Factors Affecting Enjoyment of Virtual Reality Games: A Comparison Involving Consumer-Grade Virtual Reality Technology

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Abstract

Objective: This study investigated psychological responses to playing videogames using a virtual reality (VR) head-mounted display (HMD). We also investigated how cybersickness impacts the sense of presence one feels in the virtual environment, as well as how cybersickness affects enjoyment.

Materials and Methods: Participants played randomly assigned VR games that varied in the level of sensory conflict they provided: “Lucky’s Tale,” “Elite: Dangerous,” and “Minecraft.” Results were compared based on two headset conditions—the Oculus DK2 and the recently released Oculus Rift Consumer Version (CV1).

Results: Cybersickness was not reduced by playing games with a VR HMD of higher technological quality—the Oculus Rift CV1. Furthermore, cybersickness responses were significantly different based on the level of sensory conflict in the games. Games with less sensory conflict, such as third-person platformer games, or space and flight simulator games, produce less cybersickness in players than first-person games. Enjoyment of VR games was shown to be directly influenced by a sense of spatial presence, which was affected by interactivity and realism. Findings suggest that the variables that are important to the enjoyment of console, mobile, or motion-based games are consistently important to enjoyment of VR games.

Conclusion: Better technology does not affect the frequency or severity of cybersickness for players; but sensory conflict has a significant impact on how sick users become. Additionally, we present a model that indicates how enjoyment is produced in VR gaming experiences. These findings bear further investigation as new methods of interacting with VR games are developed.

Keywords: Virtual reality, Videogames, Enjoyment, Cybersickness, Presence

Introduction

2016 WAS INDEED “a golden year for virtual reality.”¹ With this growth in popularity comes an increased need to understand the psychological and physiological effects of using virtual reality (VR). As one of the most popular applications for VR, videogames are an appropriate focus for such research. This article reports on an investigation into how users engage with and react to interactive media (videogames) displayed using one of the latest VR head-mounted displays (HMDs)—the Oculus Rift CV1. In the area of psychology, the variables especially salient to this project are spatial presence, perceived reality or realism, perceived interactivity, and, ultimately, enjoyment. We have also investigated the physiological response of cybersickness, seeking to understand the factors that may contribute to it, and how it may be avoided for the increased

well-being of VR users. In doing so, this article answers the call that Caroux et al.² issued. They asserted that much research has been done on methods of input for gaming, but much less on recent innovations such as new output methods like VR HMDs. Much research has been published in recent years on this topic, but areas still remain to be explored further.

Psychological variables

Spatial presence is the feeling that one is located in the virtual world. The virtual world takes up the primary position in one’s consciousness. It is “experiencing the computer-generated environment rather than the actual physical locale.”³ *Realism* is how realistic the virtual world feels to the user. One factor of realism is the idea that the mediated form of an object is very similar to the idea of that object that is

already present in a user's mind. It can also be the perception that the virtual environment feels, looks, and sounds real.⁴ *Perceived interactivity* is the extent of mastery a user feels that they have over the game. The mechanics of the game and the control interface have a great deal to do with how interactive the user perceives a game or system to be.^{5,6} *Enjoyment* in the context of this project is the pleasure a media user experiences because of being exposed to a certain media stimulus,⁷ particularly interactive games.

We propose that these psychological variables are all interrelated in a predictable way. Numerous past studies have established that spatial presence is an important contributor to enjoyment of videogames.^{4,8–14} Interactivity has also proven to be a key factor in the enjoyment process.⁵ Measured as two dimensions—effectance and control—interactivity was found to positively impact enjoyment¹⁵ as well as realism and spatial presence.⁴ Past studies on important factors that produce videogame enjoyment^{8,9} show that that perceived interactivity, realism, and spatial presence all work together to explain a significant portion of the variance in enjoyment. The relationships among the variables are described in Figure 1.

This model, originally proposed as an explanation of enjoyment of motion-based games,⁴ has been tested with several types of gaming situations. It has been shown to be predictive of enjoyment in motion-based games⁸ and in games played on consoles and mobile devices.^{9,10} The variables that lead to enjoyment in those gaming situations should also be important to the process of enjoyment of VR games. Mellecker et al.¹⁶ include many of the variables we focus on in their analysis of what produces fun in exergames. One part they highlight that has not been included in our model so far is a consideration of physiology. We propose to begin remedying that situation by initially including cybersickness in the model, thereby integrating one physiological variable with the psychological variables that have been shown to produce enjoyment. But first, we investigate some of the factors that can predict cybersickness.

Cybersickness is one of the most significant negative issues associated with modern VR, and overcoming it continues to be a major hurdle for HMD makers. Our research investigating cybersickness and VR indicates that between two generations of VR HMD technologies (the Oculus Rift DK1 and DK2),

there was no significant difference in feelings of cybersickness that users experienced while playing a videogame.¹⁷ Symptoms of cybersickness include headaches, eyestrain, stomach awareness, and nausea, sometimes severe enough to result in vomiting.^{18–20} Cybersickness is similar to motion sickness and manifests itself through many of the same symptoms. The primary difference between motion sickness and cybersickness is that motion sickness is experienced when actual physical bodily motion does not match what is perceived visually.²¹ Much industry effort has been devoted to the discovery of ways to reduce cybersickness when using VR HMDs.²² Our research into cybersickness has a theoretical grounding in sensory conflict theory,^{23,24} which proposes that cybersickness is likely when the eyes, the vestibular system, and the nonvestibular proprioceptors send conflicting signals (i.e., your eyes perceive motion that the other systems do not sense). Cybersickness is also likely when those motion-sensing systems send signals inconsistent with what would normally be expected based on previous experience in similar situations.^{23,24}

There are other theories that attempt to explain how simulator sickness or cybersickness occurs; however, sensory conflict theory is the best theory for our purposes. Applying the principles of sensory conflict theory, it is possible to predict the circumstances under which cybersickness is likely to occur. Other theories such as postural instability theory or poison theory²⁰ lack such predictive power.

A motion sickness theory like sensory conflict theory is valuable to our present research because the VR experience aligns closely with the situations described by the theory. According to sensory conflict theory, the severity of the motion sickness (or, in this case, the cybersickness) will depend on how great the conflict is between what is being perceived by the senses and what is expected.²³ Many VR experiences are cybersickness-inducing because there is a great degree of conflict between expected and perceived motion. However, games have now been developed that provide various levels of sensory conflict. Previous findings by Bonato et al. indicate that higher sensory conflict potential (increased via rotation of a virtual cube) does indeed increase cybersickness in virtual environments.²⁵ The present study tests this hypothesis in more interactive VR experiences, namely VR games. Testing

FIG. 1. Hypothetical model of videogame enjoyment.

the hypothesis in this context is an important advancement of knowledge in this field, because most casual users of VR try out VR games or game-like experiences as their first foray into virtual environments. Knowing what can contribute to cybersickness in that context will be quite useful for scholars and VR software and hardware developers alike.

In addition to testing the psychological factors associated with playing VR games, this study seeks to determine if commercial VR HMDs (specifically the Oculus CV1) are able to alleviate or overcome feelings of cybersickness as compared to a development version, the Oculus Rift DK2. We also ask if exposing players to games with different levels of sensory conflict will produce concordant cybersickness responses. The earliest of the modern prototypes, the Oculus DK1, was technologically inferior to its successors.¹⁷ Oculus and HTC initially placed a great deal of importance on technical considerations and their impact on cybersickness.^{26,27} Several reports asserted or implied that improving the technology by reducing latency, controlling field of view, eliminating or reducing judder, and improving resolution would reduce or eliminate cybersickness.^{28–30} The trend of improving the technology continued with the Oculus CV1. The CV1 boasts improved display technology, including increased resolution for each eye, a higher refresh rate, and better head tracking, as Table 1 shows.

Our initial investigation into this matter reveals that simply improving technology is insufficient to reduce cybersickness.¹⁷ The ways experiences represent movement is incredibly important to the user's experience.²⁵ Therefore, the current investigation has been guided by the following hypotheses and two research questions:

H1: Games with high, moderate, and low levels of sensory conflict will result in concordantly high, moderate, and low levels of cybersickness.

Based on preceding work,¹⁷ we expect that the technological improvements implemented in the Oculus CV1 will have little to no impact on cybersickness. Therefore, we predict that:

H2: There will be no significant differences in levels of cybersickness reported by Oculus Rift CV1 players and Oculus DK2 players.

To investigate the factors leading to enjoyment of VR experiences, here we investigate the following research question:

RQ1: Will the relationships predicted by the hypothetical model developed in earlier research^{4,8,9} be observed in the same way for players of VR videogames (Fig. 1)?

Methodology

The Baylor University Institutional Review Board (IRB) approved this study. Recruiting was accomplished via online announcement posted in a learning management system. Informed consent was obtained via an online consent form that was read and acknowledged before any study activities taking place. Participants were given an opportunity to ask and receive answers to any questions they had before beginning the study. They were informed of their right to end their participation at any time with no penalty.

Participants were 160 undergraduate students recruited via email and online announcements from various communication, film, and journalism/PR courses at Baylor University. Participants were offered extra credit for their participation, among other options for extra credit. The gender breakdown for the sample was 59% male ($n=94$) and 41% female ($n=66$). Average age was 20.5 years. Via random assignment, 49% ($n=78$) participants were assigned to the Oculus Rift CV1 condition, and 51% ($n=82$) were assigned to the DK2 condition. About 46% ($n=74$) participants reported that they had no previous experience with the game they played or another game like it. About 35% ($n=56$) reported that they had played a similar game in the past, and 19% ($n=30$) reported that they had played the game previously. Table 2 shows the statistics on age, gender, and previous exposure broken down by condition. All participants completed the study questionnaire online via surveymonkey.com.

Stimulus and systems

Participants were randomly assigned to play one of three games that varied in level of sensory conflict. They played on one of the two headsets, resulting in six possible assignment conditions: a 3 (sensory conflict) $\times$ 2 (device) factorial

TABLE 1. COMPARISON BETWEEN OCULUS RIFT DK2 AND OCULUS CV1^{31–35}

	<i>Oculus DK2</i>	<i>Oculus CV1</i>
Field of view	100°	110°
Display technology	AMOLED (Samsung Note 3 Pentile)	Dual low-persistence Samsung AMOLED (Diamond PenTile subpixel matrix)
Display panel size	5.7"	7"
Display screen resolution	1920 $\times$ 1080	2160 $\times$ 1200
Per eye resolution	960 $\times$ 1080	1080 $\times$ 1200
Total pixels per eye	1,036,800	1,296,000
Display refresh rate	60, 72, 75 Hz	90 Hz
Head tracking	6 DOF positional tracking (based on combination of 3-axis rotational plus 3-axis positional), USB connection using near-infrared CMOS sensor	6 DOF constellation camera, optical 360°IR LED tracking

CMOS, Complementary Metal Oxide Semiconductor; DOF, Degrees of Freedom.

TABLE 2. AGE, GENDER, AND PREVIOUS EXPOSURE STATISTICS BY CONDITION

	<i>Minecraft CV1</i>	<i>Minecraft DK2</i>	<i>Elite CV1</i>	<i>Elite DK2</i>	<i>Lucky CV1</i>	<i>Lucky DK2</i>
Average age (SD)	20.4 (1.8)	20.1 (2.1)	20.5 (1.9)	20.1 (1.2)	20 (1.3)	22 (5.0)
Women	8	10	10	12	9	17
Men	17	16	21	15	13	12
No previous exposure to game	16	28	30	27	20	28
Previously played assigned game	12	14	1	0	2	1

design. Participants were assigned to play “Minecraft” (Windows 10 edition for the Oculus Rift) in the high sensory conflict condition; “Elite: Dangerous,” a space dogfighting game for the moderate sensory conflict condition; or “Lucky’s Tale,” a third-person platform-based game for the low sensory conflict condition. All players controlled their game using a Microsoft Xbox One USB controller, which interfaced with each game via Oculus’ game launcher software. Computers used for this study were Dell Precision PCs, configured with Intel Xeon 3.6 GHz octa-core processors, 16 GB RAM, and nVidia GTX 1080 graphics cards.

Criteria for determining sensory conflict potential of interactive stimuli

When considering what level of potential sensory conflict a stimulus may offer, a careful analysis was conducted of each experience. The stimuli were scored based on how the self and self-motion are represented in the VR experience or game. Factors considered were (1) presence or absence of an avatar that represents the player³⁶; (2) first- or third-person point of view, with first-person point of view representing a higher sensory conflict^{37,38}; (3) whether movement is represented through movement of the avatar’s physical body, movement of a vehicle in which the avatar is seated, teleportation, or third-person follow³⁹; and (4) presence or absence of a frame of reference or stabilizing element between the player’s avatar and the environment.^{39,40} Point values for each criteria are described in Table 3.

For instance, a VR experience that (1) has an avatar that represents the player directly, (2) views the virtual environment from a first-person perspective, (3) represents movement through movement of that avatar’s physical body (e.g., walking, running), and (4) has no frame of reference or stabilizing environmental attributes (such as the dashboard of a car, the cockpit of an aerospace vehicle, or a helmet heads-up display) would score a 5 in sensory conflict potential. A game that has a third-person view of a representative avatar, but still represents movement through movement of the avatar’s physical body and has no frame of

reference between the avatar and the environment, would score a 4. A game that has a character that is not representative of the player, provides a third-person point of view, but offers no stabilizing frame of reference would score a 1 according to our criteria.

We searched for games that would differ according to these criteria. We first considered and selected “Minecraft,” which we have used in previous studies.¹⁷ “Minecraft” is played from a first-person perspective, has an avatar that is representative of the player, represents movement via locomotion of the avatar’s physical body (walking and running), and has no stabilizing frame of reference between the avatar and the environment. Therefore, “Minecraft” scored a 5 in sensory conflict potential.

We then considered “Elite: Dangerous,” a space flight simulator similar to “Strike Suit Zero” or “EVE: Valkyrie.” “Elite: Dangerous” provides a representative avatar from the first-person perspective. It lessens potential sensory conflict by implementing movement through the player’s ship. The player’s avatar is seated in the cockpit, mirroring seating in the real world. “Elite: Dangerous” also provides a stabilizing frame of reference through the cockpit structure. Therefore, “Elite: Dangerous” scored a 3. We selected “Lucky’s Tale” as the game with the least sensory conflict potential. “Lucky’s Tale” does not have a representative avatar, so it is not the player themselves that appears to be moving. Players guide *Lucky* from a high third-person perspective, and movement simply follows *Lucky*. However, there is no frame of reference provided, so the movement of the player’s camera, if you can, is sometimes disorienting. “Lucky’s Tale” has a sensory conflict potential of 1 according to our criteria.

Procedure

After giving informed consent, participants played their assigned game for 20 minutes. They were told they could end their participation at any time for any reason. After playing the game for the required time or ending the play session early, participants completed the measures of spatial

TABLE 3. SENSORY CONFLICT POTENTIAL CRITERIA CHART

<i>Game</i>	<i>Representative avatar: 1 = yes, 0 = no</i>	<i>POV: 1 = first-person POV; 0 = third-person POV</i>	<i>Movement: 2 = avatar movement; 1 = vehicle movement with avatar seated; 0 = teleportation or third-person follow</i>	<i>Stabilizing frame of reference: 1 = no, 0 = yes</i>	<i>Total sensory conflict potential</i>
“Minecraft”	1	1	2	1	5
“Elite: Dangerous”	1	1	1	0	3
“Lucky’s Tale”	0	0	0	1	1

presence, realism, interactivity, enjoyment, and cybersickness. All players who ended their session early managed to play the game for over 10 minutes; therefore, it was determined that their data was valuable and hence retained for analysis.

Measures

Spatial presence was measured using the 19-item Spatial Presence subscale of the ITC-Sense of Presence Inventory (ITC-SOPI⁴¹). Some example items include “I had a sense of being in the scenes displayed” and “I felt as though I was in the same space as the characters and/or objects”. Observed Cronbach’s α was 0.93.

Perceived reality was measured using Popova’s^{4,42} perceived reality measure for videogames. When combined, the 29 items yielded a single aggregate measure of perceived reality with observed Cronbach’s α of 0.87. Questions invoked the player’s notions about how realistic the game environment seemed to be; for example, “The sounds in the videogame were true to life”; “The texture of the surfaces looked right.”

Interactivity was measured using the 11-item effectance and 9-item control scales used in previous research on the impact of interactivity and game enjoyment.¹⁵ Effectance and control were combined and averaged into a single measure of interactivity. Observed Cronbach’s α was 0.92. Example items include “The game responded immediately to my inputs” (effectance), and “My actions affected the game as I had hoped” (control).

Enjoyment was measured using Klimmt, Hartmann, and Frey’s eight-item enjoyment questionnaire.¹⁵ Example items include “I found the game entertaining”; “The game was not at all interesting to me” (reverse coded). Observed Cronbach’s α was 0.87.

Cybersickness was assessed using the 16-item Simulator Sickness Questionnaire (SSQ⁴³). It measures a wide range of possible symptoms of cybersickness, including (but not limited to) fatigue, nausea, eyestrain, dizziness, and vertigo. Each symptom was rated on a severity scale that ranged from 0 (none) to 3 (severe). The scale had an observed Cronbach’s α of 0.91. The scale was aggregated to produce a single measure of cybersickness that could range from 0 to 48. Cybersickness was treated as a continuous variable in the analysis.

Gender was assessed via a simple single-item question: “Sex”, with “Male” and “Female” as answer choices.

Analysis

H1 and H2. Data for H1 and H2 were analyzed with a univariate analysis of covariance procedure general linear model (GLM) using SPSS 24. Such a test is appropriate for comparing means of a continuous or scale-level independent variable across categories of more than one dependent variable.⁴⁴ Data for RQ1 were analyzed using WarpPLS 6.0. WarpPLS is capable of nonlinear structural equation modeling and path analysis and provides significance tests of each path coefficient as well as effect size indicators for each endogenous variable. It is more suited for the hypothesis testing found in this study, rather than analysis focused solely on model fit. WarpPLS does produce three indicators of model fit: the average path coefficient (APC), average R^2 (ARS), and average

variance inflation factor (AVIF). A full description of these indicators can be found in the WarpPLS user manual⁴⁵ (see URL in reference list). In brief, the APC and the ARS are calculated through resampling. Because these indices are computed as averages of other parameters, Bonferroni-like corrections are used to calculate P values.⁴⁵ Recommended P values for the APC and the ARS is <0.05 . The AVIF, which is an indicator of multicollinearity in the model, should be <5 .⁴⁵

Results

Baseline statistics

For easier interpretation of later results, Table 4 presents baseline statistics (means, standard deviations) for all variables under study. These statistics show the values of the average score on each variable independent of the influence of other variables.

Hypothesis testing

Hypothesis 1 predicted that games with high (“Minecraft”), moderate (“Elite: Dangerous”), and low (“Lucky’s Tale”) levels of sensory conflict (SC) would result in concordantly high, moderate, and low levels of cybersickness such that the more sensory conflict a game should produce, the more cybersickness will be experienced by players. Hypothesis 2 predicted that the headset used (either the DK2 or the CV1) would have no significant impact on cybersickness. Both hypotheses were tested using a univariate GLM (ANCOVA) procedure that included gender and previous exposure to the games as covariates. Gender was found to be a significant covariate: $F_{(1, 152)} = 12.76$; $P < 0.001$; $\eta^2_{\text{part}} = 0.08$. According to a follow-up ANOVA analysis, women ($M = 10.42$; $SE = 1.14$) experienced significantly higher levels of cybersickness than men ($M = 6.62$; $SE = 0.72$) across conditions: $F_{(1, 158)} = 8.77$; $P = 0.004$. The ANCOVA results indicated that 20% of the variance in cybersickness can be explained by the level of sensory conflict potential in the games: $F_{(2, 152)} = 18.9$; $P < 0.001$; $\eta^2_{\text{part}} = 0.20$. “Minecraft” users reported the highest levels of cybersickness ($M = 13.42$; $SE = 1.11$). “Elite: Dangerous” users reported less severe cybersickness ($M = 6.65$; $SE = 1.03$), and “Lucky’s Tale” users reported the least cybersickness of the three games ($M = 4.71$; $SE = 1.05$), as predicted. Therefore, H1 is supported. However, the difference between cybersickness scores for “Elite: Dangerous” (moderate SC) and “Lucky’s Tale” (low SC) was not statistically significant ($P = 0.566$). This nonsignificant difference could be a function of the small sample size of the study. Cybersickness scores could range from 0 to 44, indicating that even “Minecraft” players’ cybersickness scores were not severe, and scores

TABLE 4. BASELINE VARIABLE STATISTICS

Variable	Mean	Standard deviation	Min. value	Max. value
Cybersickness	8.19	8.20	0	44.00
Spatial presence	3.65	0.63	1.00	5.00
Interactivity	3.62	0.066	1.45	5.00
Realism	2.70	0.46	1.28	4.10
Enjoyment	3.89	0.71	1.50	5.00

for “Elite: Dangerous” and “Lucky’s Tale” were, practically speaking, quite similar.

In the interest of removing any possible bias from our results, it was determined that the data should be reanalyzed, excluding participants who had previously played the game they were exposed to. Of the 30 players who met this criterion, 26 of them were in one of the “Minecraft” conditions. Three had played “Lucky’s Tale” previously, and one had previously played “Elite: Dangerous.” Results of the reanalysis of H1 with $n=130$ participants confirmed the previous results. Without previously exposed players, 18% of the variance in cybersickness was explained by the level of sensory conflict potential in the games: $F_{(2, 125)}=13.8$; $P<0.001$; $\eta^2_{\text{part}}=0.18$. Mean cybersickness scores followed the same pattern as in the original analysis (“Minecraft”: $M=14.14$; $SE=1.45$; “Elite: Dangerous”: $M=7.46$; $SE=0.96$; “Lucky’s Tale”: $M=4.51$; $SE=1.08$). Whether or not some participants were able to complete their entire gaming session depended in part on the cybersickness they experienced during the game. Twenty-five participants (15.6%) reported that they ended their play session early. Ending the play session early was positively and significantly associated with cybersickness scores ($r=0.32$; $P<0.001$), indicating that cybersickness symptoms were moderately related to ending play sessions early. Eleven of the 25 participants who ended their play sessions early did so due to self-reported strong symptoms of cybersickness (post hoc analysis showed that scores on the SSQ were 19 or above). Nine of those participants were “Minecraft” players. Of the remaining study dropouts, only two “Elite: Dangerous” players dropped from the study due to cybersickness. The other 14 study dropouts ended participation due to technical difficulties with the study.

Hypotheses 2 predicted that there would be no significant difference in cybersickness scores for players using the Oculus Rift CV1 as compared to those using the technologically inferior Oculus DK2. Results confirmed H2: there was no statistically significant difference in cybersickness scores between the CV1 ($M=8.61$; $SE=0.91$) and the DK2 ($M=7.79$; $SE=0.89$).

Research question analysis

RQ1 inquired as to the relationships between the variables predictive of enjoyment, as found in previous studies.^{4,8,9}

The question was analyzed based on the diagram in Figure 1, wherein perceived interactivity predicts spatial presence and realism, realism predicts spatial presence, and spatial presence predicts enjoyment. Cybersickness was included as a covariate influencing enjoyment, and previous exposure was included to determine its impact on cybersickness. The model was tested using path analysis in WarpPLS 6.0. Figure 2 shows the model with path coefficients, and total variance explained (R^2 values) for each endogenous variable. WarpPLS fit indices show that the model fit the data well: $APC=0.38$; $P<0.001$; $ARS=0.27$; $P<0.001$; $AVIF=1.17$.

A second path model was specified that included direct links from perceived interactivity and perceived reality to enjoyment. The second model increased the variance of enjoyment explained by only 5%. Therefore, it was determined that the model in Figure 2 represents the most parsimonious model. Please note the weak influence of previous exposure on cybersickness. Although the path is statistically significant, previous exposure to the game or a similar experience only explained 5% of the variance in cybersickness.

Discussion

This study investigated both cybersickness and psychological responses to games that were varied in their potential level of sensory conflict. Games were also divided between two display conditions—the Oculus Rift CV1 and the Oculus DK2. In terms of cybersickness, technological differences between the two headsets did not cause a difference in cybersickness responses. Between the two conditions, average cybersickness scores were relatively low (an average score of about 8.2 on a 44-point scale). The average player did not experience severe cybersickness symptoms as they played. However, when looking at the potential level of sensory conflict produced by each game, we can begin to discern some of the causes behind the cybersickness experienced by some of the players. Participants in the study played either a high (“Minecraft”), moderate (“Elite: Dangerous”), or low (“Lucky’s Tale”) sensory conflict game. Players of “Elite: Dangerous” and “Lucky’s Tale” reported similarly low levels of cybersickness. However, “Minecraft” players

FIG. 2. Enjoyment path model. Path coefficients are β -weights indicating the strength of the relationship between the linked variables, given the contribution of the other variables in the model. * indicates that the coefficient is significant at the 0.001 level.

experienced much higher levels of cybersickness than their counterparts in the other two conditions. Results of a follow-up analysis that excluded players who had played their assigned game previously were consistent with the results of the initial analysis. Effects of sensory conflict were consistent whether previously exposed players were included or not.

These results seem to indicate that cybersickness is attributable in part to the way motion is represented in VR games. Games that put the player into the avatar's perspective (i.e., first-person perspective) are much more likely to produce cybersickness than games that do not. Also, even if the game does provide a first-person perspective, cybersickness can be reduced or alleviated by providing visuals and motion cues that do not conflict with what the player is experiencing physically, such as in "Elite: Dangerous." If a player is sitting in a chair in the real world and sitting in a chair in a cockpit in the game, sensory conflict should be (and our findings suggest that it is) much less than if a player who is seated in the real world is portrayed as running or walking in a game like "Minecraft." In addition, if a game provides a stabilizing frame of reference, cybersickness may be reduced.⁴⁰ In the case of "Lucky's Tale," cybersickness is even more unlikely due to the third-person follow perspective. The player takes on the role of a protective guide, moving a character through the game environment from above. There is very little sensory conflict in such an environment and, consequentially, a much smaller chance of cybersickness. This is by design. "Lucky's Tale" creator and owner of Playful Corp Paul Bettner explained that avoiding cybersickness was a chief in the development of the game. One specific measure taken was to provide consistent, steady camera movements in relation to the VR environment. By placing an emphasis on the third-person tracking of *Lucky's* movements, the developers were able to provide an environment low in sensory conflict.⁴⁶

As we have found in past research,¹⁷ improvements in the technical aspects of the VR HMD did not result in reduced cybersickness. Average cybersickness scores were not statistically different across headset conditions (CV1 vs. DK2). This finding contradicts the conventional wisdom that seemed to guide early predictions about improvements in HMD technology—namely that adding elements like positional tracking would greatly reduce cybersickness over early prototypes.³⁰ That prediction did not come true when the DK1 was improved upon with the DK2,¹⁷ and further improvements did not contribute to reducing cybersickness in the present study.

This finding indicates that cybersickness does not depend upon improvements in the display technology. This is not to say that HMD manufacturers need not worry about how "good" their headsets are. Certainly, a more aesthetically pleasing and potentially more realistic experience is desirable, but those improvements evidently do not reduce likelihood of cybersickness. Our findings also seem to show that for certain types of games, cybersickness is not a significant problem. We suggest that both software and hardware developers focus on reducing sensory conflict in games either by providing devices for the translation of physical motion into the game environment (such as omnidirectional treadmills), or by continuing to develop in-game locomotion techniques that spark less conflict. These developments are

ongoing, and future research should focus on the effectiveness of various techniques.

Following previous research on motion-based and casual games, we tested the fit of a model that incorporates player scores on perceived interactivity, realism, and spatial presence on enjoyment.^{4,8,9} This previous research indicated that, for the types of games tested, perceived interactivity and realism are predictors of spatial presence, which goes on to be a strong predictor of enjoyment. Our model indicates that the paths of influence found in previous research hold true for VR games as well. The model we have laid out consistently explains 20%–40% of the variance in enjoyment across several gaming situations.^{8,9}

Limitations

One possible limitation of this study is that the analysis of H1 and H2 may be underpowered. A power analysis conducted using the program G-power indicated that for the number of variables and covariates in our ANCOVA, we had a power level of 0.60. This fell short of the minimum preferred power level of 0.80. However, a power calculator from rpsychologist.com indicated that we achieved a power of 0.81. Given these mixed results, the study may be subject to type I error, meaning there may be significant differences that our study was not powered to detect. Replication with a larger sample is recommended.

Future research

More research is necessary to determine which factors matter most across a wide range of genres in the VR gaming space. Developers, users, and scholars will all benefit from further investigations into methods of locomotion. For instance, future research should investigate whether first-person games with representative avatars such as "Minecraft" are significantly more comfortable when using devices such as the Virtuix Omni treadmill that allow actual physical movement. New developments in haptics, such as Haptx gloves and the Teslasuit, offer exciting ground for new research focused not only on cybersickness but also on the psychological factors of human beings' interaction with virtual environments. Also important for future research will be investigations into non-gaming VR applications, such as VR tourism, VR sports spectatorship, and education and therapy. These efforts are ongoing and show much promise.

Author Disclosure Statement

No competing financial interests exist.

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