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Impact of VR and Desktop Gaming on Electroencephalogram (EEG) Ratings

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***Abstract*— User experience (UX) studies in video games have become increasingly prevalent in the literature in recent years due to an increasing global focus in UX, multiple new video game platforms and the growing utilisation of virtual reality technology. To have a video game perform at an acceptable level for the user, research scientists must investigate which parts of a video game are effective in terms of overall game enjoyment and playability. There are various factors that affect the overall user experience in a video game. In this study, we take a closer look at the differences in brain waves using an electroencephalogram (EEG) and UX satisfaction metrics in both desktop and VR gaming conditions utilising a commercial EEG device capable of measuring a range of brain activity.**

Keywords*— *VR gaming; electroencephalogram (EEG); video game UX, video games; gaming user experience

I. Introduction

There are many factors that affect overall video game user experience. Some of these factors include player immersion, creative freedom for the user, usability/playability, and the amount of presence a user experiences while being immersed in a video game. When most of these factors are measurable on a video game, the output will be dependent on the level of user experience with the game, which can affect the overall enjoyment of the game for the user.

In addition to enjoyment, previous work has indicated that engagement may also play a significant part measures of game satisfaction. This has been seen to be an indicator of video game quality, where higher levels of player engagement would result in a better video game experience [13].

Another prominent factor in overall user experience is the player's level of immersion in the game. This involves not only how much the player is driven by the narrative of the game, but it also refers to the player's love of the game mechanics and the strategy that goes into playing the game [6].

A number of researchers have investigated levels of player immersion with Virtual Reality (VR) games and developed visual aesthetic rating systems. Immersion can be defined as "the sensation of being surrounded by a completely other reality, that takes over all of our attention, our whole perceptual apparatus," immersion and presence do not actually fall very far from each other, and are in fact often used as synonyms [5]. Immersion is also partly a function of the plot of the game, or narrative, in which the plot is essentially the extent to which the game or simulation is self-contained, has its own dynamic, and presents an alternative world to that of the real world [1]. Most scholars and scientists tend to agree that total photorealism and audio realism are not necessary for a virtual reality environment to produce in the viewer a sense of immersion, a sense that the world they are in is real and complete. This awareness has not stopped VR game developers from continually aiming to improve photorealism and audio-realism [6].

People often misinterpret the terms "immersion" and "presence" and misuse one in place of the other. Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another [17]. Immersion is a description of a technology and describes the extent to which the computer displays are capable of delivering an inclusive, extensive, environment and providing a vivid illusion of reality to the senses of a human participant [16]. Both of these terms do have significant involvement within each other when considering game user experience ratings.

A. Flow/Zone

VR can be used as a storytelling mechanism, which allows the user to enter a virtually recreated scenario that represents a story [14]. VR based video games are unique in their ability to portray different genres and allow storytelling adventures. To adequately measure the effect of VR in a video game, researchers often focus on the experience of *flow*, which can be described as the holistic sensation that people feel when they act with total involvement and concentration [10].

According to flow theory, we experience flow when an activity's challenges fully engage our skill sets, without overwhelming them [2]. According to Csikszentmihalyi, flow has eight possible dimensions of measurement [4]:

- a clear sense of what has to be done moment by moment;
- immediate feedback as to how well one is doing;
- an intense concentration of attention;
- a balance between opportunities for action (challenges) and capacity to act (skills);
- exclusion of irrelevant content from consciousness;
- a sense of control over the activity;
- a distorted sense of time - usually hours pass by in minutes; and
- a feeling that the activity is intrinsically rewarding, or worth doing for its own sake.

Despite high expectations and popularity, it remains unclear whether users feel *presence* and *flow* during immersive experiences, whether immersion influences cognition, and in what ways the UX is improved by new forms of heightened immersion in VR [14]. In this study, the authors investigated these measurements of flow using the MyndPlay software and the EEG headset while the participant plays the video game in both VR and PC screen conditions.

B. Electroencephalogram (EEG)

As VR headsets become more widely available, and increasingly utilised for gaming – more low cost, commercial EEG devices have also become available. EEG has been demonstrated to have the capability to measure player ,experience. Nacke et al. assessed the player experience across various game levels, each designed to induce boredom, immersion, and flow in the players [11]. The participants played each of these levels (created as mods within the game *Half-Life 2*) while measuring their brain activity using EEG, the participants also completed the Game Experience Questionnaire (GEQ) after completing the game levels. The researchers were able to observe changes in brain waves across the different levels and correlate that information along with information from the GEQ to determine that the specific levels they created were having the intended effect of causing immersion, flow, and boredom respectively.

McMahan et al. aimed to assess the impact of various stimulus modalities on participants and to isolate video game events such as death in the game using EEG data [8]. They were able to find significant differences in the Beta and Gamma bands between the different modalities of gameplay. They were also able to see an increase in power estimates during high intensity gameplay compared to low intensity gameplay moments. They concluded that their findings suggested that commercial EEG technology can be used to assess differences in frequency bands during varying levels of stimulation.

During these experiments, McMahan et al. assessed user engagement using the Emotiv EEG, a low cost, commercial EEG measurement device [8]. The researchers compared engagement indices during video game modalities with Emotiv EEG indices to identify the best correlations between them. The indices used were:

- Index 1 [(Beta / (Alpha + Theta)],
- Index 2 [(Theta/Alpha)], and
- Index 3 [Frontal Theta].

The researchers were able to identify significant differences in engagement for the three indices used and were able to observe significantly increased engagement levels during death events compared to general gameplay events when using Index 1 and 3. They suggest that low cost, commercial EEG equipment (such as the Emotiv EEG) can be used to assess varying levels of engagement as players experience different events in a game [8].

Previous experiments with VR and usability undertaken by the authors relied solely on the use of self-reporting measures to collect data [18]. The authors aimed to extend the metrics during experimentation and produce more robust data based on physiological measures, to achieve significant results which could be correlated with participant data from self-reported measures. It was hoped that adding physiological metrics (such as EEG) would overcome some of the issues associated with self-reported data, which can be highly susceptible to influences outside of the participant's own targeted attitudes [15]. A number of other researchers have reported that asking participants about their experience after playing a game can sometimes lead to missed information or false information [3].

This paper describes an experiment that was undertaken to compare the experience of game players of both VR and desktop (screen based) systems. Data was collected using a more modern EEG device (the Myndband BLE EEG headset) and self-reporting data collected using the Game User Experience Satisfaction Scale (GUESS) questionnaire. There were two primary hypotheses addressed by this experiment:

- Participants will have a higher overall UX satisfaction in the VR condition as compared to the desktop condition
- Results from the EEG will show higher levels of attention and flow in the VR condition as compared to the desktop condition.

Lastly, there was an expectation that a comparison of the physiological results with the results of the self-report measure would identify what differences, if any, were present.

II. METHOD

The goal of our study was to understand how brain waves were affected when playing a game in VR compared to playing the game under normal conditions on a flat screen. We compared data from participants playing a VR game on the Oculus Rift HMD and a desktop version of the same game.

A. *Design*

The experiment was conducted as a within-subjects design with counter balancing. The participants experienced both the VR and desktop conditions while wearing the EEG headset. The independent variable was the display being used (Oculus vs Desktop) and the dependent variable was their game UX satisfaction as measured by their GUESS scores as well as the EEG data collected during play.

B. *Participants*

A total of 31 participants were recruited in this experiment. Participants were recruited by email and were directed to sign up through a web application for a timeslot for the experiment.

C. *Materials*

The experiment made use of the games *Defense Grid 2: Enhanced VR Edition* and *DG2: Defense Grid 2* available on steam and the Oculus rift store. The experiment also utilized the use of the Oculus Rift, Oculus Touch controllers, and an Xbox One controller connected wirelessly to a desktop computer running Windows 10. Qualtrics.com was utilized to administer the GUESS questionnaire after each task to collect the self-reporting data.

a) VR Headset: The experiment utilized an Oculus Rift HMD. It has features such as stereoscopic 3D, positional tracking, an accelerometer, and a gyroscope. It also makes use of two OLED displays, one in front of each eye, with a resolution of 1080x1200 for each eye, a 90Hz refresh rate, a 110-degree field of view, and integrated headphones (Oculus, 2020)[12]. The use of this VR headset created an immersive and compelling virtual environment for the participants and allowed the players to use their head to look around in the environment and immerse themselves with the game.

b) MyndBand BLE EEG Brainwave Headset: The Myndband BLE EEG Brainwave Headset is a research grade, commercial, customizable EEG Neurofeedback headset that has the ability to integrate with VR headsets. The headset uses 3 dry sensors on the forehead to measure brainwave activity that is transmitted via Bluetooth to a computer allowing researchers to monitor brain activity, focus, relaxation, and mindfulness states in real time. The Myndband outputs raw brainwave data at 512Hz (Alpha, Beta, Theta, Delta, and Gamma bands), in addition to providing measure of Attention, Meditation (Relaxation), Zone (Flow), Blink detection, as well as providing a measure of EEG signal quality ~~(Myndband, 2020)~~[9]

c) Game User Experience Satisfaction Scale (GUESS): The GUESS questionnaire is a psychometrically validated construct created to avoid some of the limitations present in other gaming related measures. It contains nine different subscales that are indicative of video game enjoyment and satisfaction such as Usability/Playability, Narratives, Play Engrossment, Enjoyment, Creative Freedom, Audio Aesthetics, Personal Gratification, Social Connectivity, and Visual Aesthetics ~~(Phan et al., 2016)~~[13]. GUESS includes a total of 55 items, rated on a 7-point Likert-scale. Given the nature of the First Person Shooter (FPS) game used in this study, the dimensions of Narratives and Social Connectivity were not applicable, and thus, were excluded from the questionnaire. In line with the scale's scoring guide ~~(Phan et al., 2016)~~[13], an average subscale score for each of the remaining seven dimensions was computed, which were then summed up to calculate an overall GUESS score for each participant.

D. *Procedure*

Participants were instructed to sit down at the computer and fill out an informed consent form. The experimenter then placed the Myndband headband around the head of the participants and provided them with information about the games they were going to play. The controls for the game were explained on the specific controllers for each designated condition.

Under the VR condition, the headset was placed on the head of the participant and the Myndband BLE unit was clipped to the side of the Oculus Rift allowing for a USB cable to be connected from the sensors on the headband. For the desktop condition, the BLE unit was clipped directly to the Mynband headband and a USB cable connected.

The game was then loaded, and the participants were instructed to play for 15 minutes continuously, starting at the prologue stage in story mode. As gameplay began, the experimenter began recording the EEG data using the Myndplay software for Windows.

III. RESULTS

To test the hypotheses presented earlier, several statistical tests were conducted. The hypotheses addressed by this experiment were as follows:

- Participants will have a higher overall UX satisfaction in the VR condition as compared to the desktop condition
- Results from the EEG will show higher levels of attention and flow in the VR condition as compared to the desktop condition.

After the experiments were completed, the raw data from the Myndband headset was aggregated into measurements of participant Attention, Zone, Meditation and Presence. These aggregated results are shown in Table II.

After the experiments were completed, the data from the GUESS questionnaire was aggregated into overall measurements of participant experience. These aggregated results are shown in Table I.

Analyzing the individual categories of aggregated data from the Myndband EEG headset allows a determination of significance to be made. A paired samples t-test was conducted to compare participants' Attention level, Zone level, Meditation level, and Presence in VR and PC game conditions of the experiment.

Regarding Attention as measured by the EEG headset. Results showed a significant difference in Attention levels between the VR and PC game conditions $t(31) = -2.814$, $p = .008$. This difference is shown in Fig. 1.

As for Zone, the aggregated results showed no significant differences between the VR and PC game conditions $t(31) = -0.690$, $p = .495$. This difference is shown in Fig. 2.

TABLE I. DESCRIPTIVE STATISTICS FOR DEPENDENT VARIABLE BASED ON AGRREGATED EEG MEASURMENTS

	M(SD)	*t(31)*	*p*
VR Attention	49.53 (8.79)	-2.814	0.008
PC Attention	54.82 (9.32)		
VR Zone	52.84 (4.08)	-0.690	0.495
PC Zone	53.52 (5.15)		
VR Meditation	56.65 (6.58)	2.696	0.011
PC Meditation	52.72 (5.98)		
VR Presence	5.13 (1.07)	5.22	0.000
PC Presence	3.83 (1.22)		

Alpha level set to .05 for all hypothesis tests.

TABLE II. DESCRIPTIVE STATISTICS FOR DEPENDENT VARIABLE BASED ON GUESS QUESTIONNAIRE

	M(SD)	*t(31)*	*p*
VR GUESS	39.01 (4.50)	1.374	0.179
PC GUESS	38.01 (4.75)		

Alpha level set to .05 for all hypothesis tests.

As for Zone, the aggregated results showed no significant differences between the VR and PC game conditions $t(31) = -0.690$, $p = .495$. This difference is shown in Fig. 2.

For Meditation, aggregated results indicated that there was a significant difference between the VR and PC game conditions $t(31) = 2.696$, $p = .011$. This difference is shown in Fig. 3.

However, aggregated results indicated that there was a significant difference in Presence between the VR and PC game conditions $t(31) = 5.216$, $p = .000$. This difference is shown in Fig. 4.

A paired samples t-test was also conducted to compare participants' aggregated GUESS scores. The results showed that there were no statistically significant differences in GUESS scores between the VR and PC game conditions $t(31) = 1.374$, $p = .179$. This difference is shown in Fig. 5.

IV. DISCUSSIONS/ CONCLUSIONS

The purpose of this study was to compare video game UX ratings between Virtual Reality and Desktop gaming, using data collected from the GUESS questionnaire. Additional data was also collected from a commercially available EEG headset to compare participants mental state between the two modes of game play under examination. It was hoped that the data from the EEG headset could be correlated with the self-reporting results from the GUESS questionnaire to see what differences, if an existed.

The first hypothesis predicted higher UX satisfaction in the VR game condition than the PC condition. The aggregated data from the GUESS questionnaire showed no significant difference between the two gaming conditions, hence the hypothesis was not proved. While regrettable that the GUESS questionnaire did not yield significant results, this result was not unexpected based on previous use of the questionnaire by the authors in similar experiments [18].

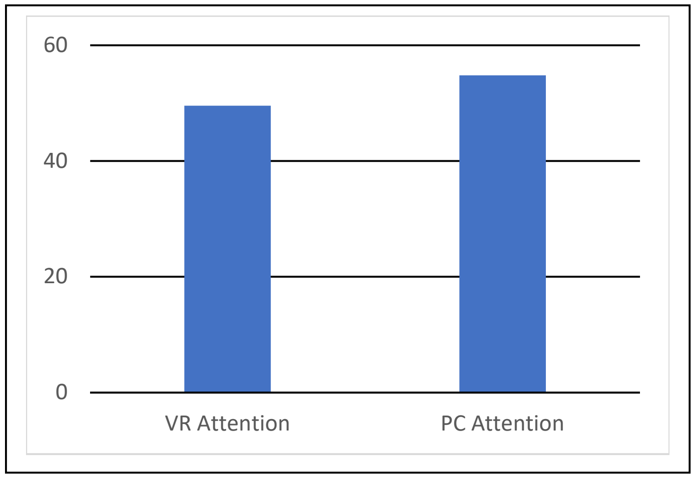

Fig. 1. Difference in Attention Measured by the EEG Headset.

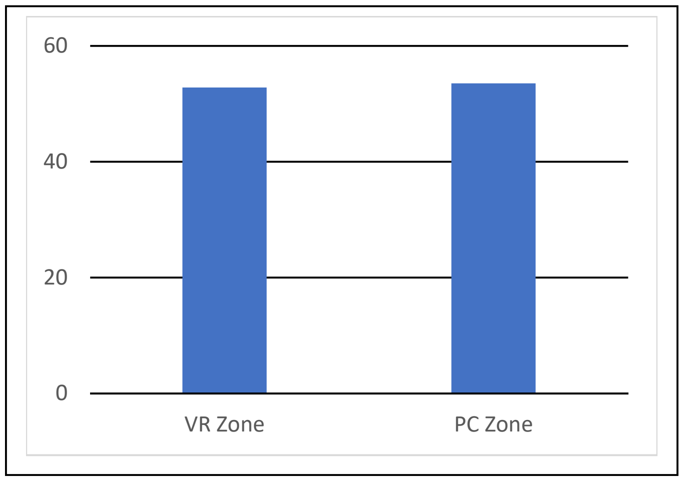

Fig. 2. Difference in Zone Measured by the EEG Headset

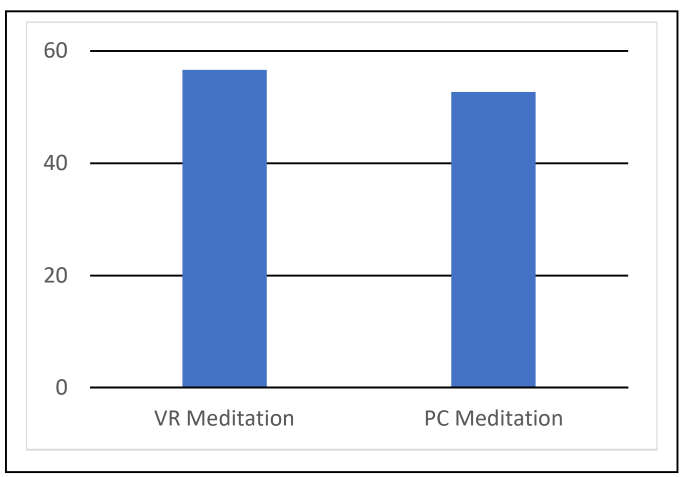

Fig. 3. Difference in Meditation Measured by the EEG Headset

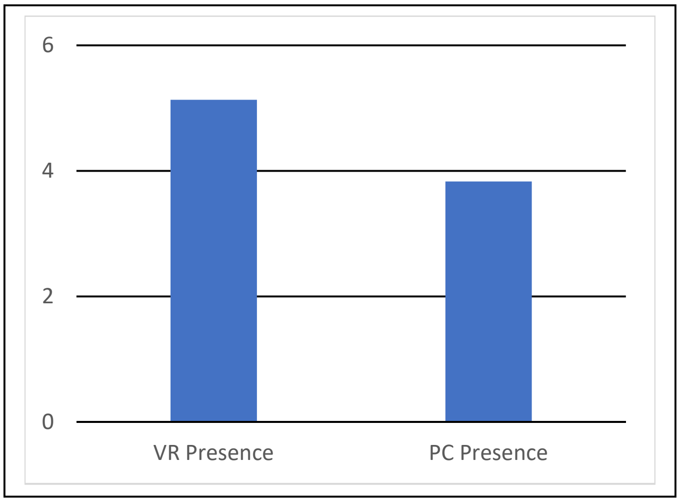

Fig. 4. Difference in Presence Measured by the EEG Headset

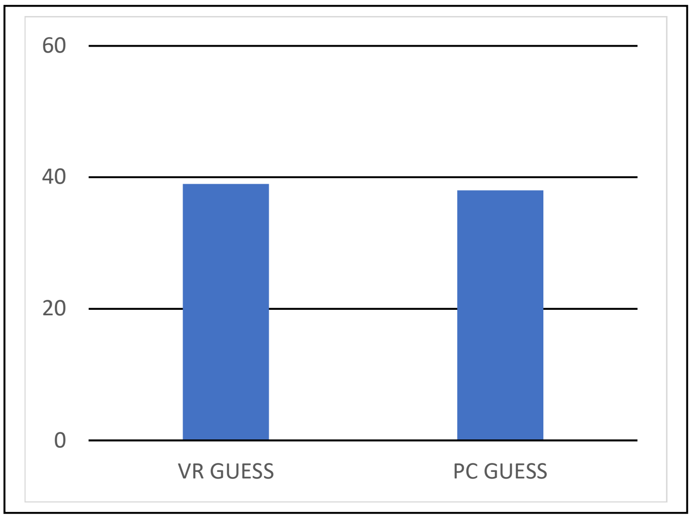

Fig. 5. Difference in Experience Measured from the GUESS Questionnaire

The second hypothesis predicted higher greater attention and zone in the VR game condition than the PC condition. The aggregated data from the EEG headset showed that attention was significantly higher in the Desktop game condition compared to the VR condition. There are a number of potential reasons for this results, but it the authors suspect that this may be attributed to the participants having to devote more attentional resources in the desktop gaming condition to filter out distractions from the outside environment surrounding the game and screen.

In the VR gaming environment, the HMD may filter out many of these distractions by fully immersing the participant in the game. This explanation is backed up by claims from the Myndband manufacturers, who describe a VR experience as providing a linear focus. This focus gives any VR user the ability to block out external stimuli and distractions and this feature is often represented in the EEG data [9].

The aggregated data from the EEG headset also showed that showed no significant differences in zone between the Desktop game condition compared to the VR condition. Since participants experience flow when an activity's challenges fully engage their skill sets, we could expect that under the experimental conditions encountered, participants would be fully engaged with the game tasks assigned for the short time periods involved [2].

The aggregated data from the EEG headset indicated that the VR game condition had a significantly higher meditation score compared to the Desktop condition. The manufacturer of the Myndplay headset describe meditation as something akin to relaxation and representing a stress-free mental calm [9].

Hence, as with the explanation given for the difference in attention between the two conditions, the increase in the meditation score can be similarly explained. When the participants are in the VR gaming condition, they are free from many external distractions and become fully immersed in the game, which allows the players to more easily lose themselves in the game world.

Lastly, the aggregated data from the EEG headset indicated that the VR game condition had a significantly higher presence score compared to the Desktop condition. This is an expected result, given the definition provided for presence as the subjective experience of being in one place or environment, even when one is physically situated in another [17].

One would normally expect the presence score from the aggregated EEG data to be higher in the VR game condition than the desktop condition, due to past research demonstrating that VR provides a more immersive experience. Thus, the results from this experiment continue to back up the previous work, demonstrating once again that VR, due to its higher sense of presence, would also be a more immersive experience. [17, 18]

The experiment described in this paper was intended to allow the researchers to correlate and compare data from gamers in VR and desktop modalities, using a commercially available EEG headset and the GUESS self-reporting questionnaire. The results of the experiment were interesting and useful but did not validate the hypotheses proposed by the researchers. The significant differences identified, however, do lead to some potentially promising results that merit further study.

A number of potential problems exist with the methodology adopted in the experiment. Firstly, the experiment data was possibly limited in accuracy. The Myndband EEG headset has not been extensively tested against already existing hardware, specifically higher-end, professional, research level equipment. Also, there is a potential issue with the use of the GUESS questionnaire to measure user experience in experiment of this nature, and this has been reported by the authors in previous work [18].

Hence any future work aiming to validate, and expand upon, the results of this experiment would benefit from increased data regarding the validity and accuracy of the both the EEG headband used and the self-reporting questionnaires being used.

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