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

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ABSTRACT
Virtual reality games have grown rapidly in popularity since the first consumer VR head-mounted displays were released in 2016, however comparatively little research has explored how this new medium impacts the experience of players. In this paper, we present a study exploring how user experience changes when playing Minecraft on the desktop and in immersive virtual reality. Fourteen players completed six 45 minute sessions, three played on the desktop and 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. Participants strongly preferred playing Minecraft in VR, despite frustrations with using teleporation as a travel technique and feelings of simulator sickness. Players enjoyed using motion controls, but still continued to use indirect input under certain circumstances. This did not appear to negatively impact feelings of presence. We conclude with four lessons for game developers interested in porting their games to virtual reality.

CCS Concepts
•Applied computing → Computer games; •Human-centered computing → Empirical studies in HCI;

Author Keywords
Virtual reality; user study; video games; emotions; Minecraft

INTRODUCTION
Virtual reality games have rapidly grown in popularity since the release of the Oculus Rift CV1 in March, 2016. Due to the significant cost in developing new AAA content, many major game developers are beginning to port existing games to work in VR, in addition to developing new content. Prime examples from major developers include the recent VR ports of Skyrim, Fallout 4, Doom, Payday 2, and Elite Dangerous. Several popular indie games have also been ported to VR, including Superhot and Subnautica. These ports often generate strong interest; for example, Skyrim VR immediately rose to the top 10 best seller list on the Steam marketplace after it was released for pre-ordering.

When porting a game to VR, one of the major challenges faced by developers is adapting the controls of the non-immersive game to work in the new immersive context. Several options are open to developers. At the most basic level, developers can change nothing and continue to allow users to play the game using a keyboard or a gamepad. This method relies purely on *indirect input*, as no aspect of the player's bodily motion is used to interact with the game (expect for head motion). At the most advanced level, developers can completely recreate the controls to take full advantage of the motion controls afforded by immersive virtual reality (for instance, players could attack an enemy by drawing a virtual sword from a scabbard and then swing it at the enemy, which succeeds if the sword connects). This method relies (almost) entirely on *motion controls*, such that buttons are only used to pick up or drop objects. For instance, a trigger could be pressed to pick up a key, but then the key is used to unlock a door by inserting it into the keyhole and twisting it. A blended approach can also be used, such players select objects via motion controls by pointing at them, but then use buttons to interact with them (e.g. pointing a sword at an enemy and then pulling the trigger to attack it).

In this paper, we investigate users' experience when playing Minecraft on the desktop and in immersive VR with motion controls. This was accomplished using the unofficial mod Vivecraft [1], which adds full VR support to the game. Vivecraft allows users to bodily interact with the environment in Minecraft using the HTC Vive controllers. Players can swing axes to chop down trees, pick up food and eat it by holding it up to their mouth, shoot a bow and arrow by actually nocking and drawing the arrow, and fighting enemies by swinging a sword. Motion controls are enabled whenever possible. When motion control is not physically possible, such as when attempting to climb a virtual ladder, a close facsimile is used instead (e.g. mimicking the climbing motion to move upwards). Room-scale travel is afforded in the local environment (up to the limits imposed by the physical environment), and teleportation is used to traverse longer distance.

We recruited 14 participants for a within-subject experiment, where each participant played three 45 minute sessions of Minecraft on both the desktop and in VR. Survey data was collected after each session, and participants were debriefed after

[1] http://www.vivecraft.org/

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the experiment and asked to discuss their experiences in both mediums. Survey data showed strong increases in presence and positive emotions when playing Minecraft in VR. Multiple themes emerged in participant interviews: participants' heightened emotional experience 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. We discuss these themes in more detail later in the paper, and conclude with suggestions for game developers who are working to port existing games developed for non-immersive systems to VR.

RELATED WORK

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 [22]. 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 [11]. 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 [20]. 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) [17]. Playing in VR increased feelings of spatial presence, however the use of motion controls actually *decreased* perceived naturalness.

Motion Control in Non-Immersive Games

Motion controls have been studied extensively in non-immersive settings. Major commercial examples of motion controllers include the Nintendo Wii, the Microsoft Kinect, and the Playstation Move. Motion controls have a complex relationship between the factors of perceived control, immersion, and enjoyment. Several studies have shown that perceived control is reduced when using accelerometer based motion controls (e.g. a Wiimote), [9, 1], and this reduction in control leads to reductions in enjoyment [9]. However, motion controls can increase feelings of immersion[13], and both spatial presence and social presence (with gender effects) [1], all of which are also linked to enjoyment. Feelings of immersion also improve as motion recognition accuracy increases [13]. Other research has show that the type of motion being performed is also important; performing "power poses" can increase enjoyment, presence, and perceived controller responsiveness, while maintaining low-dominance poses evokes more negative effects [14]. Motion controls can also affect how players behave after the game; Charles et al. found that players expressed less aggression in the real-world after playing a violent game if motion controls had been used [6]. Other research has compared simple motion controllers vs. whole body motion input (e.g. Microsoft Kinect) and found that immersion, presence, and positive affect increase as more of the body is used to control the game [18, 3]. The type of control system used can also influence players' cognition during a game and how the game creates enjoyment [10].

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 [12]. Shewaga et al. found that room-scale travel increased immersion in a serious game for epidural preparation, as compared to a seated VR experience [21]. Bozgeyikli et al. found that teleportation compared favorably to two other travel techniques (walking in place and joystick control) [4]. 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) [5]. 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.

Contributions of this Research

This research extends on the above prior work by considering how the use of motion controls in a VR port alters user experience. Prior work with VR ports examined early ports to VR systems that did not yet support motion controls. We consider how players use motion controls in an immersive VR game, how they affect user experience, and what types of motion controls are perceived as most enjoyable. We also consider how changes in travel methods (continuous travel via keyboard to discontinuous travel via teleportation) also impact user experience and enjoyment.

METHODS

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 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

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

Figure 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.

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.

Procedure

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 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 âĂŸ5 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) [7], the i-Group presence survey (IPQ) [16], a social presence survey [2], and the Simulator Sickness Questionnaire (SSQ) [15]. We conducted semi-structured interviews with participants after their final session. Participants were not compensated for completing the experiment.

Apparatus

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.

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 [23].

Gaming Experience Questionnaire

Players completed the Gaming Experience questionnaire (GEQ) [7] 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 2. The linear mixed model parameters for modality are reported in Table 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 [8]. 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 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.

Presence and Social Presence

Players completed the IPQ [16] 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. [2] 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. The linear mixed model parameters are reported for modality in Table 2. Based on these effect sizes, modality had a large effect on Spatial Presence, General Presence, and Experienced Realism, and a moderate effect on Involvement and Social Presence.

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 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.

Simulator Sickness

Players completed the SSQ [15] 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 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 4. The linear mixed model parameters are reported for modality in Table 3. Based on these effect sizes, modality had a moderate effect on all simulator sickness factors.

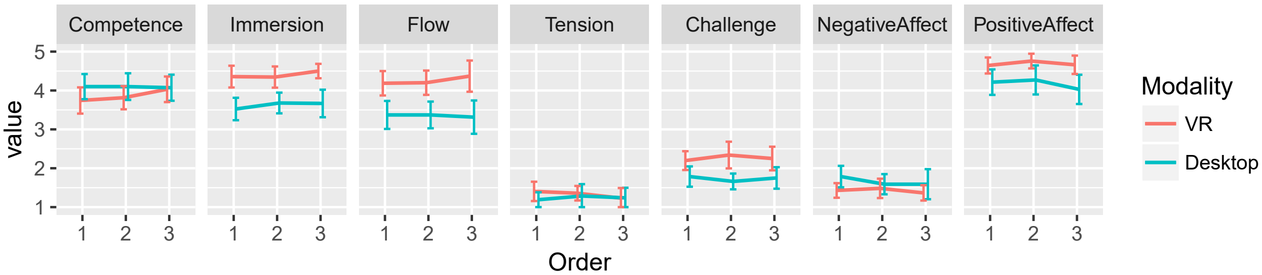

Figure 2: Average scores for the GEQ factors, divided by session number (Order) and by Modality (Desktop or VR). Error bars represent 95% confidence intervals. Significant differences were observed for all factors except Tension/Annoyance.

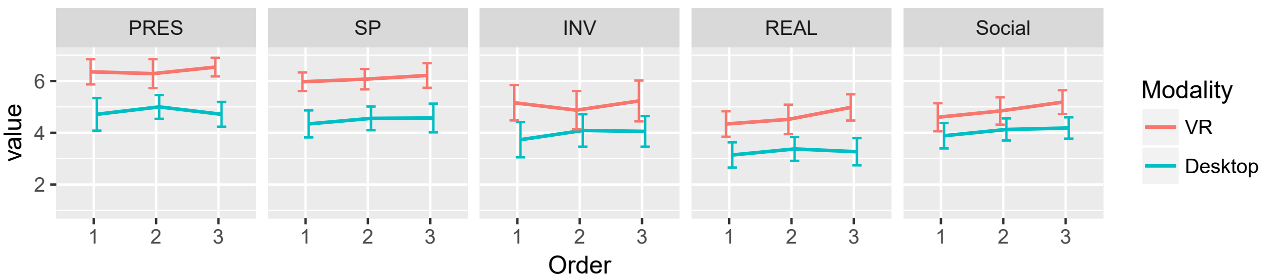

Figure 3: Average scores for the presence factors, divided by session number (Order) and by Modality (Desktop or VR). Error bars represent 95% confidence intervals. Significant differences were observed for all factors.

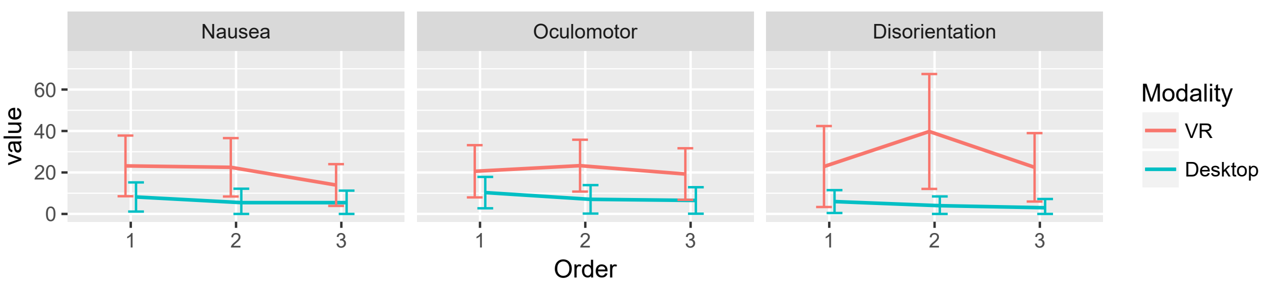

Figure 4: Average scores for the simulator sickness factors, divided by session number (Order) and by Modality (Desktop or VR). Error bars represent 95% confidence intervals. Significant differences were observed for all factors. An order effect was also observed for Disorientation, such that the participants felt significantly more disoriented after the second session in VR.

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: 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.

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.

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.

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.

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.

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, underscore that visual realism is not essential for deep presence and immersion, but that it can also be achieved in appropriately stylized environments.

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).

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.

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.

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).

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 [19]. 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*".

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.

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.

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).

DISCUSSION

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

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 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.

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.

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.

Inconsistency in Reports of Sickness Over Time

Unsurprisingly, the results of the SSQ showed significantly stronger feelings of simulator sickness in VR than on the desktop (where it was essentially non-existent). No standards for acceptable thresholds for the SSQ exist for use in modern HMDs, however the values reported by participants appear to represent a meaningful deviation from a completely healthy state. Standard deviations were large, indicating a high amount of variance in how players experienced sickness in VR. Most intriguing is the order effect observed for Disorientation, where players felt significantly more disorientated in the second session. We saw in the interviews afterwards that players frequently experimented with situations they felt might make them sick, such as jumping off a tall tower or rowing a boat into flowing water. Many of these activities could not be achieved in the first session, due to the need to gather resources and master the controls. The peak for Disorientation observed in the second session may be linked to these instances of experimentation, which ceased once player curiosity was satisfied. However, it is striking that only Disorientation increased during the second session. Future research is needed to disambiguate how different behaviors in VR games are linked to specific manifestations of simulator sickness.

Though the results of the SSQ remained relatively flat over time, except for Disorientation, interviews with players revealed a perception that sickness actually decreased over time. This discrepancy is surprising. One explanation is that people who reported that simulator sickness decreased over time were also the people who experienced the least sickness. However, we compared SSQ scores to statements made in the interview and determined that participants with low-to-moderate SSQ scores were the most likely to say their sickness decreased over time in the interviews. Players who had very low SSQ scores tended to just not mention simulator sickness at all. Only P10 reported simulator sickness increasing, and her SSQ scores were among the highest recorded. It is possible that the discrepancy between quantitative and qualitative data is linked to the passage of time between the surveys and the interviews. Players' memories of their feelings of sickness may have been moderated during reflection by the overall positive nature of their experience. Developers should be aware that players may try novel experiences, even if it will make them sick. However, so long as players can recover from momentary bursts of sickness, they will still be capable of enjoying the game.

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.

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.

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