Immersion in Cardboard VR Compared to a Traditional Head-Mounted Display

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Abstract. This paper describes a study that aims at finding the difference in levels of immersion between a Cardboard VR and a traditional Head-mounted Display (HMD)—the Oculus Rift DK2. Three groups of participants—the experimental group for Cardboard VR, and two control groups for Oculus Rift and a Desktop display—played *Cryoblast* in the same experimental setups for this study. Jennett et al.'s Immersive Experience Questionnaire was used to measure immersion for all the groups. The results indicate that the Cardboard VR, despite its simplicity and small screen size, is capable of providing an acceptable level of immersion compared to Oculus Rift's larger screen size. Since 'immersion' plays an important role in VR pain distraction, knowing the level of immersion for Cardboard VR may help determine its potential as an accessible VR device for chronic pain self-management.

Keywords: Mobile virtual reality · Cardboard VR · Oculus rift · Head-mounted display · Measuring immersion · VR for pain distraction · Pain management

1 Introduction

Virtual Reality (VR) – defined as three-dimensional, stereoscopic, interactive computer graphics – is a computer-generated environment that can simulate physical presence in virtual worlds by engaging human sensory experiences. In health research, VR has been demonstrated as a successful method for mitigating pain in numerous small research studies [7]. The VR simulation, typically designed as a game, helps distract patients from their physical pain and thereby reduces their perceived pain, and in some cases related anxiety. To make the distraction effective, it is thought that the more immersive an experience the patients have, the more distracted they will be from their pain [3, 4]. Moreover, researchers in a study by Hoffman et al. [5] found that the more sophisticated the VR technology, the greater the reported level of pain mitigation. Although the researchers admitted confounding variables, no other comparisons of HMDs for pain distraction had existed. Their assumption is nevertheless important, particularly because Cardboard VR does not merely present lower resolution or a smaller field of view than the Oculus Rift, but achieves VR through a fundamentally different technological approach.

Studies of the use of VR as acute pain distraction initially involved burn injuries among veterans. SnowWorld [1], for example, was a desktop VR simulation developed

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by Hunter Hoffman et al. As the researchers described it, the VE drew patients' attention away from their pain experience and redirected it into the immersive 3D environment. Others, such as Steele et al. [2], used an HMD with a tracking device that controlled the movement of the gun inside 3D game. In a study of two adults undergoing painful dental procedures, Hoffman, Garcia-Palacios, et al. [3] demonstrated that an immersive VE resulted in lower subjective pain ratings during painful dental procedures than watching a movie without VR technology. Carlin et al. [4] also found that immersive VR distraction using SpiderWorld resulted in lower subjective pain ratings in two adolescents undergoing wound care for severe burns, compared to trials in which they played Mario Kart or Wave Race on a Nintendo without VR. More recently, VR combined with biofeedback and mindfulness-based stress reduction (MBSR), proved effective in reducing pain over short periods [6].

However, all of the VR simulations in these examples were based on older desktop platforms and traditional head-mounted displays that required professional technical operations and expensive VR equipment in medical settings. Considering the relative expense of HMDs, these factors together make VR inaccessible for patients' everyday interactions and varying needs. Compared to higher-end VR devices like the Oculus Rift, Google's Cardboard VR, which is cut out of pieces of cardboard and folded into a 3D viewer for smartphones, is significantly less expensive.

Given that VR pain distraction is an effective non-pharmacological analgesic, and Cardboard VR is more accessible because of its affordability and ease of use, it has the potential to act as a means to more accessible pain management which patients will be able to use themselves. Therefore, in order to discover if and to what degree Cardboard viewers may be effective for pain management, it is important to study the level of immersion that the Cardboard is capable of, compared to a traditional HMD. To this end, a research study was designed to compare immersion in three displays: a Cardboard VR, a desktop display, and a "traditional" HMD – an Oculus Rift. Because of its hardware limitations, the Cardboard VR was not expected to perform better in any way than the Oculus Rift. However, the Cardboard was predicted to provide a significantly better sense of immersion than the desktop display, despite its smaller size as a handheld device that relies on a user's smartphone. A comparatively higher level of immersion would suggest that Cardboard has the potential to become a VR self pain-management tool that many chronic pain patients could easily access. In the following sections, the method of measuring immersion, design of the study and results are described. Findings of studies such as the one reported in this paper may prove beneficial in designing more effective and immersive experiences on mobile VR platforms, particularly for patients who need to manage their on-going, long-term pain.

2 Traditional HMDs vs. Cardboard VR

Immersive VR, developed primarily in research labs and popularized by the media in the 1990 s, built upon a number of technologies and approaches to computer graphics that were initially described and tested in Ivan Sutherland's Sword of Damocles. At that time, VR was often described as a version of Star Trek's Holodeck [9] and as a

"consensual hallucination" [10]. However, because the hardware for VR was extremely expensive and limited, and because 3D software and programming VR was so complex, it didn't become commercially viable in the 1990 s. Therefore, VR's popularity was eclipsed by the advent of the worldwide web and a number of other more accessible computational devices, networks and software.

After decades of commercially failed products and unfulfilled promises, Oculus Rift [12] is credited with bringing life back to the VR industry, and people again became excited about immersing themselves in a computer-generated world. Advanced HMDs like Samsung's GrarVR [13] are also now in the VR market. Although these devices are significantly cheaper than HMDs were a few years ago, they possibly are still not inexpensive enough for large-scale mass consumption, since their prices range from $350 to $1,500. The concept of do-it-yourself (DIY) VR, e.g., Google Cardboard VR, aims at closing this gap. Since the number of smartphone consumers are increasing at a geometric rate, the potential for DIY VR devices are tremendous (Fig. 1).

Fig. 1. The Oculus Rift DK2 (top left), Samsung Gear VR (top right), ARCHOS mobile HMD (bottom left), and Do-It-Yourself Cardboard VR (bottom right).

Although the Oculus Rift and Sumsung Gear VR quickly became commercially viable VR displays, other approaches to VR displays have also begun to emerge. One example is Google's Cardboard VR, which is cardboard that the consumer folds up into a viewer and includes plastic lenses. Another example is the plastic VR HMD designed for mobile phones like Archos Mobile VR. These are less expensive than Samsung Gear VR, but still provide a sense of immersion for VR applications.

Cardboard VR is a do-it-yourself (DIY) kit that utilizes a piece of cardboard with a magnet, a rubber band and a couple of pieces of plastic lenses. It has been manufactured by various companies and is priced from $3 to $30, according to material quality and design of the device. Although these cardboard or DIY VR displays are described as inexpensive alternatives to more traditional immersive VR HMDs, they differ from

traditional HMDs in their design, construction materials, optics and reliance on smartphones. Moreover, their methods of interaction are quite different from more traditional VR HMDs since those rely on handheld input devices (joysticks, mice, data-gloves) and desktop or laptop computers.

Despite limitations, the Cardboard-like DYI VR systems have an immense potential of getting a larger consumer base than the traditional HMDs since these are affordable and easy to carry. With a large user base, it has the possibility of becoming a regular device, which promises to give a taste of VR to users in their everyday lives. In cases of pain patients who have acute or chronic pain, and a percentage of who are disabled, expense is a considerable factor that determines whether or not an HMD is viable for home use.

3 Measuring Immersion

Jennett [8] describes immersion as "a lack of awareness of time, a loss of awareness of the real world, involvement and a sense of being in the task environment". Immersion in this sense relates to how present the user feels in the simulated world and how real (or engaging) the virtual environment (VE) seems. Jennett's definition involves two negatives – lack of awareness of time and loss of awareness of real world – along with two positives – involvement and a sense of being in the task environment. Jennett's likert type of survey instrument includes questions such as: "To what extent was your sense of being in the game environment stronger than your sense of being in the real world?"

The Immersive Experience Questionnaire (IEQ) consists of 31 items overall; they can be categorized as questions concerning basic attention (4 questions), temporal dissociation (6 questions), transportation (6 questions), challenge (6 questions), emotional involvement (5 questions) and enjoyment (4 questions). Participants are asked to rate how they felt at the end of the game on a scale of 1 to 5 (1 = not at all and 5 = a lot). The majority of questions are marked positively; while 6 are subjected to negated marking (Q6, Q8, Q9, Q10, Q18, Q20). Immersion scores are computed by summing participants' answers to all 31 questions.

This questionnaire was deemed appropriate since it was developed to measure immersion in video games and this study used a game that was played on three different platforms. Moreover, the questionnaire brings forward insights about attention, dissociation, transportation, challenge, emotional involvement and enjoyment that may be associated with each type of display.

4 Study Details

This section includes the study design, demographics of the participants and a brief description of the game used for this study. In the next section, findings from the study are described, followed by discussion and analysis.

4.1 Study Design and Method

The study was a between-subjects comparison of immersion across three platforms — Cardboard VR, Oculus Rift and a desktop display. There were three groups of participants. Participants in the experimental group used Cardboard VR, control group-1 used the Oculus Rift and control group-2 used the desktop display. Each participant played *Cryoblast* [15], a game designed for pain-management, on his or her respective display type for 10–15 min. Thereafter, the participant filled out the Immersive Experience Questionnaire based on the experience of playing the game on their display.

4.2 Participants

Aged between 22 and 19, thirty participants in total participated in this study. The participants were randomly assigned to one of the three groups—the experimental group (for Cardboard VR), control group-1 (for the Oculus Rift) and control group-2 (for the desktop). All participants had previous experiences of playing games on smartphones.

4.3 Apparatus

For the experimental group, a Google LG Nexus 5 smartphone and a *Dodocase* Virtual Reality Kit 1.2 [11], a standard version 1 of Cardboard VR commercially manufactured and sold by *Dodocase*, was used. An elastic head strap, attachable to the Cardboard viewer with Velcro, was used for mounting it to the head. For the control groups, Oculus Rift's Development Kit 2 (DK2) and an Alienware desktop PC (Alienware_X51_R2) was used. The desktop PC had an Acer GD235 Hz HDMI LCD display. For sound, Koss UR29 Full Size Headphones were used in all the three groups.

4.4 *Cryoblast* – the Game

Cryoblast [15] was developed for pain distraction using Unity3D for VR platforms. In this First Person Shooter (FPS) game, the player needs to shoot at "enemy" characters,

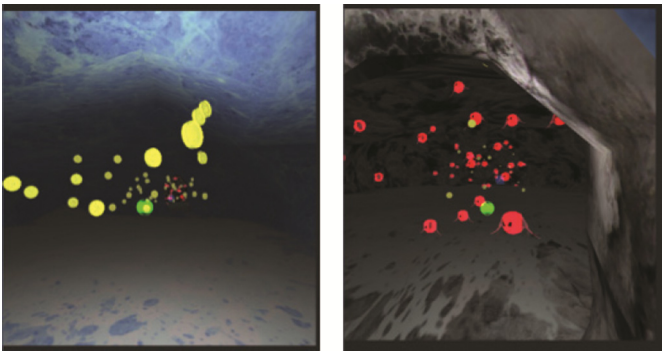

Fig. 2. Screenshots of *Cryoblast* on a smartphone in two different caves

and earn points by collecting as many coins as possible during the journey through six different caves. In *Cryoblast*, the enemies were designed as metaphors for the biological processes of pain, and the ammunition as a metaphor for pain-killing analgesics. The idea is to shoot analgesics at the agitated enemies (dysfunctional glial cells) to calm them down (Fig. 2).

5 Results

Immersion in the different displays was analyzed using one-way between-subjects ANOVA. The analysis revealed a significant effect of immersion for the three different displays at $p<0.05$ [$F(2, 27)=8.7824$, $p=0.0012$]. Post hoc analysis using the Tukey HSD indicated the mean scores for the Oculus Rift ($M = 115.5$, $SD = 18.08$) and the Cardboard VR ($M = 109$, $SD = 21.48$) were significantly different than that of the Desktop display ($M = 85.6$, $SD = 7.51$). However, the Cardboard VR did not significantly differ from the Oculus Rift ($p = 0.6658$) in this study.

5.1 Discussion and Future Studies

The difference in resolution and size of display play an important role with regard to immersive experiences. Compared to the smaller mobile screen used with the Cardboard VR, the Oculus Rift and Desktop PC have larger displays, with resolutions of 960×1080 and 1920×1080 respectively. The LG Nexus 5 also has the same resolution of 1920×1080 as the desktop monitor, but, while the screen size of the monitor is 23.60 inches, the Nexus 5 display is only 4.95 inches. These factors indicate an important finding: the Cardboard, despite having a small screen size, low power and graphics, performs well in delivering an immersive experience. It was quite extraordinary that the mean immersion scores of Cardboard VR ($M=109$) and Oculus Rift ($M=115.5$) were very close. It needs to be mentioned that in order for the game to be optimized for a smartphone, the graphics needed to be tuned down. The Rift is capable of handling very high quality 3D graphics, which *Cryoblast* was not designed for. Therefore, it may be argued that with high quality graphics and better game design, the Rift may have had a significantly higher mean score than the Cardboard VR.

However, the Oculus Rift's handling of high quality graphics has the drawbacks of being a comparatively expensive and heavy HMD, compared to the Cardboard. Moreover, the Cardboard has the potential to become a more common or everyday object with applications for alleviating pain, the efficacy of VR pain distraction may be enhanced since patients would be able to use their VR viewer beyond clinical contexts. Finally, although the design of the game is beyond the scope of this experiment, is very important too because without providing an engaging experience, it is difficult to manage and maintain a user's attention. The game that was used for this study is a prototype. Future developments include building a better, more polished version for smoother and more engaging gameplay. The next phase of this study, clinical testing of the Cardboard VR with chronic pain patients, is the most important since it is planned to determine Cardboard's performance compared to traditional VR systems, which recent studies

suggest is problematic in terms of tolerance [14]. While this, of course, is a small study, it marks the beginning of examining the feasibility of Cardboard VR in the context of pain alleviation for patients who are suffering from long-term chronic pain.

6 Conclusion

Combined with an Android smartphone, Cardboard VR works as a more accessible albeit new kind of virtual reality gaming platform. Though the concept of "DIY VR" is very new, it has the potential to grow a large consumer base because of its low cost. More importantly, it can potentially be used for the large numbers of patients who might use it to alleviate their pain. The simplicity of Cardboard VR, if coupled with a carefully designed pain management game, can ensure the ease of use for chronic pain patients. For this reason, the next phase of the study aims at finding if and how Cardboard VR may be effectively used for pain management. Despite the limitations of the study described in this paper it gives a more solid grounding for the next phase of this study, which will repeat the experiment with acute and chronic pain patients to find out how effective Cardboard VR may be as a method of VR pain distraction. Findings from this study suggests that, for playing a small 3D VR pain-management game, the Cardboard VR can perform significantly well compared to the high end Oculus Rift HMD. The game used in this study was a small prototype and required the participants to play around 10-15 min to complete it. So, for a short time period Cardboard VR is capable of providing an acceptable amount of immersive experience. The performance of the Cardboard depends a lot on the users' smartphones. With the advancement in smartphone technology it can be predicted that Cardboard-like DYI VR systems will be capable of providing better, more engaging and longer immersive experiences in near future.

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