 minute orientation session explaining how to use the HTC Vive and how to play Minecraft in VR. Their interpupillary distance (IPD) was also measured and the HTC Vive set accordingly. This orientation took place in a

Minecraft world specifically created for use as a tutorial. Participants were instructed how to safely move around the space without running into walls, how to use teleporation to cover long distances in Minecraft, how to interact with tools, weapons, nearby animals, villagers, and enemies, and how to use the virtual crafting interface (see Figure 3.1 for examples of these activities in Vivecraft). This orientation session was separate from the three VR sessions, and a new world was loaded when participants began their first VR session. As all participants were well acquainted with Minecraft, no desktop orientation session was provided.

Participants completed the experiment over a three week period; they completed the first modality in the first week, took a break in the second week, and completed the second modality in the third week. Participants could not complete more than one session on any given day. Sessions in a given week were scheduled in advance to prevent scheduling conflicts with other participants. We also asked participants to refrain from playing Minecraft or any VR games for the duration of the experiment, so as to avoid the experiences in other games from affecting participants impressions after the experiment.

At the start of each session, we provided a binder to participants that contained the recipes required to create common items in Minecraft. We did this to allow participants in the VR session to familiarize themselves with recipes they may have forgotten, as they would not be able to look them up after they put on the headset. If a participant forgot a given recipe, they could ask the study proctor for it, but they were not allowed to remove the headset unless they were experiencing distress (this did not occur for any participant). Near the end of the session, the study proctor gave a verbal '5 minute warning' to the participant. This allowed participants to complete any tasks they were currently working on and to find a safe place to log off.

Participants completed several surveys at the end of each session, including the Game Experience Questionnaire (GEQ) [37], the i-Group presence survey (IPQ) [72], a social presence survey [4], and the Simulator Sickness Questionnaire (SSQ) [69]. We conducted semi-structured interviews with participants after their final session. Participants were not compensated for completing the experiment.

3.1.4 Research Questions

This research extends on prior work by considering how the use of motion controls in a VR port alters user experience. Prior work regarding VR ports examined early ports to VR systems

that did not yet support motion controls. As a result of these findings, we sought to understand how player experiences may differ in an immersive VR game as compared to traditional gaming affordances. We narrowed down three essential questions that are currently unanswered in the research literature:

R1: How are user experiences affected by the use of motion controls in an immersive VR game?

R2: How do users perceive the use of motion controls when engaging in an immersive VR game?

R3: How are user experiences affected by the travel methods implemented within an immersive VR game?

3.2 Quantitative Results

Linear mixed models were used to analyze the results of the various questionnaires. Modality and session number within a given modality were used as fixed effects (including an interaction term). As random effects, Participant ID was used for both intercept and slope with respect to modality. Unless stated otherwise, visual inspections of residual plots did not reveal any obvious deviations from homoscedasticity or normality. P-values were obtained by likelihood ratio tests of the full model with the effect in question against the model without the effect in question [106].

3.2.1 Gaming Experience Questionnaire

Players completed the Gaming Experience questionnaire (GEQ) [37] after each session. The GEQ contains seven factors: competence, immersion, flow, tension/annoyance, challenge, negative affect, and positive affect. Each factor was analyzed using a separate analysis. Modality significantly affected competence ($\chi^2(1) = 19.465, p = 0.0015$), immersion ($\chi^2(1) = 96.455, p < 0.001$), flow ($\chi^2(1) = 60.365, p < 0.001$), challenge ($\chi^2(1) = 38.876, p < 0.001$), negative affect ($\chi^2(1) = 28.694, p < 0.001$), and positive affect ($\chi^2(1) = 73.263, p < 0.001$), but not tension/annoyance ($\chi^2(1) = 9.489, p = 0.0911$). Order was observed to only affect positive affect ($\chi^2(1) = 9.6523, p < 0.0467$). No interactions between order and modality were observed.

The relationship between Modality and Order on the GEQ factors is shown in Figure 3.2. The linear mixed model parameters for modality are reported in Table 3.1. We do not report model parameters for order because order had little effect on the models. The Estimate column reports

the average change when moving from the desktop to VR (the slope in a linear model). Effect sizes are reported as r^2 values, as calculated by the piecewiseSEM package in R [43]. Based on these effect sizes, modality had a large effect on Immersion and Flow, a moderate effect on Challenge and Positive Affect, and a small effect on Competence and Negative Affect.

GEQ Factor	**Estimate**	**SE**	**T**	**p-value**	r^2
Competence	-0.357	0.154	-2.311	0.028	0.037
Immersion	0.833	0.152	5.474	0.000	0.343
Flow	0.814	0.221	3.686	0.001	0.307
Tension/Annoyance	0.214	0.170	1.254	0.219	0.012
Challenge	0.410	0.165	2.486	0.018	0.215
Negative Affect	-0.357	0.169	-2.104	0.046	0.047
Positive Affect	0.429	0.162	2.641	0.016	0.181

Table 3.1: Modality parameters for the linear mixed model for the GEQ items. Estimate reports the average change in score when moving from the desktop to VR. Effect sizes are reported as r^2; by convention, effect sizes < 0.1 are small, between 0.1 and 0.3 are moderate, and > 0.3 are large.

3.2.2 Presence and Social Presence

Players completed the IPQ [72] after each session. The IPQ contains four factors: general presence (PRES), spatial presence (SP, i.e. the sense of being within the virtual space), involvement (INV, i.e. the extent to which one becomes fully involved with the virtual world and forgets the real world), and experienced realism (REAL, i.e. how real the virtual world seemed). Each presence factor was analyzed using a separate analysis. Modality had a significant effect on PRES ($\chi^2(1) = 85.315, p < 0.001$), SP ($\chi^2(1) = 98.389, p < 0.001$), INV ($\chi^2(1) = 59.926, p < 0.001$). and REAL ($\chi^2(1) = 59.01, p < 0.001$), Order was not observed to affect any factor, nor were any interactions observed between order and modality.

Players also completed a modified version of a social presence questionnaire developed by Bailenson et al. [4] after each session; the questionnaire was modified to refer to "people and/or creatures", rather than to refer to a specific social entity. This questionnaire contained a single factor. Social presence was affected by both modality ($\chi^2(1) = 52.916, p < 0.001$) and order ($\chi^2(1) = 12.618, p = 0.013$), however no interaction was observed ($\chi^2(1) = 0.9285, p = 0.629$).

The relationship between Modality and Order on presence is shown in Figure 3.3. The linear mixed model parameters are reported for modality in Table 3.2. Based on these effect sizes, modality had a large effect on Spatial Presence, General Presence, and Experienced Realism, and a

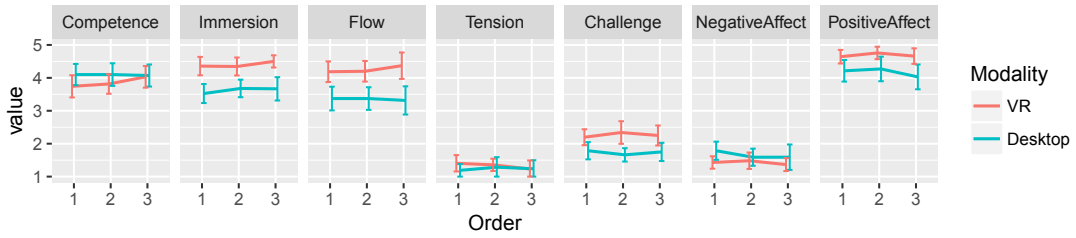

Figure 3.2: Average scores for the GEQ factors, divided by session number (Order) and by Modality (Desktop or VR). Error bars represent 95% confidence intervals. Significant differences were observed for all factors except Tension/Annoyance.

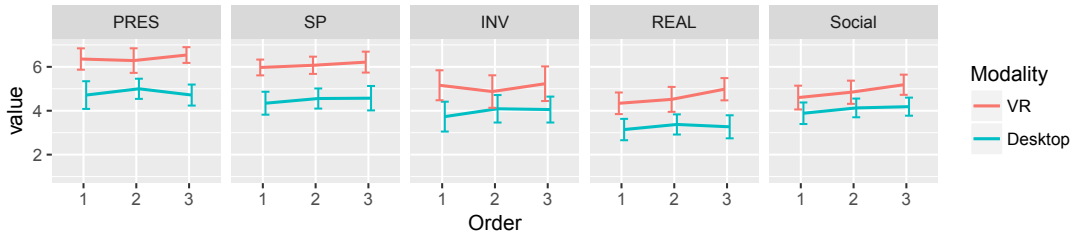

Figure 3.3: Average scores for the presence factors, divided by session number (Order) and by Modality (Desktop or VR). Error bars represent 95% confidence intervals. Significant differences were observed for all factors.

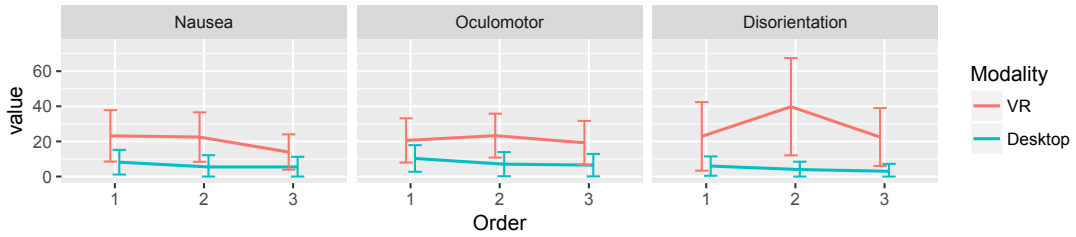

Figure 3.4: Average scores for the simulator sickness factors, divided by session number (Order) and by Modality (Desktop or VR). Error bars represent 95% confidence intervals. Significant differences were observed for all factors. An order effect was also observed for Disorientation, such that the participants felt significantly more disoriented after the second session in VR.

moderate effect on Involvement and Social Presence.

3.2.3 Simulator Sickness

Players completed the SSQ [69] after each session. The SSQ divides simulator sickness into three factors: nausea, oculomotor, and disorientation. Each factor was analyzed using a separate analysis. Modality affected nausea ($\chi^2(1) = 40.826, p < 0.001$), oculomotor ($\chi^2(1) = 40.300, p < 0.001$), and disorientation ($\chi^2(1) = 72.833, p < 0.001$). Order was observed to have a significant effect on disorientation ($\chi^2(1) = 10.654, p = 0.0307$), but no other factor. An interaction effect

Presence Factor	**Estimate**	**SE**	**T**	**p-value**	r^2
General Presence	1.642	0.244	6.717	0.000	0.393
Spatial Presence	1.628	0.246	6.622	0.000	0.451
Involvement	1.429	0.404	3.537	0.002	0.162
Experienced Realism	1.196	0.261	4.584	0.000	0.315
Social Presence	0.714	0.226	3.154	0.004	0.146

Table 3.2: Modality parameters for the linear mixed model for the presence factors. Estimate reports the average change in score when moving from the desktop to VR. Effect sizes are reported as r^2; by convention, effect sizes between < 0.1 are small, between 0.1 and 0.3 are moderate, and > 0.3 are large.

between modality and order was also observed for disorientation ($\chi^2(1) = 6.1914, p = 0.0452$).

The relationship between Modality and Order on simulator sickness is shown in Figure 3.4. The linear mixed model parameters are reported for modality in Table 3.3. Based on these effect sizes, modality had a moderate effect on all simulator sickness factors.

Sickness Factor	**Estimate**	**SE**	**T**	**p-value**	**r^2**
Nausea	14.991	6.234	2.131	0.024	0.120
Oculomotor	10.287	5.606	1.835	0.078	0.123
Disorientation	16.903	10.737	1.574	0.130	0.155

Table 3.3: Modality parameters for the linear mixed model for the SSQ factors. Estimate reports the average change in score when moving from the desktop to VR. Effect sizes are reported as r^2; by convention, effect sizes between < 0.1 are small, between 0.1 and 0.3 are moderate, and > 0.3 are large.

3.3 Semi-Structured Interviews

Participants completed a semi-structured interview after completing all six sessions in Minecraft. In this interview, participants were asked to talk about their experience and were queried about specific components of the game (e.g. navigation, combat, crafting, etc) and how each modality impacted their experience. These interviews were then transcribed for later analysis. We analyzed the transcripts with a focus on three core themes: general user experience, travel and simulator sickness, and interactions with the world. Multiple sub-themes emerged within each of these core themes, all of which are discussed below.

3.3.1 General User Experience

We first discuss several themes related to general user experience in VR, and the relationship between user experience and feelings of presence.

3.3.1.1 Scale is a Big Deal

Players were almost universally impressed by the sense of scale created by VR. Most players referenced the unexpected "bigness" of the Minecraft world early in their interviews, e.g. "*The first time I put the goggles on, the sense of scale was what really drew my attention. I was just like whoa!*" (P2). Many first expressed surprise at how large the blocks were, but later reflected that the scale was accurate given that each block is intended to be a cubic meter, e.g. "*In Minecraft, a block is a cubic meter. It felt like that was to scale, but [the blocks] were still a lot bigger than I imagined*" (P3). Players felt that "*real scale ... makes it a lot more immersive*" (P2), often because it enhanced "*the sense of being in an environment instead of staring at a screen*" (P9). This scaling not only elicited higher presence, but also affected whom the players interacted with. For example, when describing that animals, P8 stated that "*they're more appropriately scaled to the player model and eye level*" and P13 perceived his enemies as "*pretty life-sized... it was like it was there!*" This increase in presence in turn heightened players' emotional responses, such that enemies appeared to be "*a lot more scary*" (P15) and "*a lot more intimidating in VR because it felt like they were really there*" (P10). P8 stated that he felt "*more engaged*" because the enemies were "*more about your height*" and made him feel "*like there's a lot more present danger*". Scale also made some players feel more engaged when building structures, e.g. "*Everything is a lot bigger in virtual reality, right? So it actually feels a lot... a lot more real, and a lot more interesting to build things*" (P7). The larger sense of scale did make it more difficult for some players to build vertically in VR, however these players reported they still preferred VR due to its overall more enjoyable experience.

It should be noted that at least part of the sense of scale created by VR can be associated with an increase the field of view (FoV). Given where players were seated in the Desktop condition, the display's horizontal FoV was approximately 55 degrees, compared to the 100 degrees of the HTC Vive. However, non-immersive displays that can achieve FoV's similar to VR are very rare, so an increase in sense of scale is likely to be expected for most users when porting a non-immersive game to VR.

3.3.1.2 Weaker Control Over the Environment, Heightened Emotions

Participants also linked their heightened emotion experience to the feeling that they had less control over their environment, e.g. "*I was really nervous about what's around corners, I feel like I have less control of the environment*" (P5). Tension and fear were the most frequent emotions linked to the loss of control, e.g. "*it felt a lot more scary when you're fighting in VR, partially because it's a lot easier to control and move around on desktop*" (P15). Though we often think of tension and fear as negative emotions, they can be desirable in games if associated with challenge and opportunity. Players felt that VR actually provided them with additional information about the environment, e.g. "*I could actually tell where sounds were coming from. I feel like they're actually there with me*" (P9), but this didn't lead to increased feelings of control. It seems likely that these specific discussions of control are not actually linked to the performance of motion controls, but instead center around heightened perspective and involvement with the world, leading players to develop a better perspective of the threats present in the world that are not under their control.

3.3.1.3 Players Accepted Minecraft's Non-Realistic Appearance

Minecraft makes no attempt to appear visually realistic, either in geometry or in texture. Most players made no reference to the visual appearance of Minecraft in VR. Three participants did make reference to the "*pixelated graphics*" (P2), and how it reminded them that "*it's Minecraft*" (P5). However, these players mentioned the pixels in the context of expressing surprise at how the experience was "*a lot more immersive than I thought it was going to be*" (P2). P10 linked the feeling of presence she experienced to how she was "*actually seeing it, and when I turned my head, it's all around me and I looked down and I can see my arms even though they're, you know, pixels*". While most players linked presence to interaction, like P10, P2 also linked it to the visual experience of the world, e.g. "*I actually just sat down and watched the stars move. I mean, they're just pixels, but it felt really cool. Like being on top of mountain... I definitely felt present in those moments*". These observations, especially when coupled with the high presence scores shown in Figure 3.3, underscore that visual realism is not essential for deep presence and immersion, but that it can also be achieved in appropriately stylized environments.

3.3.1.4 Enhanced Identification with the Minecraft Avatar

Playing Minecraft in VR increased players' feelings that they actually were *the* Minecraft avatar, as opposed to seeing through his eyes from the outside. Players regularly switched between third- and first-person perspective when talking about the transition from playing Minecraft on the desktop to playing in VR, e.g. "*You feel like you're falling a little bit, definitely, compared to the desktop where you're just watching the model fall*" (P2, discussing what it felt like to jump off an edge in Minecraft). Perspective switching was often closely associated with the sensation of being "in" the world, e.g. "*On the desktop, it's more like you're looking into the world ... As opposed to VR it's like– BAM! you're in the world*" (P12).

This feeling of ownership was attributed to both the first-person point of view afforded by VR, e.g. "*Like when there's something running at you, it's not just like running at the camera point on a screen, but it's more like it's running at my face*" (P6), and to the ability to interact with the world through the motion of one's hands, e.g. "*It actually felt like you were holding the tools, like your hands were right in front of you right, like they were in the game. And you could move them, I guess more realistically*" (P9).

Players could not see the bodies of their avatar while playing Minecraft, only their hands. Like the rest of Minecraft, these hands were blocky and pixelated. However, they were also sufficient to create strong feelings of hand ownership "*I think the hands were cool in VR, to be able to see the hands, that made me feel like this is me*" (P13).

3.3.2 Travel and Simulator Sickness

Vivecraft allowed players to travel via either motion controls or indirect input. Players could either move by physically walking, or by pointing where they wanted to move and pushing a button to teleport there. Teleportation is primarily used because the virtual world is much larger than the physical space available to walk in.

3.3.2.1 Teleportation Was Generally Disliked by Players

Players did not like being forced to use teleportation as their main travel technique. Players recognized it as a "*limitation of the technology*" (P2) and thought it was "*easy to use*" (P3), but also felt that it was "*immersion breaking*" (P2) and "*boring*" (P8). At least part of the frustration

with teleportation is that it did a poor job of communicating the feeling of actually walking through a world. Instead, players felt like they were "*just standing still and hopping around*" (P8) because "*you're not actually walking you're just teleporting everywhere*" (P15). This in turn affected their sense of presence because, unlike many other aspects of VR, "*it didn't really require any immersive activities on your part*" (P2). Players also sometimes found teleportation to be disorienting, e.g. "*when teleporting you get kinda choppy, like once you teleport you're like 'where am I?*" (P13).

Players did appreciate some aspects of teleportation, but this was always couched in terms of a change in game mechanics. Teleportation made it easier for players to travel long distances quickly, e.g. "*trying to get long stretches*" (P9), and "*access different areas quicker*" (P7). P12 mentioned that teleportation changed his entire play style, saying that it was easier to "*go up cliffs and walls*" and that "*once I got used to it that became my normal VR play.*" Teleportation also opened up "*a new way to look at combat*" (P8), where some players became "*more likely to like attack enemies because I could teleport away if necessary*" (P11). In contrast, other players were less likely to engage in combat because while "in the desktop version I'm able to jump to the side or stuff like that" (P6), dodging in combat actually became more difficult when forced to rely on teleportation. Overall, teleportation "*definitely changed the play style*" (P7) of players. These changes may not be desirable from the developers perspective, as they may break carefully balanced systems.

3.3.2.2 Room-Scale Locomotion Isn't Much Better

Nearly all players would have preferred moving around by physically walking, as opposed to teleportation. Players felt that moving via physically walking increased involvement and immersion, e.g. "*Your definitely more physically involved when you're like walking around. That's why I don't like the teleporting, you know you're not walking*" (P2), and enjoyment "*being able to like actually walk around would be even more fun*" (P6).

However, players also quickly ran into the physical limits of the real world. As the world in Minecraft is much larger than the physical environment available to players, the Vive displays a safety barrier (the "chaperone bounds") when players are near the edge of their playspace. Players found the need for chaperone bounds frustrating, e.g. "*it's frustrating having to center yourself to be able to move more so you have to walk back to the center to get a few more feet of walking*" (P11), immersion-breaking, e.g. "*when you run into a [chaperone bound], it takes you out a little bit because you're somewhat more aware of [the real world]*" (P13), and thought that it interfered with their

ability to play the game, e.g. "*I had to change what I'm doing because I had to react to something in the room that I was in rather than where I was in the virtual game*" (P12). This limitation was the least favorite part of the experience for many players, who regularly wished for alternative solutions, e.g. "*I wish you could walk around more but I realize the space is a limiting factor*" (P11). Players suggested that the game might be more fun if "*you had those 3D omnidirectional treadmills*" (P6) or could play with "*an untethered headset, in like a huge warehouse where you can just walk around*" (P3).

3.3.2.3 Players Adapted to Simulator Sickness

Players experienced significantly more simulator sickness in VR than on the desktop. The symptoms most commonly reported were disorientation, eye strain, and headaches. Other players mentioned that they experienced "*a really bad headache*" (P15) and felt "*dizzy*" (P2, P10). When players first entered VR, they sometimes said that "*[the ground] felt like uneasy beneath me*" (P2). However, in the interviews, many players felt that these feelings diminished over time, e.g. "*after the first day I didn't notice it at all*" (P11), "*during each session it got better*" (P15), "*I was slightly dizzy on the first day, but in the other 2 sessions I didn't feel any sickness or anything*" (P2), and "*the first day was the worst but then it got better, and today I had little problems*" (P13). Only one player said that the experience get worse over time, e.g. "*I feel like I got more dizzy as the days went on*" (P10).

Prior research has shown that simulator sickness is strongly linked to incongruities between virtual and physical motion [77]. Participants discovered this connection for themselves during the experiment, saying that sickness happened because "*what you're doing in the real world doesn't match to what you're doing in the game*" (P9). Two common sources of simulator sickness were mentioned by participants: being swept away by running water, e.g. "*your person starts flowing with the water, and you feel like you're supposed to be moving but you're just standing still*" (P3), and jumping off a cliff, e.g. "*falling, you feel like you're falling but you're not really falling so it's...kind of visually... or I guess physically confusing*" (P9). Thankfully, these participants felt that the effects of these events "*doesn't last very long*" (P9) and that they "*got better as I get used to it*" (P12). More than one participant deliberately set out to experience these activities, motivated by curiosity for new experiences "*like walking off edges*" (P12). P13 "*knew that I wanted to try falling*" when he started the experiment. Other players intentionally walked off of the edges of cliffs or jumped

out trees because "*that kind of stomach turn was interesting, thrilling I guess*" (P2). P2 even went so far as to build the tallest tower possible in order to jump off it. Smaller vertical motions, like stepping up and down blocks on normal irregular terrain could also "*get easily disorientating*" (P8). A few other singular events were also mentioned. For instance, P12 instantly "*got a headache*" when he went through a nether portal, because "*everything started moving*".

3.3.3 Interaction with the World

Most common actions performed in Minecraft are supported in Vivecraft via motion controls, including mining, combat, shooting a bow, placing blocks, eating, rowing a boat, swimming, and climbing ladders. Many of these actions (though not all) could also be performed via indirect methods. For instance, mining could be performed by either swinging a pickaxe into a block or by pointing the pickaxe at a block and pulling the trigger. We focus primarily on mining and combat behaviors in this section, as these were the behaviors players spent the most time discussing.

3.3.3.1 Preferences for Motion Controls Depends on the Task

Players did not reveal a straightforward preference for either motion controls or indirect input for either mining or combat. When discussing the tradeoffs between both methods, one player summarized it thus: "*With the motion controls, it felt like you put more effort in, and you got more out of it*" (P3). Whether or not players actually used motion controls depended on whether the reward they got out of it exceeded the additional cost imposed by it. A complex web of factors influenced the respective rewards and costs associated with the use of motion controls. These factors include the enhanced sense of immersion and enjoyment created by using motion controls, the physical cost of using motion controls, the emotional intensity associated with the action being performed at that point in time, how reliable players felt the motion controls were, how important it was that the action succeed, and the frequency with which an action was performed. Mining is one of the most commonly performed activities in Minecraft (we consider collecting wood and other resources under this heading as well). The general consensus was that while it was fun to be able to swing the pickaxe, it quickly got tiring and repetitive, which led people to switch to using indirect input while mining, e.g. "*it was neat I could actually swing my arm to pick at ore or dig or tunnel line or whatever. Usually after a while my arm would get tired so I would give it a rest. Or if I get tired of that I would just go back to using the button*" (P9). Another player,

speaking of using the trigger, said that it was "*just easier, more convenient, less tiring*" (P10). Players generally experienced little reward when using motion controls for mining, as mining was a common activity with little emotional reward (on average), and the physical cost required to actually swing the pickaxe was high. However, under certain rare circumstances, mining took on a greater degree of emotional import. Occasionally while mining, players would discover a very rare and useful item, such as a diamond. Under these circumstances, players reported that they stopped using the trigger to mine and switched back to physically swinging the pickaxe, e.g. "*When I finally actually [found] some diamonds, I made sure to use the actual physical controls for that– That was real fun*" (P6). It seems as though the use of motion controls serves to amplify the intensity of the emotions experienced when performing an action. Players are willing to pay the extra physical cost required to swing a controller so long as the action is exciting.

A second consideration also influenced players use of indirect input while mining: motion controls could only be used to mine blocks their pickaxe could touch, while the trigger could be used to mine blocks that were further away (the standard behavior in Minecraft). This difference in capabilities motivated some players to use the trigger to mine, even when they would have otherwise preferred to physically swing the pickaxe, e.g. "*I wish that you could extend your [physical] reach a little bit further. Then I probably wouldn't have been using the trigger at all*" (P6). In this case, the increased capabilities of the indirect method also increased the cost of physically swinging the pickaxe, as it reduced the number of blocks which were accessible from a given location.

Players found motion controls to be more rewarding during combat. Much of this reward came from the enhanced sense of immersion that direct input provided, e.g. "*it felt more authentic, of course doing the actual combat with the sword, you're actually swinging your arms*" (P9), which also increased feelings of excitement, e.g. "*combat stuck in my mind because it felt more exciting, being able to swing with your arm to actually kill things*" (P2). The enhanced perspective afforded by VR also strengthened the instinct to physically lash out at approaching enemies, which was satisfied when the player physically swung a weapon, e.g. "*the enemies were moving and coming at you and stuff. You just feel more like, like you wanna get at them*" (P2). Like mining, physically swinging a sword was sometimes less effective than pointing the sword at an enemy and pulling the trigger. Some players responded to this by switching to using indirect actions to attack. However, other players instead merged motion controls and indirect methods, where they would swing the sword while also pulling the trigger, so as to get the enhanced immersion without reduced effectiveness,

e.g. "*I couldn't get [the swinging] to work consistently, so I just kinda swing and click the button just to make sure it would go off*" (P2). This behavior emphasizes the enjoyment players derived from being able to use motion controls in combat. Frequency of combat is another consideration, though not one referenced by players; mining is a very common activity, and one that is often engaged in continuously for long stretches of time. In contrast, combat occurs sporadically for short periods of time. Accordingly, the costs imposed by physically swinging the sword don't have time to accumulate like they do with mining, which means frequency was not a significant problem when using motion controls in combat.

In addition to mining and combat, players occasionally mentioned motion controls for other activities as well. These references were almost always positive. Examples include eating "*I did like being able to eat the carrot by just holding it up to you, I thought that was cool*" (P11), feeding a wolf "*I have food in my hand and it was just looking up at me and, I mean– it's like half my height. That was really cool*" (P2), rowing a boat "*having to physically have to row my boat over the ocean, that kind of stuff made it feel more of like if I'm actually exploring around*" (P5), and swimming "*when I first got into VR I jumped into water and I didn't know how to swim, and I figured out how to swim, it was just natural of like 'Oh, I'm gonna pretend to swim' and then I was swimming. It was cool for the things that are intuitive*" (P13). The key point raised in this last example is the intuitiveness of these minor actions. In each case, players wanted to perform an action they knew how to do on the desktop, but didn't necessarily know how to do in VR. Figuring out how to successfully perform "intuitive" motion controls produced increased feelings of engagement and enjoyment.

3.3.3.2 Inconsistent Motion Controls Lead to Negative Experiences

Some players also experienced difficulty getting some motion controls to function consistently. This negatively impacted player perceptions of the motion controls, overall preferences, and the game itself, e.g. "*It felt natural to swing, but I couldn't really get the swing to really work... I was using the button but that was only because I was just having mechanical issues with the swing*" (P2). Difficulty with motion controls associated with one action lead some players to avoid motion controls for other actions as well, e.g. "*I had trouble hitting the blocks repeatedly to break them all the way. So, I guess I got more used to using the button for that, and then did the same thing for attacking*" (P7). This also impacted the feeling of presence, as P7 went on to say "*so that took a little bit away from the feeling of actually being there*". Some players went so far as to say that motion

control failures were "*the main thing that draws you out of the immersion*" (P11). These failures eventually lead some players to exclusively use indirect input simply because those techniques were "*a lot more reliable*" (P15).

3.4 Discussion

In our discussion, we consider four major lessons learned for developers who are interested in porting their games to VR.

3.4.1 Presence Heightens Emotions, Creates Preference for VR

Our results emphasize the strong interconnection between emotions, presence, and enjoyment of VR. Though many participants felt that specific aspects of Minecraft were better on the desktop (e.g. mining, or building), only one participant said he would prefer to play Minecraft on the desktop overall. This strong preference for VR was not caused by being able to *do* more in VR, as players reported real frustrations with using teleportation as a travel technique, with the limited range of motion controls in mining and combat, and the general "slowness" of Minecraft in VR, compared to the desktop. Instead, this preference for VR is almost certainly linked to the enhanced emotional experience reported by players. Of the seven GEQ traits, three desirable traits increased dramatically in VR (Immersion, Flow, and Positive Affect). Challenge also increased significantly in VR; this most likely represents a desirable outcome given the low overall challenge rating reported for the desktop version. Feelings of Competence did decrease in VR, though this reduction may fade with time (see Figure 3.2). Also notable is the decrease in feelings of Negative Affect in VR, and that feelings of Tension/Annoyance show no significant changes, even though players reported feeling frustrated with some of the motion controls in VR and experienced moderate levels of simulator sickness.

In their interviews, players frequently linked the emotions they experienced with the feelings of presence and immersion created by VR. The sense of scale afforded by VR created feelings of surprise and awe towards the world, interest towards buildings and animals, and fear towards enemies. The enhanced immersion experienced when using motion controls successfully amplified exciting experiences, like finally acquiring a diamond or fighting off enemies. Players experienced delight when instinctively using natural motions to engage with the world, like swimming or eating,

and discovering that these motions actually worked. Tension was amplified by players' enhanced spatial awareness underground, where corners took on new meaning as obstacles that hid enemies and sound provided new clues to where threats were hidden. This link between emotion and presence underscores that the key selling point of VR is not necessarily being able to play games *better*, but being able to get a new perspective on games. VR enables games to take on new life because it enhances players' sense of scale, presence, and involvement within the virtual world. Game developers should leverage these features to enhance player experiences: play with scale, where narrow caverns open up onto gigantic vistas; make virtual characters that look the player in the eye (or tower over them); and create opportunities for mundane interaction within the world.

3.4.2 VR Games Need Improved Travel Methods

Players often need to move through virtual environments that are much larger than their physical space, and teleportation is an easy solution to this. However, teleportation was also strongly disliked by our participants. Teleportation broke players' feelings of immersion and took away the feeling of actually *moving*, as it required players to discontinuously hop from location to location and reinforced the feeling that they were standing still. These discontinuities also created disorientation and made it harder for players to keep track of where they were in the world, sometimes leading them to feel lost.

Players did appreciate teleportation for how it made fast travel easier, made it simpler to escape from enemies, and easier to scale cliffs. However, these are exactly the type of changes game developers must avoid if they are to create a consistent experience when porting a game to VR. Teleportation's discontinuous nature makes it function very differently from the travel methods most commonly employed in modern games. Its different affordances can result in radically different, and potentially imbalanced, gameplay experiences. New travel methods are needed that facilitate the experience of immersion without altering players' capabilities in the game world, while also avoiding simulator sickness. This will not be an easy task.

3.4.3 Create Motion Controls, but Provide Indirect Alternatives

Players enjoyed using motion controls in Minecraft, and found them intuitive to use (so long as they worked consistently). However, a number of factors influenced whether or not players actually

used motion controls in any given setting. Before considering these factors, we first point out the most important lesson: players naturally blended the motion controls and indirect input methods while playing Minecraft, as they deemed appropriate for the given situation. The availability of indirect input did not interfere with players enjoyment of the game, or with feelings of presence. As such, developers should consider providing players with both motion controls and indirect input, and allowing players to chose which method to use in any given situation.

When considering why players chose to use motion controls or indirect input, the most important factor is (unsurprisingly) whether or not the motion controls were *reliable*. Inconsistent motion recognition for a single activity can cause players to lose trust in other motion controls as well. After reliability, the next major consideration was the trade off between the cost required to use motion controls and the reward associated with it. Costs took numerous forms, including physical exhaustion, time commitment (it was faster to push a button than to swing an axe), and action capabilities (players could reach further with the indirect method). Rewards came primarily in the forms of enhanced immersion and emotional engagement. These costs should be carefully balanced when implementing indirect input methods; it may make sense to allow motion controls to actually reach *further* than indirect input, so as to balance the increased physical toll with increased action capabilities. The final consideration is how motion controls seem to serve as emotional amplifiers; mining was a low emotion activity on average (frequently performed, often boring), which made many players prefer to use indirect input to mine. However, upon discovering diamonds, some players switched to using motion controls again due to the excitement of finding a diamond. As such, low impact actions are likely more amenable to being implemented using indirect input (so long as motion alternatives are also available). Regardless, developers should strongly consider offering both motion controls and indirect input, so long as both input methods are balanced to make each one viable.

3.5 Conclusion

Players strongly preferred playing Minecraft in VR, as supported by the GEQ results and by interviews, even in spite of increased feelings of simulator sickness, meaningful frustrations with teleportation, and some inconsistencies with the motion controls. This preference for VR was driven by a complex interchange between enhanced perspective (particularly scale), increased feelings of

being present *in* the world, and satisfying interactions between the player and the world. Developers can take specific steps to enhance these feelings in their games, so as to make their VR ports more successful. A surprising result of this study was that motion controls are not always better, and that indirect input does not necessarily degrade players' experience in a VR game. Instead, players frequently merged motion controls with indirect input depending on the task being performed and how exciting and meaningful the task was to them. Developers should consider how to provide both motion controls and indirect input in their games, so long as the capabilities of each are balanced. Travel via teleportation is an easy solution to the problem of simulator sickness in VR games, but also weakens the user experience and directly conflicts with our goal of increasing feelings of immersion. Developers should experiment with new travel options that maintain feelings of immersion and spatial awareness without creating simulator sickness. Simulator sickness remains a problem, even when using teleportation. However, it is also something that most players can adapt to, given time and opportunities to rest without experiencing conflict between motions in the real and virtual world.

3.5.1 Limitations

In order to avoid learning effects related to Minecraft, we specifically recruited people with significant prior experience playing the game. However, this also means that playing Minecraft on the desktop had potentially lost some appeal to our participants, which could explain why we saw such strong increases in presence and GEQ scores, as VR brought some much needed novelty to the game. However, we saw that the enhanced emotional experiences and feelings of presence persisted across multiple sessions, which suggests that, if these effects are linked to novelty, they are strong enough to not immediately fade after a single play session.

Chapter 4

Study 2: An Analysis of Longitudinal Trends in Consumer Thoughts on Presence and Simulator Sickness in VR Games

This study helped to answer more leading questions by gathering data from a large sum of voluntary user discussion. This perspective is very crucial, because unlike our initial study, this is public information gathered from users who want to share their honest experiences, with a limited chance of the conversation being steered by Hawthorne effects or being rushed due to outside obligations. These perspectives were unique in that way, and offered the opportunity to hear from a more diverse group of users in regards to their VR gaming experiences. From the data gathered here we understood that while users had a varying understanding of presence and simulator sickness, as compared to a researcher perspective, their understanding was still valid and the amount of extensive detail of accounts surroundings their sentiments was invaluable. The themes gathered here also showed trends over time, not as as it relates to a single game, but as a collective of experiences being a VR gamer. Where a user could spend large amounts of time spanning across a multitude of VR games but still feel that there were certain aspects of gaming that remained

important to their experiences regardless of any particular game itself.

In this study, we gathered posts made on the /r/Vive subreddit from the first two years after the HTC Vive's release and presented the results from an in-depth qualitative analysis concerning immersion, presence, and simulator sickness. Over time, as users moved from passive to active, their attitudes and expectations towards immersion and simulator sickness matured. The major trends of interest in this study centered around game design implementation and locomotion techniques.[1]

4.1 Experimental Design

For this study, we collected all posts made on the /r/Vive subreddit (subreddits are focused communities hosted on Reddit, a major user-driven website) for a two year period, starting on April 5th, 2016 (the day the HTC Vive was released). Conversations on reddit are structured around posts and comments, where a post is made by a user to start a conversation and comments are made within a post, either addressed to the original post or to a comment made by another user. This results in a more complex discussion structure than is common of most online forums. 121,550 posts and 2,183,924 comments were made on /r/Vive during the sampled period.

As our interest was how users' discussions about their experiences with the HTC Vive evolved over time, we chose to sample posts at a three month interval, where posts were sampled in month 0 (April 5th 2016 to May 4th 2016), month 3, month 6, month 9, month 12, month 15, month 18, month 21, and month 24 (April 5th 2018 to May 4th 2018). Posts were collected for each month using the reddit API, via the portal hosted at *www.redditsearch.io*; the total number of posts returned for each search term are shown in Figure 4.1. The searches for each date range were performed manually by one of the authors. We chose to focus at the post level, rather than the comment level. Thus, our search only returned results where the initial post contained the search term. All comments made to that post that were also relevant to the search term were also included in our analysis. If fewer than 40 posts were returned for the search period, each post and all of their comments were read. If more than 40 posts were returned for the search period, a sample of 40 posts were selected. This selection process was performed by one of the authors, with preference given to posts that appeared to discuss topics different from posts already selected for that month. We also attempted to select posts made during the entire time period, rather than only from a single portion

[1]Proceedings of the 2019 Annual Symposium on Computer-Human Interaction in Play, Pages 277-285

of the time period.

We performed three keyword searches, one for 'immersion,' one for 'presence,' and one for 'motion sickness'. These search terms were selected after an initial exploratory search of terms related to presence and simulator sickness, our topics of interest in this paper. These three keywords were observed to be widely used by the community when discussing these topics of interest, stretching back to the time when the Vive was released. This observation is supported by Figure 4.1, which shows that these keywords remained in fairly constant use, proportional to the total number of posts made in each period analyzed. While the topics of presence and simulator sickness are both very distinct phenomenon, they are also essential to user experience in VR games. Presence being one of many major factors that drive player interest in VR games, and sickness being a major deterrent. As such, we chose to investigate how user discussions of each of these factors have evolved over time together.

Each search was conducted sequentially, beginning with 'motion sickness,' then 'immersion,' and finally 'presence'. Although initially we performed separate searches for 'immersion' and 'presence,' the results from the two were later merged due to their strong similarity. To analyze the data, all posts were read for a given month, and then re-read to extract relevant quotes or notes. Once each month was processed, we then categorized the collected data into various themes at the month level. Finally, major themes were extracted across all months. As previously mentioned, upon completion of both the 'immersion' and 'presence' analyses, we concluded that the themes identified for 'presence' mapped almost entirely onto the themes identified for 'immersion'. As there were few differences between people's use of the terms, we felt that it would simplify discussion to collapse similar topics found in both presence and immersion into one. If a topic was not mirrored for both keywords, then it was retained as a separate topic in the new 'presence/immersion' category.

4.1.1 Research Questions

we sought to understand what shifts had taken place within the two years since consumer VR became available. We narrowed down two essential questions that are currently unanswered in the research literature:

R1: What do users who engage in VR games discuss in regards to simulator sickness and presence?

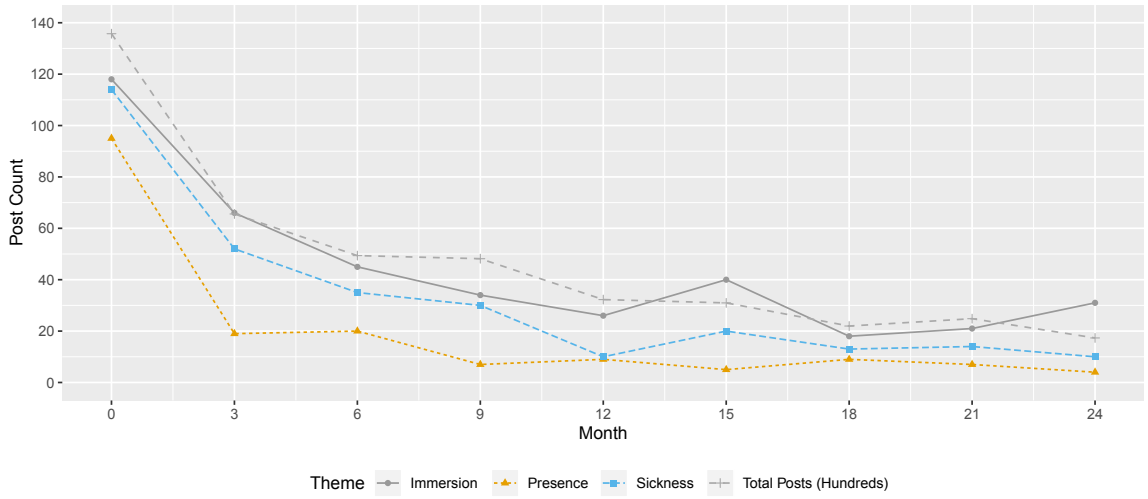

Figure 4.1: The plot shows total posts returned for each search term, by month. It also reports the total number of posts made in each month (in hundreds). While the number of posts containing our keywords decline over time, it can be seen that this decline is representative of a decrease in the number of total posts, not decreased interest in these topics.

R2: What trends over time concerning user understanding, and experiences in regards to presence and simulator sickness can be identified?

4.2 Qualitative Analysis

4.2.1 Presence and Immersion

We identified 3 subtopics within the 'immersion/presence' keyword searches: *Immersion Amplification* focused on the hardware and design factors many users believed help amplify their feelings of immersion; *Immersion Impediment* focused on the opposite, hardware and design factors that impeded feelings of immersion; and *Locomotion's Effect on Immersion* focused on various locomotion techniques and their impact on users' feelings of immersion.

4.2.1.1 Immersion Amplification Discussion

During the two year period we examined, users discussed several factors that enhanced their feelings of immersion. From these factors, 4 sub themes were extracted regarding this sentiment: *Hardware Sets the Stage for Immersion* focused on the impact the Vive's natural affordances had

on user immersion; *Modifying Hardware and Software to Improve Immersion* then expanded on how outside hardware and software had amplifying effects on immersion as well; *Good Game Design is Essential for Immersion* highlighted the various aspects users enjoyed seeing in their games; and, *Social Aspects add to Immersion*, where users focused on how social aspects come into play when experiencing immersion in games.

Hardware Sets the Stage for Immersion: In the first month after release, discussion of immersion was scattered and often focused on the raw experiences of immersion, rather than what helped reinforce it. By month 3, users were:

> "convinced that roomscale + tracked controllers were half the experience of VR, not just a nice addition, and that without these things, they don't even want to call it VR"

While often praising the Vive on it's "vertical FOV, motion controls," "fantastic tracking, room scale and 90Hz refresh rate," throughout the months, users slowly focused their thoughts more on specific items they believed amplify their immersive experiences beyond the hardware, still agreeing that even though "the initial novelty of VR had worn off, the immersion hadn't." By month 6, conversations highlighting the hardware began to fade and more game-centered discussions began to rise, where users who would sometimes blame the hardware were often met with comments such as "you are overthinking it. Let go and stop focusing on the headset. Focus on the game." From here on much of the discussion regarding this faded as focus shifted from the hardware of VR instead to its applications.

Modifying Hardware and Software to Improve Immersion: In month 3, users highlighted how the use of peripheral hardware "made a world of a difference." Many users mentioned how when using gaming wheels "the force feedback felt amazing, and coupled with a VR headset it's incredibly immersive." This sentiment continued into month 9 where users began to seek more outside manipulation, noting that "other elements like touch and smell can also be manipulated to enhance immersion" and how they would "like some [software] mods to help out with immersion and stuff." Users began to ask questions like "why does this game have no haptics?" and demanded "more and better vibrations" in their applications. By month 15, debates had broken out concerning how different interactive controls influenced immersion, where some users believed that having a "HOTAS [controller] was very helpful...as it's one of the most immersive VR experiences currently possible," while others said that a "steam controller could be just as immersive as any hotas." But

during this same month, users had also now become acclimated to the Vive's affordances and grew anxious for new immersion amplifying tools. Refusing to wait for companies to decide on what tools would be best for them to feel more directly engaged, many decided they "would like to try and build [their own]." Peripheral developers were falling behind on the wants of gamers who felt that when playing their games, "[holding] the rifle vs imagining it makes all the difference" as it "would significantly increase the immersion and improve [their] vr feeling." In month 21, the release of the TPCast "tetherless VR" system made "everything feel so much more immersive." But after many discussions concerning its pricing and unreliability, many users sought to find their own way and "mounted [their cables] to the wall instead" creating a "pulley system [to] satisfy" their immersive needs. In the following months, users continued in this modifying role by swapping the lens in the HTC Vive with others they found made their experiences "SO MUCH better...focused and vibrant, [taking] the immersion factor through the roof." Many were astonished and "could not believe that any 'user hack' could be better than a manufactured/tested product." This lead more users to continue to tinker and modify their hardware even more. Many users had now swapped out the padding in their Vive headsets with slimmer ones, as it had become commonly known to "increase your FOV dramatically." This sentiment had also carried over into software as well, where many agreed that incorporating "weather, texture, lighting, mesh, and audio mods took [their] immersion to visceral levels."

Good Game Design is Essential for Immersion:

> "Good gameplay causes better immersion, bad gameplay hurts immersion; not the other way around"

This comment captures how users' often felt about the impact good game design has on enhancing feelings of immersion. Starting at month 6, users highlighted how they "don't think graphics actually affects the feeling of [immersion] as much as gameplay, scripting, and design do." In month 12, users agreed that "audio got less props than it should," and that "both sound fx and music made a huge difference in how a game 'feels' to play" as "it's often the sound more than the visuals that triggers a response from players." Level design was also an important mark of discussion, where one user highlighted one design that was so "spooky and atmospheric..that it made me feel like I was in another world with a real person." As time progressed, the role of interaction became prominent:

> "it's not just the style of graphics, but the interaction...being able to do things that you

both expect and surprise you"

Users often gave examples of specific forms of interaction that enhanced their immersion, frequently with reference to holding objects (e.g. "physically equipping your pickaxe") or saying that "using your hands makes immersion in the game so much more real." This sentiment only grew with the arrival of the Vive trackers which allowed users to "finally achieve full body movements." By the last month of our search, most users had by then become familiarized with immersion and utilized it as a metric to review games, (e.g. "Skyrim is awesome the world is great... but the immersion is OFF by A LOT," or how "swinging at the vein of ore to extract it...is such a fun, lovely little detail for immersion").

Social Aspects add to Immersion: From the early months users wanted social experiences involving other people, saying that "it always adds a level of immersion when there are other humans walking about the virtual environment" and that "seeing another player in there with you just adds SO much immersion and joy." Users were also concerned that the lack of many non-player characters (NPCs) in games was "something we don't get enough of in VR" because they "LOVE seeing the characters come in and talk to [them], it felt so... real...." By month 6, users had actively experienced more social interactions in games and felt that "multiplayer gave [them] immersion, because [they] focus so much on being social that [they] lose that focus of it all being fake." This sentiment had grown by month 9 and users noted how their feelings of immersion were amplified when these social aspects were integrated well into the environment around them. For example, one user recounted how:

> "One of the moments that hit me the hardest was when I entered a space port and entered my assign docking bay and looked up to see another player in a much more massive ship cruise over head and begin his own docking sequence. There is just something about the experience in VR, of being in a world of that scale while encountering another player who is in your same world and carrying out his own business"

By month 15, more games had successfully incorporated many of these ideals and users discussion shifted focus back to NPCs, where many still agreed that "having NPCs walking around...adds to the immersion by giving it a social feel." From here discussion fades concerning social topics until month 24, where many users by then had praised developers for finally taking NPCs "so far beyond what one can get playing the flat version" and how "[they] actually feel like [they're] being talked

to, like really being talked to instead of just an NPC reading a script."

4.2.1.2 Immersion Impediment Discussion

Although users were able to find all the things they enjoyed about immersive VR, their experiences were also impacted negatively due to mirrored concerns. These concerns were condensed into 3 major sub themes: *Users are not Entirely Satisfied with the Hardware* focused on how users still have some issues regarding the Vive's shortcomings; while *Improper Game Design and Affordance Implementation Hurts Immersion* highlighted sentiment on gaming aspects that often held users back from achieving a fully immersive experience; but in *Users Can Hurt their own Immersion* we also found that the user themselves often assisted in their own immersive impedance.

Users are not Entirely Satisfied with the Hardware: Upon release, users complained about the many hardware issues they were experiencing, such as missing frames, flickering, and dead pixels. This lead to some backlash on the Vive and many follow-up discussions concerning return policies. Users also complained about how they felt when "the cable tension snapped your head back, as this is INCREDIBLY frustrating and sucks your immersion right out." By month 6, most users had begun analyzing the hardware, highlighting how the Vive's "Godrays are annoying" and as a result many "didn't feel a lot of immersion in the Vive because of the Fresnel lens artifacts." But discussion regarding these sentiments quickly faded as users began to "only notice it if [they] looked at it" and that eventually while "in games [they] were so involved with other stuff that [they] didn't think about it." No major discussions regarding these issues persisted after month 6, although small isolated comments would sporadically arise in the months to come.

Improper Game Design and Affordance Implementation Hurts Immersion: Early month discussion regarding this impact occurred because users noted that many "games' physics were terrible," and that although many users were:

> "able to accept a cartoon world, [but] if the physics was really off it was strange...and made it so [they] were not as invested in what's going on in the world"

One exemplar of this instance, was in month 6, when one user stated how:

> "immersion-breaking [it was] to pick up a bucket with an object in it, only to watch that object clip through the bottom of the container and fall to the floor"

At this point, users demanded more from developers in regards to proper in-game affordance implementation, wanting more simplicity in some aspects (e.g. discerning which "buttons you cannot press" or what "small objects that you cannot lift"), and more complexity in others (e.g. wanting the game to not simply "ready an arrow in my hands, [but instead] make me draw it from a quiver.") In month 9 developers were warranted to "avoid including extremely extraneous or tedious actions for the sake of realism" because while "interactivity is important, it's not how much you have, so much as how you go about it." Meaning that while users did care about some elements of the visuals, they were much more focused on the implementation rather than visual style. This was noted when users felt that in some games "there was zero immersion because of how bad the scale was" and how seeing "the jagged edges" or "the horrible aliasing" in others broke their immersion. By month 12, most users had become fully accustomed to using motion control affordances in their games and had come to expect it. For most, a game having "no motion controls was a deal breaker...This kills the immersion" and that for some a game "COULD have been a blast, if they just added motion controller support." At this point, users had now become much more assertive in their understanding of what they wanted to see in their games, constantly hinting to developers in the forums that "room scale is extremely immersive, as long as everything is within reach," and to make sure that certain in-game components "translated well into VR." They also mentioned that when developing to consider how:

> "locomotion is a crucial aspect of the gaming experience...[and that] having the 'wrong' kind for you can kill immersion or make you sick"

Users Can Hurt their own Immersion: Not all discussion of impedance is on the burden of the developer. A common theme among users, especially early in the Vive's release, was how users would oftentimes be the cause of their own impedance. The most common being when users were "experiencing some major tracking issues" and "it turned out the room setup was the problem." There were also many recorded HMD-related issues in the early months, where users realized their "headset wasn't perfectly adjusted," or their IPD was not taken into consideration because upon arrival, their Vive "had the lenses adjusted to half way" and they had not taken the proper steps to customize them. But for most, their issues could be solved simply by going "through room-setup again, [where] the immersion kicked in almost immediately" for them afterwards. These postings lasted until month 6 when we noted a drastic reduction of discussion regarding these issues. By

month 9, these 'self-made error' discussions had transformed into advice columns where budding new users were brought up to speed on much of the knowledge previously discussed in the earlier month postings (e.g. how "setting [your Vive] up properly is crucial" and "re-centering the tracking is the cure" to most disruptions users experience with immersion).

4.2.1.3 Locomotion's Effect on Immersion Discussion

From early on, most users typically agreed that:

> "teleportation does not aid in immersion, it's not a realistic or natural form of movement, but due to the current limitations in VR, it's detriment to immersion is offset by its ability to keep you from hurling your guts out"

Some users still refused to "support teleport-only games," while other users agreed that "if teleporting was really that central to your game design... [you should just] force everyone to teleport." This lasted until month 9, when the incorporation of trackpad locomotion (also known as smooth locomotion, where users navigated through virtual worlds as you would in a traditional console game via a trackpad or thumbstick) in games had become more prominent in discussion. This had little impact on the community however, as users thought that "magically sliding around a world with a trackpad was still no less immersive than pointing and teleporting." But at this point most users had compromised, agreeing that "forcing either type of locomotion...is bad for everyone" and that "it's nice to have both options available," so "offering both options is the best way to go." As a result, much of the earlier locomotive debates died down extensively by month 12 and many users agreed that "the answer is [for developers] to support multiple types of locomotion in a game." One user even stated that:

> "at least 3 movement options should be available in my opinion...[and developers should] let the player choose what they are most comfortable with"

During months 15 and 18, we noticed that users had become more aggressive in their demands for more immersive locomotion techniques from developers. Many highlighted how teleportation was "rather immersion breaking," and how trackpad locomotion "gave some people simulator sickness." Although by this point "most games seemed to provide options, which is definitely the best way to go," even if discussion over preferences still remained a somewhat "polarizing issue." At

the 2 year mark, two new community driven techniques had just arrived, Natural locomotion, and Freedom Locomotion. Natural locomotion was met with mixed response, where some felt it "made the immersion experience so much better...somehow just swinging my arms to move around gave me a sense of real physical movement." Others believed that "arm walking felt very unnatural" and it "did not seem like it provided me enough control compared to a joystick for movement." But because Natural Locomotion was a plug-in, many users could seamlessly add it into their games, even combining it with other locomotive techniques to get the most out of each, which helped to increase its acceptance as a viable addition. Freedom Locomotion, on the other hand, was very popular amongst users because it "felt real and natural and was more diverse in all the motions it integrated." But, due to it needing to be directly incorporated into games by developers, its overall use and incorporation suffered as a result.

4.2.2 Motion Sickness

We identified 3 subtopics within the 'motion sickness' keyword search: *General Advice* highlighted the best communally agreed practices to avoid, treat, and overcome sickness; *Causes of Sickness* focused on debates regarding the impact that gaming elements had on creating sickness and limiting experiences; and, finally, *Understanding Sickness* went through the development of the community's theoretical understanding of simulator sickness over time and how it related to individuals.

4.2.2.1 General Advice Discussion

Upon release, when inquiring about sickness, a large amount of comments regarding safety advice for combating motion sickness formed immediately as many users remained ignorant to proper hardware setup such as running suitable GPUs, using the correct USB ports, and proper room setup. This often lead to many "creating issues for [themselves]...so much it was causing [them] to be motion sick." Users were often advised by each other to first look for hardware issues because "maintaining a highly responsive VR system reduced motion sickness." This included "checking to see if you're dropping frames," "being sure your PC can always output 90 FPS," and that if "you start seeing it glitch out [to] either close your eyes and let it adjust or take the headset off." At the earliest signs of sickness symptoms, users recommended each other to "hit the pause button and exit the game immediately." Many experienced users often advised new users to:

> "stick mainly to games that utilized room-scale or teleportation, and avoid ones with standard FPS [also known as smooth] locomotion as it feels very unnatural, which [they] believe is the origin of the nausea"

To negate negative effects, medical remedies were also recommended, including taking Dramamine and eating different variations of ginger, which were seen as helpful combatants to motion sickness. In months 3 and 6, focus shifted more to preventing simulator sickness before and while inside the environment, rather than just reacting to it. This encompassed a variety of topics including keeping yourself cool during the experience, mentally preparing before entering for the environment, keeping your center of gravity, and "tweaking your IPD and making sure the headset is not loosely fitted to your face." Users were also instructed to "deal with any reflections on the lighthouses that [could be] causing any stuttering or juddery-ness." Although, some users would often still "mess with settings," creating an environment that intensified the chances of experiencing "motion sickness...[that] was completely [their] fault." But over the course of the next 6 months, users discussed more active approaches to breaking past simulator sickness, such as "slowly acclimating by exposing yourself to it a bit at a time." To reduce sickness when using certain locomotion techniques, many users advised "freezing your body" in place or "squinting your eyes during the sliding movements" and other visually intense events. Others advised more general advice such as "activating the comfort options" and "FOV reduction" in game settings, "knowing your personal limits," and "taking breaks periodically." By now, the use of ginger and Dramamine had now become widely received in the community as "over the counter medications for motion sickness." For the remainder of the sample, veteran users now understood that "different types of locomotion have their own difficulty and require their own adjustment period" and continued to guide new users and beginners accordingly. Many advised them to avoid starting with more complicated locomotive techniques such as smooth locomotion, and to begin with games that use teleportation locomotion, as it has now been generally agreed by the community to be the softest and least sickness inducing of the techniques.

4.2.2.2 Causes of Sickness Discussion

Upon release, users began to feel the symptoms of simulator sickness while playing their games, and immediately debated on what could be causing it. Users debated whether certain in-game mechanics were the main culprit for inducing sickness, such as developers "moving the player's

point of view without them moving their head," "having locked points of references," and how "there weren't many feedback or visual cues to let you know what is happening" in certain games. Others referenced how some users may simply just be inducing their own sickness, as result of improper setup, technical issues, and general irresponsibility. By month 3, users had "experimented and made locomotion method[s]" of their own in order to curb simulator sickness symptoms e.g. ("a semi-teleportation method. You pick where you want to go but instead of it being instant it moves you in a path to that spot"). At this point there was also a growing understanding that some users just possessed a natural ability to handle artificial locomotive methods better than others. Many agreed that "the teleportation mechanic is great for people prone to nausea, [but still] wished more developers would give players different options." However, others still concerned with the safety of the overall community rebelled, stating that since "[teleportation] helps people who suffer from motion sickness" and "you don't want to risk someone feeling slightly uncomfortable," that all games should just use teleportation as a means of travel. This continued until month 6, where many games had only one means of locomotion, limiting access from those uncomfortable with certain techniques. Unsatisfied, the sentiment continued to grow where many believed that:

> "there shouldn't be some games where touchpad users feel they aren't getting the best experience they could, and motion sickness prone users feel as though they just have to put up with artificial locomotion"

More continued to urge developers to "just give us both options so everyone will be happy" because "people are different." By months 12 and 15, users had discovered "options for movement [they] hadn't found before" and "more than half the people that get motion sickness often, [were finding] options that reduced it considerably," many "overcoming their locomotion sickness by having shorter play sessions." Starting at month 18, more forms of locomotion were being added to commercial games, although some users were still uncomfortable with these forms and were still unable to experience certain games. As a result, users continued to offer suggestions to developers on how to improve and expand the current locomotive techniques to support a broader audience and persistently requested for multiple in-game locomotive options for users to choose from. By month 21, most users realized "just how varied people's triggers for VR sickness are" and were willing to sacrifice immersion for more stability and control in games to avoid symptoms. In the meantime, users continued to aggressively seek and craft new locomotion techniques, but now understood that

not all techniques will tailor to the majority.

4.2.2.3 Understanding Sickness Discussion

In month 0, users debated the difference between the terms 'motion sickness' and 'VR sickness' (simulator sickness) and why they are both being used regularly to describe similar symptoms. Many "consider them to be two different things" that "work with different triggers," where:

> "VR sickness isn't related to regular motion sickness...one is feeling like you're moving but not seeing movement, the other is the opposite"

By month 3, additional sickness-related terms had begun to surface and vetted users continued to explain the differences and similarities. Additionally, three distinct groupings had formed based on how strongly users were generally affected by simulator sickness. The sentiment being that "some get sick, some don't, and some adapt," where some users have a very high natural resistance, others a low resistance, and the remainder possess a moderate resistance with the ability to increase their resistance over time. This increased resistance was known by the community as obtaining one's 'VR Legs,' which was described as being "like sealegs, but for VR." The idea being that:

> "practice makes perfect, and VR can take some getting used to. Some have it easier, some have it a bit more difficult, but if you power through you should be able to get your VR legs after a while"

With the understanding that this did not hold true for everyone because "some people [will still] get motion sickness, no matter how much they 'train' themselves." As time progressed some users began to theorize the underlying reasons of why some people were more or less subject to 'VR sickness,' such as if "previous experience in gaming" or if playing any specific gaming genres may have had any influence. But generally most were waiting to see "if research could actually start narrowing down WHY some people can get vr legs and some can't." Many researched studies, practices, and theories that were known concerning 'VR sickness', such as the importance of the vestibular system[21, 65], were widely discussed among the forums. But because researchers were still unable to agree on any single major explanation, the classification of the 3 groupings of user resistance became widely accepted. As a direct result, the community safely concluded what was believed in the beginning, in that "some people get it, and some don't, it's as simple as that."

Discussion regarding this topic then sharply declined until months 21 and 24, where new users would come in occasionally to ask questions regarding these issues and would be met with the knowledge previously mentioned.

4.3 Discussion

4.3.1 Users' Transition from Novice to Expert

Throughout all posts in both forums, we identified a major shift in how users' addressed both their enjoyment and their concerns. In the early months users discussed a variety of topics, detailing situations they stumbled across while experiencing VR in the Vive for the first time. Users often sought out for advice and guidance from one another regarding issues they had come across regarding both hardware or software. And although many would actively voice their opinions leading to a rich amount of discussion and debate, there were still many who would cloud discussion with crude jokes and irrelevant opinions. But within a year's time, most discussions had matured in their language and conversation. Soon many users that were not providing valid input in the topics being discussed were becoming identified and ignored by the community. More active users continued to discuss VR vocabulary and theories, as well as create their own. Eventually topics began to narrow and were becoming more strictly monitored by those within the community. Communal understanding and practices had began to form and many had become veterans both within the forums, as well as in their matured understanding of VR. By the end of our sample, users were now actively addressing developers and demanding changes rather than passively hoping for them. Users had shifted from being merely consumers of VR, to creators and analyzers, in both hardware and software. We also began to notice a more active role of developers reaching back within the forums to get more feedback from the community.

4.3.2 User's Influence over Game Design

Throughout the months, we saw that sentiment and discussion regarding game design and implementation changed over time between both forum searches. Initially, users were excited about all the new games and demos they were exposed to. But as time went on, many became familiar with the various gaming mechanics and their effects on the user experience in regards to both immersion

and sickness. As more users continued to share their experiences with one another, certain patterns and techniques soon arose. Users had shifted from being merely consumers of VR, to creators and analyzers, in both hardware and software. Many highlighted ways to improve them by making sure developers knew what they enjoyed, as well as what made them sick. By the halfway mark, user focus shifted from gaming visuals to interaction techniques. We believe this was due to the initial 'awe' of VR visuals wearing off, where users were now more concerned with how they could make their experiences feel more personal. This included providing a more diverse amount of locomotion techniques as well as more social implementations, both with other players as well as AI characters. Many soon began creating and sharing their own content regarding these things, as they often felt large scale industry was not keeping up with their demands. By the end, users had become critics and reviewers of immersion rather than consumers of it, using it as a metric to weigh and rate games they played. In regards to motion sickness, the focus of game design by now was based entirely on having a diverse amount of locomotive techniques in games.

4.3.3 Evolution of Locomotion

Over the span of the 24 month period, user consensus over locomotion evolved constantly.

During the earliest months, most games used the same limited set of locomotion options: teleportation, smooth locomotion, and real-world walking (within a limited space), with teleportation being the most common method. User discussion around these options quickly focused on how they affected two factors: immersion/presence and simulator sickness. While no consensus was reached, the most common opinion in this period was that while teleportation produced low levels of immersion, it was still the best method as it was safe and did not produce much simulator sickness.

But as time passed, users became increasingly anxious, pushing developers to create more locomotive techniques centered around more fluid and natural interactions. Within a year after release, many users took the initiative upon themselves and developed techniques to increase the pool of locomotive techniques.

Eventually many discussions regarding exemplar locomotive techniques had ceased, as more users agreed that every user is unique and there is no one-locomotive-fits-all model for gaming. The conversation instead had now shifted to if the locomotive technique being applied was appropriate to each game's overall style. This change marked a new transition where users were then taking a more active role in conversations concerning future game development, often demanding that developers

consider implementing a diverse amount of in-game locomotive options. Over the remaining months, this sentiment became a standard metric and a major factor of discussion among users regarding whether or not certain games should be purchased.

4.4 Conclusions and Future Work

Consumers in VR matured in both their attitudes and their expectations regarding immersion and simulator sickness. After initial user disappointments wore off, many were able to focus on the more positive aspects of VR. Users moved from passively accepting shortcomings provided to them to actively fixing them, or demanding that they be fixed. At first, hardware played a major role in immersion and simulator sickness discussion, but over time, hardware concerns were either addressed or noted as non-essential. From here, software became the major focus of these discussions for consumer VR users. Consideration of a variety of locomotive techniques when designing applications is recommended when creating new games. Developers also are encouraged to continuously seek out the latest information regarding safe and intuitive game design, both professionally and communally. Game design is a crucial factor which, if not implemented effectively, could risk many users to become sick. Likewise, game reviews from influential people can sometimes be the defining factor of its acceptance or rejection, so following good interaction technique implementation is also recommended. Therefore, developers are recommended to actively seek user feedback while in the process of creating applications for VR consumers to make sure they are in line with these sentiments. Users of VR are becoming increasingly active in the general community, both as consumers and creators, and are demanding more from both researchers and developers, in both speed and accuracy.

4.4.1 Limitations

A limitation with this research is that we only used three keywords when searching for relevant posts: immersion, presence, and simulator sickness. We chose to limit our search to these three terms after a long period of observing the forum wherein we noted that the majority of posts relevant to these topics contained these keywords. While these terms may not have captured all relevant posts, they were in common use by the community and were present in most discussions we observed.

Chapter 5

Study 3: Lingering Effects Associated with Virtual Reality: An Analysis Based on Consumer Discussions Over Time

This study shed an additional perspective on the question of "How does extended exposure to a VR game affect the user's experience?" for the same reason mentioned in the previous chapter. The data in this study uniquely showed the magnitude of the experience itself, and how if left alone in VR for long enough, it has the power to affect a user's perceptions and behaviors even outside of the virtual space. Again, I felt the perspective used here from a diverse group of unsolicited individuals would be best when gathering discussion and themes related to these experiences, as it very difficult to attempt to replicate the effects discussed in this chapter within a laboratory-setting experiment. The themes found here suggest that while users have found many ways to enjoy their experiences in VR gaming, there were still potential risks we needed to monitor as more users started to engage in VR unsupervised for longer periods of time. The effects outlined in this chapter come as a direct result of extended exposure to VR games, and highlight how the findings outlined in the previous chapters, though enjoyable, have the potential to go beyond VR and begin to affect a user's

everyday life experiences.

In this study, we used the same posts in the previous study made on the /r/Vive subreddit from the first two years after the HTC Vive's release. We again examined this data to gain insights on what sorts of "lingering effects" users reported having experienced after VR, and on the progression of these effects over time. We found three major categories of lingering effects (besides simulator sickness) during our qualitative analysis: perceptual effects, behavioral effects, and changes in dreams. The perceptual and behavioral categories were further divided into sub-themes: disruption of body ownership and proprioception, loss of a sense of depth in the real world, visual aftereffects, the need to verify the reality of the real world through touch, hesitation when moving in the real world, and attempts to apply VR interaction metaphors to real life interactions.

5.1 Experimental Design

To gather consumer discussions about lingering effects in VR, we turned to the popular discussion forum Reddit, specifically the subforum /r/Vive subreddit. We chose to focus on the HTC Vive, as opposed to other available headsets, such as the Oculus Rift, due to the more advanced capabilities of the HTC when it was originally released. Specifically, the HTC Vive supported motion input controls and wide area tracking upon release, whereas these features were only made available at a later date to the Oculus Rift. Furthermore, the /r/Vive subreddit was more active than other subreddits devoted to VR in general, meaning that more data was likely to be available.

All conversations made within two years following April 5th, 2016, (the day the HTC Vive was released) were included in our search. Conversations on Reddit are composed of an initial post followed by a nested threads of comments. Posts are made by an initial user and comments can either be made to that post, or to other comments already made in the conversation. This results in a more complex conversation structure than is common of most online forums. During the two year period we sampled, 121,550 posts and 2,183,924 comments were made on /r/Vive. We performed our search using the Reddit API, specifically through the portal hosted at *www.Redditsearch.io*. We included both posts and comments that met our search criteria, which enabled us to identify both root discussions of interest, as well as relevant tangential discussions that emerged in the comments.

Prior to performing a structured search, we engaged in an exploratory phase where both authors tracked posts made to the forum, with the goal of identifying conversations that were

relevant to our topic of interest. Based on the conversations identified in this phase, we identified phrases and words that were often present in the majority of the relevant observed conversations. These phrases include: 'feels weird after', 'side effect after', 'disassociation', 'disoriented after', and 'weird dreams'. These search terms were then used to identify more conversations made in the first two years following the HTC Vive's release that involved discussion of lingering side effects. We began reaching saturation when searching with the fourth and fifth term (meaning that most of the returned posts had already been identified). In total, 1,710 comments were retrieved using these search terms. Though this number is small in comparison to the total number of comments made during the searched period, discussions concerning lingering effects were rare overall and did not constitute a major topic of discussion in this subreddit.

During the search, each phrase was independently input into the Reddit API, which was configured to return all conversations where the all individual words in the search phrase occurred somewhere within a single post or comment; the exact search phrase was not required to be present in any particular order. Using this 'bag of words' search criteria, all conversations returned were identified as relevant to our topic. After all relevant conversations were identified, comments made in each conversation were reread individually while notes and relevant quotations were extracted. After notes had been made on each individual comment, we then categorized this data into our major themes: perceptual aftereffects, behavioral aftereffects, and changes in dreams.

5.1.1 Research Question

we again sought to understand what shifts had taken place within the two years since consumer VR became available. We narrowed down three essential questions that are currently unanswered in the research literature:

R1: What side effects do users in the r/vive/ subreddit discuss regarding their individual use of games and applications on the HTC Vive Headset?

R2: How long does it take users, as indicated in their comments, to experience these effects of using the HTC Vive headset?

R3: For how long after using the HTC Vive headset do these effects persist?

5.2 Qualitative Analysis

The three major themes identified within consumer discussion of lingering effects that they attributed to their time spent in VR were: perceptual aftereffects, behavioral aftereffects, and changes in dreams. From these major themes, sub-themes were identified that captured the nuances of all discussions pertaining to these themes. We consider each of these themes, and their sub-themes, in the following section. After which, we discuss what can be inferred about the duration of these effects, and also discuss the explanations users proposed for these effects.

5.2.1 Perceptual aftereffects

The first theme that emerged from users' conversations dealt with perceptual aftereffects. In these cases, users' perception of their own bodies and the world around them was altered. These effects were predominantly visual in nature, however a haptic after effect was also reported, as were proprioceptive aftereffects. Users generally felt that these effects were mildly disconcerting, but not grossly unpleasant like the experience associated with simulator sickness, and one of the effects was actually reported to be enjoyable by most users.

5.2.1.1 Disruption of body ownership and proprioception

Many users also reported disrupted feelings of body ownership. This phenomenon typically manifested itself either across users' entire body, or specifically in their hands. Disruption of the hands was more commonly reported than disruption of the entire body. With regard to disruption of the hands, two sub-themes emerged: feeling that their hands were not their own, and feelings that their hands were in the wrong position. We argue that the first sub-theme indicates disruption of body ownership, and the second disruption of proprioception.

Disrupted Hand Ownership In these discussions, users reported feeling surprised that they could see their hands, and that they did not feel like they belonged to them: "I feel like my hands are not part of my body anymore." Another user described this feeling as though the hands he saw moving in front of him belonged to a puppet: "It's just such a powerful feeling of seeing my real hands and they don't feel like my real hands... just like puppet hands moving in front of me." Being able to see ones' hands was also linked to more general feelings of unreality, such as this user's comment stating that, "After jumping out of VR, I get in the car and feel my brain debating

if it's still in VR, looking at my hands and such." Users also expressed surprise at how their hands physically interacted with the world around them saying, "When I interact with real objects, I'm surprised that my hands don't go straight through them."

Users frequently linked this effect to when they were holding their phones (one user generalized this to any held object that kept his hands in view). Examples include: "When I hold up my phone my brain expects no hands to be there," "When I text on my phone my hands seem to go out of focus and it feels like my hands are not part of my body anymore," and "When holding my phone sometimes randomly my hand seems to not be my own hand. It looks like my hand but it feels like a random third ghost hand holding it." In these cases, users do not feel that their hands are generally unreal, but only when holding or manipulating an object. This potentially can be attributed to a common convention in current VR games; upon grasping an object in VR (such as a phone), the controller model representing the hand was replaced by the object being grasped. As such, when manipulating objects in VR users saw the object where their hand was located without any representation of their hands (or even the controller that stands in for the hands).

Disrupted Hand Proprioception Users also reported moments when their hands merely appeared to be in the wrong location, rather than being completely unreal stating, "My hands feel like they are in a slightly incorrect position in the real world from where it was tracking in the game." Users sometimes also reported the feeling that their hands were lagging behind their actual motion, "I was driving around in LA Noire VR the other day for a couple of hours. The next day my hands felt weird for a split second on my actual steering wheel, like my brain was waiting for lag or something." Other users described their hands as seeming to go out of "focus," or saying that they have "lost track of depth" when looking at their hands.

One user reported an experience where he was unable to successfully grasp an object in the real world due to the misperception about the location of his hands. During the game Job Simulator, the user explains that "your 'hands' in are positioned at the end of the wand, extending unnaturally longer than your normal hands." While in VR, he "completely accepted this," but when returning to the real world "his mind rejected the position of his normal hands." This then led to his experience where he was unable to accurately interact with the world around him stating, "I found myself unable to grab a carton of milk from the fridge on the first try after playing for an extended session, which immediately made my mind reel inwards in recoil to this... I needed to sit down and re-evaluate before feeling better." When attempting to grab a carton of milk, the user

found that he under-reached and missed the carton. He attributed this to the time spent playing a game where his virtual hands were positioned further from his body than his actual hands.

Bodily Disruption With regard to their entire bodies, some users reported moments when they "would bump into stuff because [they] forget [they] had a body." Others experienced moments when they felt like they "lost tracking in real life" and had to "freeze for a second until [they] reacquired [themselves]." For one user, this experience went beyond mere body ownership to complete loss of self, saying that "When I laid down after very long vive session I felt like I was not there." While most users did not link these events to specific conditions, one specifically mentioned "going down the stairs" as a cause for this feeling, in addition to "just moving around." Several users felt the need to stop and focus for a time to restore their normal sense of body ownership: "I just felt strange mentally, somewhat detached, and felt like I had to try to be myself for a while before it became natural."

Self-avatars are currently rare in VR games. As such, most reports about disrupted body ownership were concerned with feeling detached from their body. However, one user reported on an experience he had with an early VR game that attempted to simulate a self-avatar using the Oculus DK2, the Razer Hydra, and inverse kinematics. He reported that "after getting out of the game it would usually take me to up to half an hour for my mind to accept that my RL arms were actually my arms, and not some 'foreign' part (pinching my arms helped my brain to accept that they were part of my body)." This suggests that additional forms of body ownership disruption may be experienced as consumer VR applications begin to simulate self-avatars.

5.2.1.2 Loss of a sense of depth in the real world

Many users reported that they were having experiences where something about the real world seemed "off" after spending time in VR. This "off-ness" was typically linked to difficulty judging the distance to real objects, or feelings that the world had somehow become more two-dimensional. These experiences varied in terms of intensity, ranging a user who reported "[their] depth perception was a tiny bit off," to users who said that "I feel like my brain can't tell distance anymore in real life." Another user mentioned things appearing two dimensional. "People and things lack a sort of presence and weight. They look almost two dimensional, and it's hard to tell things apart from their surroundings." No clear pattern in the direction of the misperception was present in the data; different users reported feeling both that people and objects were closer and further away

than they knew them to be, and other comments simply described the difficulty without indicating the direction of the misperception (as was seen in the quotes reported earlier in this section).

Onset of this effect was not necessarily immediately after exiting VR. While the feeling of "off-ness" could occur immediately, others reported it suddenly occurring while engaging in other activities, e.g. when "sitting at my desk looking at my keyboard typing, when I just [had] this sort of removed feeling. Feeling further away than normal." External stimuli could sometimes trigger this feeling, such as how "flickering fluorescent lights made [them] feel like [they were] in low fps VR" or how "when I closed my eyes, or blinked, I felt like the world around me was jumping or lagging."

5.2.1.3 Persistent visual elements in VR persist in the real world

In addition to distortions in depth perception, participants also reported other categories of visual aftereffects. The first group focused on how constant visual elements of VR could appear to persist in the real world. These sorts of effects included feeling like the outline of the HTC Vive's lenses could be seen in the real world, persistance of the screen door effect in real life, and seeing the HTC Vive's chaperone bounds appear in real life.

When speaking of the lenses, users seem to be referring to the restricted field of view created by the HTC Vive, with the periphery of their vision being blocked and darkened. One user described this, saying "everything looked as if I was looking through the Vive lens." Another linked this to night, potentially due to the associated darkness: "Especially at night, when I close my eyes I could see the outline of the [HTC Vive] lenses." Users compared this effect to how very bright lights can linger after looking away, until the pupil adapts: "It's like light persistence, where you're looking at something really bright then close your eyes and keep seeing it." However, unlike pupillary adaptation, the duration of this effect could be highly variable, sometimes "going away in a minute" and sometimes "lasting for hours and even into the next day." The potential for this effect to persist for a prolonged duration, and for delayed onset (such as appearing at night) suggests that this effect cannot be solely attributed to the response of the retina to prolonged dimming of the periphery.

Many users reported seeing something like the screen door effect, where the real world appears to be composed of pixels: "I felt like I could see pixels in real life." In a similar fashion, other users reported that "[the real world] seemed kinda rendered." Sometimes this effect could be triggered by seeing a grid in real life, such as when one user reported that they "noticed a screen

door effect in real life, which was caused by a grid pattern messing with my eyes." The community also referred to this effect using the term "grid eyes." In addition to seeing pixels, one user also referred to seeing fresnel patterns in real life, saying they could "see pixelation and fresnel lines up to 12 hrs after [they] stopped VR." This effect could persist for a long duration in some users, even to the extent that users would "see grid eyes when they wake up [the next day]" after long play sessions spent in VR.

A similar effect was also reported with the HTC Vive's chaperone bounds. Unlike the lens outline and the screen door effect, the chaperone bounds are not necessarily always visible. They are also not fixed in the visual field, as they are spatially situated and will move in the visual field as the user moves. As such, this does represent a slightly different effect than those discussed previously. Some users reported "seeing chaperone bounds where they would have been in VR, but within [their] real life rooms," while others also reported that this could occur in environments other than where they normally play in VR. This effect was convincing enough that it can affect a user's behavior, as in the case of the user who said that the effect"was really weird, and has made me make a dead stop in the middle of a stride, because for a second or two I thought I was going to hit my wall."

5.2.1.4 Additional visual aftereffects

In addition to aftereffects related to persistent visual elements of a VR display, users also reported two other unusual aftereffects pertaining to vision in the real world: a heightened sense of dimensionality for 2D text or images and a strong awareness of the individual pixels present in a display.

Some users spoke of "visual glitches" that occurred outside of VR, where "text would randomly appear 3D." This included "floating text when browsing the web" and seeing "stuff on regular 2D TV appearing a bit like 3D-glasses." This effect was frequently linked to text, with one user specifically referencing the "text on your screens created a 3D effect against contrasting backgrounds." It may be that this effect was tied to high contrast situations, of which text was one of the most frequently encountered examples. However, like the earlier reference to 2D TVs, other users felt that "everything just seemed to pop out in 3D." This effect is an interesting contrast to the first perceptual after effect we discussed, where depth perception becomes difficult and the world appears more flat. In this case, flat images and text seemed to take on an additional sensation of dimensionality. It is also worth noting that many users reported enjoying this effect, telling new

users who mentioned it to "enjoy it while it lasts. I kinda miss it."

Another unusual visual effect was a heightened awareness of the pixels present in a display. This was distinct from the previous instance of observing the screen door effect in real life; where rather than seeing pixels where there are none, users instead become more aware of pixels when they are present, even in high density displays. One user reported being able to "notice pixels on an iPad Pro from a normal lap-resting viewing distance," which is notable given the "retina" resolution of an iPad Pro. Other users did not make reference to specific devices, but reported the same effect, saying "I now see the pixels on high density mobile displays, which required a bit of work to see clearly before," and claiming that they could "easily distinguish between all of the pixels."

5.2.1.5 Persistent haptic aftereffects

The final perceptual after effect that we noted was not a visual effect, but a haptic effect of an ongoing sensation that the HTC Vive's cord is running down their back, even after removing the HMD. Users often referred to this effect as the "phantom cord." Many users reported that "after using [their] Vive, [they] could still feel the cord down the back of [their] neck even when the HMD was off." This effect became so familiar to some users that "it just felt like there SHOULD always be a cable coming out of the back of my head." This effect could also manifest itself behaviorally, where if users were to "run over some wires with a chair at work" they would "rush to make sure my HMD wasn't about to fall over."

While this effect seems less notable than some of the previous effects, it was unique in that it was the only non-visual after effect we observed. Even the aftereffects related to body ownership and proprioception contained a visual component, as these conflicts were created when users saw their bodies. Additional haptic aftereffects may be expected in future VR systems that provide additional haptic stimulation, especially if this stimulation is provided consistently, or with high frequency.

5.2.2 Behavioral aftereffects

The second theme that emerged from users' conversations dealt with behavioral aftereffects. In this theme, the aftereffects led users to alter their behavior. While perceptual effects inevitably would also alter behavior, users did not frequently discuss these changes, instead preferring to focus on the altered sensation. The sub-themes discussed here are different in that they were always linked

to explicit behavioral changes.

5.2.2.1 Verifying the reality of the real world through interaction

Users commonly reported a sense of unreality associated with the real world after exiting VR: "Especially right after I take off the headset, I have a hard time figuring out whether I am in reality or not." In order to verify the reality of their experiences after removing the headset, users would deliberately touch objects to confirm their real nature, e.g. "I would often touch things (my desk, the wall, my phone, etc.) just too reaffirm they are indeed real," and "I would touch or pickup objects IRL and question if they were real". It is notable that users fall back on the haptic sense to verify that the objects they are seeing are in fact real. While current VR systems are capable of simulating visual input with high accuracy, haptic simulation remains crude, at best. As such, users have grown accustomed to virtual objects not providing any haptic feedback, which ensures that if an object does provide haptic feedback, it is real. This may have interesting implications for future VR systems capable of more accurate haptic simulation. In this event, it seems likely that users would not fall back on haptic sensing to reassure themselves of the reality of the real world.

5.2.2.2 Hesitation when moving in the real world

In addition to verifying their world's reality through touch, users also reported they would "walk a bit slower in their house to make sure the chaperone system didn't pop up." Others attached emotional significance to this change in behavior, expressing "[fear] to walk because I feel penned in by the imaginary cage of the chaperone bounds." In addition to moving slowly due to feelings that they might encounter a chaperone bound, users also expressed hesitation about attempting to support themselves using physical objects. One user reported that he "never shifts my weight onto anything unless my hand is on it for about a second for my brain to make sure its real." This behavior emerges from the risk of "just falling through it" associated with attempting to support oneself on objects in VR, which have no real existence. This hesitation was then carried over into the real world after exiting VR.

5.2.2.3 Attempts to use VR interaction metaphors in real life

While the previous two effects dealt with new interactions with the real world, the final effect users describe involved instinctively attempting to use VR interaction metaphors in real life.

These included both locomotion metaphors and interaction metaphors.

Users regularly report attempting to teleport in real life after spending time in VR. As the inverse to users hesitancy to walk due to fear of encountering a chaperone bound, users "feel like [they] should just teleport somewhere instead of walking." Users felt this instinct for both general motion throughout a space and for motion intended to facilitate interactions with the local environment: "I try to teleport to things I need to pick up." As teleportation is one of the most common locomotion metaphors used in consumer VR experiences, attempts to teleport were the most frequent VR locomotion metaphor applied to real life. However, at least one user also referred to an attempt to use sliding locomotion, saying he would "put my hand out with the non-existent wand that was no longer in my hand to point at the part of the room they wanted to 'walk' to." This suggests that the frequency of references to the metaphor of teleportation was more likely to be due to its prevalence in consumer VR applications, rather than any inherent aspect of the metaphor. As other locomotion metaphors become more common, it seems likely that users will also experience instincts to use them to move in the real world.

Interaction metaphors from VR were also applied to real life interactions. Users would "try to press the trigger button to pick up objects in front of me in real life," or "try to pick up a drink by pointing my 'controller' at it and pressing the grip button." Going beyond attempting to initiate interactions by pushing an appropriate button, another user reported an event where the rules governing ongoing interactions in VR were carried over to the real world stating that, "After a few hours in VR, I got some coffee, and then just let the cup drop from my hand, spilling all over my carpet. I think I had been in a game where you only pull the trigger once to pick up an object and then it stays bound. My brain just forgot to hold on." VR games will commonly allow some objects to be held by pulling a trigger once, rather than requiring users to continuously hold the trigger down. The object can then be released by pulling the trigger again. This lowers the strain placed on users' hands while holding these virtual objects, that otherwise would be held for a significant amount of time.

While the majority of attempts to use VR interaction metaphors in real life centered on attempts to use controller-based interactions, one user reported changes in his physical motions used while engaging in an activity:

> "I've been having a whole lot of fun with 2MD VR Football lately. After a few weeks of playing an hour or so a day, I went to throw [a football] with a coworker in between

shifts. Even with only a few weeks of play in VR, I noticed my release was way earlier than it had been. I'm pretty sure it's because the Vive wand is significantly lighter than a football, so I accidentally trained myself to release faster since I go through my throwing motion faster in VR. I had to re-learn my throwing motion a bit after that. This is particularly interesting to me because I work in athletics (totally different sport) and proprioceptive response training is a big part of my work."

While the previous application of VR interaction metaphors to real life are relatively harmless (and even humorous), the disruption of a user's muscle memory required to perform a physical activity is more concerning. While we only observed a single user describing how their muscle memory for an action in the real world had been disrupted due to learning a different motion for the same action in VR, this anecdote suggests that it may be very important to carefully engage the same muscle systems and motion patterns in training systems where skills with a muscle memory component are being learned, even if the primary goal is to train a cognitive component of the task.

5.2.3 Increased Vividness and Lucidity in Dreams

Unlike the first two major themes, which focused on changes in perception and behavior in the real world, the final theme that emerged focused on changes in users' dreams. At the most basic level, some users reported dreaming about VR experiences, either in general (e.g. "I had dreams about VR the first few days after I got my Vive") or in part (e.g. "the interface of my dreams is different, almost like playing VR in a dream."). Given the brain's tendency to integrate recent events into dreams, it was not particularly notable that these sorts of dreams were reported. Of more interest are instances where specific interaction metaphors from VR are incorporated into non-VR dreams. Users spoke of how they "definitely teleport around in dreams now," how "all of a sudden a chaperone grid popped up [in my dream]," and how "the dream I had last night involved a climbing mechanic from the game I played." In these cases, specific interaction mechanics, locomotion techniques, and safety features of VR experiences are integrated alongside more mundane experiences in users' dreams.

Going beyond the mere content of the dreams, other users spoke of how their dreams had become more vivid: "The more time I spend on VR, the more vivid my dreams become. I've dreamt all kinds of things. They're not always related to the games I play, but it feels like my brain is more

used to be in dreamlike environments so I'm more aware and even in control sometimes." Dreams were not only more vivid, but could also become lucid. In lucid dreaming, the dreamer is able to control what happens in the dream, rather than merely experiencing it: "The only thing that happened to me [when I started using VR] is I had these really lucid, vivid dreams where I was in VR, but they only lasted a few weeks." In users who already experience lucid dreams, they felt that VR increased the number of lucid dreams they had: "I have many more lucid dreams (where I know I'm dreaming). Presumably as a product of my mind constantly reminding me that VR isn't real."

Out of all of the aftereffects reported by users, the dreams associated with VR were the most well received and enjoyed. These vivid dreams were described as "amazing" and "the best side effects IMO." One user said he "kind of digs the dreams actually. Some really wild entertainment is going on in my head at night now." One user, who no longer experienced vivid dreams after spending time in VR shared how he missed them: "God it was so beautiful having VR lucid dreams. I miss those the most from my first VR experience."

Past research has found that playing non-immersive video games can influence the dreams of the players, and that this influence can grow stronger the most immersed players feel in the game [61, 27, 102]. Based on this research, it was not surprising that users reported dreaming about VR, or that their dreams had become more vivid. However, the increase in the rate of lucid dreaming goes beyond previous observations with non-immersive video games. It may be that the increased agency afforded by direct manipulation in fantastical VR settings prepares the mind to exert more agency within dreams as well.

5.2.4 Reports on the duration of lingering effects

While discussing the type of aftereffects experienced when using VR, users frequently made reference to the duration of these effects. During our first pass through the comments, it became clear that the community agreed that these aftereffects eventually stopped occurring once users had spent enough time using VR. As such, we coded all comments made by users pertaining to lingering aftereffects for four temporal concepts: 1) the amount of time required to spend in VR before lingering aftereffects emerged, 2) when aftereffects began after ending a session, 3) the amount of time aftereffects lingered after ending a VR session, and 4) the amount of time that lingering aftereffects could be experienced at all.

5.2.4.1 The amount of VR time required to create aftereffects

Users were nearly unanimous in that the aftereffects described above only occurred after extended play sessions in VR. The shortest duration mentioned in association with aftereffects was one hour. One user specifically said he did not play for longer than 40 minutes at a time, so as to avoid a "VR hangover." While the lower threshold set by users was one hour, the longest duration mentioned by users lasted an entire day. Between these limits, users mentioned other durations, including "two hours," "a few hours," "a long session," "extended use," and "a long session of 5 hours." Several users obliquely mentioned that they had engaged in shorter VR sessions prior to their first "longer" session (exactly how long was not stated), which is when their first aftereffects began to appear: "It started after I started to play longer sessions," "the first time I got it, I had spent hours in VR playing games," "it started after my first day of extended use," and "they usually start after a users initial extended use." As such, it appears that side effects are triggered by the amount of consecutive time spent in a single session, not cumulative time spent across multiple sessions.

5.2.4.2 The time required for onset of effects upon exiting VR

We found few explicit references to when aftereffects began after exiting VR. This seems to be because users generally understood these effects to begin immediately after a play session had ended. Comments to this effect included "[they started] after getting out of the game" and "especially right after I take it off." However, other users reported that the effects could start later, such as when "I laid down after very long Vive session," or "when I saw a grid pattern [in real life] messing with my eyes." Of all of the temporal questions concerning the aftereffects discussed in this paper, this question was the least discussed by users, and the most uncertain.

5.2.4.3 The duration of aftereffects upon exiting VR

Users discussed the duration of these effects more frequently than the time required for onset. There was also little agreement for this topic. Users reported aftereffects lasting from only "a few seconds" to "12 hours" or more. Some users also reported that these effects can persist through sleep, such that they are still present the next day after waking up: "Even on the next day, e.g. during car traveling , I still have this insecure feeling, that somehow my depth sense is distorted."

As such, it is difficult to draw conclusions about the "typical" duration of these aftereffects. It may be that different aftereffects are associated with different lengths, or the the time spent in VR prior to the aftereffects appearance is related to the duration the effect lasts. Work by Champney et al. suggested that the time to recalibrate after performing a pointing task in VR was related to the amount of time spent in VR [18]. It may be that a relationship of this sort is generally true for the aftereffects we observed here, which would account for the lack of agreement among users concerning how long these effects last.

5.2.4.4 The time required for aftereffects to permanently stop

Users were also unanimous in their agreement that these lingering aftereffects eventually stopped occurring. Some users reported effects disappeared in as little as two to four days. However the most common length of time reported was after "a couple of weeks" of regular VR use. Most users reported that these effects completely disappear: "It went away and has never returned to me," "I don't get a hint of it anymore," and "your brain adapts and these feelings go away." Rarely, people would speak of the effects mostly disappearing, where they would infrequently reappear: "You will get used to it and it will go away. It is pretty rare for me now." The one exception to this claim was dreams. Some users report that their dreams have remained exceptionally vivid: "Vivid dreams are a noticeable side effect and have persisted to now." Other users, who once had vivid dreams but since lost them, reported that these vivid dreams reappeared when they returned to VR after taking a break of several weeks: "[The vivid dreams] all go away after a while, but if you take a break for a few weeks they could return."

Within our search, we noticed a significant drop of discussion regarding all of these topics in the second year, compared to the initial year when the Vive was released. We believe this to be attributed to the fact that new users were surprised to encounter these effects and became eager to reach out to see if other users experienced the same. Upon enough discussion, as well as a majority of these novices no longer experiencing these effects, we believe a large enough portion of the community had by then exhausted their opinions on these subjects. A significantly smaller amount of discussion was still found, but became more centrally focused around expert users sharing their past experiences and comforting new users of what is to come.

5.2.4.5 Discussion on the duration of lingering aftereffects

Users unanimously reported that these lingering effects only occurred after spending a significant amount of time in VR, and that they eventually seemed to disappear, typically over a period of several weeks (with the assumption that the user continues to spend significant amounts of time in VR during this period). With the exception of changes to dreams, these effects were rarely observed to reappear, even if the user took a prolonged break from VR.

It is important to draw a distinction between users *reporting* that the effects disappeared, and the effects *actually* disappearing. It is possible that the unanimity expressed in the eventual disappearance of these effects can be attributed to these effects actually disappearing, or to the users adapting to their presence. This determination would require controlled experiments that examine users' perception and behavior after prolonged exposure to VR. Ideally, this would be carried out in a longitudinal experiment. However, experiments could also shed light on this by comparing the perceptions and behavior of inexperienced VR users to experienced VR users.

We observed that few users attributed these temporal effects to specific aftereffects, but instead more generally referred to feelings of "off-ness' after VR. As such, we were unable to identify different temporal patterns for each of the aftereffects discussed above. Instead, we consider the duration of each of these effects as a whole. While we found significant agreement in the minimum amount of time required for temporal concept one (see above), users reported significant variability in the amount of time associated with the other temporal concepts. While many factors could explain this variability, including individual differences between users, the time spent in VR, and the activities engaged in while in VR, it may also be that each of the aftereffects identified here have unique temporal properties.

5.2.5 Users' understanding of VR aftereffects

Users referred to these side effects using a range of different terms; including terms coined by the community (such as "VR hangover", or "the Matrix effect") and terms imported from medical or scientific literature, including the "Tetris effect", "dissociation", and "derealization." Other users simply referenced these effects descriptively, speaking of "weirdness", or experiencing an "off" feeling.

Regarding the Tetris effect, which was first described in association with the game Tetris, prolonged exposure to repeated stimuli resulted in continuing to experience this stimuli even after

ceasing that activity [22]. In the original context, people who played Tetris for extended durations (i.e. multiple hours) reported feeling like they could still see Tetris blocks falling in real life. Users regularly referred to this Tetris effect within plausible contexts, such as when discussing how users continue to see chaperone bounds in real life. We did not observe any instances where the Tetris effect was applied inappropriately, such as to problems with perceiving depth in the real world. The Tetris effect has been observed in VR before [45], however this study reported on users' seeing the environment of a specific game when they closed their eyes, not aspects of the supporting technology while acting in real life, as was reported by our users.

Others used the terms "disassociation" or "derealization" when describing these effects as well. Users were more likely to reference scientific experiments, or scientific experts when employing these terms. One user compared this to the disassociation experienced in the rubber hand illusion, where a participant can be convinced that a rubber hand is their own hand [11]. With this in mind, the user said "I think being in a new reality without seeing my hands dissociates them in real life." Another user referenced speaking with a friend who has a masters degree in psychology, who said this sounded like a form of sensory disassociation. Derealization was used in a similar context (e.g. a user said that "people do report symptoms similar to derealization"). When speaking of "derealization", another user expressed concerns as to whether this was at the root of these experiences, and what impact this could have at a societal level. Interestingly, these users never defined the terms disassociation or derealization, but instead leave the user to infer their meaning, or search out a definition themselves. This makes it difficult to gain more insight into the specific meanings applied to these terms, beyond the observations of the contexts they are used in.

By characterizing these effects as the "Tetris effect", or "disassocation/derealization", users implicitly attempted to explain these effects using these phenomenon. Other users put forward additional explanations that were not explicitly linked to a term describing these phenomenon. Possibly the most common basic explanation was that these side effects were believed to be linked to inaccurate interpupillary distance (IPD) settings on a users' HMD (e.g. "If your depth perception feels weird after taking off the Vive, your Pupillary Distance is set incorrectly."). Users' awareness of the importance of setting the IPD accurately can most likely be attributed to instructional material provided with the HTC Vive, both in paper format, online materials, and tutorials shown to the user when setting up the system. This is useful information, as it suggests that the (current) VR community may be receptive to scientific information that can help to explain or improve their

experiences with the technology. Users also attributed these effects to how "your brain adjusts to the slight lag in VR tracking in intensive games, and that in real life it tries to apply what it knew in VR, which causes a slight disparity resulting in a real life ghost hand." This user demonstrated not only an awareness of the importance of minimizing latency, but also the concept of calibration in the human perception-action system (although not the terminology). The idea of calibration [1] was widely accepted in this community, although terminology such as "reprogramming" was typically used instead. One concept that was notably missing was the accommodation-vergence conflict problem [36]. While this problem was tightly linked to distance misperception issues within the scientific literature, this concept was not invoked by the community when discussing these issues.

5.3 Conclusions and Future Work

Our analysis of consumer discussions on the /r/Vive forum suggested that VR does create lingering side effects in users after they finish a VR session, but that these effects seem to completely disappear within a relatively short period of time (at the most, several weeks). The most commonly reported side effects were perceptual side effects, including altered perceptions of body ownership and proprioception, altered depth perception, an assortment of unusual visual phenomenon, and a lingering haptic sensation from the cord connected to the HTC Vive. Behavioral side effects were also reported, including feeling a need to verify the reality of the real world through touch, hesitancy when walking or leaning against objects in the real world, and attempts to use VR locomotion and interaction metaphors in real life. Users also reported experiencing more vivid dreams, and even more lucid dreams. Users agreed that these effects only seemed to occur after spending at least one continuous hour in a VR application. The duration of an effect could vary considerably, from mere moments to lasting into the next day. Users also agreed that they eventually stopped experiencing any side effects, usually within several weeks.

We proposed several recommendations to VR developers based on this work: 1) developers should caution new users that they may experience specific perceptual aftereffects after long VR sessions; disruption of depth perception is one of the most dangerous aftereffects reported, as this could interfere with driving or operation of other potentially dangerous equipment. 2) developers should inform users that aftereffects of the sort noted here become more likely after spending 60+ minutes consecutively in VR, 3) researchers should investigate how to bring about the (perceived)

extinction of these aftereffects more quickly, so as to better enable new users to make the fullest use of this technology, and 4) researchers should investigate whether these effects actually are extincted, or if users merely perceive them to stop because they grow accustomed to their presence after a long VR session. These questions cannot be answered using the qualitative methods employed in this paper, and will require controlled laboratory experiments.

5.3.1 Limitations

This work only considered posts made on the /r/Vive subreddit. As such, it was largely specific to the HTC Vive hardware. This was evident in some of our findings, which make reference to the "chaperone bounds," a system that is not present in all VR systems. However, we argued that the majority of the findings from this research can be applied, either directly, or indirectly, to other current VR hardware. However, future systems that provide improved haptic simulation or dramatically different visual experiences (such as a verifocal display) are likely to evoke different lingering aftereffects from those we observed here.

This work is also limited by the search terms we used: "feels weird after," "side effect after," and "disassociation." While we selected these terms after close observation of these forums to identify the types of effects discussed by the community, it is possible that other effects escaped our notice.

Finally, it is important to put this work in context: it examines what side effects are associated with VR, and how long they can last, *through the lens of a user's experience*. While this gives us access to more material than can typically be gathered in controlled laboratory experiments, it also introduces at least two limitations. First, our data relies on subjective self-reports drawn from uncontrolled settings. This limits the extent to which specific details can be quantified (e.g. the amount of depth compression typically experienced, the average duration of lingering effects), and users are unable to report on effects of which they themselves are unaware. Second, there was an element of self-selection involved in this data set. We observed that users unanimously agreed that lingering effects disappeared after several weeks of VR usage; however, given their potentially unpleasant nature, it is possible that these effects persisted in some users, who then stopped using VR and thus did not engage in this forum. It is important that these limitations be considered when applying these results, and for future research to test and quantify our observations in controlled experiments.

Chapter 6

Study 4: Changes in Presence over the Short-term: An Analysis using After Action Reviews

This study helped further answer the question of "*How is presence affected as a result of this increased exposure?*". We took the data found in the previous chapters regarding presence and centralized them into a single study that could showcase those underlying themes and directly test their impact on a user's feelings of presence across time in a controlled laboratory setting. The themes gathered here strengthened the notion that a user's feelings of presence can change drastically throughout a single session of gaming. The answer of "*"How is presence affected as a result of this increased exposure?*" is given more light as a result of this study due to the data suggesting that increased exposure can be measured in changes across seconds as well as across days. In this study, we explored how user experiences changed over time while engaging in 'The Secret Shop' experience, and used an After Action Review (AAR) technique to graph their feelings of presence over time. Presence was shown in these graphs to both rise and fall, gradually and rapidly, throughout the course of a user's experience due to the impact that user's expectations, the affordance inconsistencies encountered, and the level of engagement had throughout the experience.

6.1 Experimental Design

6.1.1 Experimental Simulation and Setup

The simulation consists of a setup of hardware using a HTC Vive Pro, a Windows PC with an Intel (R) Core (TM) i7-8700 processor, a NVIDIA GeForce RTX 2080 graphics card and 32 GB of Memory RAM. Participants will play "The Secret Shop" using the HTC Vive Pro in a 15' by 15' space. The Vive chaperone bounds were configured to create a safe space within which participants could walk freely without the risk of running into obstacles.

6.1.1.1 The Secret Shop

Figure 6.1: The Secret Shop

" The Secret Shop," as shown above in Figure 6.1, is a short experience created by the Valve company that is set within the shop of a fictional magical world. This experience begins with the player being placed within the center of the shop, and a virtual "shopkeeper" character soon entering through the front door. After giving a brief scripted introduction, the shopkeeper simultaneously affords the player a glowing ball of light that could illuminate and engage various items and entities around the shop. After the shopkeeper takes his leave, the participant was then free to explore the environment by either physically walking around within the space provided or teleporting via their Vive Controller. This experience runs on a random timer, which only allowed players to stay within the environment for between 4 to 5 minutes maximum, signaling its end with a large monster appearing outside of the shop and ripping off the roof. Random in-shop events would also occur, such as a jack-in-the-box randomly popping out at a player or a small goblin escaping from the

underground cellar and climbing out of the shop's window. While within the shop, there are a few virtual entities that the player could attempt to engage with, including a small dragon and a petite squid. However, some entities could not engage, such as a tiny man riding on a flying carpet around the shop, which cannot be stopped or collided with by the player's controller. The shop is full of many interactable objects, such as a hanging sword and hammer, along with some white 'glyph' circles scattered around, which when tapped using the afforded ball of light, allowed the player to shrink down to wherever that glyph was placed. But again, there were also objects scattered along the shelves which could not be interacted with, such as various potions and trinkets, because they did not have collidable properties that afforded player interaction. These inconsistencies with interactions and engagements between items and entities are why this experience was selected. The differing affordances allowed for a diversity of possible interactions, disappointments, and enjoyable experiences, all of which have been shown to impact presence based on what we know from the literature. However, this knowledge was not disclosed to the participant by either the proctor or the game, and so all players had to discover these interactions and affordances through trial and error.

6.1.2 After Action Review

Many other experiments in the past have measured for presence either after an experiment is over using a trusted survey tool, or during by asking the participant throughout the experiment to give a self-reported estimate. In our experiment, we still plan to have participants complete a survey after their experience, but with the added measure of an after-action review (AAR) phase, where users can see exactly what they just experienced and have the opportunity to give an account for how present they remember feeling just minutes ago. The term after-action review (AAR) was originally used to describe reviews of military events (e.g., combat missions) and eventually the practice of conducting these AARs has since spread outside the military to a variety of training situations [19]. Other recent studies in VR have also used this technique to generate visualizations used for review, evaluation, and feedback [64, 41]. Results showed that by using this technique to help review experiences, students became more self-aware of their actions and gained better insights into how to improve future interactions. We hope that by using this technique, users can give a more in-depth at their experiences of presence as it relate to minute intervals and events they are experiencing.

6.1.3 Participants

In this experiment, we obtained a total of fifteen participants with ages ranging from 18 to 34 ($\mu = 23.47, \sigma = 5.23$). Six of the participants reported having 50+ hours of previous experience with some form of virtual reality equipment; two reported having spent anywhere between 20 to 40 hours in virtual reality; two reported anywhere between 1 and 3 hours, and all remaining players reported having less than 1 hour of prior experience. All but one participant recorded being avid gamers with over 10 years worth of experience playing various games, with only two participants feeling they are not good at the games they play. We sought to recruit participants that had never previously experienced the game titled "The Secret Shop" to avoid any prior knowledge that could affect their natural progression of presence in a new gaming environment.

6.1.4 Methodology

Upon entering the testing area, each participant was given a brief overview of the purpose of the experiment and asked to sign an informed consent form. We then asked each participant to define their current understanding of the word "presence" to gauge their knowledge surrounding the term. Regardless of response we then offered the most current scientific meaning regarding how it relates to feeling immersed within the virtual environment you are in. We asked that each participant keep this understanding in mind as they engaged in "The Secret Shop" as it would become relevant again during the After Action Review (AAR) portion of the experiment. Participants were then instructed to complete the Steam VR Tutorial experience, where they were given a brief overview of basic virtual reality affordances and concepts. This included the use of their HTC Vive controller's various triggers and buttons and how to identify the HTC Vive chaperone bounds.

After completing the tutorial, each participant was then immediately placed into the "The Secret Shop," where they were not given any instruction, other than to explore the shop at their own discretion. While in "The Secret Shop," each participant's journey was recorded using a screen-capturing software, resulting in a video that showed the experience through the eyes of that participant when replayed. This video was saved and stored to be used later in the After Action Review (AAR) phase of the experiment. During each participant's experience, there were 2 timed occurrences where the proctor would cover a base station using their hand to disrupt that participant's tracking without their knowledge. The first occurrence would happen within the first 2.5 minutes of

Figure 6.2: Each participant's gameplay was recorded and replayed to them on a monitor after leaving the experience. While watching the video, participants seamlessly reported the amount of presence they felt moment to moment indicated by the position of the pointer added at the bottom of their video (right is high, left is low)

their experience, and the second within the remaining time left. An online random time generator was used for the selection of both times within their respective bounds. One occurrence was categorized as "*short* break", where the proctor covered the tracking station for one second, verifying that the participant experienced a slight disruption in tracking. This resulted in a brief flicker in the participant's visuals between 1 to 3 seconds due to the time taken for the simulation to completely recover. The other occurrence was categorized as "*long* break", where the proctor would cover the tracking station for roughly 3 seconds, verifying a complete disruption in tracking. This resulted in the participant's visuals being completely disrupted for anywhere between 3 seconds to 10 seconds before the simulation's full recovery. The range of time needed for full visual recovery was again based solely on the time needed for the tracking stations to fully restore after the proctor removed their hand. The order of which occurrence happened first was counterbalanced between all participants.

Upon completion of their experience in "The Secret Shop", each participant was then asked to immediately complete an After Action Review (AAR) of their experience. During this review, participants watched the recorded video of their recently completed journey, where they were also instructed to elicit how "present" they felt from moment to moment throughout the experience. Participants were instructed to slide their thumb across the HTC Vive controller's touch-pad to signify how present they were feeling at any particular moment, with the far-left of the pad signifying not feeling any presence at all, and the far-right signifying feeling very high levels of presence. While watching and reviewing, Figure 6.2 shows the interface we created in Unity, which allowed

participants to observe a small pointer that overlaid their AAR video. This pointer was connected to the Vive controller touch-pad the participant was holding and helped maintain accuracy for the participant by giving them the ability to visually follow along with their presence rating. After completing this review phase, the proctor then conducted a semi-structured interview based on what they observed during the participant's journey, generally centered around what interactions and entities the participant had encountered. Moments of extreme highs, lows, and transitions recorded during the AAR review phase were also expanded upon during this interview phase. All interviews were recorded and later transcribed for further thematic analysis.

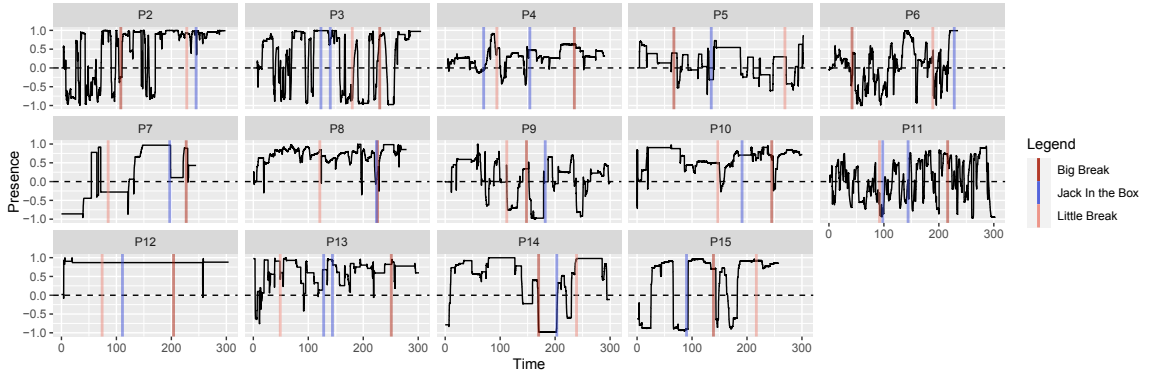

Figure 6.3: These graphs visualize the amount of presence over time each participant reported using the AAR interface. The various colored lines show the start of a particular event in the data for each participant. The red line indicates when the long break event was administered, while the pink line indicates when the short break event was administered. The blue line indicates when a participant encountered or engaged with the in-game Jack-in-the-Box, of which some participants engaged multiple times.

6.1.5 Research Questions

In this paper, we report on the use of an *after action review* to explore how users' sense of presence evolves over the short term during an experience. In particular, we focus two major research questions:

R1 :What is the general trend in changes in presence over time? In particular, do changes in presence typically manifest as gradual changes, or instantaneous changes?

R2 :How much is presence affected by specific events? How do levels of presence change once the event is over?

We believe this work is timely as the adoption of VR continues to grow and VR devices become readily accessible and thus we make two key contributions to the VR community. First, we address the lack of scholarship regarding formative temporal assessments of presence and how instead presence can be measured moment to moment, and as a result, looked at over time. Secondly, the methodology itself, as this nuanced approach to understanding the progression of presence can be adopted and used by the VR and AR community to better understand how specific moments within the environment can inform, impact, and influence one's presence. Looking at the relationships between the timing of these events can be helpful in understanding how quickly users can recover from negative events. This method can also help show extreme peaks and lows that you cannot get from a traditional summative analysis of presence at the end, by showing exactly when a change in presence occurred. A few limitations have emerged in prior literature. First, the majority of research focuses on measuring presence summatively, which may or may not reflect the whole of a person's natural behaviors. Second, traditional methods such as self-report often ask participants to revisit their current mental state in the environment and do not demonstrate their progression of presence such as highs or lows within the environment. This limits the measurement of presence to focus solely on the overall experience rather than specific moments within the environment. We believe through the use of the After Action Review (AAR) method, we can take a unique look at how presence changes and flows throughout a user's experience over a short period of time, which has not been typically captured by other summative methods.

6.2 Results

6.2.1 AAR Graphs

One participant's AAR data was dropped due to an error in the recording. Figure 6.3 shows a visual breakdown of the remaining participants. All participants experienced the same events at the beginning and the end of the experience. However, they decided what to do or engage with during the time between those two events. Because of this, the middle portions of the AAR graphs are not directly comparable with each other. Instead of comparing single points in time, we looked at both 1) how *patterns* of presence changed during their experience, and 2) changes that occurred during specific events across participants.

Several patterns appeared in the AAR graphs. First, when participants reported a change

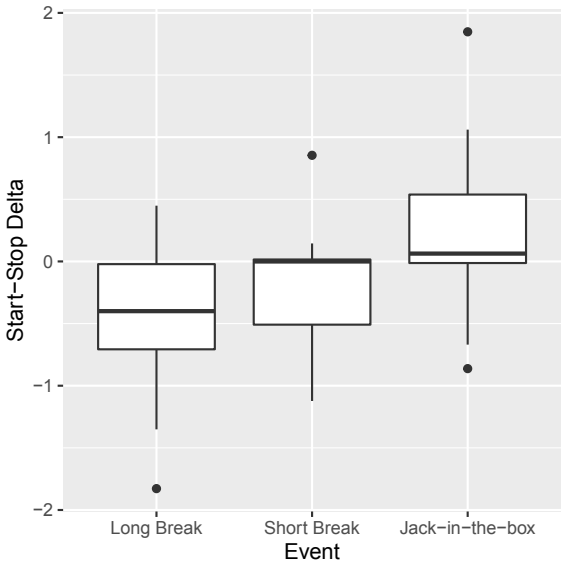

Figure 6.4: Expected events that occurred during every participant's journey around the Secret Shop. The long break event showed a significant decrease in presence ($p = 0.0122$), with the short break event showing no significance ($p = 0.161$). The jack-in-the-box event trended towards a significant increase in presence (0.0519), but with a low median, signifying not all participants recorded this change.

in presence, it was typically a rapid, large change up or down. While gradual, continuous changes did sometimes occur, they were not the norm. Second, participants often quickly rebounded after experiencing strong drops in presence, showing quick recovery potential. Third, many participants (though not all) reported presence values that were almost always in flux. Finally, most participants did not demonstrate a clear trend towards increased or decreased presence over time.

Though specific points in time cannot be meaningfully compared in the AAR data, we can identify comparable moments linked to specific events. As participants were able to do different activities, participants did not necessarily experience all events. This analysis focuses on three short events that everyone experienced: the long break in tracking, the short break in tracking, and engagement with the jack-in-the-box. To examine how these events impacted presence, we compared participants' reported presence at the start of the event against the presence at the end of the event. Pairwise t-tests were used to test whether the change in presence during a event was statistically significant. The normality of the data was confirmed using a Shapiro test.

The long break lasted for 9.43 ± 8.94 seconds. This was due to a longer re-calibration needed for the tracking hardware. Presence decreased significantly during the long break in tracking

($p = 0.0122$). The short break lasted for 2.36 ± 1.01 seconds. Presence did not change significantly during the short break in tracking ($p = 0.161$). The jack-in-the-box event lasted for 13.44 ± 6.54 seconds depending on if the player continued to engage with the box after it's initial spring. A trend towards an increase in presence was observed during the jack-in-the-box event ($p = 0.0519$). Each event's change in presence is visualized in Figure 6.4. It can be observed that the median values for the Jack-in-the-box and short break are both close to zero, despite there being a wide-spread in the data. This indicates that several participants reported little to no change in presence during these events. However, participants frequently discussed these events during the interviews and addressed some other events that not everyone experienced. We visit this in the next section.

6.2.2 Interview Findings

From our interviews, two themes emerged, *Consistent experiences sustain presence* and *Key events cause rapid changes in presence*. The first theme highlights influencing factors on how a player's feeling of presence can be initially set, and gradually amplified or impeded according to how well implemented and consistent the environment and its affordances are. The second outlines how in-game events can drastically impact a player's feeling of presence at any moment, emphasizing on player engagement and expectation.

6.2.2.1 Consistent experiences sustain presence

This theme explores how feelings of presence can gradually rise and fall based on how the player's comfortability and understanding about their environment changes over time. Participants often noted that *"when things were happening in the environment, it made the environment seem more real. But when I was just inspecting things, or trying to interact with things that I thought I should be able to, but couldn't, that lowered the presence I felt"* (P9). This sentiment was felt most often during the initial exploration phase and/or any downtime between unique in-game events. During these times, we found that participants often were initially present and amazed by the visuals of their surroundings, but could become less present after too many failed attempts to engage with it. This led us to create two sub-themes, *Consistent Environments Set the Stage for Presence*, and *Inconsistent Affordances Impede Presence*, to separate these thoughts and explore further.

Consistent Environments Set the Stage for Presence

Even while in virtual reality, mimicking basic physics was said to help easily situate participants into their new environment, resulting in increased levels of presence overall. Audio feedback was also an important contributing factor because *"before the monster was even there, you could hear it coming, and that led to more presence"* (P9). The sum of these seemingly subtle cues gave players a mental compass and met their natural expectations, which made them feel more present, thus setting the mood for them to want to progress and engage further. In fact, every participant mentioned in some way how *"encompassing*" (P7) the environment was and how they felt *"higher feelings of presence when looking at the details up close"* (P11). Many recounted how so many things in the world felt natural to them *"from the shadow rendering, to the lighting from the candle, and even the way the sword moved (even though I couldn't actually pick it up)"* (P1). These details, and more, made the environment look and feel more real to participants, leading them to want to look closer and explore even more, often gradually increasing their presence in the process.

Inconsistent Affordances Impede Presence

But over time, we found that visuals were not enough to maintain initial elevated feelings of presence, because upon reaching out, participants were often met with inconsistent interaction responses. Some items were collidable with player controls, so *"the sword increased my immersion because then I knew I could interact with things"* (P8), and *"when the hammer was swinging, it made me feel a decent amount of presence"* (P15). But not all objects had these colliding properties, where some *"objects looked as though they were there, but once you tried to interact with them, you realized some of them couldn't be interacted with"* (P1). As a result, many felt that *"the fact that it was unclear whether or not I could interact with stuff, kind of generally lowered my feelings of presence"* (P11), which left many *"feeling like I'm not there, like I was a ghost or something"* (P15). This frustration with inconsistencies was felt all across all participants and showed it's potential to deteriorate a person's presence over time, sometimes even to a point where it is difficult to recover. For example, some participants were noted to have changed their behaviors entirely after too many failed or disappointing interaction attempts. P3 *"didn't touch the little squid because I saw him but then immediately assumed he was gonna be just like all the other entities, and by that point I was already disappointed by the [failed] collisions of those other entities"*. This was also true in regards to objects also, where after *"the first time I'm like, 'okay, so I can't actually interact with*

this object,' But then as I tried to interact with a few more objects, it was much more like, 'okay, this is just the normal' so I just became accustomed it" (P1). This showed that if engaged with too many inconsistencies among affordances, participants can actively alter their natural patterns and expectations away from future experiences that could have the potential to make them feel higher levels of presence. As a result of this, players eventually moved away from static objects and/or entities in searching for more engaging ones.

This led to another major consensus, where participants felt *"generally pretty immersed until I tried to figure out what I was supposed to be doing and then that slowly started to pull me out of it"* (P11). Participants became increasingly frustrated when they were unsure about what they should do next or how to proceed. This frustration slowly took a negative toll on their feelings of presence over time because many felt that the game had not properly explained important and unique gaming mechanics/affordances very well. For example, P2 mentioned feeling *"frustrated because I didn't know how to interact with the glyphs until near the end. I felt like this guy who came in at the beginning just left me to die. He didn't tell me anything about the glyphs, and there's no instructional video or anything about them"* (P2). These glyphs are a key game mechanic that allowed players to shrink down for a unique perspective and were activated by taking the light given during the intro and pressing it against the glyph. Often in traditional games, figuring out things like is welcome, but for many, *"the glyphs just really confused me because I couldn't figure out what or if there was something I was supposed to do [and eventually] I gave up on them and I didn't really come back to them"* (P11). Again, showing how player frustration created from improper implementation can lead to an increased avoidance of further interactions, impeding presence.

6.2.2.2 Key events cause rapid changes in presence

The majority of participants' discussion centered around unique in-game event experiences. We were also able to link many rapid and sharp changes in presence recorded in the AAR graphs to these discussions. The consensus being that many *"felt like what really disrupted my presence was a big event like the tracking breaking, and what increased it was something that really, maybe startled you like a jump scare or something"* (P11). They also *"felt my presence was a little bit higher whenever I actually interacted with objects and they reacted to me, as opposed to other objects, where I would touch them and nothing would happen, like my hand would just go through them"* (P13). These quotes highlight two important factors to consider regarding how certain events can rapidly and dras-

tically impact a player's feeling of presence at any given moment. Those factors are 1) the engagement being experienced during the event and 2) the expectation surrounding the event's occurrence. The term engagement here refers to how interactive the event is concerning the participant. The term expectation, refers to if what a participant feels should happen, does happen. This is also true for the alternative, where what they expect should not happen, never occurs. These factors led to our two subthemes, *Social and Emotionally-Charged interactions can swiftly increase presence* and *Failed Expectations can quickly reduce presence*, detailing the magnitude that these events can have on presence.

Social and Emotionally-Charged interactions can swiftly increase presence

We found that social and emotionally-charged events have the largest potential to bring about significant increases in a participant's feeling of presence at any given moment, if they felt properly engaged. Participants often felt that having a social guide was very helpful because it helped them feel more present as they integrated into an unfamiliar environment. P16 pointed out that the shopkeeper, who greets players at the start of the experience, *"drew me in a little bit more because he was there talking to me, and it's just the fact that there was someone else there who was interacting with me"* (P13). These social interactions were also found to maintain or increase a player's feelings of presence during stagnant situations by just being present. For example, P7 felt that *"my presence was actually higher around the squid and the small dragon because they were doing something exciting, whereas, with the chessboard, nothing was happening"*. Emotionally triggering events were also specifically noted as having the potential to spike significant rises in a player's presence. As mentioned earlier, all participants experienced the Jack-In-The-Box, and likewise, everyone felt that experience *"actually really pulled me into the game because it managed to evoke an emotional response out of me"*(P11), as supported by the AAR statistics. In fact, many players still felt *"pretty present even after the jack in the box, because I just felt like something else was coming, so I was preparing to fight or flight"* (P2). Other emotional responses were internally created, and players would just *"laugh at the dragon, because he just brought me joy"* (P2). While others, like P11, *"messed with the squid and then after seeing how it did nothing back, made me feel like it was a kind of a jerk. So I guess my presence in that sense was increased. I was like, 'fine! I'm just not gonna talk to you then if you're just gonna look at me through your telescope!'. So it pulled me in because now there was something in the game that made me want to go and interact with something else just to feel that emotional companionship, which I guess is about as close to feeling present as someone can get"*.

Failed Expectations can quickly reduce presence

At first, participants were amazed to see *"all the cool stuff in here that obviously could do things, [only to eventually find out that] my interactions, [and by extension], my presence doesn't seem to matter"* (P11). Where we found that for many, presence is *"not in the things I wanted to do, but in the things I expected I should be able to do, but couldn't"* (P9). Because as participants reached out for objects/entities and did not get their expected response, it lead to rapidly reduced feelings of presence. This stems from the issue referenced in the previous section regarding affordance inconsistencies, focusing instead on the experience of the interaction failure, rather than the frustration that comes before or after. For example, when attempting to engage with the small man on the flying carpet, P11 said that because *"he didn't end up doing anything, and my hand just phased right through him as he just kept riding along his same track, that my experience felt more artificial"* (P11). Highlighting a need of agency by participants, as another metric consider, to feel present within the space. But as time went on, participants eventually sought out other engaging entities and/or events and were able to rebuild their feelings of presence. For example, P8's presence *"came back pretty quickly once basically anything pulled my attention away from what I just did, which is really simple when it's just the controller going through a little bit of wood."*

Participants often noticed when *"something was happening that I didn't really have a choice in"* (P11), and those events made them, again, question the amount of agency they actually had on what was happening around them. For some, this came in the form of the in-game mechanics because they were not properly introduced. For example, upon activating a glyph, players weren't that told that they would immediately shrink, and since this *"was kind of unexpected, it took me out of the space"* (P11), mostly due to *"the fact that there was no feedback or acknowledgment that it had happened"* (P9). But eventually, *"later, when I understood that it was a [game] mechanic, I didn't have a problem with it anymore"* (P11). As mentioned before, participants were also purposely exposed to scheduled losses in tracking, and with them being unexpected, most felt like these events *"took me out of it the most...with my feelings of presence essentially dropping to zero"* (P11). But again, we found that it was easy for participants to bounce back from these types of events as well, since *"when the game is back, you forget about it after a short while and try to get back into it"* (P15). A key point to note here is that if the tracking loss *"just happened really quickly"* (P15), such as the scheduled "short" break, then it had no impact on their feelings of presence, and that overall

"it was pretty easy to get back into it once I was back in the game" (P12).

6.3 Discussion

Using thematic analysis on our interview findings, we identified two major themes, *Consistent experiences sustain presence* and *Key events cause rapid changes in presence*. During our thematic analysis, we examined all entries of our interview data and identified common themes and patterns of discussion that came up repeatedly from multiple users regarding their experiences. These themes were also supported and informed by the numerical AAR graph data we collected regarding the two scheduled tracking breaks and the jack-in-the-box in-game event. First, we note that the long break in tracking significantly reduced participants' feelings of presence, recorded both numerically and qualitatively, due to being taken completely out of the experience, which resulted in participants not feeling present. Second, there was no numerically significant drop in presence due to the short break in tracking because, as participants mentioned, it was easy to regain presence since they were only out of the space for a short amount of time. Our analysis of temporal changes in presence informed us of how presence could be manipulated and altered over time depending on both the physical interferences of the world as well as expectations of the player.

We found that a baseline for presence is often set by the player's visual and spatial expectations and how well these are met. However, after the player has become comfortably situated in the space, they begin to look for what they can do, testing the affordances given to them. If inconsistencies in these affordances are found, it can often lead to frustration and discouragement from seeking new interactions. If continuously experienced, this worsens these low feelings of presence gradually over time with each additional failed interaction, often also making players highly sensitive to other deterring factors because as *"the frustration would bring my presence slowly down, the joy and curiosity of what's around me, brought me slowly up"* (P2). This is because a player's natural internal curiosity, if entirely not crushed by frustration, can work oppositely to slowly recover feelings of presence by eliciting more attempts at movement and engagement. This back and forth pull of what alters presence is not as easily noted in the use of other summative measures of presence because they are solely based on looking at the whole of the experience, rather than the parts that make it up and how and when they interact with each other.

We also found that we supported many of the previously cited works surrounding certain

events having large influences on presence. Socially engaging avatars and creatures were shown to quickly grab the player's attention away from lesser negative experiences and could swiftly bring presence to a high positive state within seconds. Emotionally charged events (even if unexpected) were also verified to able to swiftly increase presence. However, improperly introduced affordances rapidly reduced presence, often putting players in a feeling of shock or confusion. But these instances were shown not to leave a heavy impact on presence over the long term, as they could be easily be recovered from when later engaged with more positive events. Regardless, when designing affordances, it is still important to consider what mechanics should be left for exploration and what should be explicitly scaffolded.

From our findings, we have also determined that the smaller gradual changes in presence over time were largely affected by whether the participants' expectations were being met. This meant that as participants' explored the world around them, they were constantly building a mental understanding of what was possible and what was not. As they encountered more objects, they began to interact with them based on their experiences with similar objects in the past. Where they succeeded in their interactions, they felt more present, and this pattern continued. However, if their expectations were unmet, the first time, they were simply confused. But added with consecutive failed attempts, this quickly grew into frustration, and eventually, disinterest. Likewise, we also determined that the sharper rapid changes in presence were again linked to player expectations, with the positive/negative direction of presence being determined by proper engagement. This meant that players were more likely to feel high levels of presence after experiencing an emotionally charged event that led them to feel human emotions even if surrounded by virtual characters and objects. Likewise, they are more likely to feel significantly low feelings of presence when they were improperly engaged or caught off-guard, whether by an entity or an in-game mechanic.

6.4 Conclusion

Many of the themes and findings discussed in the previous sections have been found by other studies revolving around understanding presence. This includes highlighting the positive influences that visual realism, auditory cues, engagement, and multi-modal experiences have on a user's sense of presence as well as the negative influences of discomfort and loss in tracking. But alongside verifying the continued existence of those findings from previous work, our study was able to show

them through a temporal lens, thus allowing us to make connections between them in regards to when they occur and how they impact one another. Through a combination of After Action Reviews and directly-accompanying interviews, we were able to show when exactly high or low moments of presence occurred, for how long, what events may have been linked to any of those changes, and if any additional reactions in presence may have occurred after an event and why. This information cannot be obtained by summative analysis and allows researchers to see trends and extreme peaks throughout a user's journey, therefore allowing for more accurate patterns to be analyzed and justified. After investigating the After Action Review methodology for measuring presence in "The Secret Shop" experience, we found that not all of our participants encountered the same events, even though they were readily available to them. For example, not every participant was able to figure out how to work the glyph mechanic, some not even attempting to engage with them at all. Therefore, one limitation to consider when using the AAR methodology is that it is best suitable for situations where the proctor knows that all of their participants are sure to experience the same things of interest, even if at different times and outcomes. This will allow researchers to get the most statistical analysis data from these types of graphs. Nonetheless, by using After Action Review graphs, we were able to identify various patterns surrounding how presence changes over time, which is not possible with other "after-the-fact" or summative measurements. This new type of methodology was able to map out both subtle and large changes, which, when supported by qualitative analysis, yielded very interesting findings surrounding both temporal and formative changes in presence. The amount of time spent in this experience only lasted for up to 5 minutes, but this methodology can be applied to longer experiences. We recommend researchers interested in using AARs to graph changes of longer experiences use a "thin-slice" approach to reduce the effects of fatigue and incorrect recall of participant memories. This approach claims that perceptions based on "thin-slices" of another's behavior can still predict many consequential constructs at greater than chance levels [96] and is widely used in psychology research. We advise designers to consult the findings found here when thinking about how to design a more temporally consistent high-presence experience and avoid fostering potential presence-breaking affordances, mechanics, and experiences.

Chapter 7

Study 5: Changes in Presence over the Long-term: An Analysis of the relationship between Presence and Time

In my final study, I sought to take the themes and lessons identified from the previous four and verified them through direct contact with consumer users. Unlike study 4, this study allowed users to take virtual reality headsets to their home in order to explore their experiences without interference or direct monitoring, making it as close to normal use as possible. The themes outlined below directly confirm those found in the earlier studies, answering all 3 leading questions. The themes gathered here show that even across multiple users with different interests in their applications of choice, there is consensus in regards to what is important to them regarding presence, from day one onward. In this study, I also found a significant amount of users experienced lingering effects, which each one experiencing something unique without being related to any specific game or experience. Where a single user could spend a vast amount of time in VR spanning across a multitude of games, and still come to similar conclusions regarding their perceptions of presence or their experiences of lingering effects with other users who did not share their same interests in virtual

games or experiences. In this study, we analyzed how over time, novice users gradually evolved in their understanding of presence and what was most important to them in order to maintain and create it. Over time, users were found to mature in what they viewed as important for fostering their feelings of presence as it related to visual appeal, interactions techniques, and locomotion. The level of engagement experienced throughout the study was also shown to be linked to experiencing various lingering effects, perception of time spent within VR, and interest in investing in future VR-related purchases.

7.1 Experimental Design

Twenty students were selected to participate in our study (5 females) with ages ranging from 18 to 33 Participants were selected to participate in this experiment based on a set of criteria which includes: having less than 1 hour of prior experience with any form of virtual reality, being housed local to the surrounding area, having enough space in their home to use the device, affirmation that they would be the sole user of the device, consent in the use their personal Facebook account to login to the device, consent to participate in two separate interviews, and affirmation that they would return the device in working condition at completion of the study. Participants were encouraged to purchase any games or applications that were of interest to them, which would remain their property even after the studies duration, although it would not be required.

Upon enrollment in the experiment, we explained the study procedures and our expectations to participants before requesting their informed consent. After consenting, each participant completed a demographic survey and given a $50 visa gift card. Participants were then loaned a single Oculus Quest device which included a head-mounted display and two controllers in order to play any virtual reality games or applications of their choosing over the course of four weeks. Participants were asked to spend anywhere between five to ten hours of time engaging in VR each week, and were informed that they would be contacted for 2 distinct interviews across the four weeks. Ten participants were interviewed after their first and third weeks of receiving their device, with the remainder being interviewed after their second and fourth weeks. After taking their headsets home, participants were emailed a link to a 15 minute orientation session explaining how to navigate the menus of the Oculus Quest in order to find games and applications. After conducting both interviews and returning their devices, participants were compensated with an additional $75 Visa

gift card.

7.1.1 Research Questions

This research extends on prior work by considering how the user perceptions and feelings surrounding presence can change over time when observed outside of a laboratory setting. Prior work regarding user experiences in virtual reality observed within laboratory settings has also been limited to shorter periods of time observed across multiple gaming sessions with no analysis on how users are effected during their initial weeks engaging with VR. As a result of these findings, we sought to understand if the themes identified in those studies could still be verified across users for an extended period of time. We narrowed down two essential questions that are currently unanswered in the research literature:

R1: In regards to presence, what is important to novice users when playing and exploring VR games, and how does that change over time?

R2: What lingering effects can be observed in a consumer VR setting as new users become accustomed to VR?

7.2 Interview Findings

From our interviews we were able to derive the applications most played/used across all 20 participants were 'Super Hot', 'Rec Room', 'Beat Saber', 'Enjoy the Fight', 'VR Poker', and 'Youtube'. These games were the ones which inspired most of the comments mentioned throughout our thematic analysis. During their two interviews, users were asked similar questions during both in order to keep track of any changes of feelings or user perception regarding presence and time. From these questions, 4 major themes were identified. The first theme *Importance transfers from Visual Appeal to Intuitive Engagement* highlights how over time users began to focus less on how their experiences looked and more on the quality and diversity of the interactions they engaged with. The second theme *Engagement linked to user perception of time spent within VR* details how a user's perception of time spent in VR was directly related to how engaged they were during their experience. The third theme *Fleeting After-Effects experienced by Users after prolonged exposure* showcases how some users experienced a diverse set of phenomena after spending a large amount of

time in VR in their early weeks. The final theme *Affordable and Positive experiences lead to future VR Interests* highlights how the overall enjoyment of a user's initial experience within VR can have an impact on their views of VR and how likely they are to seek out future VR experiences.

7.2.1 Importance transfers from Visual Appeal to Intuitive Engagement

The most prominent change across all participants was what fostered presence for them. Initially, aesthetics was what carried the most impact on a participant's feelings of presence. They were often awe-inspired by the fully encompassing world around them, but after reflecting between interviews, many participants mentioned that during

> *"the first week, I just thought they were cool details, like in the rec room where you have your own little space and I was like, 'Oh, this is cool! I can pick up a water bottle and dump it out', and now it's like, wait!...that's really immersive, I can't do that in other games where there are water bottles on the table and I could only just look at them"* (P1).

This highlights the realization many participants had when reflecting on their experiences across time and realizing things previously overlooked were actually what continues to keep them present, while things they thought kept them present before, weren't actually all that important. One participant expounded on why by mentioning that during

> *"week one, visuals might have been number one, and then interactions, because I didn't know the extent to which I would be able to interact. I just didn't know if it was possible or not. So I was mostly going off of how much I feel like I'm there just based on looks alone and how it was like...mind blowing, just to see all of that. But once I kind of knew all the stuff that I could be doing or what was possible, now the interactions is number one because I want to do more things, than just seeing them"* (P20).

This clearly captures the feelings of all participants, who were initially captured by the visuals of a nuanced experience, but soon realized that their engagement with the environment itself is what kept them intrigued. As a result, the reliability of those interactions became just as important to their presence, because "*when they don't work, or there's like some input lag or something like that, I can get really aggravated. So having it working and being on time is actually super important, the more I think about it*" (P2).

While visuals of course were still important to users, over time they just became secondary to having reliable and engaging interactions within the environment itself. One participant highlighted this point by mentioning the importance of realism in the interactions and how

> *"just little things make me feel like it's actually me, and feeling totally interactive with the game is something that is a reason why I would invest in it and is really important to me. The graphics don't have to be all that to me, that's kind of secondary to me because if I can do everything that I wanted, you know, move my arm anywhere, pick up a gun, reload the gun, reload the clip, pull the slide back, pull the trigger, take the safety off. If I can do all that stuff, that's what's important to me rather than having a 4k vision, because I'd be fine with 480"* (P10).

These intuitive and realistic interactions are what amplified these users feelings of presence in their games, and once they were exposed to them, they judged future experiences accordingly. Now seeking out "*the [experiences] where it's like you interact with the environment more than just, you go and see it. Because I found that I liked games more when I interact with them and I don't just like, see cool things if that make that makes sense*" (P11). As users became more confident in their search for more presence fostering experiences, they became more selective in them as well. Where during

> *"week one I would download like five or six random games and I think the screenshots and little previews on all of them looked relatively good because it was more of like, an eye catcher than it is now. Because I was like, Oh! this looks good I'll try this, or Oh! this looks cool, I'll try this. But now, I'm more apt to go look at the reviews and see, you know, how does it really run? More than Oh! it looks nice"* (P3).

After realizing the importance of having access to good interaction techniques, some users began to emphasize their need for a variety of engagements as well. One user mentioned how "*most VR apps seem to have one defined path because they're trying to show stuff off. But it's all just flashy, lasts for three hours, and then you're out of it. I just feel there's a lack of more open ended experiences* " (P2). As a result of this, over time some users eventually stopped

> *"playing it as often, and I don't know if it's because that wow factor has worn off, but now I'll only pick it up if I don't have anything going on. In the beginning I would be*

like, Oh, I have an hour, let's stay up late and try and beat this level or let's play poker for a little while tonight. Whereas now, it's just kind of like the games get repetitive after a while because there's no like skill that you can progress in. I think what brings me back to games is being able to progress and get better and better and better. Whereas in games like Super Hot or Poker, there's not really much progression and eventually you just feel kind of like, you're going through the motions I guess" (P3).

This shows the while users eventually learn the value of interactions and engagement within their environment, they still seek to be challenged and experience a variety of engagement as they would from other forms of entertainment and not "*feel like you're doing the same thing for too long...[that way] I'll never really get bored with it*" (P20).

Discussion around locomotion techniques also came up among users. P1 originally felt that since

"there's like two different types of walking in VR, actual walking and teleportation, this is kind of dumb to just teleport around [but over time] realized it really doesn't make that big of a difference and either is fine. Maybe I was thinking about how cool it actually was [to walk around]. But after a while I was like, wait, walking is such a minute detail. I don't care about it as much if we're gonna be honest".

This was because in the beginning, most users were typically interested in having the most amount of interaction possible, including real world walking. But after experiencing more applications, and realizing the benefits of multiple techniques and how they can be incorporated into different experiences, their preferences of one over another soon dissipated. Although when comparing locomotion to visuals and interactions in regards to fostering presence, some users still affirm that locomotion is

"*super important. But I still feel like if the visuals are not there, and if the interactions are like sub-par, then there's not much I can do with the movement, so there's no point to it, you know? So I would say it ranks third in importance both in how I felt initially and still even now"* (P20).

7.2.2 Fleeting After-Effects

During our interview, we asked participants if they 'noticed anything interesting or strange' after leaving a VR session, and fourteen users confirmed a series of lingering effects they experienced as novice users while acclimating to VR. A list of all representative quotes are reported in Table 7.1. The types of after-effects experienced varied from user to user, with most being a different effect that was unique to them. Although, there were a few experiences shared between users that shared a common theme of disruption in body ownership. Where one user felt there was a "*disconnect between my hands and the rest of my shoulder. So it's like, while my hands are holding something, I still kind of feel like they're the disembodied hands that you see when you're playing in the Oculus*" (P12), and another was "*surprised that I had legs that were carrying me instead of just standing in one place"* (P18). Some others experienced lingering effects hours later, like "*dreams that were kind of like VR"* (P20) or "*feeling like I was moving even though I wasn't moving when I was closing my eyes"* (P17). The amount of time spent in VR before exiting seemed to relevant as well, where after spending numerous hours in VR one day, a user had to tell himself that "*I know where my hands are! This is stupid I have to say this, but I know where they are in proximity to myself!"* (P2). Across participants, the most common types of effects mentioned included perceptual effects such as a questioning of body ownership, questioning of hand ownership or proprioception, distortion of depth perception, and increased visual sensitivity to real world imagery. There were also behavioral lingering effects mentioned such as increased lucidity in dreams and attempts to use VR interaction metaphors in real life. These types of lingering effects and others supports what has been found within consumer online forum discussions. While they often occur during a user's initial journey into consumer VR, it not always experienced by everyone. But for the users who do experience it, initially they are often both shocked and intrigued by these occurrences because "*it's kind of exciting"* (P3), and oftentimes they even seek to further understand and recreate these events. Typically, effects disappear anywhere between a few seconds or a few minutes after noticing them. Eventually all of these effects were verified to have completely disappeared "*after that first week, upon which [most participants feel] kind of sad about it because it was pretty cool"* (P2). VR consumers believe this to be a by-product of the brain attempting to delineate between the transition of reality and virtual reality after experiencing increased exposure within a virtual environment during a user's first few weeks in VR, but no laboratory studies have been conducted to confirm this.

Participant ID	Participant Quote
P1	'"*after I picked up my box of goldfish, I was just like, 'I wonder what would happen if I dropped it right now'. I just wanted to let it go."*
P2	'"*now I'm questioning even basic things and it's like, making me step down harder on myself being like, 'I know where my hands are! "*
P3	'"*in the headset, you get used to the images with the graphics not being super high def, like HD, and then when you take the headset off, you can see like, so crisp and so clear"*
P4	'"*like the peripherals, while I'm looking at the screen, like the background, kind of just makes me think of VR"*
P5	'"*when I'm, you know, looking at a screen in my hands, I get this sense that my thumb's are like, not part of my body. Which is very strange"*
P6	'"*right after I went to sleep, and then I want to have my eyes shut, I guess I felt like I was looking into a screen type thing"*
P7	'"*definitely feel like you're opening your eyes more when you come back out of VR. So just like realizing how things are like far away like the walls I guess"*
P10	'"*it just feels like when you try to grab something or you try to reach for something it's like, your arm's extended or your grabbing motion is kind of more game like"*
P11	'"*The world seems less detailed than I feel like the game is with having brighter colors and more detail....I'll look and I'll be like, Oh! it's not as bright anymore"*
P12	'"*I feel a disconnect with my hands and the rest of my shoulder...like they're the disembodied hands that you see, when you're playing in the Oculus"*
P15	'"*I start to adjust in the real world with moving my head as slow or as fast as I would in VR because that's what my eyes are used to"*
P17	'"*when I closed my eyes, it definitely felt like I was, I don't know, just like rolling around. It wasn't like, nauseous or anything, it was honestly quite fun, but it was just like I felt moving"*
P18	'"*a second I was like surprised that I had legs that were carrying me instead of just standing in place and then I felt myself moving the joystick in my finger even though I was walking"*
P20	'"*but now it's like, my dreams are kind of in VR a little bit"*

Table 7.1: Participant quotes that highlight a variety of lingering effects that were experienced

7.2.3 Engagement effects User Perception of Time spent in VR

After learning what made presence so impactful for users, we then asked how often they spent in VR. Most users spent at least thirty minutes per gaming session, and depending how engaging it was, would spend a couple of hours at a time. We then asked how long they felt like they spent per session compared to how long they actually did. From this we found that many users often "*thought I was in the VR headset for maybe like, I thought a half hour...and it had been two hours*" (P2) and "*felt like time kind of flies by because when I'm when I'm playing, I'm having fun, sweating and everything, so when I hop out and I look at the clock, I say wow! how long was I in there? "* (P10). We found this to be directly related to the amount of engagement users were

experiencing when playing their game, even if its a game they already like. One experienced Beat Saber user mentioned that for her

> "*it really depends on the difficulty of the songs just because when I play like a bunch of easy songs, then time kinda drags on because you know, like you're just kind of standing there doing the easy stuff. But if you do the harder songs then I feel like time goes a lot quicker because, you know, they're just a lot harder and you're more engaged and then time will pass a lot quicker just because you're so focused on like getting a better score*" (P11).

Users who find a game they are really enjoying typically "*feel like that's just due to good game design. I feel like it's just the Quest and a good game working together to make me have a good time and forget about what I'm supposed to be doing*" (P1). While of course on the other hand, users who had a harder time finding a game to keep them engaged throughout the four weeks mentioned that "*before I wouldn't really realize how long it's been. But now I guess I judge it off my attention span and when I'm getting bored, and that's usually about an hour, so that usually gives me like a judgment of like, okay, I've probably been on here for like, an hour or so.*" (P3). This shows that although this didn't happen to any users in the early weeks, that as they progressed in their understanding of what kept them engaged and present, there remained a possibility that the games that captivated their attention initially, could not keep it.

7.2.4 Factors promoting Future Interest in VR

Finally, we asked users if after their involvement in this study, if they would consider investing in a VR headset of their own in the future. Most agreed that they"*definitely see this as my future. I'm like, I'm into this thing* " (P2). We found that the reason behind this was mostly connected to the positive experiences they had with the applications and games they were able to find. One user mentioned that they were"*really never a big single player video game player before this. And now I've played a ton of single player games and I think that presence has become very important to me, just because that's basically what VR is. And I think that's why I'll probably end up purchasing one because I've come to enjoy single player immersion games, and I just don't know if that's something I can get with a computer games now* " (P1). This showed that users do learn that presence is a unique quality that can only be experienced in VR, and that through it they can

experience an entire new form of gaming. These types of comments were given mostly by users who were known to have found experiences they were very happy with. Although, not all users shared this sentiment if they were unable to find the experiences they were looking for. Where those users "*would need to see where it goes in the next like five or 10 years. Am I interested? Yes, but what I jumped to go and buy one? Probably not unless it changed to where I'd be able to play like, my type of games, like a first person shooter*" (P3). another subset of users where also on the fence because they "*don't really see myself purchasing a VR headset for myself in the future, at least not now. I just don't really think it's worth it right now because it's pretty expensive, even though I definitely enjoy it*" (P4). These two items were the main things holding some users back from eagerly seeking a future in consumer VR purchases, even if they did enjoy the experiences they had in this study.

7.3 Conclusion

We found that if users were able to find applications that kept them engaged, they experienced higher levels of presence. Initially, users were captured by the visual appeal and spatial affordances that VR had to offer compared to other competing entertainment platforms. But over time, users matured in their expectations, as expected, and became more critical of where they should spend their time. As a result, users began to do more in-depth research concerning the games and applications they were interested in, learning from what had helped to foster presence from previous experiences. As time passed, they increasingly sought out information regarding an application's interaction techniques and affordances before attempting to try it out themselves as they would initially. This showed that as time passed, users increasingly valued how they spent their time in VR, and less about just having access. Our data also showed that higher the levels of engagement and the amount of time spent in VR had a major impact on a user's likelihood of experiencing in-boarding lingering effects. A variety of lingering effects was shown to be experienced across users regardless of where they spent their time in VR. These effects lasted temporarily after exiting VR and were met with awe-inspiring surprise and confusion, but over time were shown to stop manifesting completely. If user's were able to find applications with engaging interactions and capturing visuals, their perceptions of the time spent in VR was inflated. Likewise, if they were not, then they stayed accurate or deflated, often being the cause for user's to seek out new applications to spend their time in. This same principle applied to whether or not user's showed interest in seeking

out additional VR related experiences and purchases after the studies duration.

Chapter 8

Conclusion

8.1 Introduction

The leading question driving this dissertation was to find out "*What's most important/concerning to users in regards to their VR gaming experiences?*" Which led to 2 additional questions of "*How does extended exposure to a VR game affect the user's experience?*" and "*How is presence affected as a result of this increased exposure?*" From the findings laid out across the 5 studies in this manuscript, I was able to answer all 3 of these questions from various angles previously unexplored in the literature. I can confirm that there are 3 large areas of interest when it comes to answering these questions. The first, being "Presence", or a feeling that causes users to suspend disbelief and believe that they are actually in the virtual environment, reacting to stimuli as they would in the real world. The second, "lingering effects", which defines various changes in a user's behavior and/or mental framing of the real world as a direct result of increased exposure to VR. With the last being, simulator sickness, or the VR equivalent of motion sickness, which has already been researched very extensively by the VR community. As a result, I focused more heavily on what I found regarding the first two major themes. But before discussing the interwoven themes and perspectives found between these 5 studies, I will first briefly go over their individual motivations, designs, and major results.

8.2 Overview

In study 1, I explored how user experiences compared when playing Minecraft on the desktop against playing Minecraft using an immersive virtual reality port. Fourteen users completed six 45 minute sessions, three sessions were played on the desktop and three in VR. The Gaming Experience Questionnaire, i-Group presence questionnaire, and Simulator Sickness Questionnaire were all administered after each session, and users were interviewed at the end of the experiment. As a result, users strongly preferred playing the VR option, despite frustrations with using teleportation as a locomotion technique and any feelings of simulator sickness. Users were also noted to enjoy using the motion controls afforded to VR, but still continued to use indirect input under certain circumstances which did not appear to negatively impact their feelings of presence.

In study 2, I sought to understand what shifts had taken place within the first two years that consumer VR had become available to the general public in order to consider what could be learned about long-term consumer VR use through an analysis of online forums discussions. I gathered posts made on the /r/Vive subreddit from the first two years after the HTC Vive's release. As a result, consumers were shown to mature in both their attitudes and their expectations regarding presence and simulator sickness. After initial disappointments wore off, many were able to focus on the more positive aspects of VR. Over time, users became less passive in accepting shortcomings and began to either actively fix them or demand they be fixed. During the Vive's early release, hardware played a major role in discussions around presence and simulator sickness, but as those issues became addressed, game design became the central point of discussion for consumer VR users.

In study 3, I again examined data taken from the /r/Vive subreddit forum posts to gain insights on what "lingering effects" users reported experiencing after using VR, as well as, the progression of these effects over time. The most commonly reported side effects were perceptual side effects, including altered perceptions of body ownership and proprioception, altered depth perception, an assortment of unusual visual phenomenon, and a lingering haptic sensation from the cord connected to the HTC Vive. Behavioral side effects were also reported, including feeling a need to verify the reality of the real world through touch, hesitancy when walking or leaning against objects in the real world, and attempts to use VR locomotion and interaction metaphors in real life. Users also reported experiencing more vivid dreams, and even more lucid dreams. Users agreed that these effects only seemed to occur after spending at least one continuous hour in a VR application within

their initial weeks of experiencing VR for the first time. The duration of each effect found to vary based on the effect and the individual considerably, anywhere from a few seconds to the following day. However, all users agreed that regardless of what effect they experienced, they eventually stopped experiencing them after a few weeks or discontinued use of VR.

In study 4, I examined how user experiences and trends regarding presence changed throughout a single gaming session. Participants were immersed in a virtual experience called 'The Secret Shop' and given the freedom to explore their surroundings with no guided direction. Users then performed an After Action Review (AAR) activity while watching their recent experiences on video followed by a semi-structured interview. From the AAR graphs, I was able to graph each user's feelings of presence over time from second to second. Presence was shown to rise and fall, both gradually and rapidly, throughout each user's experience. The combined analysis of user AAR graph results and their interviews showed that presence was found to be significantly impacted by user expectations, confidence and trust in affordances, and the intensity of engagement experienced throughout a single session.

Finally, in study 5, I loaned out VR headsets to local novice users in order to track their perceptions of presence across the span of four weeks. Users were given the freedom to explore VR games and applications of interest to them, off-site, in order to simulate the experience of regular VR consumer. I then interviewed each participant twice, once around their initial weeks, and once around their final weeks of using their headsets. I then analyzed and mapped out the findings between interviews findings, and discovered that novice users had gradually evolved in their understanding of presence and what became most important to them in order to maintain and create it. This was found to be connected and heavily influenced by the amount and quality of visual appeal, interactions techniques, and locomotion affordances provided by the VR application. The level of engagement experienced throughout their experiences was also shown to be linked to experiencing any lingering effects, having an altered perception of time spent within VR, and having the potential to alter their interest in investing in future VR-related purchases.

8.3 Final Conclusion

With the studies outlined above, I have taken a look at what user's find most important to their VR gaming experiences and how that has the potential to change over time. I also uncovered

themes that stayed consistent across users irrespective of time as well. When comparing Minecraft across PC and VR, Study 1 showed that users viewed VR as a competitive gaming experience. From there, studies 2 and 3 uncovered themes from hundreds of consumer VR user experiences that was able to verified from users recruited in studies 4 and 5. In relation to time, study 4 verified what users found to be important during a single gaming experience in VR, with study 1 looking across a few stringed gaming instances, and study 5 looking across a variety of gaming experiences in both type and amount. In relation to the variety of experiences, study 1 focused on users who were known to enjoy a certain gaming experience, study 4 focused on users who were introduced to an entirely new gaming experience, and study 5 gave users the freedom to explore as many different experiences as they wanted with no limits or direction. Finally in relation to data collection, studies 2 and 3 were informed by users who discussed among themselves freely over the course of 2 years at their own discretion, while studies 1,4,and 5 were informed through direct interviews with users regarding recent experiences. Through these different angles, I was able to form numerous themes and recommendation in regards to VR user gaming experiences and how they alter over time.

The first major theme verified across studies was how user perceptions of presence changed as they gained more time and experience in VR. Study 2 outlined how consumers initially focused on their disappointment in VR because of issues with hardware and software glitches . But that eventually subsided as users began to discuss more about their gaming experiences, more specifically their opinions on VR game design. Over time, these discussion focused less on gaming visuals and more on engaging interaction techniques, as more users matured from being merely consumers of VR, to creators and analyzers, in both hardware and software. This pattern was verified in study 5, when during the final interviews, user discussion centered more around how engaging interactions and affordances kept them engaged with regards to feeling presence, more so than the visuals and locomotive techniques alone. In both studies users were shown over time to become more critical of how they spent their time in VR, and were more active in creating and seeking VR game reviews. This maturity was shown in regards to locomotion techniques, where in both studies users initially were very critical of what techniques they preferred and recommended, but over time became less interested in those discussions instead focusing on interactions. Studies 1 and 4 were able to take a more precise look at this across fewer gaming sessions, highlighting how a user's sense of presence has the capacity to change over the short-term as well based on proper game design. Studies 1 and 4 showed that met player expectations had the potential to alter a user's perceptions of presence

during a single gaming session based on intuitive interaction metaphors, clear affordances, proper scaffolding, well implemented and justified locomotion techniques, and the incorporation of engaging NPCs.

The second major theme common between studies centered around the lingering effects that novice users had the potential to experience within their initial weeks in VR. Study 3 highlighted and categorized these effects that a wide assortment of consumers discussed experiencing shortly after starting VR for the first time. These effects were verified in part by study 2 and more-so in study 5 when nearly seventy-five percent of the users I recruited in study 5 mentioned experiencing nearly all of those same effects mentioned in studies 2 and 3. This included altered perceptions of body ownership and proprioception, altered depth perception, an assortment of unusual visual phenomenon, attempts to use VR interaction metaphors in real life, and lucid VR-like dreams. Findings from study 3 also found that these effects often manifested after spending at least one continuous hour in VR, with most durations lasting for only a from mere moments until eventually they stopped manifesting completely. This again was also verified in study 5 by those users who reported experiencing this within their first 2 weeks in the study.

8.4 Contributions

From the conclusions stated above, I have shown that through a multitude of perspectives, user narratives are an integral part both in learning user preferences and tracking how they change over time. This dissertation adds to the literature by providing a new theory of how time impacts and alters what makes and maintains presence for users as they mature in VR. I have also been able to show empirically how this theory has been proven across the multiple studies highlighted within this document. The diversity of lenses, regarding both presence and time, that I have conducted across user perspectives is unique in its design and can be applied to other topics of interest to the scientific community as well. By taking user narratives across different temporal measurements, I was able to successfully gather themes that spanned across a wider base of users as well as the maturity of their opinions. With this, I was able to simultaneously decipher what themes and practices remained consistent both between users and across time. This can help improve the design of future qualitative research by highlighting the importance in running studies designed with the temporal component in mind. This allows the scientific community to not only see how findings

from user perspectives might evolve over time, but also help to verify the ones that are not effected by time. Currently in STEM research, I focus heavily on statistical significance and this research highlights how well user experience research and qualitative findings can compliment and develop deeper conclusions when used together. As user experience research becomes more widely used, and society continues to build new technologies to support, entertain, and govern mankind, the information and designs laid out within this document will become increasingly crucial.

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