Effectiveness of Mobile Virtual Reality as a Means for Pain Distraction

by

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Abstract

Immersive Virtual Reality (VR) has been shown to work as a non-pharmacological analgesic by enabling cognitive distraction in acute pain patients, including burn patients, dental patients, and chemotherapy patients. However, little research literature exists on the effectiveness of VR for chronic pain patients who suffer from longer-term pain. This thesis aims at contributing to this research gap regarding VR and chronic pain by examining the viability of Cardboard VR – a Mobile VR device. We have conducted two research studies to understand the effectiveness of Cardboard VR in the management of pain. First, we studied how Cardboard affords immersion and its underlying factors compared to a high-end traditional head-mounted display (HMD) – the Oculus Rift DK2, and, the results showed a lot of promise because the difference between the two HMDs was not significant. Next, we conducted a randomized crossover study in a clinical setting with thirty chronic pain patients to understand Cardboard’s effectiveness in pain distraction. We asked the patients to play a VR game on both Cardboard and Oculus Rift. The study results showed that Cardboard VR, coupled with a smartphone, is capable of reducing the patients’ perceived pain intensity significantly compared to the control (pre-VR) condition. However, despite the early findings from the previous studies, Oculus Rift was found to be considerably more effective with pain patients than both the Cardboard and the control condition. The results of this study encourage future research inquiries of Mobile VR in the management of chronic pain. Mobile VR, because of its affordability and ease of use, shows the potential to become an effective tool for pain management for the patients.

Keywords: Virtual reality, Mobile VR, Cardboard, Chronic pain, Pain distraction, VR games
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List of Acronyms

VR  Virtual Reality
HMD  Head-mounted Display
FOV  Field of View
PI   Pain Intensity
Chapter 1.

Introduction

Virtual Reality (VR) is the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using specialized electronic equipment, such as a head-mounted display or a cave with stereoscopic projections and various input devices. These virtual worlds consist of images and sounds and, are affected by the actions of the person who is experiencing it. The virtual realities discussed in this thesis are virtual environments that can be experienced wearing stereoscopic head-mounted displays (HMD) – pieces of hardware that occlude the visual senses from outside stimuli in order to enhance the aspect of immersion.

Researchers have found several advantages for the use of VR in neuroscience. Outlined as the most significant benefit in a Nature review paper, VR can allow naturalistic interactive behaviours to take place while researchers can monitor brain activity via imaging or direct recording [1]. In a controlled environment, it allows researchers to address many questions that would simply not be possible otherwise. In addition to the research in brain functions, VR has been demonstrated to be effective in therapeutic applications for psychiatric disorders, pain mitigation, neurorehabilitation, etc. Over the last decade some significant successes have been claimed for the use of immersive virtual reality (IVR) in the treatment of acute pain as an adjunct method for pain distraction [2]–[6].

VR is thought to be an especially effective form of pain distraction [7], although the exact mechanism is unclear. While pain-related virtual environments have built upon pain distraction, a handful of researchers has focused on a more difficult challenge: VR for long-term chronic pain. Because the nature of chronic pain is complex,
pharmacological analgesics are often insufficient or unsustainable as an ideal long-term treatment. Some research studies suggest that chronic pain patients can benefit from VR applications [8]. CP patients, although requiring long-term pain reduction strategies, also suffer from shorter-term spikes in pain intensity. However, it is not yet known if the analgesic effects of VR persist beyond the VR sessions. However, a case study [9], exploring chronic pain reports of a 36-year-old woman with a 5-year history of C4 tetraplegia and upper extremity neuropathic pain, who was exposed to standard hypnosis sessions and 40-minute IVR-augmented hypnosis sessions. This is a very different form of treatment to those explored in this thesis, but the researchers reported increased pain reduction (for up to 12h) following the IVR-augmented hypnotherapy sessions.

1.1. What is Chronic Pain?

Pain is commonly differentiated as either chronic or acute. A type of pain most individuals are familiar with is acute pain, which manifests as a temporary pain experience often attributed to observable injury on the body, such as a scrape on the skin. In most cases, the body responds to resolving the injury relatively quickly, healing the affected area and dissipating the pain experience that marks the injury over time.

Chronic pain, in contrast, is a long-term pain that may not necessarily be associated with a physically traumatic event to the body. Chronic pain is defined as pain that lasts more than 6 months and persists beyond the healing of its putative cause [10]. Chronic pain persists well beyond the time expected for an injury to heal and may continue to exist for the course of a lifetime [11]. Chronic pain can manifest as a result of an injury to the body, or it can reveal without an apparent cause or trigger. A common type of chronic pain is neuropathic pain, which can be understood as “pain arising as a direct consequence of a lesion or disease affecting the somatosensory system” [12].

Chronic pain can also be influenced by psychosocial factors, which interact with brain processes and patient perception of pain [10]. While pain fades with the injury in acute pain patients, chronic pain patients often find their pain experiences continuing without reason or clear purpose. Due to the often debilitating and unrelenting nature of
chronic pain, those affected can suffer from further decreases in social interaction and psychological health [13]. For example, there is a statistical association between the presence of CP and depression [14]. The doctors commonly prescribe opioids for chronic pain, but opioids pose a notable risk of dependency or addiction, even in patients considered to be low-risk [15]. More and more opioids are required by the patients over the time to manage their pain. Craving opioids in this manner negatively impacts patient mood, invoking urges for more medication and pre-occupying patients with thoughts of the next dose [16].

One in five Canadians suffer from chronic pain [17], [18]. According to Statistics Canada, approximately 5.6 million Canadians suffered from chronic pain in 2011/2012 [13]. An estimated 20% of people in North America and 15-20% in industrialized nations [19] suffer from chronic pain. As a serious health problem, chronic pain is under-recognized by policymakers [20] and is inadequately managed by the healthcare system. Thus, any form of help virtual reality treatment for this demographic would be beneficial for them.

1.2. Traditional and Mobile VRs

The studies in this thesis compare traditional and mobile VR systems. By traditional HMD we mean the high-tech VR viewers, which have large fields-of-view (FOV), high resolution and needs to be connected to a computer to run the VR simulation. And, by mobile VR, we refer to systems that use a smartphone to run the VR simulation. For most of the current mobile VR systems, the smartphone needs to be placed inside a VR viewer. The mobile VR mostly uses the smartphones’ screen to show the VR. Compared to traditional HMDs, smartphone-based mobile VRs have lower fields-of-view, lower resolution, and lower computational power.

1.2.1. Oculus Rift

The Traditional VR system used for the studies in this thesis was an Oculus Rift Development-Kit 2 (DK2). The Oculus Rift is a VR headset or head-mounted display (HMD) developed and manufactured by Oculus VR [21]. Oculus first started their
campaign in 2012 to fund the Rift’s development. In 2012, the tech giant Facebook purchased the company for two billion dollars. The Rift has gone through various pre-production models. Two of these models are DK1, released in 2013 and DK2, released in 2014. Previously, in Pain Studies Lab of Simon Fraser University, we conducted studies using the Rift DK1. Very recently in 2016 Oculus has released their consumer version of the Rift.

The DK2 uses a low-persistence OLED display to eliminate motion blur and judder. Also, it uses low-latency positional tracking for head movement. It has 960x1080 per eye resolution with up to 75Hz refresh rate and 100° FOV. The HMD weighs around 440 grams. The newly released consumer version has 1080x1200 resolution per eye with a 90Hz refresh rate and 110° FOV. The Rift currently costs 600 USD. Along with its 3D touch input devices it costs 798 USD.

![Figure 1.1 The Oculus Rift consumer version (left), Oculus Rift DK2 (right).](image)

Since the popularity of Oculus Rift has risen, the world has seen a number of other traditional VR systems. PlayStation VE, HTC Vive, Razer OSVR, Sega VR are some of these systems. Most of these VR systems are primarily built for gaming.

1.2.2. Cardboard VR

The Cardboard is a mobile VR platform developed by Google. Named for its fold-out cardboard viewer, the platform is intended as a low-cost system to encourage interest
and development in VR applications [22]. Google published the building specifications of this affordable VR viewer for everyone’s use [23]. Users can either build their own viewer from simple, low-cost components using the specifications or purchase a pre-manufactured one. A smartphone needs to be inserted at the back of the viewer. Pre-manufactured viewers were only available from third-party vendors until February 2016, when Google began selling their own through the Google Store. There are two versions of Cardboard. The version 1 has a smaller viewer that worked with smaller smartphone screens (up to around 5 inches). In 2015, version 2 was released; it can hold bigger smartphones with up to 6-inch displays. Nowadays the Cardboard is available in various shapes and sizes. Different third party manufacturers have built their Cardboards which are available for the consumers [24]. The very basic kind of Cardboard that Google brought out first cost 5 USD. The newly modified versions, however, are available for between 5-50 USD.

This thesis focuses on two research studies. For the first study, we used the version 1 Cardboard with a Nexus 5 smartphone. And, for the second study, we used the version 2 Cardboard with a Samsung Galaxy Note 4.

Figure 1.2. Google Cardboard VR viewer

There are other smartphone-based VR systems available in the market. The most popular two are Samsung Gear VR [25] and Google’s Daydream View [26]. The Daydream is the latest of them all. It comes with its own controller and only works with
some of the latest Android smartphones, e.g., Pixel and Moto Z. However, these two mobile VR systems are far costlier than the Cardboard.

Evidence for the use of VR for different forms of pain mitigation other than acute pain is sparse. Moreover, this handful of small research studies used the high-end, expensive head-mounted displays (HMD). There is very little or no evidence of using a more affordable Mobile VR yet since it is a very new form of technology that started gaining popularity in 2015. This thesis aims at contributing to this research gap regarding the use of mobile VR in chronic pain. The main contributions of this work can be summarized as follows.

• To best of our knowledge, this is the first research that examines the effectiveness of a Mobile VR device for pain distraction among Chronic Pain patients. The study described in Chapter 4 explores the usability of Cardboard VR, a very affordable and basic mobile VR viewer, in pain management.

• Aside from mobile VR’s affordance in providing the analgesic effects, this research explores and conveys critical insight regarding some of its fundamental aspects (e.g., immersion, presence, interactivity), which are believed to be powerful factors in providing pain distraction.

In the next chapters, we described the background of our research as well as the related literature review from the domains of Virtual Reality, Pain management, Chronic Pain, Game Immersion and Immersion frameworks. Next, we described the two studies that helped us answer the research enquires regarding Mobile VR’s effectiveness in Chronic Pain patients for pain distraction. To examine the ‘immersion’ and ‘presence’ in Mobile VR we first conducted a study with thirty healthy participants (Chapter 3) and found how Cardboard VR provides significant levels of immersion for playing a VR game. Next, we described a within subjects study with thirty chronic pain patients (Chapter 4), and found out that perceived pain levels can be significantly reduced during the gameplay session on Cardboard VR. Finally, we summarized our findings and concluded with the possible future works (Chapter 5) related to Mobile VR and pain management.
Chapter 2.

Literature Review

The research studies described in this thesis drew inspiration from multiple disciplines—health science, game design, user experience, immersion frameworks and cognitive psychology.

2.1. Health and Cognitive Sciences

2.1.1. VR as an Adjunct Therapy in Acute Pain

In health research, VR has been demonstrated as a successful method for mitigating pain in numerous small research studies. 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.

Studies of the use of VR as acute pain distraction initially involved burn injuries among veterans. *SnowWorld* [2], for example, was a desktop VR simulation developed by Hunter Hoffman. As the researchers described it, the virtual environment (VE) drew patients’ attention away from their pain experience and redirected it into the immersive 3D environment. Burn patients reported 35–50% reductions in procedural pain while in immersed in this VE, and fMRI brain scans showed associated reductions in pain-related brain activity during VR. The researchers also reported that VR distraction appeared to be most effective for patients with the highest pain intensity levels.

Several other research studies support the effectiveness of VR in alleviating perceived pain in burn patients [4], [27], [28]. In a randomized control trial, a virtual reality game was added to the procedural care schedule of children with acute burn
injuries. The introduction of VR to their normally prescribed pharmacological analgesics decreased the average of the children’s self-reported *Faces Scale* pain ratings from 4.1 (SD 2.9) to 1.3 (SD 1.8) [29]. Hoffman & Carrougher’s study with twelve burn patients undergoing physical therapy used VR as a pain distraction tool. They found that VR in conjunction with physical therapy enabled ten of the twelve participants to demonstrate limb motion greater than or equal to the control condition; pain ratings were also significantly lower during the VR condition than the control condition in all measurements. A different randomized within-subjects study of fifty-four subjects examined the effects of virtual reality on hospitalized pediatric burn patients undergoing painful physical therapy and found significant decreases (27-44%) in pain ratings during virtual reality treatment [6]. They also reported that the analgesic effect was maintained with repeated usage of virtual reality therapy over multiple sessions.

Studies with the burn patients primarily encompass the small amount of literature that is available. However, other types of acute pain have also been examined. Hoffman et al. reported reduction in pain levels for patients undergoing dental procedures like scaling and root planning [3].

VR was also reported to be effective in cancer pain patients. Wint examined the feasibility of using VR glasses on thirty children receiving lumbar punctures during their cancer treatments to distract them from the painful procedures [30]. Although not statistically significant, Wint found evidence of analgesic effect in this study. Vidyarthi indicated a key limitation of this study—the glasses used for this experiment. The authors refer to them as virtual reality glasses that “refocus [patient] attention on another event”; the glasses are meant for three-dimensional viewing of a 3D television screen. Pairing them with a television screen may not provide an adequate field-of-view for an immersive virtual reality experience [31]. Also, sensory occlusion was not well considered, which could explain their poor statistical results in comparison to other virtual reality researchers who opted for head-mounted displays.
2.1.2. Anxiety and Stress Reduction

A few studies examined the effect of VR on stress reduction. A study consisting of sixty-seven postoperative patients who underwent cardiac surgeries reported that 88% of the patients had a decreased level in perceived pain, while 37.3% experienced lower heart rates, 52.2% experienced reduced arterial pressure, and 64% experienced reduced respiratory rates [32]. The authors concluded that VR significantly reduced patients' stress and pain intensity. VR has been shown to improve upon experiences of anxiety and discomfort in other studies as well: another study concerned with the experiences of child chemotherapy patients reported that the children who participated in VR gaming during their treatment processes had their distress symptoms associated with treatment significantly reduced [33]. This distress reduction did not extend outside of the VR, but was maintained strongly while the children were at play in VR.

2.1.3. VR and Chronic Pain

VR has been known to encourage meditative practices in pain patients to reduce pain intensity [34]. The Virtual Meditative Walk (VMW), developed at Simon Fraser University features a virtual environment that enabled chronic pain patients to walk through a virtual forest while listening to a mindfulness-based stress reduction (MBSR) instructional track. The patients wore galvanic skin response sensors, and the virtual environment responded to their biofeedback by creating fog in the forest when the participant was not relaxed. Comparing the VMW experience to a control condition (MBSR only), they found patient pain levels significantly reduced in the experimental condition. The benefit of such a strategy is that the VR teaches the patient MBSR over time, providing visual feedback in response to the patient's current physical state in real-time. Moreover, MBSR is a skill that is taught in this VE, but once learned, should be useful outside of VR.

Chronic pain patients require long-term pain reduction and management strategies. However, sometimes they suffer from short-term spikes in pain intensity [35], during which they may also benefit from non-pharmacological treatment practices. Pain distraction strategies that work for acute pain patients can be beneficial for the chronic
pain patients during these spikes. *Mobius Floe* is an immersive VR game that uses the pain distraction strategy and is designed for acute and chronic pain patients [5], [36].

In a study using a relaxing virtual environment, forty chronic pain patients experienced a VR in attempt to reduce their pain intensities. The researchers found that patients’ reported pain levels were significantly reduced, and that their heart rates had slowed, and their body temperatures increased, which they argued was physiological evidence that patients were more relaxed [37]. Unfortunately, there is insufficient literature to show that chronic pain patients can benefit from immersive virtual reality applications in similar ways as their acute pain counterparts. Despite documented instances of VR’s success at pain reduction, there are still too few research papers available to confirm VR’s effectiveness on chronic pain relief. This thesis contributes to this research gap to some extent.

**Mobile VR in Treatment of Chronic Pain**

Evidence for the use of immersive VR for chronic pain management is sparse [38]. When it is about Mobile VR there is very little or no evidence. A search in the ACM Digital Library with the exact keywords “Virtual Reality” AND “Chronic Pain” gave only three results and two of those are researches of the Pain Studies Lab of SIAT. A similar search on PubMed brought thirty-three results. When the keyword “Mobile” is included, there is only one result, which is a study conducted by Wiederhold et. al. [39]; we will talk about this paper later in this section. Since Mobile VR is a new form of technology compared to the traditional high-tech HMDs, there is a huge research gap encompassing the effectiveness of Mobile VR in treatment of pain. This thesis primarily targets this research gap. In that sense, the second study discussed in Chapter 4 is a novel research experiment, which will mark the beginning of similar researches.

Conducted in 2009, one study reported the use of VR through mobile phones to reduce anxiety in patients during surgery [32]. The researchers used a Nokia N95 that fed video to an external HMD worn by the patients. A significant reduction of anxiety was reported after 45 minutes of operation in the VR group. However, since this research was conducted, the Mobile VR technology has changed fundamentally. Mobile VR is now more widely accessible and is capable of providing a lot higher resolutions.
Wiederhold et al. examined the use of mobile devices as pain management tools in a study with thirty-one chronic pain patients. They compared a traditional HMD and mobile phone displays and took patients’ self-reported pain intensities and heart rates for analysis. Their study demonstrated that significant pain and anxiety reduction could be achieved using the smaller screen of a mobile device. However, this report did not elaborate on what kind of mobile device or virtual environment was used for the study. It is quite unclear whether they used any mobile VR viewer with the mobile phone. However, the main study of this thesis took inspiration from this research.

2.2. Immersion

It is important to understand what enables the virtual environments to elicit or cause the analgesic effects. Again, there is a lack of scientific literature to accurately indicate the factors of VR that play roles in distracting the patients from perceived pain. Hoffman conducted a study which suggested embodied immersion or feeling a sense of ‘presence’ within the virtual environment could be a factor in reduced pain intensity by comparing pain experience in a high-tech immersive rig to a low-tech immersive setup. All participants attempted to immerse themselves in the same virtual reality, but some used the low-tech rig, which was a pair of stereoscopic VR glasses without a player controller or audio output, while others used the high-tech rig, which consisted of a head-mounted display with a head-tracking camera, audio output, and a player controller.

Hoffman asserted that the combination of a high-resolution display, visual and audible occlusion, the head-tracking camera as well as player agency contributed to high degree of virtual presence reported by the players in the high-tech immersive setup condition. The limitation of this study, however, is that it is not possible to point to a specific independent variable in the high-tech setup that contributed to the digital presence, as there were too many independent variables being tested simultaneously between the high-tech and low-tech conditions. Rather, we know that the combination of the high-tech variables led to higher presence over the combination of low-tech variables.
‘Presence’ is another term that is often discussed in VR-related literature along with immersion. When considering the technical components of virtual reality systems, it helps to distinguish between the concepts of immersion and presence. Immersion, sometimes called sensorimotor immersion, refers to the degree of physical stimulation impinging on the sensory systems and the sensitivity of the system to motor inputs. The level of immersion is determined by the number and range of sensory and motor channels connected to the virtual environment, and the extent and fidelity of sensory stimulation and responsiveness to motor inputs (for example, head and body movement, and hand gestures to make commands) [1]. The psychological product of technological immersion is presence — the psychological sensation of being in the virtual environment instead of the physical environment and interacting with media. Presence inside a VE is believed to be one of the key components of an immersive experience. The audio and visual display qualities and the interactivity are also important in this regard. Together, these media layers enable a user to gain a sense of immersion inside the 3D virtual world by presenting the illusion of a 3D scene.

The studies discussed in this thesis compare a high-tech traditional HMD to a low-tech Mobile VR setup. While the traditional HMD takes advantage of the computational power of a desktop computer, the Mobile VR simply relies on the power available on a smartphone. Based on Hoffman’s study it can be assumed that the low-tech Mobile VR will resolve in significantly less immersion compared to the traditional HMD. However, as discussed in details of our studies (Chapter 4 and 5), the Mobile VR actually is capable of providing an effective immersive experience compared to a traditional HMD.

Scholars from different disciplines have tried to define immersion in ways that are suitable to the discipline. While the core essence of immersion is quite similar, there are some differences. Broadly, definitions of immersion tend to emphasize either a sensory or an imaginative perspective. Mangen [41] classifies these as technological and phenomenological immersion respectively. The former is “the kind of immersion in a technologically enhanced environment that we typically experience in different kinds of virtual reality installations, computer simulations and while playing computer games. This kind of immersion facilitates a sense of being immersed in a fictional, virtual world, which
is to a large extent created and sustained by the technological features and material devices involved in its display." The latter is "largely the product of our own mental, cognitive abilities to create that fictive, virtual (in the figurative sense) world from the symbolic representations—the text, whether purely linguistic or multi-modal, digital or print ...”. To these two perspectives, video game theorists introduce a third—challenge. We are interested in the immersion in video-games-related theories because the virtual environments used for our studies are VR games.

Immersion in video games is widely discussed in literature, and is a very important part of this chapter since we have used two VR games for our studies. Within the context of video games, immersion is a critical affective element necessary to ensure that the players will be drawn into the game-space and decide to stay there.

Ermi and Mäyrä’s analysis of immersion in gameplay experience [42] can be considered valid research in this context since it has been cited over 600 times in different disciplines. They have proposed three terms to describe three variations of immersion, which can co-exist or manifest individually from a design perspective. These three variations are – Sensory, Imaginative and Challenge. They defined immersion as “the sensation of being surrounded by a completely other reality... that takes over all of our attention, our whole perceptual apparatus”. Immersion, they say, means becoming physically or virtually part of the experience itself. They have also pointed out in literature that it is often taken for granted that a bigger screen and a better quality of audio equal greater immersion [43]. They also mention it is likely that the audio-visual implementation of the game has something to do with immersive experiences, but it is by no means the only or even the most significant factor. It is important to understand these three terms in a little more depth since we have used these terms to interpret some of the findings in our studies.

2.2.1. Challenge-based Immersion

Challenge-based immersion has a definition which manifests similarly to Csikszentmihalyi’s “flow” framework [44]. The challenge-based immersion encompasses the positive feelings that a gamer experiences when they are presented with a coherent
challenge. The gamer is able to apply their skills to work toward victory and obtains it after some degree of struggle.

Such feelings of victory and satisfaction are well documented in other literary instances, such as Lazzaro’s fun keys [45]. Her definition of ‘hard fun’ manifests as the direct result of challenge-based activities. However, not all challenge-based games produce ‘fun’ in players in a conventional sense. Many games do not necessarily translate directly to a ‘fun’ experience, but are intentionally designed as stressful experiences. For example, in Papers, Please, a popular indie game, the player becomes an immigration officer on the border of a fictional country [46]. In games such as Outlast or Amnesia: The Dark Descent players intentionally subject themselves to extremely frightening, anxiety-laden horror-based situations [47].

2.2.2. Imaginative Immersion

Imaginative Immersion encompasses a wide breadth of experiences all pertaining to the engagement of the creative mind. An obvious example would be situating the player in a fantasy setting. Such a setting can allow them to experience the virtual reality through their avatar, including interactions with fictional characters and with the environment. Story-based narratives, beautiful landscapes or mysterious environments are explored in different types of games to enhance the imaginative immersion.

2.2.3. Sensory Immersion

It would not be easy to convey the narrative situations of challenge without some sort of stimuli to convey this information. Sensory immersion often plays an important part in immersing gamers in contemporary virtual spaces. All parts of the game, which stimulate the physical senses of sight, sound, and touch, are generally encompassed in the discussion of sensory immersion within this context. For example, a large HD television screen, coupled with comfortable seating arrangement and stereo sound could be considered an ideal immersive sensory rig within the home. The physical setup
surrounding the player plays a key role in not only providing immersive sensory stimuli but also occluding the distractions of the outside world [48].

Going even further from these three dimensions, Thon argues for four dimensions of immersion—spatial, ludic, narrative and social [49]. Spatial structure refers to the game space and objects therein. Ludic structure refers to the rules of the game as well as their effects. The level of narrative structure refers to the stories that games present using a variety of narrative techniques. A social structure refers to the communicative devices that allow for communication and social interaction between the players and the social space that is thereby constituted.

Steuer emphasizes vividness and interactivity as the two basic elements that determine how immersed we can become in a virtual environment [50]. Vividness, he says, is a measure of the completeness of the environment presented. Interactivity is the extent to which users can participate in modifying the form and content of a mediated environment.

There seems to be a consensus among video game scholars and developers that imagination and a good game experience are important for immersion. There is less agreement among them about the importance of sensory dimension. We agree with Emri and Mäyrä who attributed the sensory dimension equal status with imagination and challenge. However, while looking for a working definition of immersion that is more practical and suitable for our studies, Jennett’s definition seems to be a good description of game-based immersion. Jennett defines 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” [51]. Therefore, we have used the Immersive Experience Questionnaire (IEQ) developed by Jennett in one of our studies (Chapter 3).

In order to investigate the immersion in Mobile VR and a traditional HMD, the Oculus Rift DK2, we conducted a study with healthy participants.
Chapter 3.

Study 1: Comparison of Immersion

We conducted a study [52] with healthy adult participants to compare the immersive experiences between a Mobile VR viewer and a traditional head-mounted display. We used Cardboard VR with a smartphone for the Mobile VR group and the Oculus Rift DK2 as a traditional HMD. The participants played a VR game designed for pain management on these devices. Jennett’s Immersive Experience Questionnaire (IEQ) was used to take the responses after playing the game [51].

3.1. Measuring Immersion

Jennett 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 IEQ consists of 31 items overall (Appendix C); these questions are categorized into five factors—Challenge (4 questions), Control (5 questions), Real World Dissociation (7 questions), Emotional Involvement (6 questions) and Cognitive Involvement (9 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 six are subjected to negated marking (Q6, Q8, Q9, Q10, Q18,
Q20). Summation of a participant’s answers to all 31 questions gives the total immersion score. In the IEQ, the highest immersion score can be 131.

This questionnaire was deemed appropriate since it was developed to measure immersion in video games and we used a VR game in this study for our participants to play on three different platforms. It also takes into account the users’ sense of presence for measuring immersion. Furthermore, the questionnaire brings forward insights about underlying factors of immersion, e.g., challenge, control, real world dissociation, emotional involvement and cognitive involvement.

3.2. Study Design and Method

The study was a between-subjects comparison of immersion across three platforms—Cardboard VR, Oculus Rift, and a Desktop display. We assigned the two VR displays to the experimental groups and the desktop computer was the non-VR condition for the control group. The Desktop condition serves as the baseline. Each participant played Cryoblast [53], a game designed for pain-management, on their respective display type for 10 minutes. After that, the participant filled out the IEQ based on the experience of playing the game on their display. We conducted the study in the Pain Studies Lab of SIAT.

3.2.1. Participants

Aged between 22-29, thirty participants in total participated in this study. The participants were randomly assigned to one of the three groups. Each group had 10 participants. All participants had previous experiences of playing games on smartphones. Participants who considered themselves to be especially sensitive to nausea or motion sickness were not eligible for the study. There were no dropouts or missing data for this study.
3.2.2. **Apparatus**

For the Cardboard group, a Google LG Nexus 5 smartphone (4.95” screen, 1080x1920 pixels) and a *Dodocase Virtual Reality Kit 1.2* – 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 Oculus Rift group, we used Oculus Rift’s Development Kit 2 (DK2), which was plugged into an Alienware desktop PC (Alienware_X51_R2). We used the same PC for our control group. The desktop PC had an Acer 23-inch HDMI LCD display. For sound, Koss UR29 full-size headphones were used for all the three groups.

![Figure 3.1 Screenshot from Cryoblast](image)

*Figure 3.1 Screenshot from Cryoblast*

*Note: Notice the simple textures on the cave walls and the floor. The enemy characters appear in red. They turn green as the player shoots them.*

3.2.3. **Cryoblast—the VR game**

We developed *Cryoblast* for pain distraction using Unity3D for VR platforms. In this First Person Shooter (FPS) game, the player needs to shoot at “enemy” characters, and earn points by collecting as many coins as possible during the journey through six different caves.
In Cryoblast, the enemies represented metaphors for the biological processes of pain, and the ammunition did so for pain-killing analgesics. The idea is to shoot analgesics at the agitated enemies (dysfunctional glial cells) to calm them down. This game was originally designed and optimized for mobile VR displays. Later, for the purpose of this study, we modified it to be played across the three displays.

3.3. Results

Immersion in the different displays was analyzed using one-way between-subjects ANOVA. Figure 4.2 shows the mean immersion scores for the three displays. 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].

Figure 3.2. Mean Immersion Scores for the three groups.
Note: Error bars depict 95% confidence intervals.

Posthoc analysis (Table 3.1) 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 control group’s 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. Which means, the Cardboard VR, despite having the smallest display screen, was capable of providing a significant immersive experience for the participants compared to the high-end Oculus Rift DK2.

**Table 3.1. Comparisons of All Pairs using Tukey HSD**

<table>
<thead>
<tr>
<th>Level</th>
<th>- Level</th>
<th>Difference</th>
<th>Std Err Dif</th>
<th>Lower CL</th>
<th>Upper CL</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oculus Rift</td>
<td>Desktop</td>
<td>29.90000</td>
<td>7.504517</td>
<td>11.2932</td>
<td>48.50683</td>
<td>0.0013*</td>
</tr>
<tr>
<td>Cardboard</td>
<td>Desktop</td>
<td>23.40000</td>
<td>7.504517</td>
<td>4.7932</td>
<td>42.00683</td>
<td>0.0116*</td>
</tr>
<tr>
<td>Oculus Rift</td>
<td>Cardboard</td>
<td>6.50000</td>
<td>7.504517</td>
<td>-12.1068</td>
<td>25.10683</td>
<td>0.6658</td>
</tr>
</tbody>
</table>

As mentioned in section 4.1, the IEQ measures five underlying factors of immersion—challenge, control, real world dissociation, emotional involvement and cognitive involvement. We analyzed the data further to better understand the effects of these five factors for Oculus Rift and Cardboard VR. For this analysis, there is one independent variable (Display Type–Oculus Rift, Cardboard, Desktop) and five dependent variables (challenge, control, real world dissociation, emotional involvement and cognitive involvement). A one-way MANOVA was performed on the dataset in SPSS. The analysis revealed that there were significant effects of the five factors among the three displays, F(5,23) = 313.604, p<0.05, Wilk’s Lambda= 0.014.

The differences in these five factors are more easily understandable if we look at the mean scores for the two HMDs. Figure 4.3 shows differences in the Mean scores of the five factors of immersion for the two HMDs. Overall, Oculus Rift dominates the scores over Cardboard. However, the scores for challenge and cognitive involvement did not differ much. The scores for control was almost equal; which makes sense because both of the groups had only one way to interact in the game—moving their heads to target and shoot the enemy characters. The scores mostly differed for emotional involvement and real world dissociation. Since the Oculus Rift has significantly higher resolution and better occlusion than the Cardboard, the participants may have felt more involved and present in the virtual environment.
Figure 3.3. Comparison of the five factors of Immersion for Oculus Rift and Cardboard VR

Table 3.2 Mean values for five factors of Immersion

<table>
<thead>
<tr>
<th>Factor</th>
<th>Oculus Rift</th>
<th>Cardboard VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenge</td>
<td>15.100000</td>
<td>13.900000</td>
</tr>
<tr>
<td>Cognitive Involvement</td>
<td>36.200000</td>
<td>34.600000</td>
</tr>
<tr>
<td>Control</td>
<td>18.000000</td>
<td>18.300000</td>
</tr>
<tr>
<td>Emotional involvement</td>
<td>20.400000</td>
<td>18.100000</td>
</tr>
<tr>
<td>Real World Dissociation</td>
<td>27.400000</td>
<td>24.700000</td>
</tr>
</tbody>
</table>

3.4. Limitations

One of the limitations of this study was the virtual environment. Cryoblast has a very simple cave environment (Figure 3.1). It is possible that the caves did not allow the users to feel that they are in a vast space. Apart from moving the gaze pointer to shoot in different directions, the player was not required to do anything else. The shooting was a continuous process, and the player did not have any control over it. Moreover, the players did not see their scores on the screen; they found their score at the end of the
game. Possibly, this made the game less challenging and less engaging, which might have affected the overall immersion scores for both the HMDs.

Another limitation was the participant demographic. Most of the participants were young adult students (in their 20s) in SIAT (the School of Interactive Arts & Technology). These healthy participants were asked to play a game, which we built on the principles of pain distraction. One issue that has arisen is the degree of activity and challenge in VR games for chronic pain patients. Based on a number of studies conducted in the Pain Studies Lab over the past two years, it appears that CP patients have less capacity for very active and challenging VR games, perhaps because of the pain itself, or because of the sequelae associated with CP, such as cognitive impairment and anxiety. Therefore, having actual pain patients instead of healthy participants would have been the best solution. However, this study was meant to be a baseline for the next study described in Chapter 5, which involves actual pain patients.

3.5. Discussion

One of the key observations of this study was that the Cardboard VR was very uncomfortable to wear. Some of the participants remarked that the edges of the viewer put pressure on the face and nose, and therefore, they had to keep adjusting it throughout their sessions. Adjusting the HMD multiple times may have hampered their sense of presence a great deal inside the VE. This inconvenience could have contributed to the low scores for real world dissociation (Figure 4.3) in the Cardboard group.

Most of the participants in the study were familiar with VR and used a traditional HMD before. However, the majority were not familiar with the mobile VR. Therefore, the mobile VR experience was new for them, which might have had a positive effect in the Cardboard group. Some of the participants specifically mentioned that they liked the simplicity of the Cardboard and they would like to own one. The Oculus Rift had a profound effect on the few participants who never tried a VR game before. These participants had their first taste of VR.
The difference in the resolution and size of the display also might have played important roles with regard to immersive experiences. Compared to the smaller mobile screen used with the Cardboard VR, the Oculus Rift and the Desktop PC have larger displays, with resolutions of 960x1080 and 1920x1080 pixels respectively. The LG Nexus 5 smartphone also has the same resolution of 1920x1080 as the desktop monitor. However, while the screen size of the monitor is 23.60 inches, the Nexus 5 display is only 4.95 inches. These factors indicate the Cardboard, despite having a small screen size, low power, and graphics performs well in delivering an immersive experience.

Previous studies reported that users find immersive VR different from a desktop application. Studies such as those confirm that users behave and feel differently in immersive VEs. So, before conducting the study we assumed that the Cardboard would have significantly better immersion ratings than the control condition (Desktop) since it is a VR device and it relies on higher-fidelity sensory stimuli than the desktop. However, we also expected that the difference between Oculus Rift and Cardboard would be significant. It was quite surprising that the mean immersion scores of Cardboard VR (M=109, SD=29.48) and Oculus Rift (M=115.5, SD=18.08) were very close; in the analysis, the difference was not significant.

These results can be interpreted in different ways. One way of explaining the results can be the proposed framework of media immersion proposed by Vidyarthi [54]. In Figure 3.4 we can see part of his proposed framework – the yellow patches show the alternate realities created by two media—‘boring VR’ and ‘compelling book’. Its thickness represents a medium's ability to generate immersion in spectators (the smily face at the center of the black circle), and the amount of circumference occupied by a medium represents its proportion of sensory input. Thus, a ‘boring VR’ has a higher sensory encapsulation, while the book is able to provide more immersion but does not saturate the senses.
Cryoblast, the VR game used in this study can be exemplified as a ‘boring VR’ and therefore, capable of providing a ‘shallow’ immersion. If we recall from the literature reviews (Chapter 2), the video games scholars roughly agreed on the three variations of immersion: Sensory, Imaginative, Challenge. The sensory immersion in Cryoblast is less substantial than the game we used for the next study because it has monotonous graphics of the claustrophobia-inducing small caves. The sound is also monotonous throughout the gameplay and probably never evoked a sense of challenge. Overall the impact of visual stimuli is very little. Moreover, the element that evokes presence inside a VE is less obvious. If the users could see part of the body or a ship or vehicle they are connected to then, the ‘presence’ may have been more significant. It is possible that when the participants experienced this boring VR through different HMDs they did not find much difference, at least compared to the kind of AAA video games that this demographic is more familiar with.

Metaphorically, we can also think about it this way: the experience of watching a boring documentary on an old small phone versus a widescreen HD TV is likely to be similar because the show is boring anyway. However, if it is an exciting movie the user is likely to enjoy the experience more on the HD TV.
Therefore, in our next study, we opted for a more challenging and compelling VR game, which is likely to provide a deeper sense of immersion, to see if this explanation may be true. The comparison in immersion between different VEs is discussed more in detail in the next study in Chapter 4.

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, and *Cryoblast* was not designed for that. Therefore, it may be argued that with high-quality graphics and better game design, the Rift may have had a significantly higher mean immersion score than the Cardboard VR.

However, the Oculus Rift’s handling of high quality graphics has the drawbacks of being a comparatively expensive and cumbersome HMD, compared to the Cardboard. Moreover, the Cardboard has the potential to become a more common or everyday object with applications for alleviating pain because it is significantly less expensive and integrates a user’s own smartphone. For those reasons, it may enhance the efficacy of VR pain distraction since patients would be able to use their VR viewer beyond clinical contexts. Finally, the design of the game is crucial too because without providing an engaging experience, it is hard to manage and maintain a user’s attention. We used a simple prototype of a pain distraction game for this study. The next phase of this study, testing the Cardboard VR with chronic pain patients in a clinical setting, is the most important since it is planned to determine Cardboard’s performance compared to a traditional VR system with the demographic for which it is designed. While this, of course, is a small study, it marks the beginning of examining the feasibility of Cardboard and mobile VR in the context of pain alleviation for patients who are suffering from long-term chronic pain.
Chapter 4.

Study 2: Effect of Mobile VR on Chronic Pain in Clinical Settings

The baseline study of measuring immersion [52] in a mobile VR platform clearly indicated that Cardboard VR could potentially be useful in pain distraction since it is capable of providing an effective immersive experience. Although the immersion ratings in Cardboard were not as high as in an Oculus Rift, it was significantly greater than the control condition. Therefore, we designed another study in a clinical setting with actual chronic pain patients to find out how effective the Cardboard can be for pain distraction.

The research question for this study was – Can perceived pain be significantly reduced in Chronic Pain patients who engage in a VR game on a Mobile VR platform compared to a traditional HMD? This study, like the previous one, was a comparative study between two HMDs – the Cardboard VR and the Oculus Rift. However, we did not use the same apparatus and VE as the previous study. We chose, InMind VR, a more engaging VR game that can be played both on Cardboard and Oculus Rift. Moreover, we used the 2\textsuperscript{nd} generation Cardboard and a phone with a higher resolution and bigger screen. We described the apparatus more in detail in section 4.1.2.

4.1. Study Design and Method

4.1.1. Participants

Thirty adult participants (17 Males, 13 Females) of varying ages (23-68) were recruited in a pain clinic in Vancouver. Dr. Pamela Squire, a collaborating researcher with Transforming Pain Research Group, runs the clinic. We conducted the research study in a private room at the clinic. The volunteering participants were recruited either
by Dr. Squire or her secretary. The patients who considered themselves to be easily susceptible to nausea or motion sickness, patients who had severe pain in the regions where the HMDs needed to be fitted on the person, and patients who did not have any physical pain at the time of the study were not eligible to participate. Two eligible participants dropped off the study – one because of nausea and the other, because of the doctor’s call.

4.1.2. Apparatus

The participants wore an Oculus Rift DK2 and a Cardboard VR v2.0 to play InMind, a VR game. We hooked up the Oculus Rift to a Macbook Pro 2011. This time, we used the 2nd generation Cardboard VR. It is slightly larger than the one used for the previous study because it was designed to hold smartphones with wider screens. We used a Samsung Galaxy Note 4, which has a 5.7-inch Super AMOLED display with a resolution of 1440x2560 pixels (~518 ppi density).

The Cardboard had a Velcro-adjustable elastic head-strap. For sound, we used full-sized noise-cancelling BOSE headphones. The participants sat on a swivel chair so that they could move easily in case they had pain in their necks. For patients with neck pain, it was easy to move their entire body on a chair rather than only moving their head and neck.
A minor modification was done to the original cardboard body. The basic Cardboard VR is designed to be handheld. If we attach a head-strap and mount it on a person’s head, it puts pressure on the face because of the weight of the smartphone and tightness of the strap. From observations in the previous study, it was clear that the pressure is worst on the nose because most of the weight accumulates on it. Therefore, a simple nosepiece built from foam was attached to the HMD with black tape (Figure 4.1). The effect of this simple modification was significant. When asked about whether the Cardboard was putting pressure on the face, most of the participants replied that it was not. Obviously, the solution did not make the Cardboard as comfortable as the Oculus Rift because the Rift has very thick cushioning. However, it was comfortable enough for all the participants to wear it on their heads and finish their play sessions without any problem.

4.1.3. The Virtual Environment

The VR game used for this study is called InMind VR. It is a rail-based first-person shooter (FPS) game, which, in many respects, is similar to Cryoblast. In this game, the player experiences a journey into a human brain in search of enemy neurons. The enemy neurons are coloured red. As the player aims and shoots at the enemy
neuron, it becomes “cured” and turns green. Thus, the abstractions and gameplay are quite similar to those of Cryoblast. However, InMind is more engaging and has a more open environment, which provides a sense of vastness.

A previous student [55] reported in their thesis that the cave environments induced a sense of claustrophobia in some of the patients. This, they believed, contributed to patients’ feelings of nausea, which may have been significant because those participants ended their sessions prematurely. The VE of InMind was not built as a cave, and this may have helped patients avoid such situations.

Figure 4.2. Screenshot from InMind VR

Another difference in InMind VR compared to Cryoblast is the way the player shoots at the enemies. In this game, the player needs to aim at the enemy for about a second after which the target gets locked and the ammo is fired. In this way, the game appears to be capable of holding the player’s attention better and makes them concentrate more.
InMind VR can be quite challenging at times as the rail system has twists and turns, and the speed of moving forward varies, making the target-locking difficult at times. Another important factor was that the game did not require any non-HMD external input device, such as they keyboard required in Cryoblast, for the players’ interaction. Because of all these advantages, InMind seemed to be the more appropriate game for this study. This is an educational game built by Nival VR [56] and, is available for free on the online game stores.

4.1.4. Experimental Design

The study design in comparison to the previous study, discussed in Chapter 3, minimized the number of participant groups. This study used a repeated-measure design where each patient played InMind on both Cardboard and Oculus Rift in a random order. A random uniform distribution was ensured so that half of the participants used Cardboard first, and the other half used Oculus first. The primary independent variable was the HMD type.

The primary dependent variable was the retroactive pain intensity (PI). We have two kinds of PIs – Present Pain Intensity and Retroactive Pain Intensity (pain felt in the last 10 minutes). We used the retroactive PI to measure the patients’ perceived pain intensities while they were inside the virtual environment. PI levels were measured thrice – once before playing the VR game; next, after playing the game on one of the HMDs; and finally, after playing the game again on the other HMD. Patients reported the PI by filling out visual analog scale (VAS) questionnaires. The Pain Intensity and VAS instruments are standards in pain research.

Immersion was another dependent variable, which manifested in several questions on the VAS questionnaire. There were two variations of VAS questionnaires: one for the Pre-VR condition and another for the Post-VR condition (Appendix A). The questions regarding the PI were the same in the questionnaires. However, the questions regarding immersion were not appropriate for the Pre-VR condition, which is why we used two sets of questionnaires.
Since pain distraction was the primary concern in this study, we kept a single-measure question for pain distraction in the VAS questionnaire in a scale of 1-7. The question was “To what extent were you thinking of your pain while inside the VR game?” The response was reversed (e.g., 1 becomes 7, 3 becomes 5) to measure the degree of pain distraction.

In the Pre-VR questionnaire, we also asked the patients to indicate where they had pain in their body. We thought the information might be helpful in explaining the findings in our analysis.

4.1.5. Procedure

The participants filled out a short Pre-VR questionnaire at the beginning of the study after reading and signing the consent form. The questionnaire asked them to rate their present pain intensity as well as their retroactive pain intensity, or the pain intensity felt in the last 10 minutes, on a scale of 1-100. These two questions were on both Pre-VR and Post-VR questionnaires (Appendix A) to accommodate for a potential drop in analgesic effect when patients remove the HMDs later in the study.

After completing the Pre-VR questionnaire, the participants first took part either in the Cardboard or Oculus Rift condition (figure 4.3). The InMind has about 10 minutes of gameplay. Each participant played the game in both conditions in a random uniform order.

After playing InMind VR on the first HMD, the participants got a 5-minute break. During this time they filled out one Post-VR questionnaire immediately after the play session. After the questionnaire, we asked them about their experience of playing on the two HMDs. Unlike Cryoblast, InMind VR is not designed for pain patients. It also has a relatively faster gameplay. To make the game a little more challenging, sometimes the player’s ship speeds up. Continuous exposure to such a VE may induce a sense of nausea. That is why a 5-minute break was deemed appropriate in between the two conditions. After the break, the participants took part in the second condition and filled out another Post-VR questionnaire as before. In total, each participant spent about 30 minutes in the study.
Figure 4.3. A diagram of the study process

The randomization was an important factor for the study, as some of the participants would arrive to participate after seeing the doctor and may have been medicated during their appointment, sometimes resulting in lower or higher pain intensity than normal. Randomization helped balance the effects of such outliers.

Before entering the VE, we instructed the participants about how to play the game. None of the participants seemed to have any difficulty since the control was very easy. The participants only needed to move their head to target the enemies for shooting. The author and principal investigator of this study helped each participant to put on and adjust the HMDs and the headphones.

4.2. Results

4.2.1. Effect on Pain Intensity

Present pain intensity and retroactive pain intensity (pain intensity felt in the last 10 minutes) were both measured separately in Pre-VR, Oculus Rift and Cardboard VR conditions.
**Retroactive Pain Intensity**

Retroactive Pain Intensity was used to measure the pain intensity felt by the participants during the last 10 minutes inside the VR world. A repeated-measure ANOVA revealed the retroactive pain intensity in the three conditions was statistically significant, $F(2,56)=11.007, p<0.05$. Mauchly’s test indicated that the assumption of sphericity was not violated, $\chi^2(2) = 3.842, p = 0.146$.

The mean squares for the experimental effect, $MS_M = 892.544$ and, the mean squares of the error term, $MS_R = 81.092$. The effect size for thirty participants ($N=30$) is $\omega_{HMD} = 0.5$, which means the effect of VR on the pain intensity is medium.

![Mean(PainIntensity) vs. Conditions](image)

Figure 4.4. Pain Intensity reported retroactively in the VR conditions, compared to the Pre-VR condition.
*Note: Error bars depict 95% confidence intervals.*

Bonferroni posthoc tests revealed a significant difference between the Pre-VR and Oculus Rift conditions, CI$_{95} = -17.773$ (lower) -4.027 (upper), $p=0.001$. Also, there was a significant difference between Pre-VR and Cardboard VR conditions,
CI$\text{.95} = -11.516$ (lower) $-0.151$ (upper), $p=0.043$. However, although marginally, the difference in pain intensity for Oculus Rift and Cardboard VR was also significant, CI$\text{.95} = -10.131$ (lower) $-4.027$ (upper), $p=0.050$. There was no significant interaction effect for the order of use of the HMDs, $F(2,56) = 0.348$, $p = 0.708$.

**Present Pain Intensity**

The analysis of the Present Pain Intensity revealed quite an interesting output. Our analysis showed that exposure to VR had a significant effect on the present pain intensity too, $F(2,58) = 5.090$, $p<0.05$. The assumption of sphericity was satisfied, $\chi^2(2) = 0.606$, $p = 0.739$. The effect size, in this case, was rather small, $\omega_{\text{HMD}} = 0.3$.

![Figure 4.5. Present Pain Intensity for the three conditions](image)

*Note: Error bars depict 95% confidence intervals.*
This result is different from a previous study [55] of 20 participants compared present and retroactive pain intensity levels between VR (Oculus DK1) and MBSR (Mindfulness Based Stress Reduction) conditions and found that the difference in present pain intensity was not significant. However, in this study, the participants used two VR HMDs and this time the present pain intensity was significantly lower after the VR treatments.

The pairwise comparison using Bonferroni posthoc analysis showed that the difference in Present Pain Intensity ratings between Pre-VR and Oculus Rift was significant, CI$_{.95}$ = -11.11 (lower) -.889 (upper), $p=0.017$. However, the difference between Pre-VR and Cardboard was not significant, CI$_{.95}$ = -8.263 (lower) 1.263 (upper), $p=0.216$.

### 4.2.2. Effect of Immersion

Immersion was another dependent variable that was measured for Oculus Rift and Cardboard VR conditions. The difference in immersion levels for these two VR conditions was significant $F(1,29) = 7.757$, $p=0.009$. The effect size, $\omega_{HMD} = 0.42$, was within the thresholds of medium and large which is substantial. In Study 1 (Chapter 3), the difference of immersion for between-subjects and healthy participants was not significant between Oculus Rift and Cardboard.

### 4.2.3. Self-reported Pain Distraction

Besides measuring pain intensity levels, there was one question that measured the pain distraction on a scale of 1-7. The question was: “To what extent were you thinking of your pain while in the VR game?”

This single measure of self-reported pain distraction also shows the difference in the patients' perceived distraction from their everyday pain. The pain distraction in Oculus Rift was very significant, $F(1,29) = 4.917$, $p=0.035$ compared to Cardboard VR which was also obvious in the semi-structured interview that followed after the VR sessions.
4.3. Patient Feedback

The patient feedback was not dramatically diverse in nature or highly contradictory. The Oculus Rift was the popular choice for playing the VR game. Most of the participating patients did not have any experience of VR and it seemed to be an enjoyable experience for them. The participating patients who completed the study did not complain about claustrophobia.

Most of the participants used the word “fun” while some others used “outstanding”, “so cool”, and “great” to describe their experience of playing the game. The participants found the Oculus Rift to be more comfortable to wear. In addition, because of its larger field of view (FOV), it was easier to play the game. The bigger FOV let the players see multiple targets easily and they did not have to move their gaze pointer as much as in the Cardboard.

The environment of the game is same on both the HMDs. It was harder to score higher on a Cardboard because of the narrow FOV. At the beginning of the study, the investigator specifically mentioned that if the HMD became uncomfortable and/or put pressure on the face, he would take off the head strap and the participant could hold it in their hand to play the game. However, none of the participants complained that the
Cardboard VR was too uncomfortable to wear and completed the whole game with the HMD strapped to their head.

Three of the participants complained about neck pain. For one of them, the pain intensity was higher after the VR experience because the patient tried to move their head too fast, which increased the pain in their neck. The two other patients complained about looking up in the VE. As one of them said: “...looking up makes my neck hurt. So I skipped those targets intentionally.”

For playing the VR game, most of the participants sat in a relaxed position in the swivel chair with their arms on the armrests on both sides. However, there was one male participant who preferred to play standing up because of his lower back pain. He moved his entire body to look at the 360-degree environment. While moving, he hit the table in front several times while using both the HMDs. It was surprising that when he was asked about this, he said that he did not notice it.

Two of the participants expressed frustration regarding the lag time between targeting and shooting. The game requires the player to move the gaze pointer to target. As they keep the pointer on the enemy, the ammo is shot after about a second. The two participants said that they would have liked it if the shooting was instant. However, this frustration was not about the HMDs per se.

At least six of the participants explicitly mentioned that the Oculus Rift induced a sense of nausea but the Cardboard did not. Three times during the game, the player’s vehicle moves at a faster speed than the default speed. These are short transitioning periods when the player does not have to shoot, as the enemies do not appear at these times. The patients felt a little dizzy in Oculus Rift during these short periods. However, the dizziness did not persist after the game finished. Four of these patients used the Oculus Rift first and were willing to play on Cardboard afterward.

The overall effect of Oculus Rift on pain distraction was profound compared to the Cardboard VR. The participants found it comfortable to wear, and the patients who wore glasses found it particularly helpful. They also found the game easier to play on Oculus Rift than on the Cardboard because of its bigger field of view. These findings
regarding Oculus Rift were not surprising since similar feedback was found in the previous research studies conducted by the Pain Studies Lab.

4.4. Discussion

4.4.1. Duration of effect

The major findings from this study are twofold. First, there was a decrease in the patients' perceived retroactive pain intensity after using the Mobile VR setup, although patients used the VRs for a relatively short period of time (10 minutes on each HMD). Having a comparatively dramatic decrease in the pain levels was not expected. Second, the Oculus Rift’s ability to distract the chronic pain patients from their perceived pain was established in previous studies; therefore, it was a substantial finding that the inexpensive Mobile VR setup was also capable of providing an analgesic effect. The Oculus Rift, being a high-end HMD, is capable of providing high-quality graphics and resolution compared to a smartphone’s display, and patients could also detect the limitations of the Mobile VR. Despite that, patients found the Mobile VR to be effective in pain distraction.

Cardboard or Mobile VR alone, at its current stage, is probably not capable of providing a substantial analgesic effect. It totally relies on the power of the smartphone, which is very limited compared to a desktop or laptop computer. A person can only use a smartphone for a short period to play a VR game before it drains the phone’s battery of its charge. However, a combination of traditional VR and mobile VR may be more effective for the pain patients. Chronic pain is a long-term pain and it requires long-term therapy. Therefore, Mobile VR can be used in conjunction with the traditional VR to provide such treatment. For instance, the high-end conventional HMDs can be used in clinical settings, and the patients can use the smartphone powered VR at home by their own.

The persistence of decreased Present Pain Intensity was another interesting finding. In previous studies, where the patients were required to compare a VR with a non-VR control condition, the analgesic effect of VR did not persist. However, in this
study, the patients were exposed to the same VE twice and, although it was a very small effect size, the decreased pain intensity persisted. So, it is possible that prolonged exposure to a VE might provide a distraction from pain that sometimes lasts beyond the VR session. However, since the effect size was small, we can say that it happened in a small subset of the population. Therefore, it can be argued that the persistence in reduced pain intensity might have occurred randomly. However, a more structured longitudinal study that is planned as a part of our future work will reveal this effect further.

When considering the duration of effect of VR from a psychological perspective, it is important to remember that chronic pain also has a negative psychological impact on chronic pain patients. Those affected by chronic pain can suffer from additional decreases in social interaction and psychological health [13]. There is a statistical association between the presence of CP and depression [14] and feelings of helplessness [57]. Chronic pain patients can add the Cardboard or Mobile VR device to their collection of tools to help combat their chronic pain experiences. Such a VR treatment could help negate the feelings of helplessness and contribute positively to the psychological aspects of the patients’ lives.

4.4.2. Impact of immersion and presence

We cannot claim that immersion and presence in VR directly result in pain distraction, especially because the mechanism of VR pain distraction is itself not well understood. However, these are two important aspects of a VR experience and positively contribute toward the analgesic effect [40]. It is tough to point out exactly what it is about VR that contributes to its ability to distract users from their pain more than other media forms. It is possible that for some patients, the immersion had contributed more, while for other patients, it was the excitement of trying a new form of technology that caused or enhanced the distraction. As we reported in the results, immersion in Oculus Rift fared significantly better than in the Cardboard VR, and pain distraction was also greater in Oculus Rift. However, we cannot assert there is a causal effect between immersion and pain distraction.
In the previous study, we found that immersion was not significant in these two HMDs for healthy participants. We argued that the VR game provided a ‘shallow’ immersion because of its boring gameplay and hypothesized that for a more compelling VR experience the immersion between two HMDs could be significant. If we compare Sensory, Imaginative, and Challenge—the three dimensions of video game immersion—*InMind* is certainly capable of providing a better immersion compared to *Cryoblast*. Unlike *Cryoblast*, *InMind* is properly narrated and has an understandable storyline. The varied player speed and turns in the rail make the game more challenging. The whole experience gets more interesting with the sound effects. But of all these things, the one factor that probably had the most impact was the presence. In *InMind* the player moves on a vehicle or a ship. When players look around in the VE, they can see part of the vehicle to which they are attached. This provokes a better sense of presence inside the VE. Moreover, as some the patients mentioned themselves, *InMind* has a lot of visual stimuli, which also contributes to the distraction.

This argument about ‘shallow’ vs. ‘deep’ immersion probably fits the findings in our analysis. However, it has its limitations. In a different way, it can be argued that the difference in the two user groups led to the difference in the results of immersion ratings. For the first study, we had tech-savvy, young and healthy participants. The majority of them used a VR HMD before. Their prior knowledge of this technology might have helped them feel more immersed and as a result, the immersion scores did not significantly differ in the two HMDs. In the second study, we had chronic pain patients. Most of them are not as tech-savvy as the participants in the first study. Moreover, the majority of them did not like to play computer games, which we found in the interviews. It is possible that the lack of prior knowledge of the technology has played a key role in their senses of immersion.

During the stressful moments when a chronic pain patient’s pain is flaring into higher intensities, immersing themselves in a VR game may enable the patient to redirect their attention away from an inward focus and toward the digital space. Because of the affordability and accessibility, Mobile VR is an elegant solution for that. Our results suggest that patients’ attention from their embodied selves and their pain can be
diverted using a simple Mobile VR setup which will not require the patients to be highly tech savvy and will not require extensive supervision.

### 4.4.3. Anxiety

The effect of pain distraction comes from a combination of factors. The HMD is not solely responsible for this distraction. The VR application (a game in our case) also plays a key role. We observed in our study that during the VR gameplay, the patients sometimes take deep breaths. When they were asked about it in the interview, they mentioned that when the player’s vehicle starts to move faster on a twisted rail, it gives them a sense of stress. Now, this stress is not all negative. Participants also felt that this made the experience more immersive and possibly more distracting.

Our findings support a claim by Jennett et al. that anxiety felt by participants in immersive game spaces would not necessarily detract from the quality of immersion. They theorized that games, which often generate anxiety, do so because of a challenge posed from the game. Players become invested in overcoming the challenge, which increases the anxiety felt. The emotional investment put toward completing a difficult task then furthers cognitive immersion [51]. This claim was strongly observed in our participants who rated their experience in the VR as highly immersive despite any stresses that they mentioned in the interview. Their positive response to the stimulating aspects of the gameplay is promising when considering that chronic pain patients can have an increased susceptibility to anxiety and illness [10]. The existence of anxiety sensitivity in chronic pain patients strongly emphasizes the importance of finding an ideal balance of a challenge without invoking significant amount of anxiety for the VR chronic pain patient demographic. Moreover, it needs to be considered that, this sensitivity is not binary. For different individuals, there will be different degrees of sensitivity and it may be difficult to design an application for a broad range of anxiety sensitivity. Not only that, the anxiety may or may not be coupled with other neurological limitations of the chronic pain patients. It is very important to take these limitations into account while designing applications for chronic pain patients, and that is why we cannot take any off-the-shelf AAA game and use it for pain distraction for chronic pain patients.
4.5. Limitations

There were a few limitations with this study. First, the clinic where the study was conducted only had a small private room. The room was filled with a patient exam bed, a big bookshelf, a sink and cabinet, a small table and two chairs. Thus, there was not enough space to move very freely. This limitation might have affected the results of the study to some extent. For example, the game required the player to move their head in a 360-degree environment. On the swivel chair, if the participant tried to move too fast, they would hit the table in front of them or the bookshelf behind them. Certainly it affected their sense of presence and immersion, resulting in a poorer pain distraction.

Second, the recruitment process was not ideal. Since we did not have access to patients' information, it was not possible for us to recruit participants before the days of the study. The participants who came to see the doctor were asked if they were interested in volunteering. Often, there were willing patients who could not participate because of the time required for the study (30 minutes). One of the participants completed half of the study and was called off to see the doctor, therefore, their partial data could not be included. It took six days for the investigator to recruit 30 participants. Ideally, if patients could be recruited prior to the study and could be brought to a more spacious room, the results might have been different.

Third, a longer and more structured interview after each VR session would have been more useful to get insights about the HMDs. Since the patients had to come to see the doctor on weekdays, they were often not interested in spending too much time volunteering for a study. So the interviews needed to be kept short, putting more emphasis on the quantitative analysis.

Finally, this study relied on patients' self-reported level of pain. If we could take measures like heart rate and galvanic skin response and triangulated them to determine if the results were consistent with the self-reported pain intensities, then it could have been better.
Chapter 5.

Conclusion and Future Studies

Virtual Reality is not a new invention anymore. But it has yet to become a mature form of technology. Facebook, after buying Oculus Rift and partnering with Samsung Gear VR, played a big part in bringing back the hype of VR to the consumer market after a long pause that roughly began in the late 1990s. Large companies like Google, Microsoft, Sony and HTC are now investing heavily in AR and VR. Very soon indie application developers will also get involved and bring high-quality games and apps for these devices.

Despite its recent proliferation, the traditional consumer-grade HMDs are not particularly affordable. It is especially true for some of the third world countries that are large consumer markets of technologies because of their immense population. So the majority of the people in those markets still cannot afford a traditional HMD. Moreover, consumer-grade HMDs currently require the users to be highly tech savvy.

Combined with a smartphone, Cardboard VR works as a more accessible and affordable kind of VR that a large number of people can use. This is a great advantage over the traditional VR systems. Mobile VR has the potential to grow a larger consumer base than the traditional VR. We have seen how smartphones have become the main platform for web browsing and online shopping, replacing desktop computers. It is possible that Mobile VR will similarly become the mainstream VR platform in the future. More importantly, it can potentially be used for the large number of patients who might use it to alleviate their pain, and potentially use it more often if it is accessible outside of the realm of clinics.

In this thesis, we examined Cardboard VR as a potential device of pain management for chronic pain patients. We have described two studies, in which, we
compared the Cardboard VR to an Oculus Rift to better understand the immersion, presence and pain distraction afforded by these devices. In the first study, we had healthy adult participants who played a VR game on Cardboard and Oculus Rift. We used a desktop computer for the control group. The result showed that immersion scores in the two VR devices were not significantly different. We presented some possible arguments in Chapter 3 that could explain our result.

In the second study, we recruited chronic pain patients in a clinic and asked them to play a VR game on Cardboard and Oculus Rift. This repeated-measure study revealed that the ‘Retroactive Pain Intensity’ (pain felt in the last ten minutes) significantly reduced while using the Oculus Rift than the Cardboard. However, compared to the Pre-VR condition, the ‘Retroactive Pain Intensity’ was also significantly reduced for using the Cardboard VR. The results of these studies were promising and showed the potential of mobile VR as a pain management tool.

The simplicity of Cardboard VR, if coupled with a carefully designed pain management game, can ensure the ease of use for chronic pain patients. This easy-to-use and affordable form of technology may have a massive impact as an alternative form of chronic pain therapy. The study, which we conducted with Cardboard and chronic pain patients, is only the beginning; a lot more research needs to be done. It is especially important to figure out what type of applications work best as pain distraction. Games, because of their highly interactive nature, are likely to work best. However, 3D movies and social spaces may also be useful in this regard.

Next, it is important to figure out whether mobile VR can be more useful if it is used alongside of a traditional HMD. Our study results demonstrate that the Cardboard is not as effective as the traditional HMD in pain distraction for chronic pain patients. However, it is capable of providing the analgesic effect of VR to some extent, an extent that is significantly higher than the no-VR or Pre-VR conditions. It may be useful to use the traditional HMDs in the clinics or hospitals, while patients additionally use the Cardboard or other forms of Mobile VR at home.

Although the definition of chronic pain is pain that lasts for 6 months, long-term surveys show that 20-46% of the chronic pain patients have experienced pain for the last
ten years or more [58], [59]. Such a long-term pain requires a long-term adjuvant therapy. The doctors in the hospital may train the patients with the traditional HMDs, and the patients can use the similar applications at home with the mobile VR. Moreover, a diversity of types of games will probably be needed since one game or kind of game is probably not going to be suitable for all chronic pan patients, and may not be exciting for to keep using it over the long term. There will likely be a need for a combination of pain management applications – some based on MBSR and some based on the pain distraction principles. Therefore, as part of future studies, we would like to examine if the Cardboard VR can be more effective along with the Oculus Rift or any other traditional HMD.

We would also like to examine a number of different applications to understand which sort of interactions yield better results. Coupling the Cardboard with biofeedback sensors, for instance, may also bring forward important findings about chronic pain patients. Also, it might be useful if patients could measure their physical improvement over the time. Moreover, the importance of creating intelligent systems is undeniable. Rather than creating all sorts of different games to adapt to each individual patient’s need, it may be a lot more helpful to bring intelligent agents to the VR games which could determine the needs of the individuals and modify the VR as needed.

Fear of movement is an understandable psychological phenomenon familiar to many pain patients who have been living with long-term pain. Future work must therefore examine the use of virtual reality treatments for kinesophobia, including how to design virtual reality software to encourage certain types and frequencies of bodily movement. A preliminary study by Chen et al., for example, used the Oculus Rift with CP patients who had kinesophobia in order to try to manipulate the just-noticeable difference (JND) of certain neck movements to encourage bolder patient movement with some degree of success [60]. Further, the combination of interactive VR software with hardware such as the full-body Kinect sensor and interface controls such as the Razor Hydra could also provide a very meaningful experience to chronic pain patients who struggle with kinesophobia on a regular basis.
The studies described in this thesis provide some initial degree of validity for all of these future research directions with mobile VR. The limitation of using mobile VR is the reduced field-of-view, and by extension, frequently reduced sensory immersion. We have demonstrated that with a very basic form of mobile VR, Cardboard, it is possible to get a more immersive experience which is statistically significant than a high-resolution flat panel display. When the degree of interactivity is low, the Cardboard appears to be able to provide immersive experiences similar to a high-end Oculus Rift. So for applications built for MBSR, in which less interactivity is required, the Cardboard will probably perform effectively. However, for pain distraction, more interactive applications like games would be required. Cardboard or mobile VR alone cannot be effective in this regard, at least with today’s technologies. But if patients can be trained repeatedly with the help of this portable device at home, it is likely to be a lot more effective. Patients feel less motion sickness and experienced pain relief with Cardboard VR. This suggests that larger-scale studies and longer-term follow-up studies are needed. As far as we can currently determine, these devices do appear to be effective and safe when used by chronic pain patients.
References


Appendix A.

Pain Experience Questionnaires for Study 2

Pre-VR Questionnaire

1. During the **last 10 minutes** my pain intensity was on average:

   ![Pain Scale]

2. **Right Now**, my Present Pain Intensity is:

   ![Pain Scale]

3. The amount time I usually spend thinking about my pain:

   ![Time Scale]

4. In the **last 10 minutes**, the amount of time I spent thinking about my pain was

   ![Time Scale]

Figure A1. Pre-VR Questionnaire – First page
Where is Your Pain?

Please mark, on the drawings below, the areas where you feel pain.

Figure A2. Pre-VR Questionnaire – Second page
Post-VR Questionnaire for Oculus Rift and Cardboard

1. **Inside the Virtual-reality (VR) Game**, in the last 10 minutes, my pain intensity was:

<table>
<thead>
<tr>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Pain</td>
<td>Mild</td>
<td>Discomforting</td>
<td>Distressing</td>
<td>Horrible</td>
<td>Excruciating</td>
</tr>
</tbody>
</table>

2. **Right Now**, my Present Pain Intensity is:

<table>
<thead>
<tr>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Pain</td>
<td>Mild</td>
<td>Discomforting</td>
<td>Distressing</td>
<td>Horrible</td>
<td>Excruciating</td>
</tr>
</tbody>
</table>

3. To what extent did the game hold your attention?

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
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<tbody>
<tr>
<td>Not At All</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>A Lot</td>
</tr>
</tbody>
</table>

4. To what extent did you lose track of time, e.g., did the game absorb your attention so that you were not bored?

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<tr>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
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<tbody>
<tr>
<td>Never</td>
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<td></td>
<td></td>
<td>Always</td>
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5. To what extent did you feel consciously aware of being in the real world while playing the VR game?

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<td>Never</td>
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<td></td>
<td></td>
<td>Always</td>
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</table>

6. Were there any time during the game in which you just wanted to give up?

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<th>4</th>
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<tr>
<td>Never</td>
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<td></td>
<td>Always</td>
</tr>
</tbody>
</table>

7. To what extent were you thinking of your pain while in the VR game?

<table>
<thead>
<tr>
<th>1</th>
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8. To what extent did you find the game easy?

<table>
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<td>Never</td>
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<td></td>
<td></td>
<td>Always</td>
</tr>
</tbody>
</table>

**Figure A3. Post-VR Questionnaire – First page**
How immersed did you feel in the VR Game?

1 2 3 4 5 6 7 8 9 10

To what extent did you feel distracted from your pain **inside the Virtual Reality**?

1 2 3 4 5 6 7 8 9 10

**Figure A4. Post-VR Questionnaire – Second pag**